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MANAGEMENT SIGNIFICANCE OF BIOAVAILABLE PHOSPHORUS IN URBAN RUNOFF

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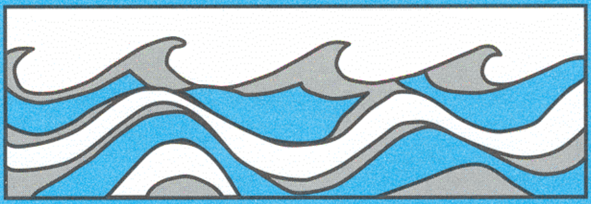

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Technical Report No.108
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DISCLAIMER

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ABSTRACT

Biologically available phosphorus (BAP) was determined monthly in Lake Sammamish at two depths and in its main tributary, Issaquah Creek, by an algal growth potential bioassay technique. BAP was more closely related to soluble reactive phosphorus (SRP) than to total phosphorus. Relationships between BAP and SRP plus sodium hydroxide-extractable phosphorus were derived to permit BAP estimation from chemical measurements in the future. A previously developed nonsteady-state, mass balance model for Lake Sammamish was reformulated in terms of BAP, calibrated, and verified. A linear relationship was also derived to predict phytoplankton biomass as chlorophyll a in the lake from BAP data. The model, this equation, and an expression from the literature were used to predict lake BAP, chlorophyll a and Secchi depth transparency for future cases of watershed development and storm runoff pollution control. Significant change in trophic state indicators is expected without controls, while state-of-the-art retention facilities, vegetated overland flow treatment, and soil infiltration of runoff could maintain the current state. The analysis led to the generation of a series of management strategies to protect Lake Sammamish water quality.

Key words: Biologically available phosphorus, storm runoff water quality, nonpoint source water pollution, lake trophic state, eutrophication, lake management.

INTRODUCTION

BACKGROUND

Urban runoff from development of an additional 5100 ha of the Lake Sammamish watershed by the year 2000 is expected to degrade water quality substantially, possibly to its state in the mid-1960's, prior to sewage diversion (Welch et al., 1985; Shuster, 1985; Shuster et al., 1986). This assessment was based on the results of a nonsteady-state, mass balance model for total phosphorus (TP). Predictions for a median-flow year showed that the following changes from the current (1980's) state could be expected, if no controls on P loading were instituted: annual mean TP to increase from 23 to 31 $\mu g\ l^{-1}$; summer mean TP to increase from 14 to 19 $\mu g\ l^{-1}$; summer mean chl a to increase from 3.3 to 5.0 $\mu g\ l^{-1}$; and summer mean Secchi transparency to decrease from 3.5 to 2.6 m. Thus, there is legitimate concern that future uncontrolled development will undo the water quality improvements accomplished following the 1968 wastewater diversion, although those improvements were considerably delayed (Welch et al., 1985; 1986).

Values from the mid-1960's were similar to those predicted for 2000, except for transparency: annual mean TP--33 $\mu g\ l^{-1}$; summer mean TP--21 mg/L; summer mean chl a--5.0 $\mu g\ l^{-1}$; and Secchi depth transparency--3.3 m. However, transparency has never been as low as 2.6 m, the prediction for 2000 without controls. Also, lake quality is currently higher than the predicted values for a median-flow year, with an annual mean TP of 13 $\mu g\ l^{-1}$, summer mean TP of 11 $\mu g\ l^{-1}$, summer mean chl a of 1.7 $\mu g\ l^{-1}$, and summer mean Secchi transparency of 5.3 m (1986 data).

Chl a and Secchi transparency were predicted from summer TP based on the models of Carlson (1977). Although Smith and Shapiro (1981) have argued for developing chl a-TP relationships that are lake specific, the Lake Sammamish data were considered to have an insufficient range of values with which to develop a reliable model.

Because control of P loading from newly developed land was expected to cost in the neighborhood of $14,000,000 over and above the cost of already mandated water quality controls, an evaluation of the P-chl a-transparency relationships in Lake Sammamish was considered important. The yield of chl a per unit TP in Lake Sammamish is lower than predicted by the Carlson model, and transparency per unit chl a is higher. Thus, for a given increment of TP, there could be less chl a increase than predicted and, therefore, even less degradation in transparency. The goals, then, of this research were to determine if the TP input to Lake Sammamish is less available for algae growth than in other lakes, and to examine the management implications of the findings. To accomplish this goal, an investigation of biologically available P (BAP) was undertaken for the lake, the main inflow stream (Issaquah Creek), and a group of smaller local lakes. By developing models for seasonal change in lake BAP and summer BAP-chl a, more accurate predictions of future runoff effects should be possible.

SUMMARY OF OBJECTIVES

1. Determine the BAP fraction of TP in the epilimnion and hypolimnion of Lake Sammamish and in its principal inflowing stream, Issaquah Creek, on a monthly basis by algal bioassay and chemical extraction procedures. Also, determine BAP in one sample each from 20 to 30 other local lakes.
2. Determine the relationship of BAP with chl a in Lake Sammamish based on past data, corrected by the determined BAP/TP ratio.
3. Calibrate a mass-balance model for predicting the effects of urban runoff on the seasonal change in lake BAP content.
4. Use BAP instead of TP to evaluate the efficacy and cost-effectiveness of watershed controls to prevent the degradation of Lake Sammamish from increased development.

RELATED RESEARCH

General

Algal growth depends on phosphorus and other nutrients in forms available for uptake. Immediately available forms are soluble inorganic compounds. Other forms can become available for uptake over time. Organics become available through bacterial degradation and constituents associated with particulates through dissolution or desorption. Whether these processes will in fact increase nutrient availability in a given case depends on the time the nutrient-bearing materials are in contact with viable algae.

Total phosphorus (TP) has been used extensively as the measure of eutrophication potential and the trophic state of lakes (Vollenweider, 1968; Carlson, 1977). Mass balance models predicting TP content have formed the basis to guide lake restoration and eutrophication control (Vollenweider, 1969, 1976; Walker, 1977; Reckhow and Chapra, 1983). Prediction of annual, "steady-state" TP content is the normal procedure, but in some instances seasonal, nonsteady-state TP has been determined (Larsen et al., 1979; Welch et al., 1985) to provide more accuracy in estimating growth season (summer) conditions. More complex models that compartmentalize P fractions (Imboden, 1974), although more realistic, have not been widely used in lake management.

The unknown significance of the unavailable fraction of TP in the current modeling and prediction approach to lake management naturally leads to large uncertainties. Smith and Shapiro (1981) showed that lakes have widely differing individual chl <u>a</u>-TP relationships, the occurrence of which accounts, in part, for the large standard error in log-log relationships involving those two variables derived from data sets gathered from a large number of lakes (Dillon and Rigler, 1974; Reckhow and Chapra, 1983). No doubt, much of this lake-to-lake variation in the chl <u>a</u>-TP relationship is due to differences in the unavailable TP fractions. While considerable effort has gone into determining biologically available P (BAP), there have apparently been no attempts to apply that determination to an assessment of lake response and control (Dillon and Reid, 1981; Cowen and Lee, 1976a,b; Schaffner and Oglesby, 1978; Peters, 1977; Lee and Jones, 1978; Dillon, personal communication).

Phosphorus Forms and Transformation Mechanisms

Researchers have categorized phosphorus (P) forms in several ways to express their relative availability to algae. Lee and Jones (1978) proposed the following classification system:

P immediately available
P becoming available through transformation
P becoming unavailable through transformation

The remainder would remain unavailable essentially indefinitely. This scheme points out that mechanisms can operate both to increase and decrease P availability.

The most common means of classifying P forms is based on the standard laboratory analyses performed on water samples. The basic categories are:

Total phosphorus (TP)
Total soluble phosphorus (TSP)
Soluble reactive phosphorus (SRP)
Particulate phosphorus (PP)

TP encompasses all of the succeeding forms, and TSP includes SRP. PP is the difference between TP and TSP. The soluble and particulate classes each contain inorganics and organics.

SRP represents ammonium molybdate-reactive phosphorus, which is measured spectrophotometrically by the ascorbic acid method (American Public Health Association, 1985). TP and TSP are analyzed by the same method on unfiltered and filtered samples, respectively, following potassium persulfate digestion to liberate bound P (American Public Health Association, 1985).

The disadvantage of the above classification system is that the forms do not necessarily reflect availability. Nevertheless, relative availability can be assessed to a degree by considering the nature of each fraction.

TSP consists of: (1) dissolved orthophosphates (PO^{-3}, HPO_4^{-2}, and $H_2PO_4^{-1}$, with proportions depending on pH); (2) condensed phosphates (pyro- and tripolyphosphates), which are prevalent in detergents, and (3) organic colloids (Wetzel, 1975). Orthophosphates and condensed phosphates, along with some high molecular weight organics, make up most of the SRP fraction. SRP is essentially all available, either immediately or within a short time, as demonstrated by the fact that it often declines below the detectable limit during algal blooms (Paerl and Downes, 1978; Schaffner and Oglesby, 1978). The minority organic colloid fraction of the TSP is thought to become available in a fairly short time, apparently through polycondensation of low molecular weight compounds to form high molecular weight compounds, which subsequently release soluble PO_4-P (Wetzel, 1975). Cowen and Lee (1976b) found that 89% of the TSP in urban runoff was SRP initially and that the remainder transformed to SRP relatively quickly.

Particulate phosphorus consists of: (1) P contained in biological organisms; (2) mineral P; (3) P adsorbed on organic particles (Wetzel, 1975). The first subcategory is comprised of various fairly stable biochemicals. Mineral P includes that adsorbed on clays, carbonates, and ferric hydroxide or substituted for silicates in clay structures (Wetzel, 1975). Most of the PP is associated with small particles; Sartor et al. (1974) found that particles under 43 μm in size held 56 percent of the TP in urban runoff, although comprising only 5.9 percent of the total solids mass. Particulates can both release and sorb formerly dissolved P over time. Availability of PP is thus unpredictable without conducting extraction studies, such as described in the following section.

Schaffner and Oglesby (1978) proposed a variation on the above classification system:

Soluble reactive phosphorus (SRP)
Soluble unreactive phosphorus (SUP)
Labile phosphorus
Unavailable phosphorus

SUP represents dissolved P that is not ammonium molybdate-reactive but is probably at least partially available through liberation from organics by enzymes such as alkaline phosphatases. Labile P is rather easily desorbed from soil particles. These workers regarded the biologically available P (BAP) as the sum of SRP, SUP, and labile P.

A set of categories for particulate P, originally proposed by Syers et al. (1973), and Williams et al. (1976), more explicitly distinguishes between available and unavailable forms:

Apatite inorganic phosphorus (AIP)
Non-apatite inorganic phosphorus (NAIP)
Organic phosphorus

AIP consists of orthophosphate present in the crystal lattices of apatite, $Ca_5(OH)(PO_4)_3$, grains and is virtually unavailable to algae. NAIP includes all remaining orthophosphate ions and is potentially the most available form. Organic P would, in general, become available over time. The disadvantage of this system is that rather complex analyses are required to measure AIP, NAIP, and organic P.

Another factor in phosphorus availability is the presence of complexing and scavenging agents. Metals, especially iron and aluminum, complex P and remove it from the soluble, available fraction. High iron content in lake sediments, for example, would be capable of complexing a relatively large quantity of P. Gloss et al. (1980) pointed out that calcite ($CaCO_3$ crystallized in hexagonal form) can scavenge SRP and reduce its availability.

The solubility of P in aquatic systems and, thus, indirectly, its availability is largely controlled by calcium, iron, aluminum, and pH. For example, a calcium concentration of 40 mg/l limits P solubility to approximately 10 µm/l at pH 7. Under those conditions, the remaining P is bound in apatite. With 100 mg/l calcium, P solubility is restricted to about 1 µg/l at pH 7 (Stumm and Morgan, 1970).

Phosphorus Availability Estimates for Various Samples

Phosphorus availability--as determined by the methods outlined above--usually has been stated as a fraction of the TP. Some investigators have defined general relationships that they considered to be applicable to a wide range of samples, while others have concentrated on specific P sources.

Lee and his colleagues conducted much of the early work designed to establish phosphorus availability, employing a combination of biological and chemical extraction techniques, working primarily with urban runoff and river samples. The outgrowth of this work was a series of equations for general application, relating available P to measurable forms. The original relationship (Cowen and Lee, 1976a; Lee and Jones, 1978) was:

$$\text{Available P} = \text{SRP} + 0.2\ (\text{TP} - \text{SRP})$$

Cowen and Lee (1976b) modified the equation to:

$$\text{Available P} = \text{TSP} + 0.3\ \text{PP}$$

Finally, Lee et al. (1980) advocated further modifying the relationship to reflect the limited particulate residence time in the photic zone, as follows:

$$\text{Available P} = \text{TSP} + 0.2\ \text{PP}$$

The authors considered this equation to apply to urban runoff and drainage from normal-till agriculture.

Other researchers have given ratios of available P to TP for general application. Schaffner and Oglesby (1978) concluded that a mean ratio of BAP/TP of 0.476 (S.D. = 0.060) is appropriate, after studying 13 primarily forested and agricultural watersheds. Armstrong et al. (1979) considered the sum of dissolved and NaOH-extractable P to represent the available quantity and found the mean ratio of BAP/TP to be 0.44 (range 0.23-0.58) in experiments on urban runoff and river water. Williams et al. (1980) conducted Scenedesmus quadricauda bioassays with sedimentary materials from the Great Lakes area and found BAP to constitute 8-50 percent of the TP and 38-83 percent of the nonapatite inorganic P. Thus, while there is some agreement on the mean portion of TP available to algae, departure from the mean can be considerable in specific samples. Clay is one material that effectively retains most of its associated P; Golterman (1977) found through NTA extractions that only about 10 percent of TP in clay samples was potentially available.

While the work cited here can provide some general guidance for trophic state analysis, lake and watershed modeling and management, the results have neither been widely verified in different systems nor applied in any comprehensive fashion to improve analytical tools or management techniques (Dillon, personal communication). It was the goal of this research to determine appropriate BAP relationships for a specific lake system, and then to employ those relationships to advance the understanding of trophic state dynamics and the predictive success of models in the interest of improving management abilities.

RESEARCH METHODS

SAMPLING

Water samples were collected on a monthly basis at the midlake station (METRO Station 0612) of Lake Sammamish from depths of 1 meter and 25 meters. The sampling period was from March 26, 1986 to February 10, 1987. Issaquah Creek was sampled at the SE 56th bridge (METRO Station 0631) on a daily basis from April 1, 1986 to March 31, 1987.

Twenty-nine additional lakes were sampled in August and early September, 1986, at a depth of 1 meter, at a station located over the deepest part of each lake. Five of these lakes were again sampled in December, 1986, at the same location. These lakes include all 23 from the METRO small lakes monitoring program in King County, (Brenner and Davis, 1986), Green Lake (Seattle), Silver Lake (Everett), Long Lake (Kitsap County) and two stations on Moses Lake (Grant County).

NUTRIENT BIOASSAY

Bioavailable phosphorus was determined with the use of the standard U.S. Environmental Protection Agency algal growth potential (AGP) bioassay (Miller et al., 1978). Stock cultures of the standard test alga Selenastrum capricornutum Printz were maintained in an exponential growth phase by frequent inoculum transfers to a synthetic algal nutrient medium. All glassware and solution water were sterilized before use. Cultures were grown at a constant temperature of 24 ± 2 C, under continuous illumination and agitation to provide proper gas exchange.

The principal of the AGP test is that the organism will increase in biomass until its growth becomes limited by the nutrient in shortest supply relative to its nutrient requirements. That is, relative to the ratio of macronutrients contained in cells, the maximum biomass attained should be proportional to the initial concentration of available limiting nutrient.

Nutrient bioassays were performed on the monthly Lake Sammamish samples and the concurrent Issaquah Creek samples, as well as on all of the additional lake samples. Within 12 hours after collection, one liter samples were autoclaved at 121 C for 35 minutes. Autoclaving releases the labile fraction of P in algal and bacterial cells and is assumed to simulate the decomposition process in which P is recycled from the particulate organic phase to the soluble inorganic phase that is available for algal uptake. Samples were diluted to the original volume and filtered through a prewashed 0.45 micron Millipore filter.

All water samples were assumed to be phosphorus limited. Triplicate 50 ml samples were transferred to specially prepared 125 ml Erlenmeyer flasks fitted with foam plugs. All reagents from the synthetic algal nutrient medium, excluding the potassium phosphate, were added in the appropriate proportions to each culture flask. An inoculum of the stock algal culture was rinsed of culture media three times and transferred immediately to the test water at an initial concentration of 5000 cells/ml. Assays were conducted under the same light and temperature conditions used to maintain the stock cultures.

The optical density of each culture flask was measured daily in a Perkin-Elmer Lambda 3 spectrophotometer at 645 nm using a 10 cm cell. Assays were continued until a maximum optical density was reached, typically in 6 to 7 days. Standard solutions of potassium phosphate and blanks were assayed in the same manner to prepare a standard curve of maximum yield versus phosphorus concentration (Figure 1). The regression equation corresponding to this curve is $y = 0.022X - 0.014$ ($r^2 = 0.979$). Additional phosphorus standards and blanks were assayed periodically throughout the study to detect any changes in observed yields. The corresponding phosphorus concentration from the maximum optical density of each assayed culture was defined as the Biologically Available Phosphorus (BAP) of that sample.

CHEMICAL MEASUREMENTS

Several forms of phosphorus were measured by various analytical techniques in monthly samples collected from Lake Sammamish, concurrently from Issaquah Creek, and all additional lakes sampled. Only total phosphorus was determined on the daily samples from Issaquah Creek. Duplicate analyses were performed on all samples.

Soluble reactive phosphorus was determined after passing the sample through a prewashed 0.45 micron Millipore filter. The sample was analyzed

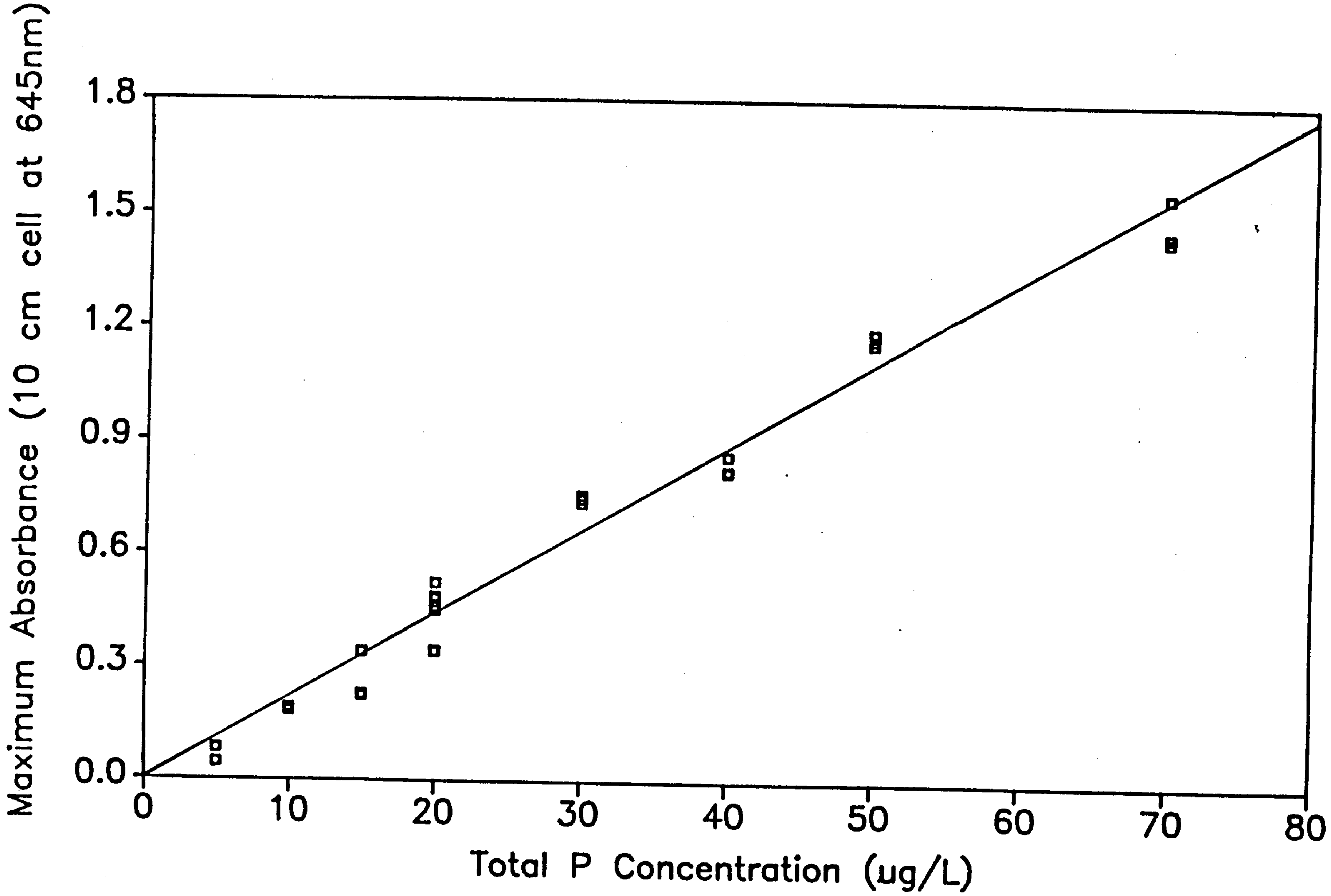

Figure 1. Standard Curve for Nutrient Bioassays

according to the ascorbic acid method, using the Perkin-Elmer spectrophotometer at 885 nm and a 10 cm cell (Strickland and Parsons, 1965).

Total phosphorus was determined in each case by subsampling after sample agitation and preservation with 1 ml concentrated sulfuric acid per liter. The sample was then digested with potassium persulfate and additional sulfuric acid in an autoclave at 121 C for 35 minutes. The samples were then neutralized and the phosphorus concentration determined by the ascorbic acid method. Corrections were made for all samples containing turbidity or color (American Public Health Association, 1985). All standards and blanks were treated in the same manner as the samples.

Total soluble phosphorus was determined by filtration of the sample through a prewashed 0.45 micron Millipore filter, followed by analysis in the same manner as described for TP. Particulate phosphorus was calculated as the difference between TP and TSP. Autoclaved SRP (ASRP) and autoclaved TSP (ATSP) were determined by preparing the sample in the same manner as for the nutrient bioassay, but the analytical methods for SRP and TSP were followed as described above.

It has been suggested in the literature that the time-consuming bioassay technique for BAP determination can be avoided by analyzing the quantity of P that can be released from a sample by sodium hydroxide extraction. In order to investigate the relationship between biologically and chemically determined BAP, NaOH-extractable phosphorus was determined on the particulate fraction of the sample by the method of Cowen and Lee (1976). A sample of known volume was passed through a 0.45 micron Millipore filter. The filter then was extracted for 24 hours in a 0.1 N NaOH + 0.1 N NaCl solution. The solution was filtered, neutralized, and analyzed for SRP. Blank corrections were made for all extract solutions and filters.

MODEL REVISION

The simple mass balance model of phosphorus dynamics in Lake Sammamish (Welch et al., 1985) was modified to predict the seasonal variations of biologically available phosphorus. The original model was based on total phosphorus and the equation proposed by Vollenweider (1969) as modified by Larsen et al. (1979). Replacing total phosphorus with the fraction that is biologically available during each time step, the model became:

$$\frac{d[BAP]}{dt} = \frac{J'_{ext}}{V} - \rho[BAP] - \sigma[BAP] + \frac{J'_{int}}{V}$$

where:

J'_{ext} = External loading of BAP (mg $week^{-1}$)
V = Lake volume (m^3)
ρ = Flushing rate ($week^{-1}$)
σ = Sedimentation rate coefficient ($week^{-1}$)
[BAP] = concentration of whole lake BAP at prior time step (mg m^{-3})
J'_{int} = Internal loading of BAP from anoxic sediments (mg $week^{-1}$)

Many of the assumptions made during the development of the new model are the same or similar to those made in the original formulation. The lake is treated as a completely stirred tank reactor (CSTR) with a constant volume. The BAP concentration calculated in each time step is the volume-weighted mean of the whole lake. Observed whole-lake BAP concentration was calculated from nutrient bioassay measurements from the epilimnion and hypolimnion weighted as 70 and 30 percent of the total lake volume, respectively, corresponding to a division between the two at a depth of 15 meters. To obtain the expected BAP concentration of Lake Sammamish in the past, it was assumed that the fractions of BAP to TP were the same in both compartments as those measured in this study. Average TP concentrations of the epilimnion and hypolimnion from available past data were adjusted to BAP with the monthly fraction and then volume-weighted to give the computed whole-lake BAP.

The loss of BAP to the sediments was assumed to be the product of the concentration of BAP and the sedimentation rate coefficient, which is a function of the flushing rate. If the sediments are to be a sink for BAP, any increase in time available for sedimentation must be larger than increased water residence time. Therefore, the sedimentation rate coefficient is a power function of the flushing rate, $\sigma = \rho^n$ where n is a positive fraction.

Because BAP can be removed in the water column by algal uptake, in contrast to TP, the sedimentation rate coefficient also includes the uptake loss during spring. Loss through uptake in the epilimnion in summer would tend to diminish the internal loading term.

The internal loading of BAP during anaerobic periods in the hypolimnion was calculated as the product of the lake area bottom below 15 meters, the sediment release rate of TP, and the fraction that was measured to be bioavailable for that particular month. The sediment release rate was assumed to be zero from December through July, a constant value from July through October, and a larger quantity in November, just before turnover.

Nonpoint source loading of BAP was calculated from phosphorus yield coefficients and land use areas (Welch et al., 1985), and the fraction of phosphorus that was measured to be biologically available for that month in Issaquah Creek. These loading values were added to J'_{ext} according to the fraction of the total rainfall for the year in question that was measured in each time step.

The model was driven from a known whole-lake BAP concentration in the first week in December, when lake turnover is expected to have occurred. A weekly time step was used, with the biologically available fraction of Total P being extrapolated over the whole month from which it was measured. Changes in loadings, sedimentation, and mass outflow of BAP modify the whole-lake concentration from the previous time step to represent the dynamics of BAP seasonally. Appendix A presents the FORTRAN source code for the model.

MODEL CALIBRATION AND VERIFICATION

To calibrate the model, daily mean flows of Issaquah Creek from a U.S. Geological Survey (USGS) gage (Station 12121600) near the mouth, and daily total precipitation were converted to weekly values. Total phosphorus data from METRO, from December, 1985, through March, 1986, and weekly means of daily measurements, from April, 1986, through November, 1986, were used to calculate the external P loading from Issaquah Creek for the calibration year. A hydraulic budget done by Moon (1972) showed Issaquah Creek to contribute 70 percent of the inflow to Lake Sammamish. That relative contribution was assumed to be constant throughout the year. External phosphorus loadings from the Westside and Eastside subbasins were estimated with phosphorus yield coefficients, fractional annual precipitation, and 1984 land use estimates (King County Department of Planning and Community Development, 1984).

TP loading for the calibration year was corrected for BAP by weighting for time and, therefore, the seasonal effect on the BAP/TP ratio. That is, weekly TP load was multiplied first by the precipitation fraction and then by the BAP/TP ratio determined for that month. This procedure was consistent with that for all verification data years in which annual TP loading was estimated from land use. TP loading could also have been computed by weighting the BAP fraction for TP loading. In that case, TP load would have first been multiplied by the BAP/TP fraction, resulting in an annual BAP load, and then distributed with time by multiplying by the weekly precipitation fraction. The former method was chosen here to preserve the seasonal importance of the BAP/TP fraction, which was high in winter and low in summer, due primarily to the activity of biota scavenging BAP. That observation was true for the lake as well as the stream. Weighting for load would have increased the annual BAP load by about 40%, over the method used, whereas loading during the spring would have increased by nearly 60%, and spring BAP concentration in the lake is the value used to predict chlorophyll a. Disregarding the seasonal variability in BAP/TP would yield an unrealistic estimate of chl a.

Sedimentation rate (σ) was solved as a power function of the flushing rate (ρ) by maximizing the coefficient of determination (r^2) between predicted and observed whole-lake BAP. Retention of P is normally considered to be an inverse function of flushing rate (Larsen and Mercier, 1976), but allowing the sedimentation term to vary with flushing was not included in earlier nonsteady state versions of mass balance models (Larsen et al., 1979). This feature greatly improved the fit of predicted to observed TP data among years in previous work in Lake Sammamish (Welch et al., 1985).

For calibration, data from METRO for TP at Station 0612 from December, 1985, through February, 1986, were converted to expected whole-lake BAP by applying the biologically available fraction of TP measured in the subsequent year. A calibration year starting December 1, 1985, through November 30, 1986, was chosen because of the availability of hydrologic data and a nearly complete year of daily total phosphorus measurements from Issaquah Creek. Sedimentation rate was computed as discussed above, resulting in the relationship, $\sigma = \rho^{0.77}$, which was then used in the model.

The sediment release rate used was 21 mg m^{-2} $week^{-1}$, which was recently measured by Schuster (1985). This value was converted to BAP using the biologically available fraction of TP assayed in each monthly hypolimnetic water sample. The extent of the increase in sediment release rate just before turnover was estimated in the same manner as the sedimentation rate. A fourfold increase in release rate for use between week 48 (November 1) and week 52 (November 30) fit the data best.

A significant removal of whole-lake BAP was observed during and shortly following the spring algal bloom. The mechanism used in the model to reflect this loss of BAP was to increase the sedimentation rate over this period. Although the high sinking rates of diatoms may be removing surface BAP to the sediments at high rates, other mechanisms are possible. An eight-fold increase in sedimentation rate from week 13 (March) through week 26 (June) fit the data best, as demonstrated by maximizing the coefficient of determination. Appendix B presents the data set for the calibration year.

The year used to verify the model, December 1, 1984, through November 30, 1985, was chosen based on the availability of data and the fact that it chronologically precedes the calibration year. Local precipitation and flow data on Issaquah Creek are from USGS and were compiled in the same manner as described for the calibration year. Data for TP concentration in Issaquah Creek are from METRO (Station 0631). In order to enter the external loading of Issaquah Creek on a weekly time step, TP concentrations were interpolated between dates or when no sampling occurred. All other model parameters remained the same as in the calibration run.

Model runs were also made for eight other years for which data were available. Appendix C contains the data base for the verification year and those eight other years.

LAKE RESPONSE MODELING

One of the main reasons for this study was the lack of a satisfactory way to predict algal biomass as chlorophyll a from P measurements in Lake Sammamish (Welch et al., 1985). The model of Carlson (1977) did not fit as well for Sammamish as for lakes in the data base with which it was developed. To investigate a new model for Lake Sammamish, a series of regressions (linear, exponential, logarithmic, and power fits) was performed to relate chl a to BAP. Years with sufficient chl a data were used, and BAP was estimated from TP and the monthly ratios established in this study. The best fit was selected to represent the lake response. Secchi disk transparency continued to be modeled after Carlson (1977).

MODEL APPLICATION

After the model was revised, calibrated, and verified, it was applied to forecast conditions in the lake. The application was parallel to that of the original model, as detailed by Welch et al. (1985). These applications represented use of high and low P yield coefficients and high and low water years to demonstrate the expected range of conditions. To investigate possible management strategies most directly, the variation of predictions was related to the probability of attaining a given flow based on a twenty-year Issaquah Creek flow record.

The same management strategies were investigated with the new BAP model as reviewed by Welch et al. (1985). They are:

1. No controls.
2. Retention facilities serving all new developed areas.
3. Retention facilities serving all new developed areas, vegetated overland flow channels serving all new residential areas, and soil infiltration serving all new commercial areas, where soils permit (known as retention and polishing). Areas considered to be suitable for infiltration were limited to the eastern I-90 corridor in Issaquah, the vicinity of N.E. 8th Street and 228th Avenue on the east side of the lake, and in the undeveloped portion of Redmond within the watershed.

The bases and assumptions for investigating these management strategies were the same as stated by Welch et al. (1985). Therefore, retention facilities were assumed to be regional, and all facilities were assumed to be designed, operated, and maintained according to the best available techniques.

Previous literature review cited by Welch et al. (1985) indicated that retention facilities can reliably remove 25-45 percent of TP, while retention plus overland flow can capture 35-95 percent. TP removal in a retention/infiltration system is expected to range from 60-100 percent, depending on whether any overflow and surface release occurs. BAP was expected, and was demonstrated, to consist largely of the soluble fraction of TP. Therefore, BAP removal would tend to be lower than TP reduction in retention basins and overland flow channels. No literature basis is available to estimate BAP reductions, but the low end of the ranges was considered to represent the minimum treatment advantages that could be gained by effective application of the management strategies.

RESULTS AND DISCUSSION

SEASONALITY OF TRIBUTARY AND LAKE PHOSPHORUS

Issaquah Creek

Figure 2 portrays the daily TP variation in Issaquah Creek, the major lake tributary, during the year of study. Concentrations were usually under 50 $\mu g\ l^{-1}$ and rose above 100 $\mu g\ l^{-1}$ on five occasions during the year. The two highest concentrations occurred during a November 15-year recurrence rainfall, 30-year flood storm. Coupled with elevated flow, such occasions can account for a significant fraction of the year's phosphorus mass loading. Limiting such peaks depends partially on effectively controlling erosion from construction sites.

Figure 3 illustrates the monthly variation of TP, SRP, TSP, and BAP at the Issaquah Creek station. The stream exhibited a definite pattern of low values in early summer and high values throughout the fall, declining again in the winter, depending on flow patterns affecting land washoff and scouring of the creek bed.

Figure 4 shows monthly ratios of BAP/TP for both Issaquah Creek and two depths in the lake. As with the P forms, the ratio was also high in the fall.

BAP closely followed SRP in Issaquah Creek. Samples collected during high runoff in February showed consistent agreement with SRP (+ an additional fraction), but the BAP/TP ratio then was the lowest of the year. This result suggests that TP during high runoff periods is not readily available for growth. An explanation for high BAP and BAP/TP ratios in the fall is not readily apparent. Decomposition of stream periphyton, as light availability and temperature declined below optimum growth conditions, and salmon excretory products may contribute to the increase. The important point shown by these data, though, is the greater similarity of BAP with SRP than with TP.

Lake Sammamish

Figures 5 and 6 illustrate the monthly variation in TP, SRP, TSP, and BAP at 1 and 25 m depths, respectively, in Lake Sammamish. BAP in the lake surface waters also showed a definite seasonal pattern, being lowest in spring and rising in the fall and reaching the highest values following Figure 2

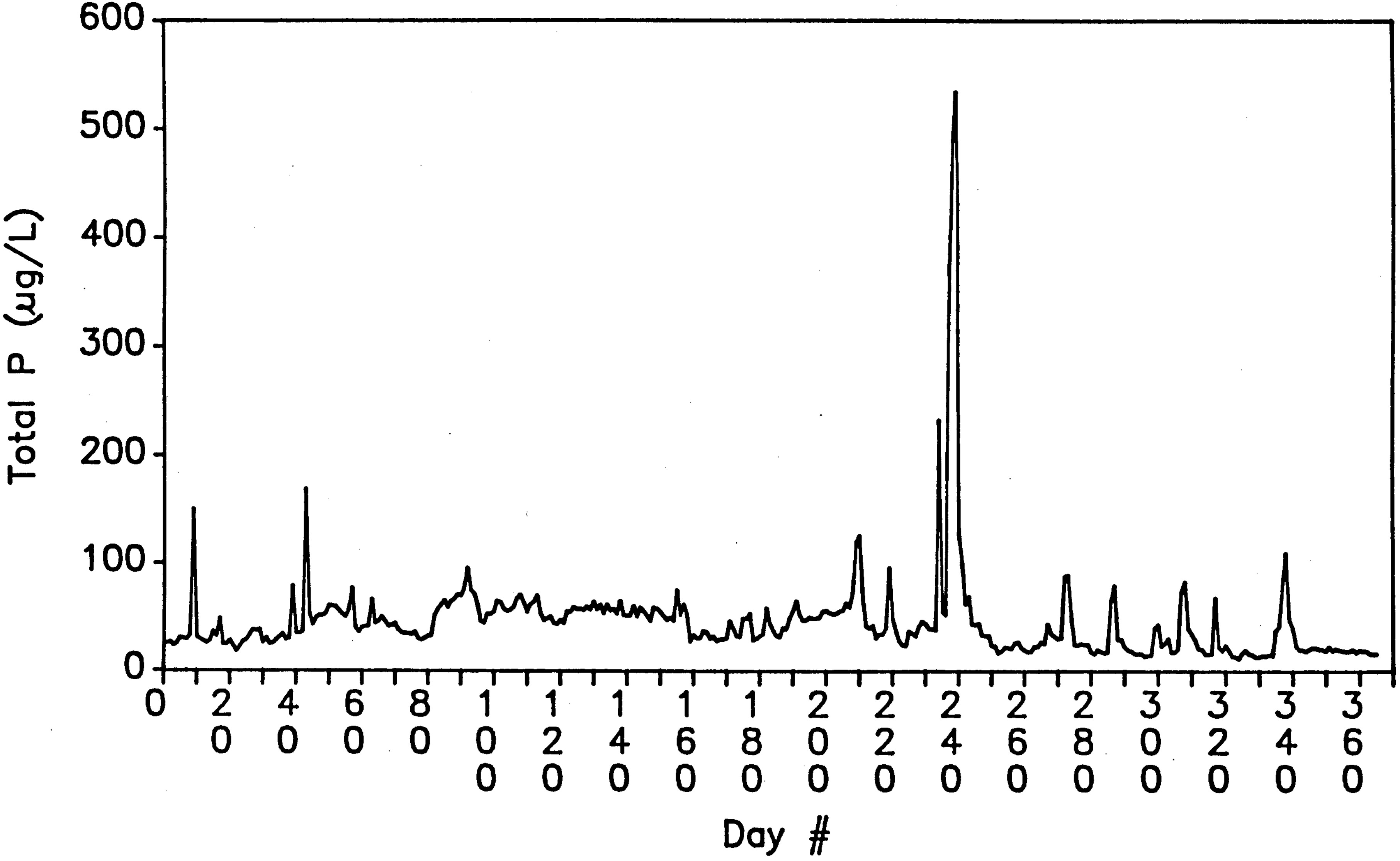

Figure 2. Daily Total Phosphorus Concentrations Near the Mouth of Issaquah Creek from April 1, 1986, Through March 31, 1987

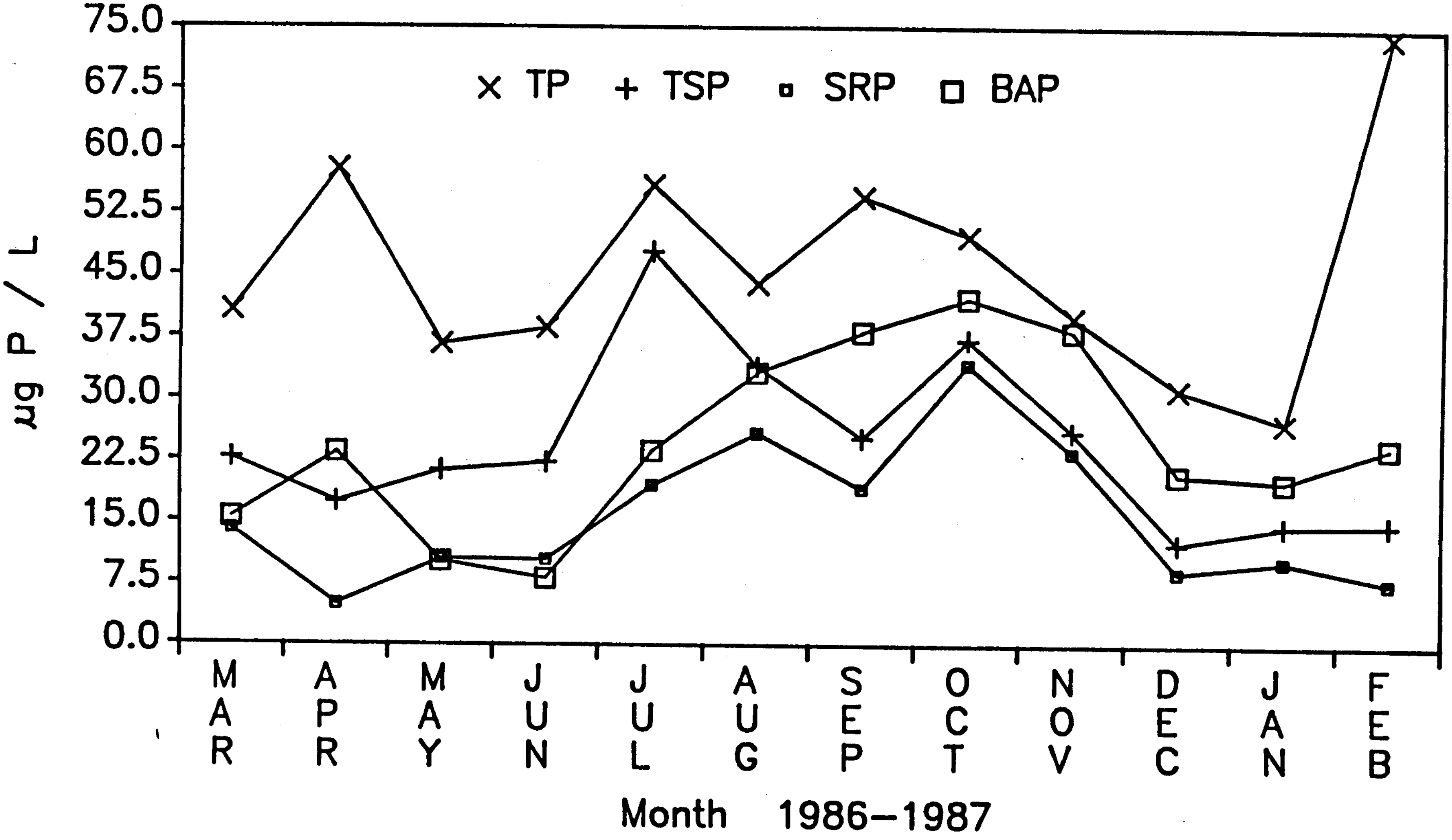

Figure 3. Concentrations of Various Forms of Phosphorus Measured Monthly Near the Mouth of Issaquah Creek from March, 1986, to February, 1987

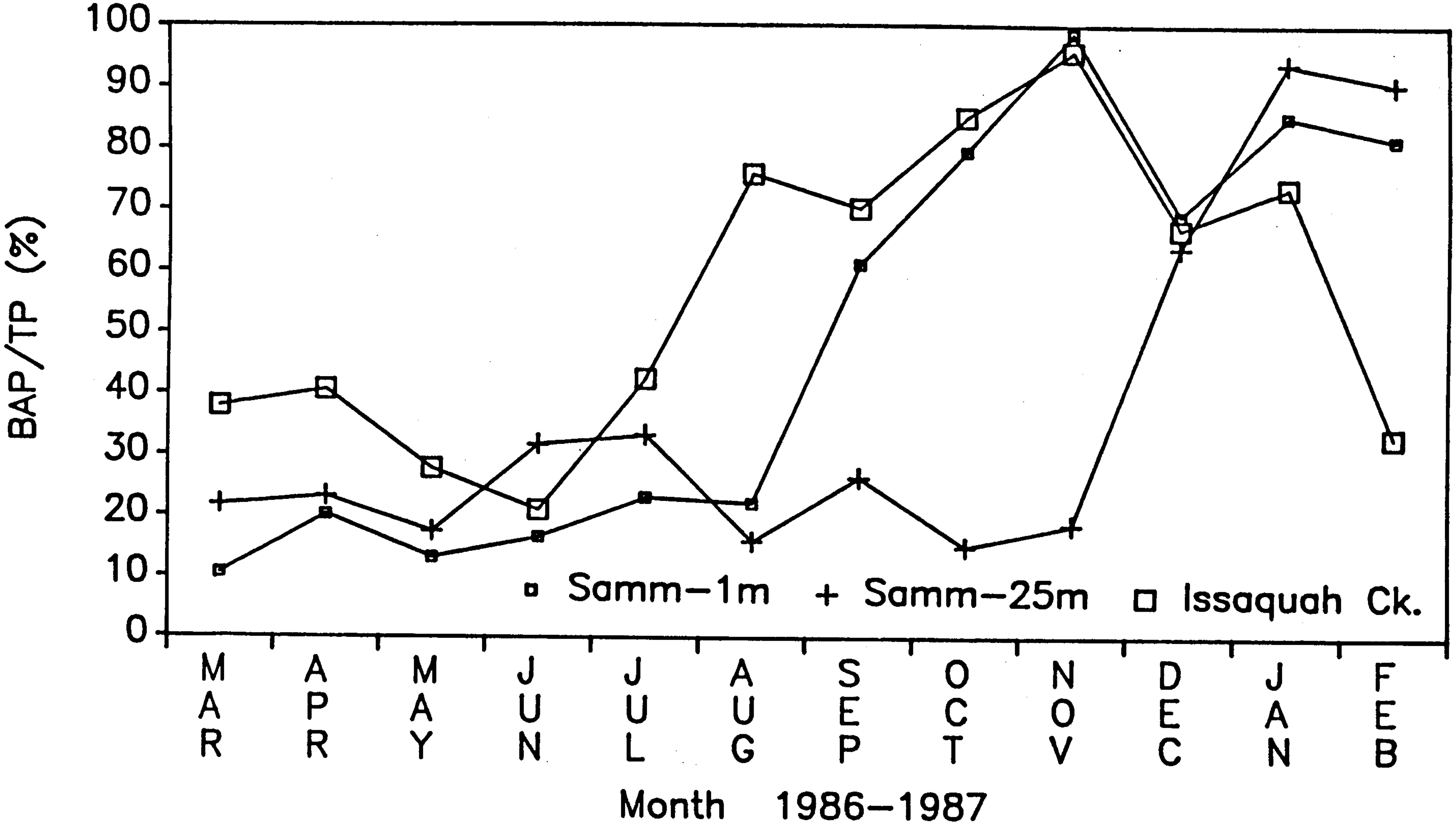

Figure 4. Comparison of Monthly BAP/TP Ratios for Lake Sammamish and Issaquah Creek from March, 1986, to February, 1987

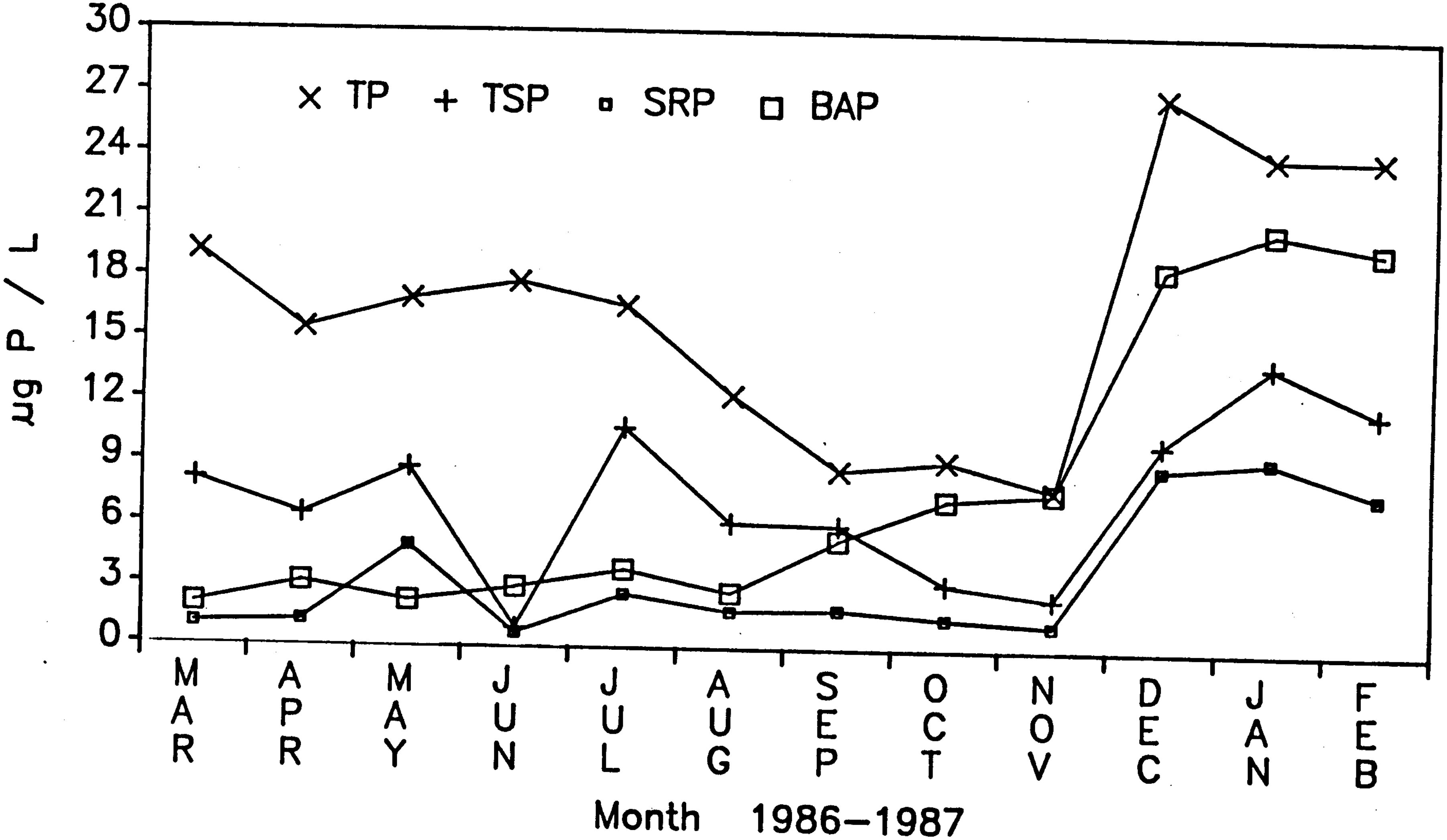

Figure 5. Concentrations of Various Forms of Phosphorus Measured Monthly at 1-Meter Depth in Lake Sammamish from March, 1986, to February, 1987

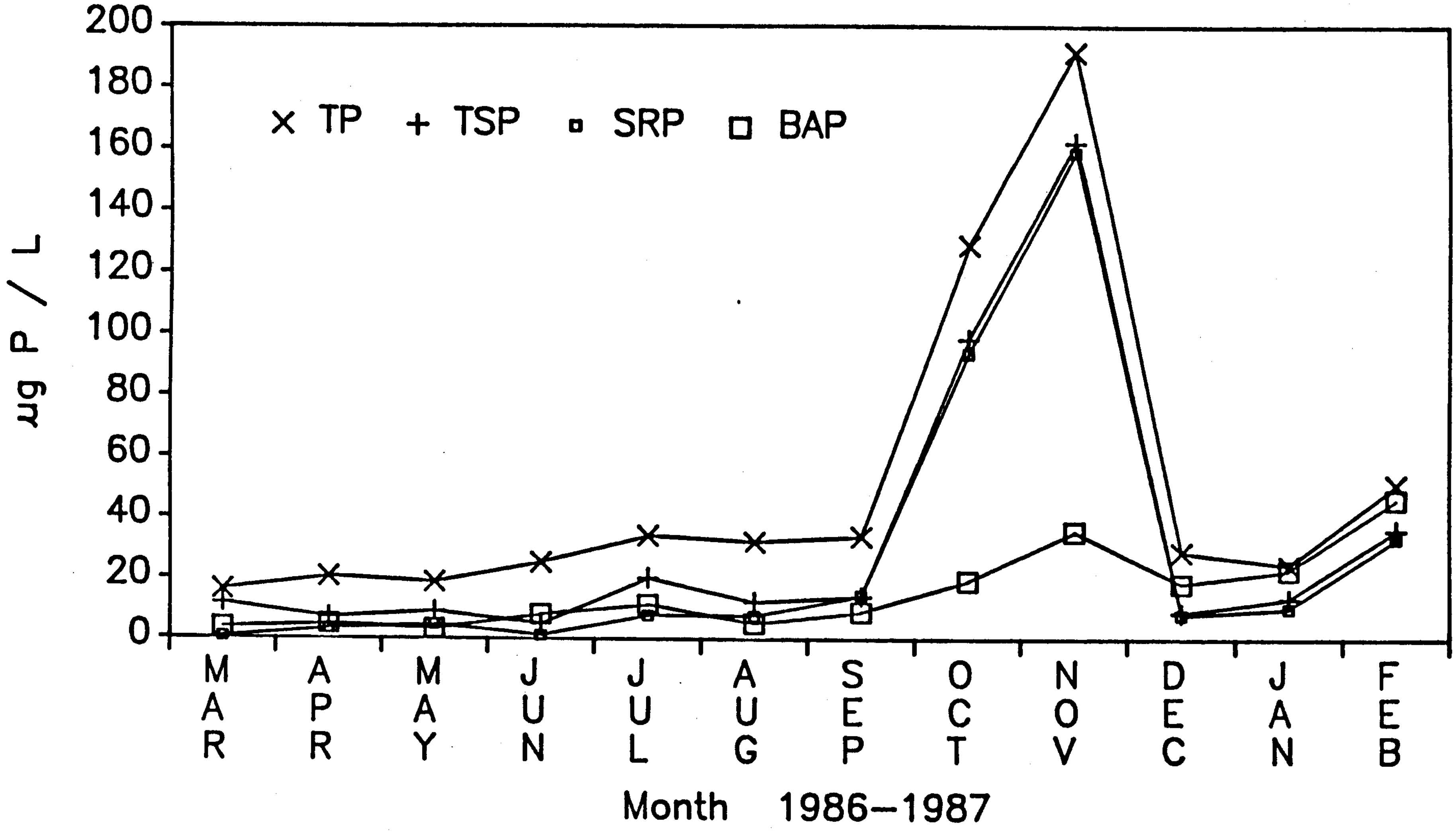

Figure 6. Concentrations of Various Forms of Phosphorus Measured Monthly at 25-Meter Depth in Lake Sammamish from March, 1986, to February, 1987

destratification. Similar to Issaquah Creek, BAP followed SRP more closely than TP, and the BAP/TP ratio was greatest when BAP was highest.

The increase in BAP and BAP/TP in the winter was probably the result of lake turnover and mixing of the high-SRP hypolimnetic water in November. This effect is partially apparent in the results from the hypolimnion, where SRP and TSP reached peak concentrations similar to TP in October-November, prior to turnover (Figure 6). The fact that BAP did not increase at that time is probably due to the analytical procedures and the high ferrous iron content of anoxic hypolimnetic waters. Autoclaving the oxygen-depleted water probably oxidized the Fe^{+2}, which sorbed the SRP, rendering it unavailable in the bioassay. Samples for SRP were not autoclaved. An alternative explanation is that the high winter BAP in the lake was a result of the high values in Issaquah Creek during the fall.

The low BAP and BAP/TP values during spring-summer are also probably due to the higher abundance of algae and their excretory products during that period.

CHEMICAL VERSUS BIOASSAY DETERMINATION OF BAP

The best fit between bioassay-determined BAP and an alternative chemical measure resulted from a linear regression of BAP on the sum of SRP and NaOH-extractable P. Figures 7 and 8 illustrate the relationships for Lake Sammamish and the other local lakes and for Issaquah Creek, respectively.

The regression equation for Lake Sammamish and the other lakes represented by Figure 7 is:

$$\text{BAP} = 1.2\ (\text{SRP} + \text{NaOH-Extractable P}) - 1.2 \qquad (r^2 = 0.80)$$

There seems to be general agreement in the data among 27 lakes in the area sampled in August, monthly samples from Lake Sammamish, and December samples from five of the 27 local lakes. The December samples were collected in order to represent the high runoff period. Therefore, Lake Sammamish is like other lakes in the region from the BAP standpoint. The agreement found means that the above equation can be applied to local lakes in any season to estimate BAP from chemical measurements. The latter are less time consuming than bioassays.

The regression equation for Issaquah Creek represented by Figure 8 is:

$$\text{BAP} = 1.3\ (\text{SRP} + \text{NaOH-Extractable P}) - 1.6 \qquad (r^2 = 0.82)$$

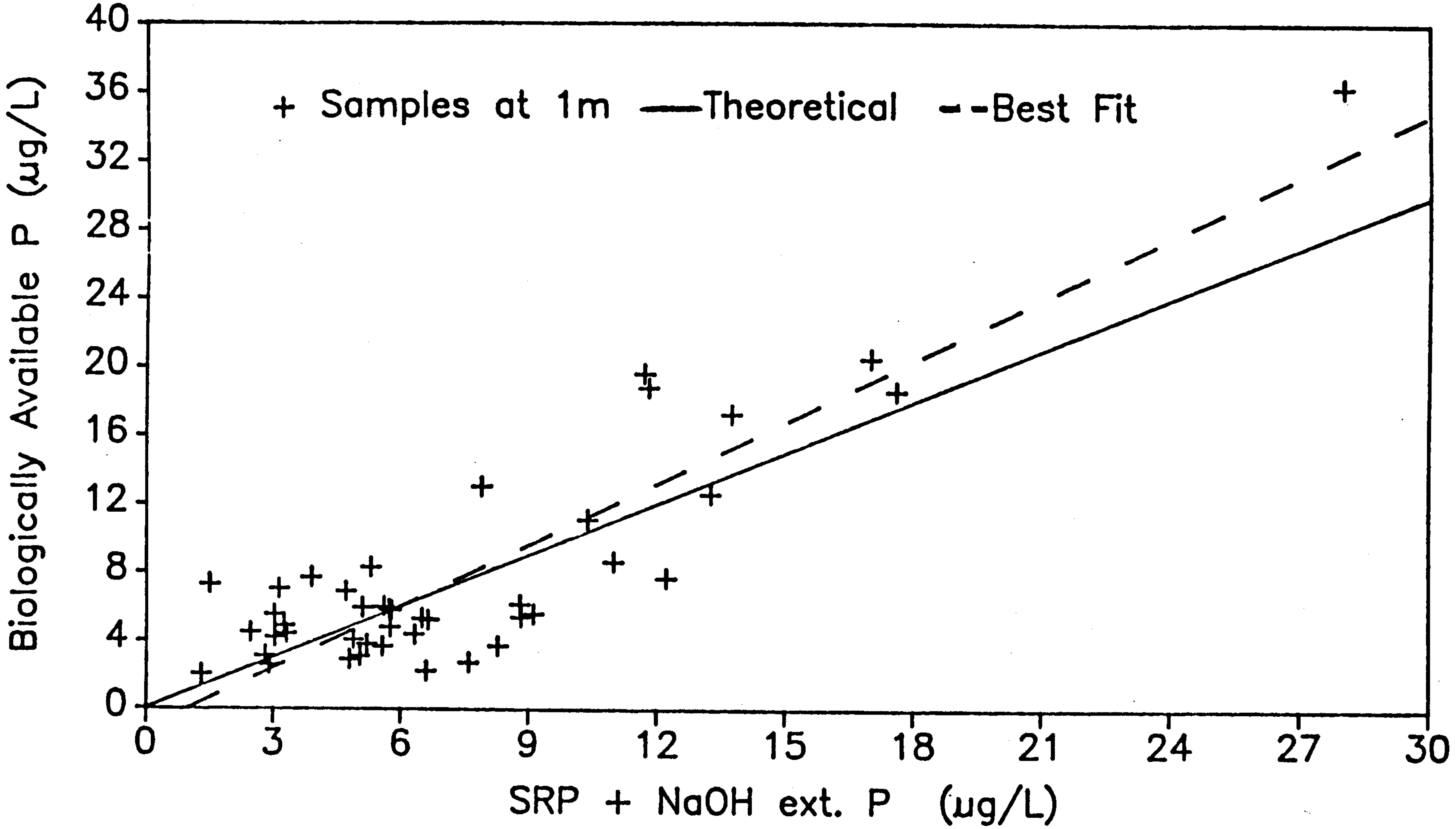

Figure 7. Relationship Between Bioassay-Determined BAP and SRP + NaOH-Extractable P for Surface Samples in Lake Sammamish and Other Local Lakes

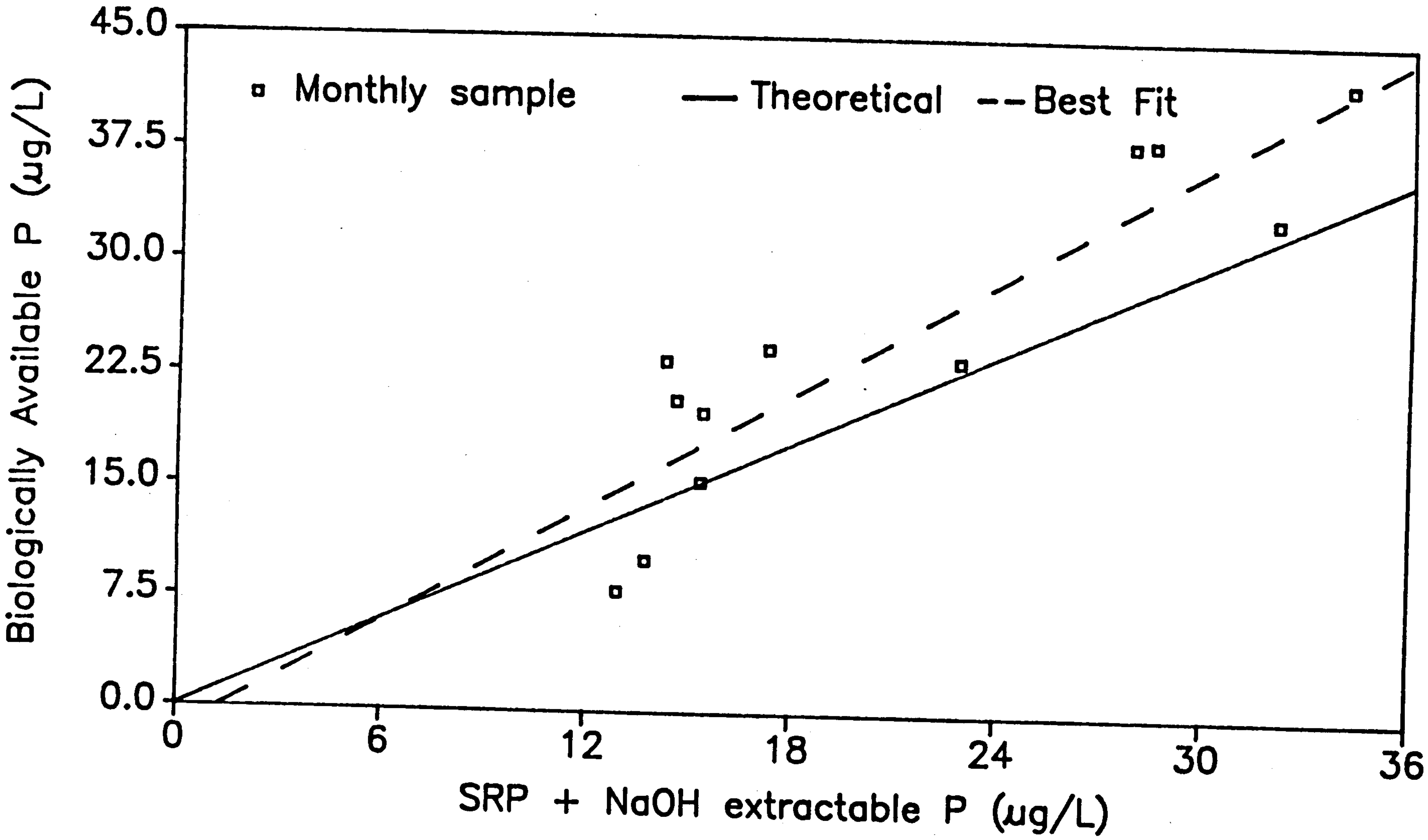

Figure 8. Relationship Between Bioassay-Determined BAP and SRP + NaOH-Extractable P for Issaquah Creek

The slope and intercept of this equation are very similar to those for the lake equation.

Additional analysis of the data showed an even higher correlation coefficient if Issaquah Creek and Lake Sammamish data were treated by multiple correlation (J.I. Shuster, personal communication). The following equations resulted from separating the effects of SRP and NaOH extractable P:

Issaquah Cr. BAP = 0.917 SRP + 1.97 NaOH ext P (r^2 = 0.98)

L. Sammamish BAP = 1.75 SRP + 0.413 NaOH ext P (r^2 = 0.92)

Combining both data sets from the stream and lake gave the following equation:

$$BAP = 1.06 + 1.46 \text{ NaOH ext P}$$

Chemical descriptions of BAP taken from Golterman et al. (1969) and Cowen and Lee (1976) tended to overestimate BAP in the local lakes except for the December samples (Figures 9 and 10). Both of these descriptions included TSP, which apparently measures P that is available when algal abundance is low in winter but not so in summer, when algae and their excretory products are more abundant. This comparison further supports the use of a portion of the TSP (SRP) plus NaOH-extractable P to estimate BAP. Consideration of both figures demonstrates further that the BAP fraction from Lake Sammamish is not different from that in other local lakes.

BAP MODELING

Calibration and Verification

Figures 11 and 12 show the BAP model calibration and verification compared to observed BAP or values estimated from TP measurements and the BAP/TP ratios determined in this research. There was good general agreement between observed and predicted values for both the calibration and verification data sets (r^2 = 0.77). The one period of disagreement was during February, when estimated BAP values considerably higher than predicted were consistently observed. The higher observed than predicted values occurred in all years for which the model was run (1970-75 and 1981-86) (see Appendix).

This poor agreement probably resulted partly from the very high BAP/TP ratios observed in the lake during the winter of 1987, while such high ratios were not present in the inflow during that time. This supposition suggests that the high winter BAP values originated not from the inflow, which is represented in the model, but from the hypolimnion. That process is not well

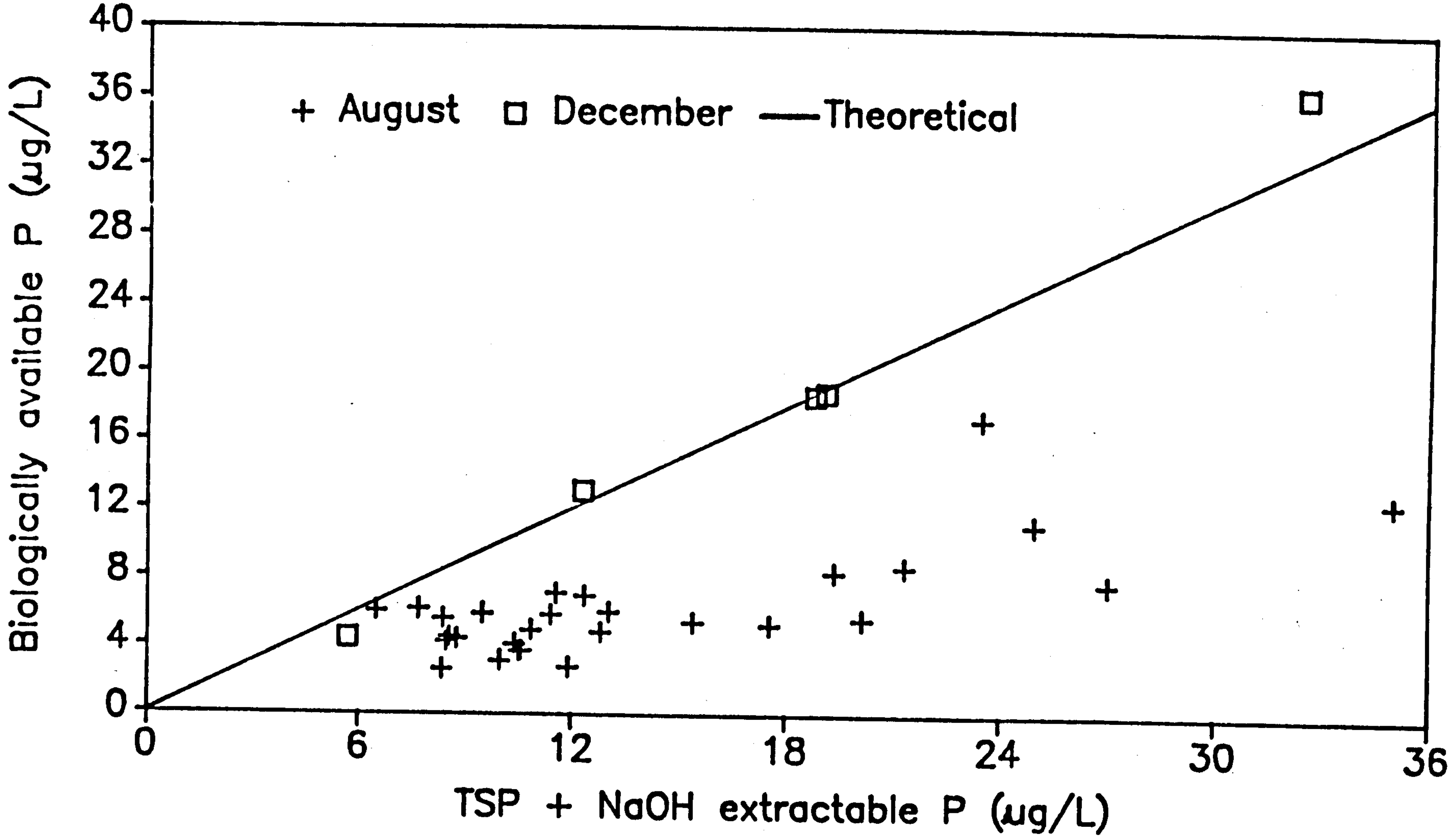

Figure 9. Comparison of BAP in Local Lakes to Estimates by the Equation of Golterman et al. (1969)

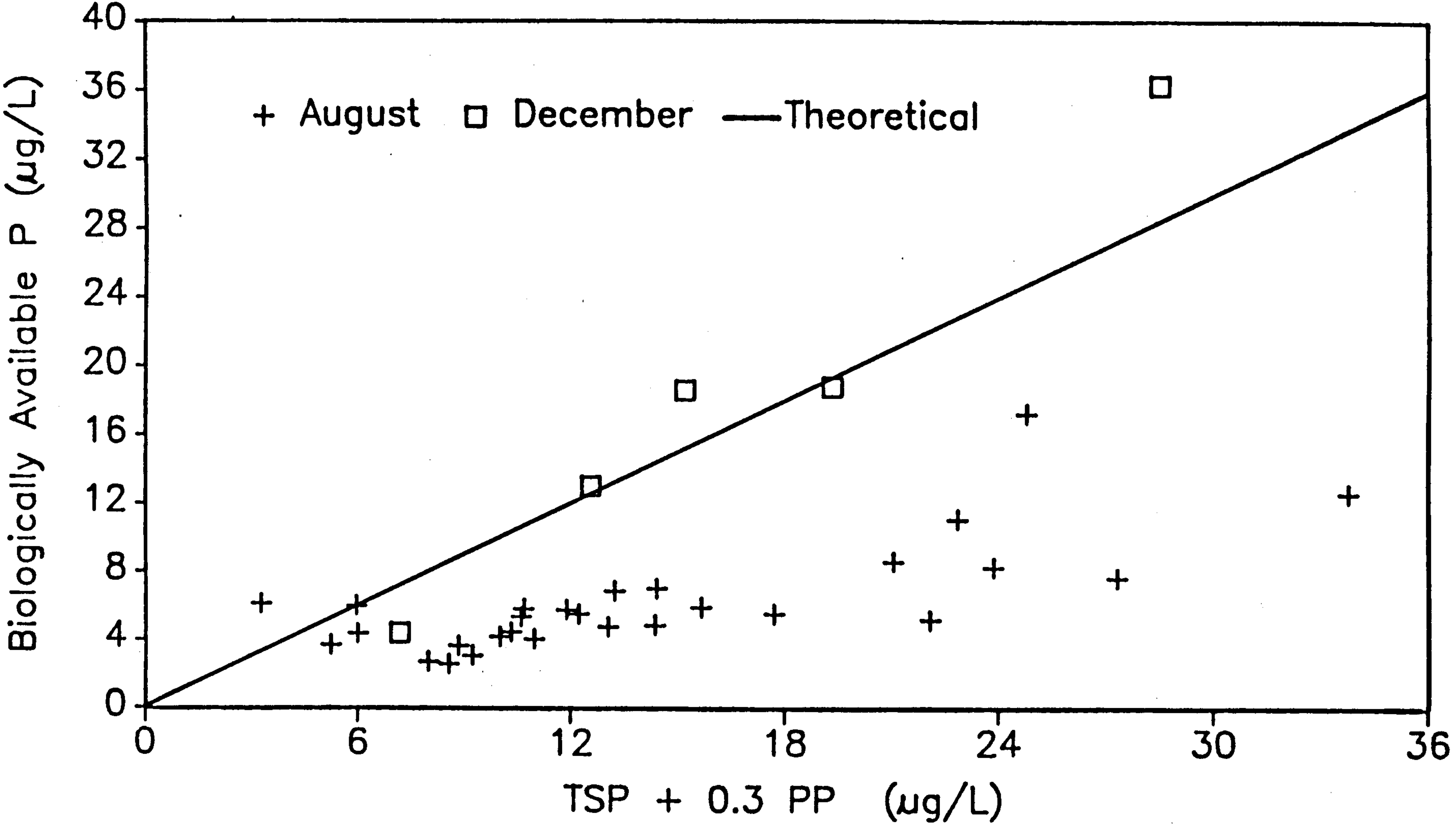

Figure 10. Comparison of BAP in Local Lakes to Estimates by the Equation of Cowen and Lee (1976b)

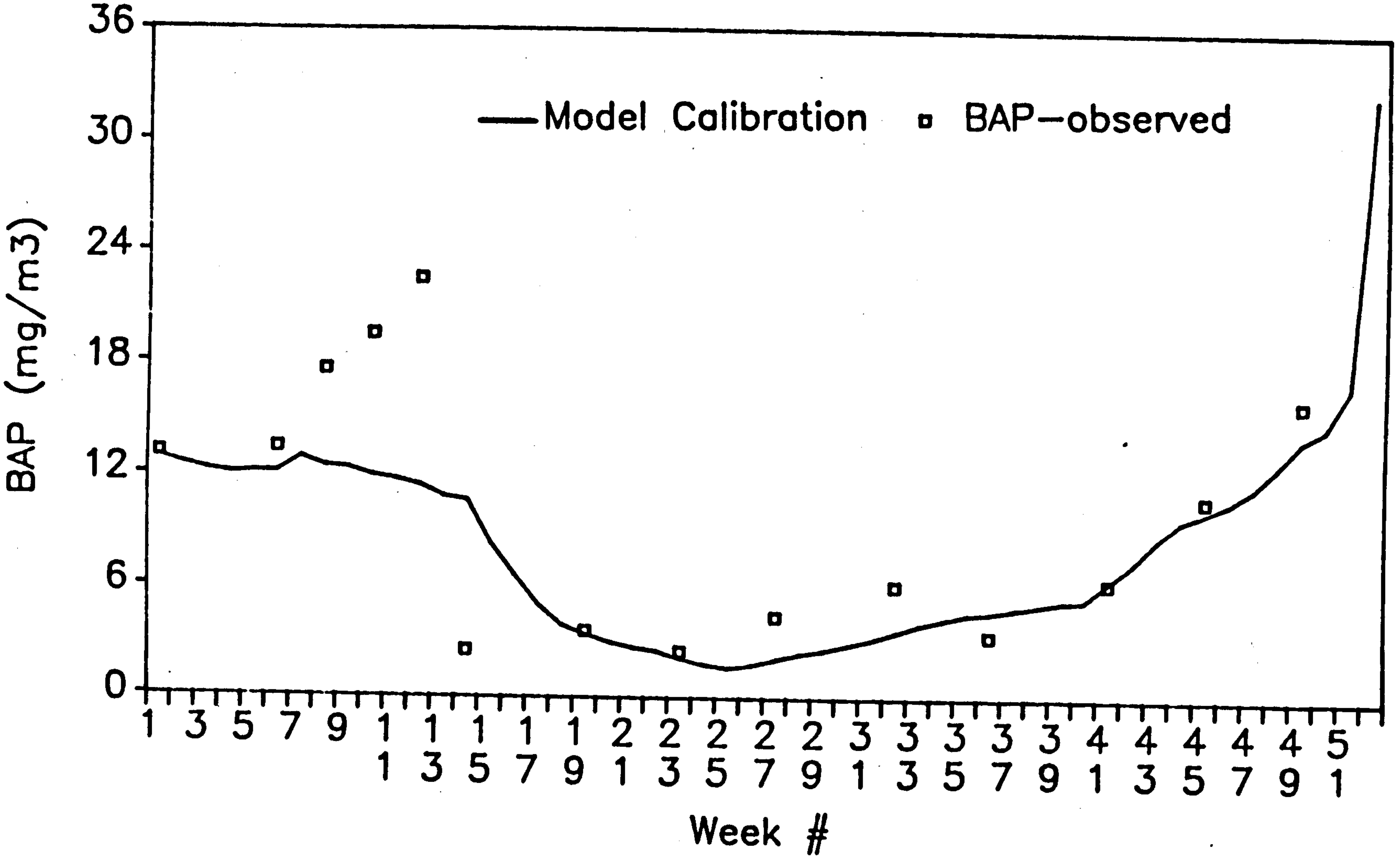

Figure 11. Model Calibration Compared to Observed or Estimated Whole-Lake BAP from December 1, 1985, Through November 30, 1986

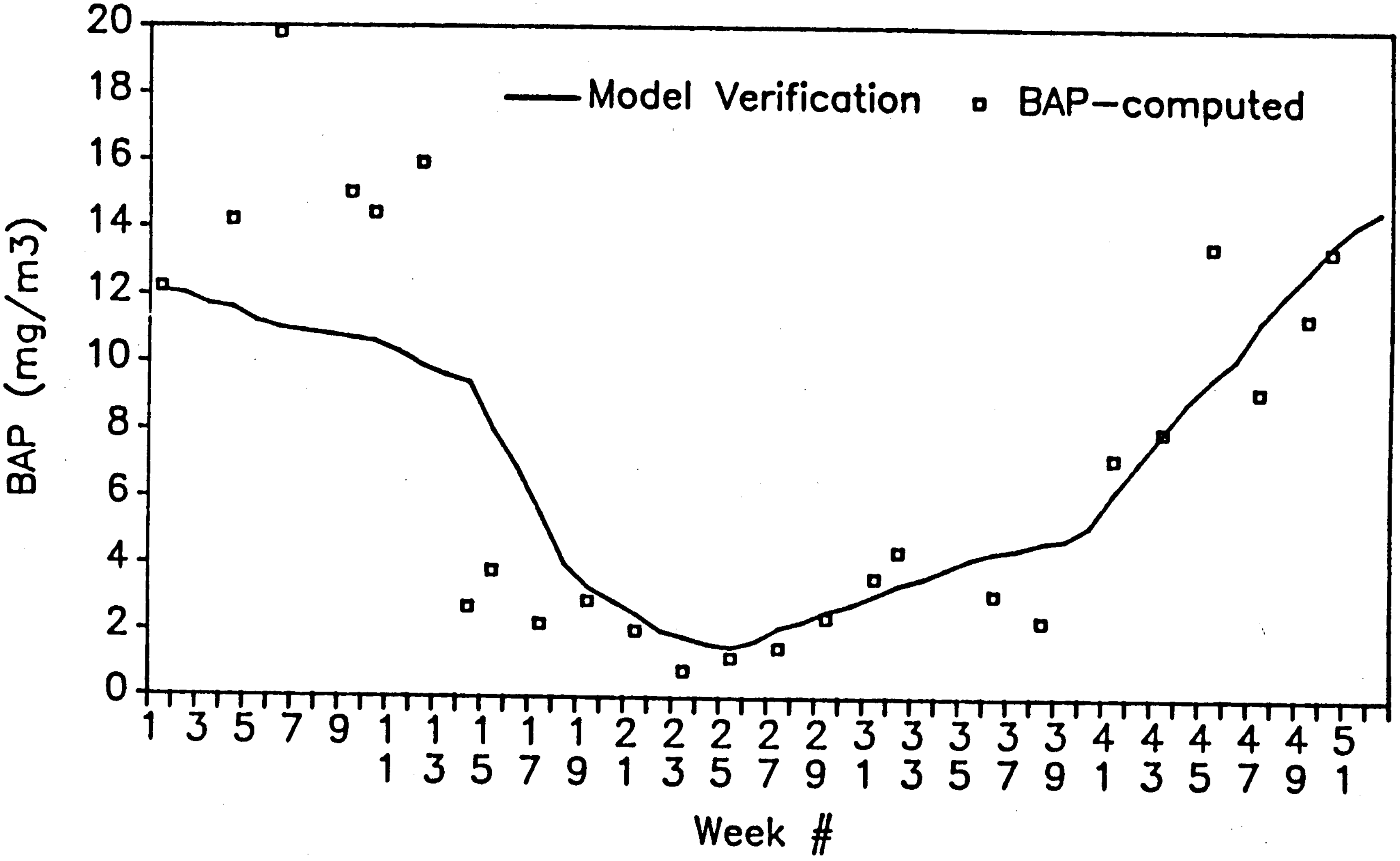

Figure 12. Model Verification Compared to Estimated Whole-Lake BAP from December 1, 1984, Through November 30, 1985

represented in the model. The high winter BAP in the lake is not represented even for the calibration year. Thus, Issaquah Creek is not a likely source for the high lake BAP. This failure of agreement during winter is not serious, however, because the predictions for BAP during most of the year are in general agreement with observed values, which is most important for chl a and transparency predictions.

A different type of model calibration was performed by comparing the BAP predicted in Lake Sammamish from measured Issaquah Creek P loading and from P land use yield coefficients from the literature. This comparison, for 1985-86, is illustrated by Figure 13. The plot shown used yield coefficients from the top of the literature ranges and achieved very good agreement with the prediction from measured loadings. Lower coefficients did not produce as good agreement. This result confirms the tendency noted by Welch et al. (1985) for the Issaquah Creek catchment to yield relatively high P mass loadings. Further predictions used the high literature values shown to be most appropriate by this analysis.

Urban Stormwater Versus Sewage Effluent

Whether or not the response of Lake Sammamish to increased TP loading from urban stormwater runoff is similar to the way it responded to increased wastewater TP is difficult to determine from the data presented here. BAP was not determined during prediversion years. The present study showed that most of BAP is SRP. Since the SRP/TP ratio in treated sewage is considerably higher (0.8-0.9) than that in Issaquah Creek now (0.3-0.4), the response will probably be less from stormwater. However, the wastewater discharge was about 2 km upstream from the lake, and that distance probably resulted in much of the SRP being cycled through periphyton and transported to the lake as particulate P. Thus, the BAP/TP ratio in Issaquah Creek prior to diversion was probably less than in sewage effluent.

LAKE RESPONSE MODELING

Figure 14 illustrates the chl a - BAP relationship that provided the best fit for Lake Sammamish. It is a linear relationship between summer (June 21 - September 20) mean epilimnetic chl a and spring (March 21 -

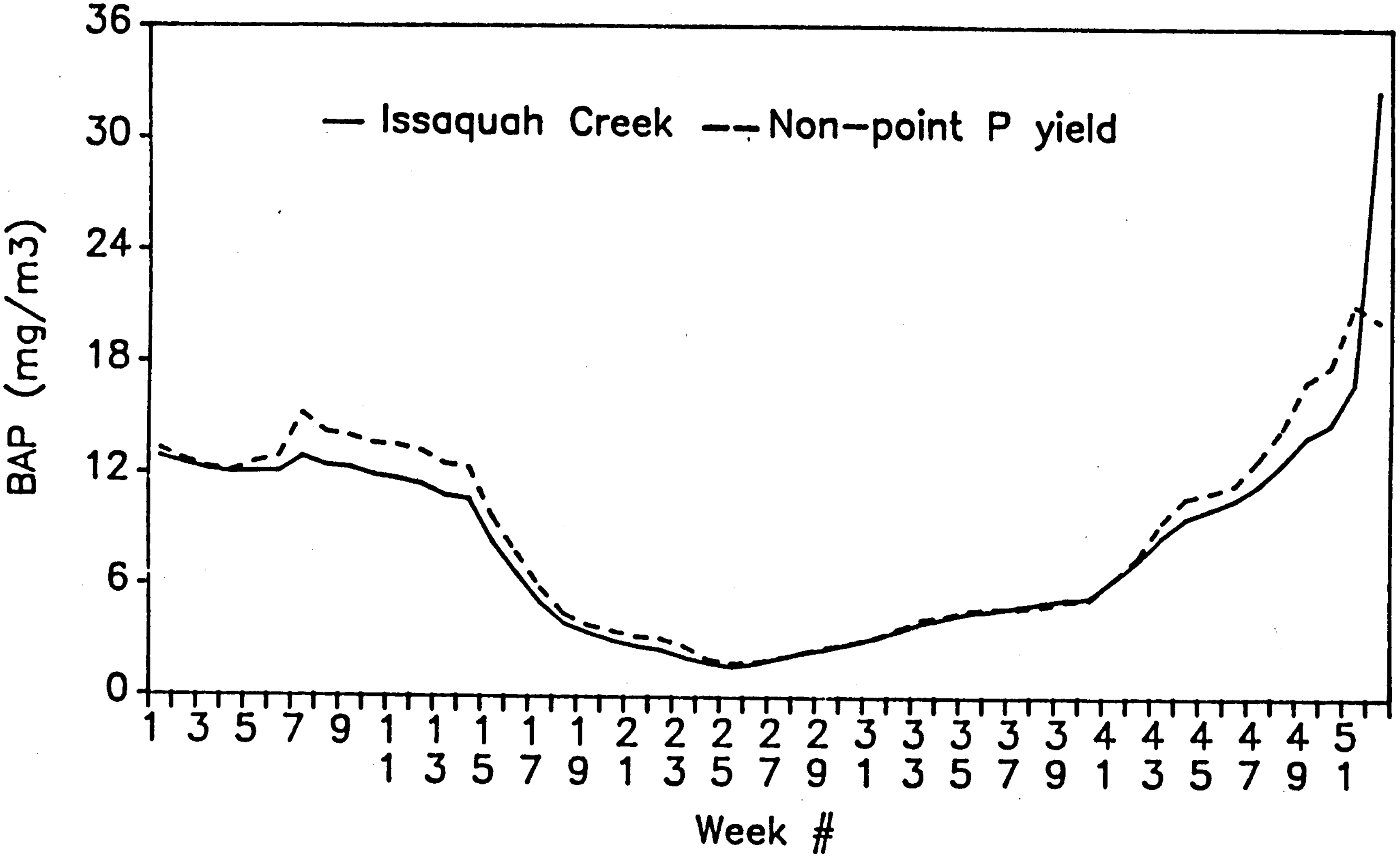

Figure 13. Lake Sammamish BAP Predicted from Measured Issaquah Creek P Loadings and from the Highest P Land Use Yield Coefficients in the Literature

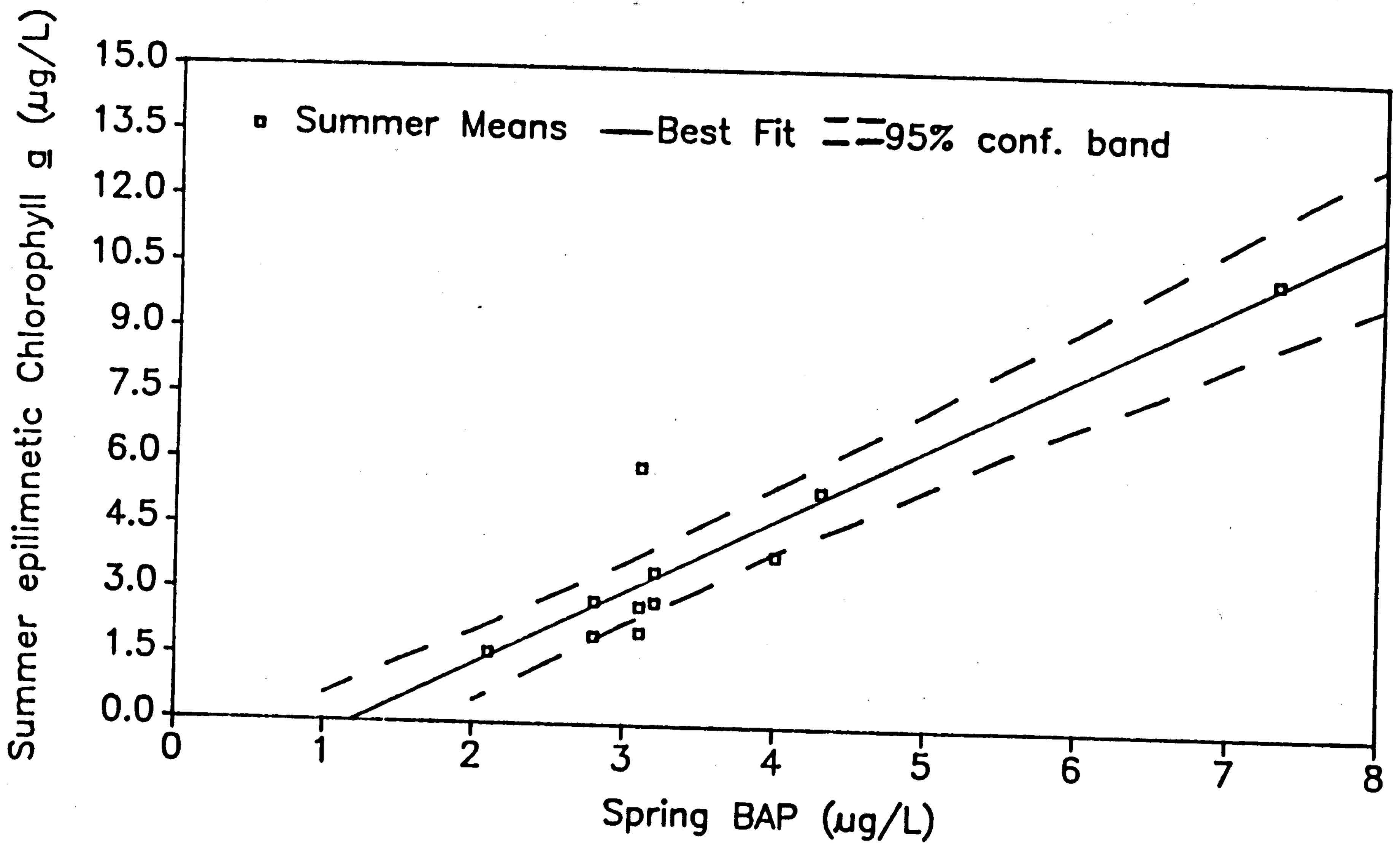

Figure 14. Summer (June 21 - September 20) Mean Epilimnetic Chlorophyll <u>a</u> Versus Spring (March 21 - June 20) Mean BAP in Lake Sammamish

June 20) mean BAP. The associated linear regression equation is:

$$\text{Chl } \underline{a} = 1.7 \text{ BAP} - 2.1 \quad (r^2 = 0.84)$$

The equation did not change if the high value was removed from the regression. This equation replaced the logarithmic relationship of Carlson (1977) to model response to BAP for Lake Sammamish.

Figure 15 shows a comparison of summer mean Secchi depth versus summer mean chl $\underline{a}$ as observed in Lake Sammamish and as predicted by Carlson's (1977) model. This fit is reasonably good, and no better one was suggested by the data. Therefore, prediction of water clarity continued to be based on the Carlson model.

The use of spring BAP as the best indicator of summer chl $\underline{a}$ has implications for the effectiveness of externally versus internally loaded P and, hence, for the prospects of controls on external versus internal P. The BAP model treats one lake concentration only; the whole-lake, volume-weighted mean. No distinction is made between epilimnetic and hypolimnetic concentrations or the exchange between the two volumes during the stratified period. As a result, the model gives no indication as to the relative importance of internal versus external BAP for summer algal growth in the epilimnetic lighted zone. However, the fact that spring BAP is the best indicator for summer chl $\underline{a}$ suggests less importance of internal P; that released from hypolimnetic sediments and entrained or diffused into the epilimnion. Substantial contributions from the hypolimnion to the epilimnion during summer would have produced less dependence of summer chl $\underline{a}$ on spring BAP than observed.

Furthermore, hypolimnetic P did not increase markedly until September (Figure 6), so there was little opportunity for high hypolimnetic concentrations to immediately affect summer (June - August) chl $\underline{a}$. There was opportunity , however, for residual hypolimnetic BAP, remaining in the water column until spring, to influence the spring BAP - summer chl $\underline{a}$ relationship, although the extent of that influence is unknown.

Vertical transport of hypolimnetic P through entrainment diffusion has been shown to be important in other lakes with high internal loading (Larsen et al., 1981), and it may have been more important in Lake Sammamish before and immediately after sewage diversion when anaerobic conditions and sediment P release were more extensive and apparently delayed recovery (Welch et al., 1986). In fact, the prominence of blue green algae, especially in the fall,

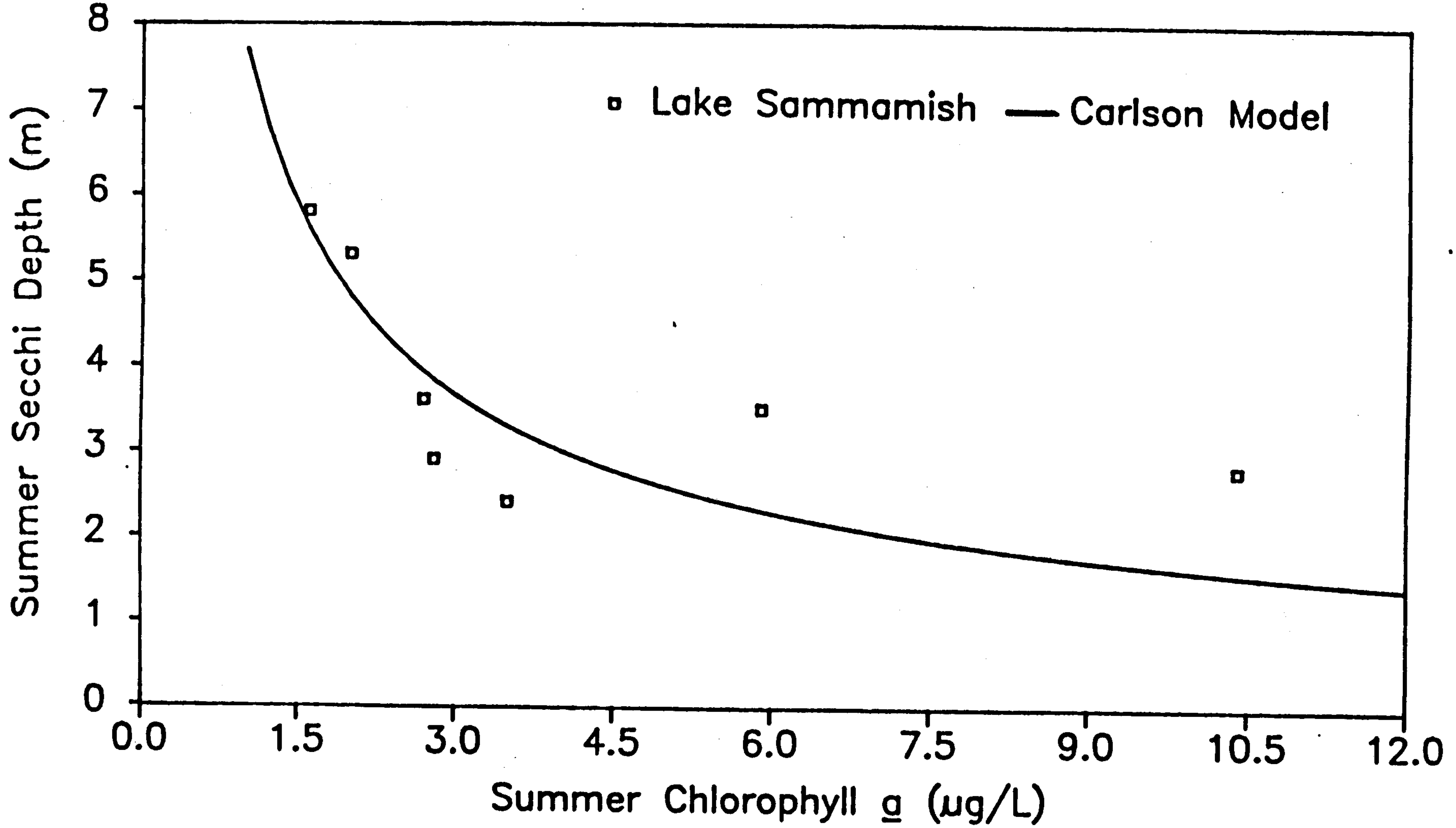

Figure 15. Observed and Predicted (Carlson, 1977) Summer Mean Secchi Depth Versus Summer Mean Chlorophyll *a* in Lake Sammamish

declined as the fall hypolimnetic P content decreased following diversion (Welch, 1977). Now, internal loading appears to be less effective than external loading in controlling summer chl a.

MODEL APPLICATION

BAP Seasonality

Figure 16 illustrates a lake-year (December 1 to November 30) comparison over BAP over time between the 1985-86 calibration year and 2000 for low and high Issaquah Creek flow conditions. Low and high flows were defined the same as by Welch et al. (1985): high flow = 5.63 $m^3 s^{-1}$; low flow = 2.59 $m^3 s^{-1}$. This forecast assumed development of the watershed at the level described by Welch et al. (1985) without the application of any management strategies.

It may be seen that BAP is predicted to be higher than 1985-86 levels under either flow condition in the fall and winter. During the remainder of the year, BAP is forecast to be higher than in the calibration year under low flow conditions but lower if there is high tributary flow and more rapid flushing.

Predicted Lake Response

Figures 17-19 present the probability distributions of predicted annual mean BAP and summer mean chl a for 1984 and for 2000, with and without the stormwater controls defined earlier. These plots were developed using the minimum efficiencies suggested by the literature review, also cited earlier. Minimum efficiencies were selected, rather than the median values used in the parallel analysis by Welch et al. (1985) using the old model, because of the dissolved state of much of the BAP. The efficiencies could be higher with soil infiltration particularly, and with application of the best design, operating and maintenance practices to retention basins and vegetated overland flow channels. Therefore, the plots represent a conservative approach to predicting lake response with controls. The right-hand portions of the curves are dashed to indicate that the available Issaquah Creek flow record on which the analysis was based does not extend into that region. Predictions were also made for 1990 but were not graphed because of the proximity of that year to the present.

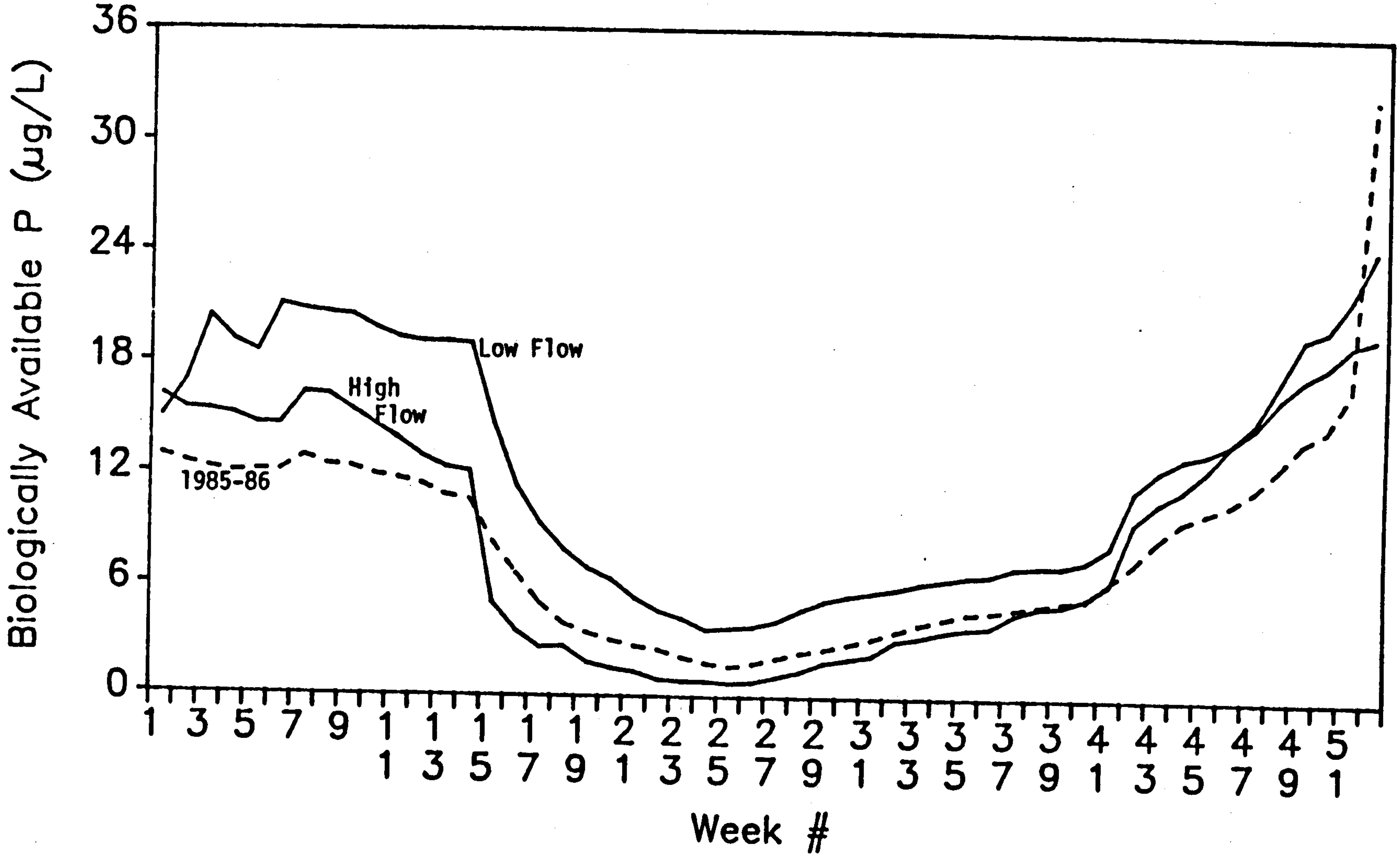

Figure 16. Predicted Lake Sammamish BAP for 2000 Under High and Low Issaquah Creek Flow Conditions, Compared to 1985-86, for Period December 1 - November 30

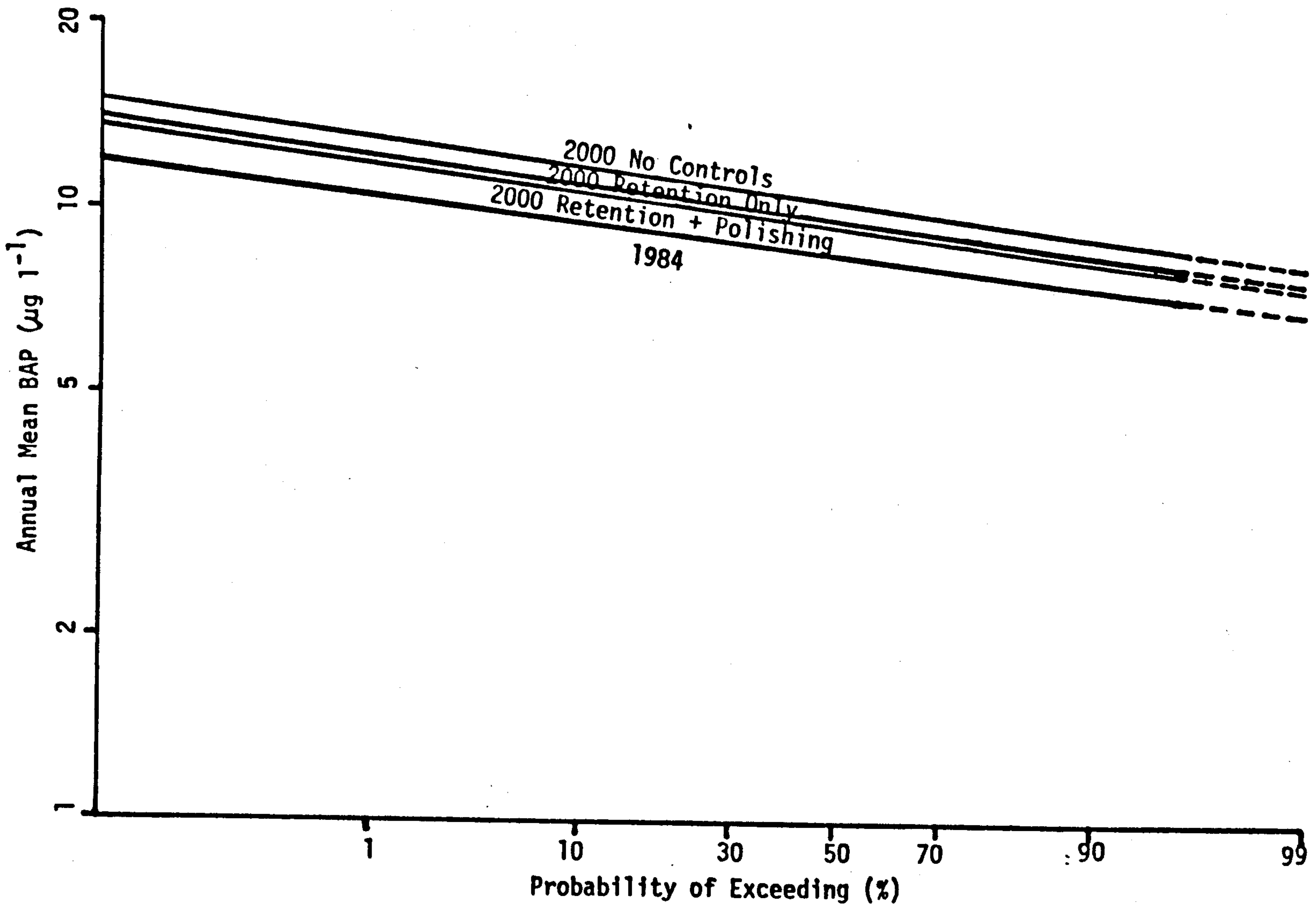

Figure 17. Predicted Whole-Lake Annual Mean BAP for 1984 and 2000, With and Without Stormwater Controls

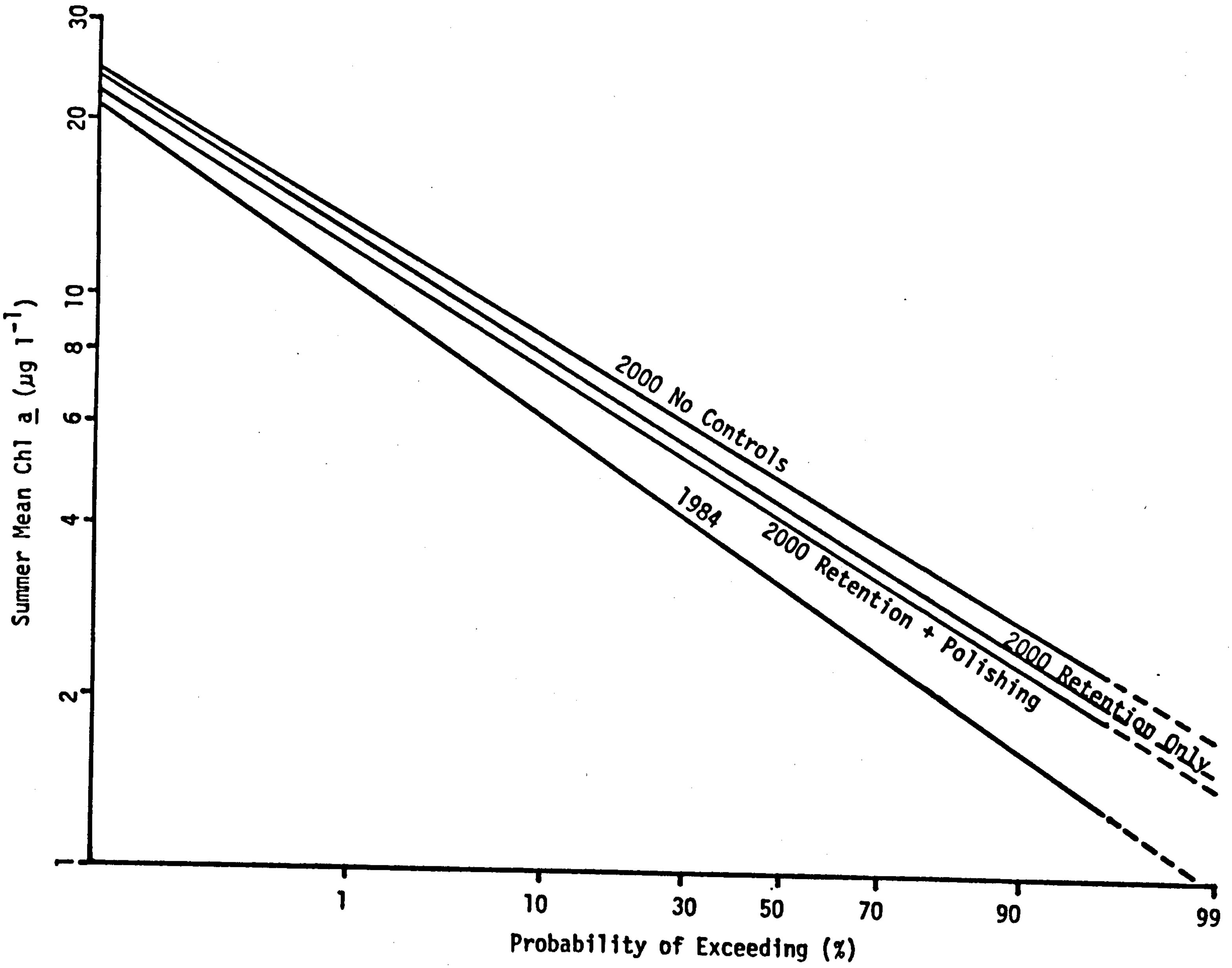

Figure 18. Predicted Summer Mean Epilimnetic Chlorophyll a for 1984 and 2000, With and Without Stormwater Controls

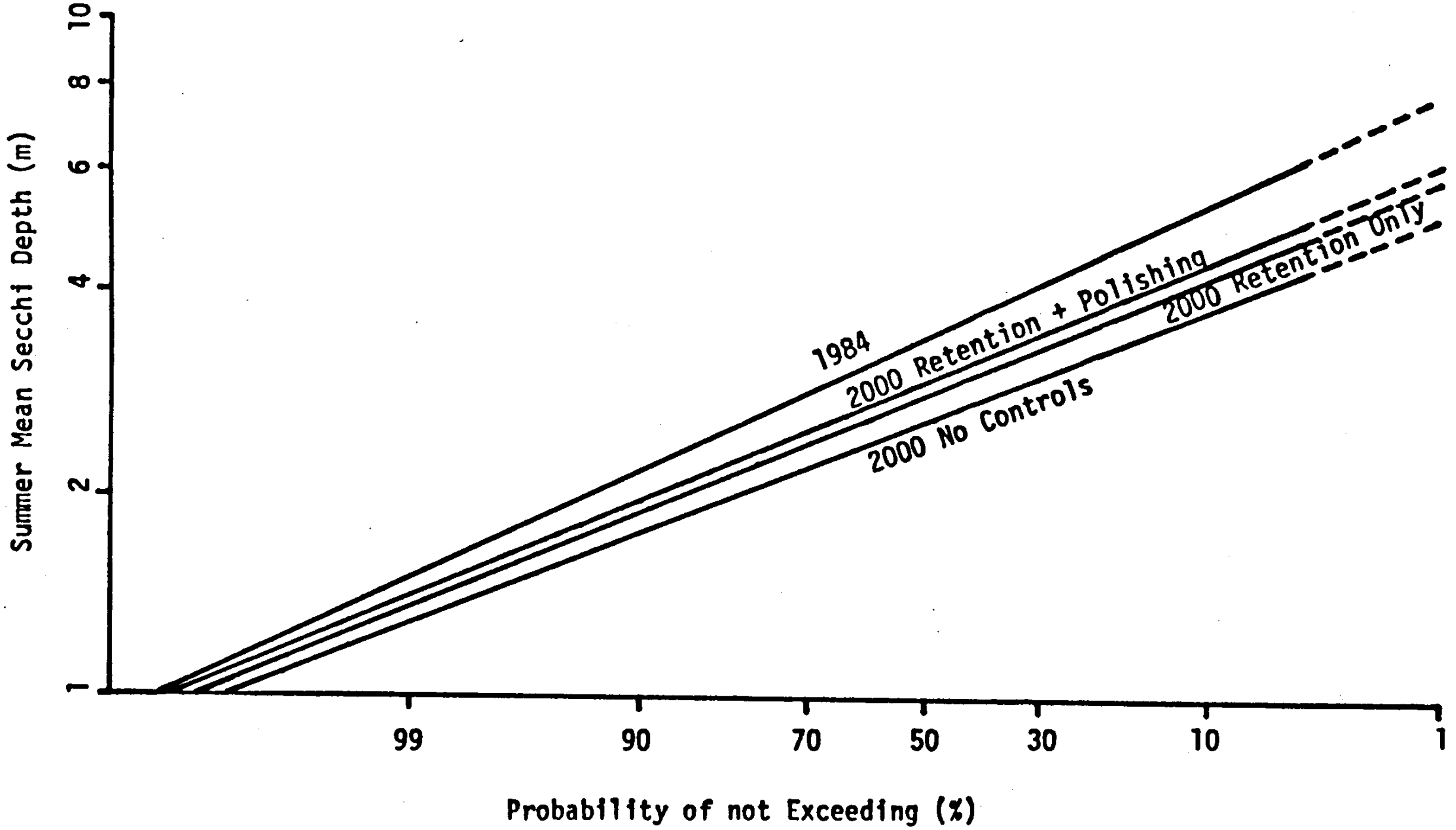

Figure 19. Predicted Summer Mean Secchi Disk Transparency for 1984 and 2000, With and Without Stormwater Controls

If Figures 18 and 19 are compared to Figures 19 and 21 in Welch et al., (1985), it may be seen that the slopes of the two sets of curves differ. The consequence of this difference is that the new model predicts a greater chance of exceeding high chl a levels (and falling below low Secchi depths) than the old model, but also a greater chance of falling below low chl a levels (and exceeding high Secchi depths). The latter predictions represent the recent experience in the lake better than did the old model. The implication of the improved model (based on BAP) is that deterioration of trophic state indicators is less likely than forecast by the old model, but that less probable events will cause greater deterioration than predicted by the original model. The two models give nearly identical predictions at the 50 percent probability level (with equivalent assumptions on effectiveness of controls).

Table 1 summarizes predictions for the same 1984 base year used by Welch et al. (1985) and for 2000 at three probability levels. This table gives ranges based on least and most optimistic levels of performance by control measures. For comparison, 1986 mean summer chl a was 1.7 and Secchi depth was 5.3 m. The base-year analysis shows that the model and long-term hydrologic record forecast a relatively low probability of achieving these favorable trophic state indicators even with no more development.

It may be seen that development without controls in 2000 is forecast to increase annual mean BAP over the base-year predictions by approximately 20 percent at any probability level. Summer mean chl a would increase by about 35-75 percent and Secchi depth would decrease by approximately 15-30 percent, depending on the probability level. A 3.5 m summer mean Secchi depth is expected to be exceeded one year in two now but only about one in seven years in 2000, without controls. While a 2.0 m summer mean Secchi depth, a common criterion for defining eutrophy, has only a one in 20 chance in the base year, the expected frequency rises to one in five years by 2000, without controls.

Even with the most optimistic assumptions of performance, retention alone cannot maintain the base year trophic state under 2000 development conditions. With the lowest levels of performance, water quality advantages of this strategy are marginal. Therefore, making their application worthwhile would require maximizing performance through good design, operation, and maintenance.

Table 1. Predicted Lake Sammamish Response to Increased Phosphorus Loading Resulting from Development, With and Without Storm Runoff Controls, for Three Probability Levels

Year	Case	Probability (%)	Annual Mean BAP ($\mu g\ l^{-1}$) Will Exceed[a]	Summer Mean Chl a ($\mu g\ l^{-1}$) Will Exceed[a]	Summer Mean Secchi Depth (m) Will Not Exceed[a]
1984	Base	5	10.0	7.4	1.9
		50	8.6	3.4	3.5
		95	7.3	1.4	6.2
2000	No controls	5	12.0	10.0	1.6
		50	10.2	4.7	2.6
		95	8.6	2.4	4.3
	Retention only	5	10.8 - 11.2	8.6 - 9.4	1.8 - 1.7
		50	9.2 - 9.6	4.0 - 4.4	3.1 - 2.9
		95	7.8 - 8.2	1.8 - 2.1	5.1 - 4.7
	Retention and Polishing	5	9.5 - 11.1	6.8 - 8.8	2.1 - 1.7
		50	8.2 - 9.5	2.8 - 4.2	3.8 - 2.9
		95	7.0 - 8.0	1.2 - 1.9	6.9 - 4.9

[a] First number in pair is associated with the most optimistic treatment effectiveness, and the second with the least optimistic effectiveness.

Model predictions indicate that retention plus polishing could maintain mid-1980's conditions with the highest levels of performance. However, minimal effectiveness would yield almost no advantage over the retention-only case. Thus, it is shown to be imperative to maximize performance to warrant the expense of installation. Being able to achieve maximum theoretical effectiveness is unlikely, but 100 percent BAP removal could be obtained in soil infiltration systems if they are kept operating properly. The case analyzed here considered these systems only in certain new commercial areas where soils are suitable. With the recognition of the importance of soluble P in bioavailability, searching for more infiltration opportunities in residential areas is a recommended management action.

It must be noted that this analysis neglects any increase in sediment P release that might accompany slowly progressing eutrophication. The increased internal loading could accelerate the rate of trophic change beyond that predicted.

MANAGEMENT RECOMMENDATIONS

DISCUSSION

Results of this study do not change the general management recommendations advanced by Welch et al. (1985), but do change the emphasis in some cases. The demonstration of the large storm event-related P loadings transported in Issaquah Creek increases the focus on construction-phase controls. Lack of effective controls during construction could cancel the gains from expensive, well-designed and well-operated measures installed in finished projects. The original recommendation relative to construction practices is strengthened in the summary below.

The new results have clarified the risk that exists of applying costly control measures and not achieving the expected benefits. The available techniques, except for soil infiltration, are less effective in removing soluble than particulate phosphorus, but the BAP results have demonstrated the need to maximize dissolved P reduction. Therefore, a careful search should be made for infiltration opportunities in residential as well as commercial areas. Suitable care should be taken to ensure that infiltration systems have sufficient capacity for expected service conditions and are protected from solids loadings that could clog the soils.

Moreover, selection, design, operation, and maintenance of retention and overland flow facilities should proceed with a focus on maximizing soluble P capture. A few specific techniques that advance this goal are noted in the summary of recommendations that follows. These techniques are derived from other recent research and literature reviews performed by the authors. Otherwise, the research needed for definitive guidelines is lacking. It is likely that knowledge of this subject will increase in the coming years. The jurisdictions should stay aware of developments and, when possible, adapt the facilities and their management to improve performance.

It must be recognized that the chance is significant that passive treatment facilities will not regularly receive the maintenance attention that is needed for the most effective performance. This uncertainty heightens the risk that the benefits expected for the investment will not accrue. If state-of-the-art design, operation, and maintenance cannot be ensured, the analysis demonstrates that maintaining the current good Lake Sammamish water quality will require controls on the extent of development. The controls that would yield the greatest advantages are listed in the summary.

In the current climate of rapid development of the watershed, the timeliness of implementation of management actions is important to prevent the onset of water quality deterioration. A delay of even another year or two could result in the loss of a significant portion of the benefits that could accrue from an effective management program. While not all the knowledge that might be desired is available, the outlines of such a program are clear and it should be instituted posthaste.

SUMMARY

1. Develop a basis for specifying sedimentation ponds in construction areas. Give particular attention to areas that are steep, near a water body, relatively large, and/or will have open ground during the storm season.
2. In addition to specifying sedimentation ponds, apply best management practices in accordance with the Municipality of Metropolitan Seattle (1981) guide and existing regulations.
3. Review the entire watershed for soil infiltration opportunities in any projected development areas.
4. Install a system of state-of-the-art regional retention ponds, supplemented by vegetated overland flow treatment and soil infiltration of the effluent.
5. Promote soluble P removal in retention ponds by:
   - Providing long retention times and low overflow velocities ($\leq 2 \times 10^{-5}$ m s^{-1})
   - Locating outlets in positions remote from the inlets (e.g., by making length/width ratio ≥ 5)
   - Installing a series arrangement of more than one basin, instead of a single large pond
   - Vegetate pond sidewalls
   - Remove settled solids regularly on a schedule that minimizes P release

6. Promote soluble P removal in overland flow channels by:

   ·Providing sufficient length (60 m, if possible)
   ·Maintaining close-growing, water-resistant grasses (not woody plants)
   ·Harvesting at the end of the growing season, before senescent plants can rerelease P. Mow to the height of the expected winter flow. Plow cuttings into soil elsewhere, or otherwise dispose of where pollutant loss will not affect water bodies.

7. Promote effective performance of soil infiltration facilities by:

   ·Careful site selection to avoid excessively rapid or restricted percolation rates.
   ·Effective preliminary solids removal to prevent clogging.

8. Provide buffers between developments and the lake, tributaries, and direct drainage conduits. Buffer zones both interrupt pollutant transport and offer space for control facilities.

9. In the event that long-term recommended operating and maintenance procedures for control facilities cannot be assured, protect lake water quality by reducing development through:

   ·Enlarging buffer zones.
   ·Removing steeper areas now projected for development from consideration.
   ·Restricting development on presently forested tracts.

   It is recognized that these recommendations involve more political than technical considerations and that legal processes would have to be developed for their implementation.

10. Conduct an educational program on proper use of lawn fertilizers and cautions against disposing of wastes in storm drains.

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APPENDIX

APPENDIX A

Model FORTRAN Source Code

```
C****************************************************************************C
C                                                                            C
C                                                                            C
C        Lake Sammamish Seasonal Biologically Available Phosphorus Model     C
C                                                                            C
C                 dBAP/dt=Jext/V-Q[BAP]/V-SIG[BAP]+Jint/V                    C
C                                                                            C
C****************************************************************************C
      PROGRAM SAMMBAP
      DIMENSION DEF(15,3),FRAC(17,3),RLOAD(12,3),AREA(10,3)
      REAL LINH,LA,JINH,LBAP,JBAP,LBAPIC,LNPH
      INTEGER FA
      CHARACTER*20 AD
      OPEN(1,FILE='BAPSAMM.DAT',STATUS='OLD')
      OPEN(2,FILE='BAPSAMM.OUT',STATUS='NEW')
      DATA BAPSPH,WK,BPSPMH,BAPSUH,BAPAN,BPSUM,BPANM/7*0./
      DATA DEF/.34,.22,1.5,.95,2.7,2.2,1.9,1.2,2.2,1.4,5*0.,
     +.12,.09,.70,.51,.91,.68,.70,.50,.81,.58,5*0.,
     +.12,.09,.70,.51,.91,.68,.70,.50,.81,.58,5*0./
C
      QFAC=0.70
      PHPPT=400+1100
C
C LAKE VOLUME IN Mm3, SURFACE AREA AND HYPOLIMNETIC AREA IN Mm2
C
      V=330.
      HA=13.1
      LA=19.8
      C=1
C
      WRITE(*,*)'ENTER INITIAL LAKE BAP CONC. FOR DEC 1 IN mg/m3.'
      READ(*,*)BAPLO
      BAPLH=BAPLO
C
      WRITE(*,*)'ENTER SEDIMENT RELEASE RATE mg/m2-week.'
      READ(*,*)RRH
C
C CALL SUBROUTINE TO DETERMINE LOADINGS BASED UPON LAND USE
C
      CALL TLU(CHECK,DEF,AREA,RLOAD,TNPH,TNPL)
C
C READ IN TOTAL PPT , WEEKLY FLOW AND FRACTIONAL PPT.
C ISSAQUAH CREEK IS ASSUMED TO BE 70% OF TOTAL FLOW.
C THIS ASSUMES NO INCREASE IN FLOW (OVER THE CREEK'S) FROM
C NON-POINT RUNOFF. QA=(Q/.7).
C
C THE FRACTION OF THE ANNUAL PRECIPITATION FALLING DURING
C EACH WEEK WILL BE USED TO PARTITION THE ANNUAL EXPORT
C COEFFICIENTS IN DETERMINING THE LOADING FROM RUNOFF AND
C ATMOSPHERIC INPUT.
C
  190 READ(1,195)TPPTH
  195 FORMAT(1X,F9.2)
C
C
      TPPT=TPPTH
C
      RF=.77
      DO 350 I=1,52
       READ(1,205)WK,Q,PPT,BAPIC,BAPHYPO
```

```
  205 FORMAT(1X,F9.1,F10.2,F10.2,F10.3,F10.3)
C
      DA=Q/DFAC
      RO=DA/V
      FPPT=PPT/TPPT
C
C CALCULATE ATMOSPHERIC AND INTERNAL LOADINGS.
C INTERNAL LOADING IS RELEASE RATE*AREA OF LAKE BOTTOM
C THAT IS ANAEROBIC (15m)
C
      ATM=(PHPPT*FPPT*BAFIC)/V
      IF(WK.LT.26.)ARRH=0*RRH
      IF(WK.GE.26..AND.WK.LE.40.)ARRH=RRH
      IF(WK.GT.40.)ARRH=4*RRH
C
      JINH=ARRH*HA
      LINH=(JINH*BAFHYPO)/V
C
C CALCULATE  NON-POINT LOADINGS
C
      LNPH=(TNPH*FPPT*BAFIC)/V
C
C CALCULATE OUTFLOW CONC.
C
      OUTH=RO*BAPLH
C
C DETERMINE LOSS VIA SEDIMENTATION
C
      SIG=RO**RF
      IF(WK.GT.14..AND.WK.LT.26.)SIG=8*SIG
      SEDH=SIG*BAPLH
C
C
C NEW LAKE CONC
C
      DPH=ATM+LINH+LNPH-OUTH-SEDH
      BAPLH=BAPLH+DPH
C
C FIND SPRING BAP TOTAL
C
      IF(WK.GE.14.AND.WK.LE.26)THEN
        BAPSPH=BAPSPH+BAPLH
      ENDIF
C
C FIND SUMMER BAP TOTAL
C
      IF(WK.GE.27.AND.WK.LE.40)THEN
        BAPSUH=BASUH+BAPLH
      ENDIF
C
C FIND ANNUAL BAP TOTAL
C
      BAPAN=BAPAN+BAPLH
C
C
      WRITE(*,300)WK,BAPLH
  300 FORMAT(7X,F4.1,2X,F5.1)
C
C
  350 CONTINUE
```

```
      REWIND 1
C
C
C PARAMETER OUTPUT
C
      WRITE(*,370)BAPLO,RRH
      WRITE(2,370)BAPLO,RRH
  370 FORMAT(3X,'INITIAL BAP CONC= ',F4.1,2X,'RELEASE RATE= ',F4.1)
C
C
C DETERMINE ANNUAL AND SUMMER BAP MEANS
C
      BPSUM=(BAPSUM/13.0)
      BPANM=(BAPAN/52.0)
C
      WRITE(*,390)BPANM,BPSUM
      WRITE(2,390)BPANM,BPSUM
  390 FORMAT(3X,'ANNUAL BAP =',F5.2,2X,'SUMMER BAP =',F5.2)
C
C
C DETERMINE EPILIMNETIC SUMMER CHLa (mg/m3) AND TRANS(m)
C
C
      BPSPMH=(BAPSPH/13.0)
      CHLAH=1.7*BPSPMH-2.09
      SDH=7.7*(1/CHLAH**.68)
C
      WRITE(*,400)BPSPMH,CHLAH,SDH
      WRITE(2,400)BPSPMH,CHLAH,SDH
  400 FORMAT(3X,'SPRING BAP=',F4.2,2X,'SUMMER CHLa=',F5.2,2X,
     +'SUMMER TRANS=',F4.1)
      STOP
      END
C
C
C
C
C*****************************************************************C
C
C LAND USED SUBROUTINE. AREAS AND RUNOFF COEFFICIENTS(kg/ha-yr)
C ARE CONVERTED TO kg/yr.
C
      SUBROUTINE TLU(CHECK,DEF,AREA,RLOAD,TNPH,TNPL)
      INTEGER B
      CHARACTER*10 ANS
      DIMENSION DEF(15,3),AREA(10,3),RLOAD(12,3)
C
C
      WRITE(*,*)'  '
      WRITE(*,*)'THE WATERSHED IS DIVIDED UP INTO 3 SUB-BASINS, '
      WRITE(*,*)'ISSAQUAH CREEK, WESTSIDE AND EASTSIDE. '
      WRITE(*,*)'FOR EACH SUB-BASIN ENTER THE AREA (HECTARES)'
      WRITE(*,*)'FOR EACH TYPE OF LAND USE AND HIGH AND LOW'
      WRITE(*,*)'PHOSPHORUS YIELD COEFFICIENTS (kg/ha-yr)'
      WRITE(*,*)'IF DESIRED.'
      WRITE(*,*)' '
      WRITE(*,*)'***ISSAQUAH CREEK SUB-BASIN, TOTAL AREA=14200ha***'

      DO 970 B=1,3
       WRITE(*,*)' '
```

```
        WRITE(*,*)'INPUT AREAS(ha) FOR EACH TYPE OF LAND USE IN THE'
        WRITE(*,*)'FOLLOWING ORDER: FOREST, AGRICULTURAL, COMMERCIAL,'
        WRITE(*,*)'SINGLE-FAMILY RESIDENTIAL AND '
        WRITE(*,*)'MULTI-FAMILY RESIDENTIAL.'
        WRITE(*,*)'PLEASE PRESS <RETURN> AFTER EACH VALUE.'
        READ(*,903)(DEF(I,B),I=11,15)
  903 FORMAT(F6.0)
C
      I=1
       DO 905 J=11,15
         AREA(I,B)=DEF(J,B)
         AREA(I+1,B)=DEF(J,B)
         I=I+2
  905  CONTINUE
C
C
C FIGURE LOADINGS FOR EACH LAND TYPE
C
  920 DO 925 I=1,10
        RLOAD(I,B)=DEF(I,B)*AREA(I,B)
  925 CONTINUE
C
C ADD UP LOADINGS FOR EACH SUB-BASIN
C
       RLOAD(11,B)=0.0
       DO 930 I=1,9,2
         RLOAD(11,B)=RLOAD(11,B)+RLOAD(I,B)
  930  CONTINUE
C
C
        IF(B.EQ.2)GOTO 950
        IF(B.GT.2)GOTO 970
C
      WRITE(*,*)' '
      WRITE(*,*)'***WESTSIDE SUB-BASIN, TOTAL AREA=4600ha***'
      GOTO 970
C
  950  WRITE(*,*)' '
       WRITE(*,*)'***EASTSIDE SUB-BASIN, TOTAL AREA=6500ha***'
  970 CONTINUE
C
C CALCULATE  TOTAL NON-POINT LOADINGS
C
      TNPH=0.
C
      DO 990 J=1,3
      TNPH=TNPH+RLOAD(11,J)
  990 CONTINUE
C
      RETURN
      END
C
C*****************************************************C
```

APPENDIX B

Model Calibration Data

Data Used for Model Calibration 1985-1986

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT(cm/wk)	Issaquah Ck. Total P(ug/l)	Issaquah Ck. BAP/TP	Hypolimnion BAP/TP	Observed lake BAP
12/01/85	1	3.65	4.85	20.0	0.667	0.637	13.1
12/08/85	2	2.80	0.02	20.0	0.667	0.637	
12/15/85	3	1.49	0.00	20.0	0.667	0.637	
12/22/85	4	1.29	0.15	20.0	0.667	0.637	
12/29/85	5	1.74	4.80	20.0	0.667	0.637	
01/05/86	6	2.43	3.83	27.0	0.735	0.938	13.4
01/12/86	7	3.82	14.20	27.0	0.735	0.938	
01/19/86	8	9.55	4.55	27.0	0.735	0.938	17.6
01/26/86	9	3.27	2.67	27.0	0.735	0.938	
02/02/86	10	2.76	1.78	25.0	0.328	0.903	19.5
02/09/86	11	2.18	5.08	25.0	0.328	0.903	
02/16/86	12	2.76	2.74	25.0	0.328	0.903	22.5
02/23/86	13	5.74	4.01	25.0	0.328	0.903	
03/02/86	14	2.37	2.72	24.0	0.378	0.217	2.5
03/09/86	15	2.25	1.80	24.0	0.378	0.217	
03/16/86	16	2.08	1.93	24.0	0.378	0.217	
03/23/86	17	2.62	1.47	24.0	0.378	0.217	
03/30/86	18	2.39	0.79	25.6	0.378	0.217	
04/06/86	19	1.58	1.12	46.8	0.405	0.231	3.6
04/13/86	20	1.47	2.97	30.9	0.405	0.231	
04/20/86	21	1.46	3.05	25.4	0.405	0.231	
04/27/86	22	1.83	4.32	31.1	0.405	0.231	
05/04/86	23	2.15	3.28	37.7	0.276	0.173	2.5
05/11/86	24	2.83	0.94	61.9	0.276	0.173	
05/18/86	25	1.91	2.62	55.8	0.276	0.173	
05/25/86	26	1.23	0.15	48.3	0.276	0.173	
06/01/86	27	0.84	0.28	47.5	0.208	0.316	4.4
06/08/86	28	0.76	0.48	37.0	0.208	0.316	
06/15/86	29	0.74	1.12	34.0	0.208	0.316	
06/22/86	30	0.61	0.00	63.2	0.208	0.316	
06/29/86	31	0.59	1.37	70.2	0.208	0.316	
07/06/86	32	0.61	1.93	55.3	0.423	0.331	6.1
07/13/86	33	0.64	2.39	60.5	0.423	0.331	
07/20/86	34	0.52	0.00	56.0	0.423	0.331	
07/27/86	35	0.46	0.00	49.1	0.423	0.331	
08/03/86	36	0.41	0.00	57.8	0.756	0.157	3.4
08/10/86	37	0.38	0.00	57.7	0.756	0.157	
08/17/86	38	0.36	0.00	53.6	0.756	0.157	
08/24/86	39	0.36	0.81	51.7	0.756	0.157	
08/31/86	40	0.38	0.02	51.5	0.756	0.157	
09/07/86	41	0.41	1.40	32.2	0.700	0.262	6.3
09/14/86	42	0.49	2.13	33.0	0.700	0.262	
09/21/86	43	0.62	5.41	38.5	0.700	0.262	
09/28/86	44	0.81	2.72	39.1	0.700	0.262	
10/05/86	45	0.49	0.02	50.0	0.849	0.148	10.8
10/12/86	46	0.49	0.00	51.3	0.849	0.148	
10/19/86	47	0.49	4.27	58.5	0.849	0.148	
10/26/86	48	2.12	6.88	66.2	0.849	0.148	
11/02/86	49	1.52	8.15	44.5	0.957	0.184	16.0
11/09/86	50	1.32	2.16	33.6	0.957	0.184	
11/16/86	51	3.83	13.84	70.7	0.957	0.184	
11/23/86	52	16.89	10.41	249.4	0.957	0.184	

APPENDIX C

Model Verification Data

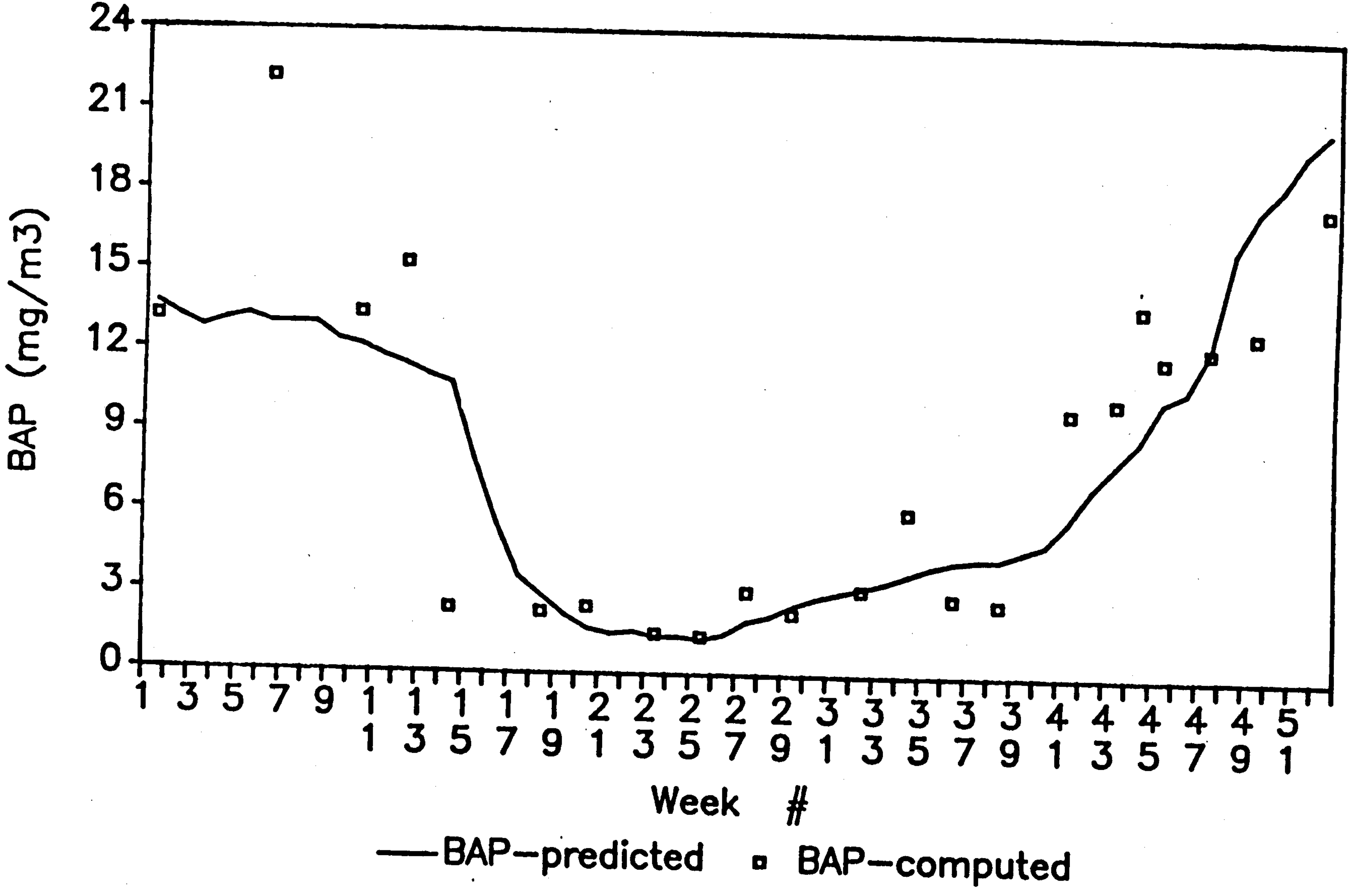
Data used for Model Verification 1984-1985

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT(cm/wk)	Issaquah Ck. Total P(ug/l)	Issaquah Ck. BAP/TP	Hypolimnion BAP/TP	Computed lake BAP
12/02/84	1	2.78	5.84	22.0	0.667	0.637	12.2
12/09/84	2	4.20	9.02	22.0	0.667	0.637	
12/16/84	3	3.23	2.67	22.0	0.667	0.637	
12/23/84	4	3.21	5.92	22.0	0.667	0.637	14.2
12/30/84	5	3.49	0.23	22.0	0.667	0.637	
01/06/85	6	2.09	0.00	22.0	0.735	0.938	19.8
01/13/85	7	1.61	2.41	32.0	0.735	0.938	
01/20/85	8	1.71	0.08	32.0	0.735	0.938	
01/27/85	9	1.23	0.79	32.0	0.735	0.938	15.0
02/03/85	10	1.09	2.67	32.0	0.328	0.903	14.4
02/10/85	11	2.89	4.72	20.0	0.328	0.903	
02/17/85	12	2.94	1.98	20.0	0.328	0.903	15.9
02/24/85	13	2.68	1.98	20.0	0.328	0.903	
03/03/85	14	1.90	1.27	20.0	0.378	0.217	2.7
03/10/85	15	1.27	0.00	20.0	0.378	0.217	3.8
03/17/85	16	1.37	4.72	28.0	0.378	0.217	
03/24/85	17	2.32	5.46	28.0	0.378	0.217	2.2
03/31/85	18	3.27	1.80	28.0	0.378	0.217	
04/07/85	19	2.04	2.44	28.0	0.405	0.231	2.9
04/14/85	20	1.66	5.69	24.0	0.405	0.231	
04/21/85	21	2.09	5.31	24.0	0.405	0.231	2.0
04/28/85	22	2.43	1.35	24.0	0.405	0.231	
05/05/85	23	1.50	1.96	24.0	0.276	0.173	0.8
05/12/85	24	1.36	1.55	29.0	0.276	0.173	
05/19/85	25	0.99	1.70	29.0	0.276	0.173	1.2
05/26/85	26	1.23	2.26	29.0	0.276	0.173	
06/02/85	27	2.41	7.82	29.0	0.208	0.316	1.5
06/09/85	28	2.02	1.09	34.0	0.208	0.316	
06/16/85	29	1.16	0.03	34.0	0.208	0.316	2.4
06/23/85	30	0.79	0.25	34.0	0.208	0.316	
06/30/85	31	0.67	0.00	34.0	0.208	0.316	3.6
07/07/85	32	0.57	0.00	34.0	0.423	0.331	4.4
07/14/85	33	0.51	0.00	27.0	0.423	0.331	
07/21/85	34	0.45	0.00	27.0	0.423	0.331	
07/28/85	35	0.49	1.27	27.0	0.423	0.331	
08/04/85	36	0.53	1.07	27.0	0.756	0.157	3.1
08/11/85	37	0.46	0.00	41.0	0.756	0.157	
08/18/85	38	0.41	0.00	41.0	0.756	0.157	2.3
08/25/85	39	0.40	0.43	41.0	0.756	0.157	
09/01/85	40	0.46	3.86	41.0	0.756	0.157	
09/08/85	41	0.56	2.24	41.0	0.700	0.262	7.2
09/15/85	42	0.52	2.29	46.0	0.700	0.262	
09/22/85	43	0.41	0.00	46.0	0.700	0.262	8.0
09/29/85	44	0.39	0.79	46.0	0.700	0.262	
10/06/85	45	0.41	3.58	46.0	0.849	0.148	13.5
10/13/85	46	0.53	3.66	33.0	0.849	0.148	
10/20/85	47	2.14	12.19	33.0	0.849	0.148	9.2
10/27/85	48	2.99	8.13	33.0	0.849	0.148	
11/03/85	49	4.22	4.67	33.0	0.957	0.184	11.4
11/10/85	50	2.17	4.60	33.0	0.957	0.184	13.4
11/17/85	51	2.25	2.74	33.0	0.957	0.184	
11/24/85	52	1.71	0.94	33.0	0.957	0.184	

Data used for Model Year 1983-1984

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT (cm/wk)	Computed lake BAP
12/04/83	1	3.17	6.76	13.2
12/11/83	2	5.41	3.18	
12/18/83	3	1.86	0.20	
12/25/83	4	1.89	4.55	
01/01/84	5	6.91	7.98	
01/08/84	6	3.02	1.83	22.2
01/15/84	7	1.60	2.36	
01/22/84	8	10.19	9.07	
01/29/84	9	3.22	0.08	
02/05/84	10	2.14	3.61	13.4
02/12/84	11	3.13	2.69	
02/19/84	12	3.57	3.81	15.3
02/26/84	13	2.83	1.35	
03/04/84	14	1.89	0.48	2.4
03/11/84	15	3.13	4.88	
03/18/84	16	4.16	6.58	
03/25/84	17	4.41	2.39	
04/01/84	18	3.09	4.47	2.3
04/08/84	19	4.72	4.83	
04/15/84	20	2.58	1.09	2.5
04/22/84	21	1.82	0.81	
04/29/84	22	2.48	4.39	
05/06/84	23	2.16	2.29	1.5
05/13/84	24	2.20	4.11	
05/20/84	25	2.25	4.42	1.4
05/27/84	26	1.92	0.25	
06/03/84	27	1.89	5.51	3.1
06/10/84	28	1.53	0.18	
06/17/84	29	2.12	4.04	2.3
06/24/84	30	1.58	1.83	
07/01/84	31	1.09	0.00	
07/08/84	32	0.84	0.00	3.2
07/15/84	33	0.69	0.00	
07/22/84	34	0.60	0.00	6.1
07/29/84	35	0.61	0.56	
08/05/84	36	0.57	0.64	2.9
08/12/84	37	0.71	0.15	
08/19/84	38	0.64	0.00	2.7
08/26/84	39	0.62	1.04	
09/02/84	40	0.61	1.32	
09/09/84	41	0.61	0.33	9.9
09/16/54	42	0.58	2.31	
09/23/84	43	0.59	0.30	10.3
09/30/84	44	0.59	0.79	13.8
10/07/84	45	0.69	5.31	11.9
10/14/84	46	0.64	0.23	
10/21/84	47	0.67	5.38	12.3
10/23/84	48	1.70	16.26	
11/04/84	49	1.89	5.79	12.9
11/11/84	50	2.93	4.70	
11/18/84	51	2.49	5.49	
11/25/84	52	4.05	5.94	17.6

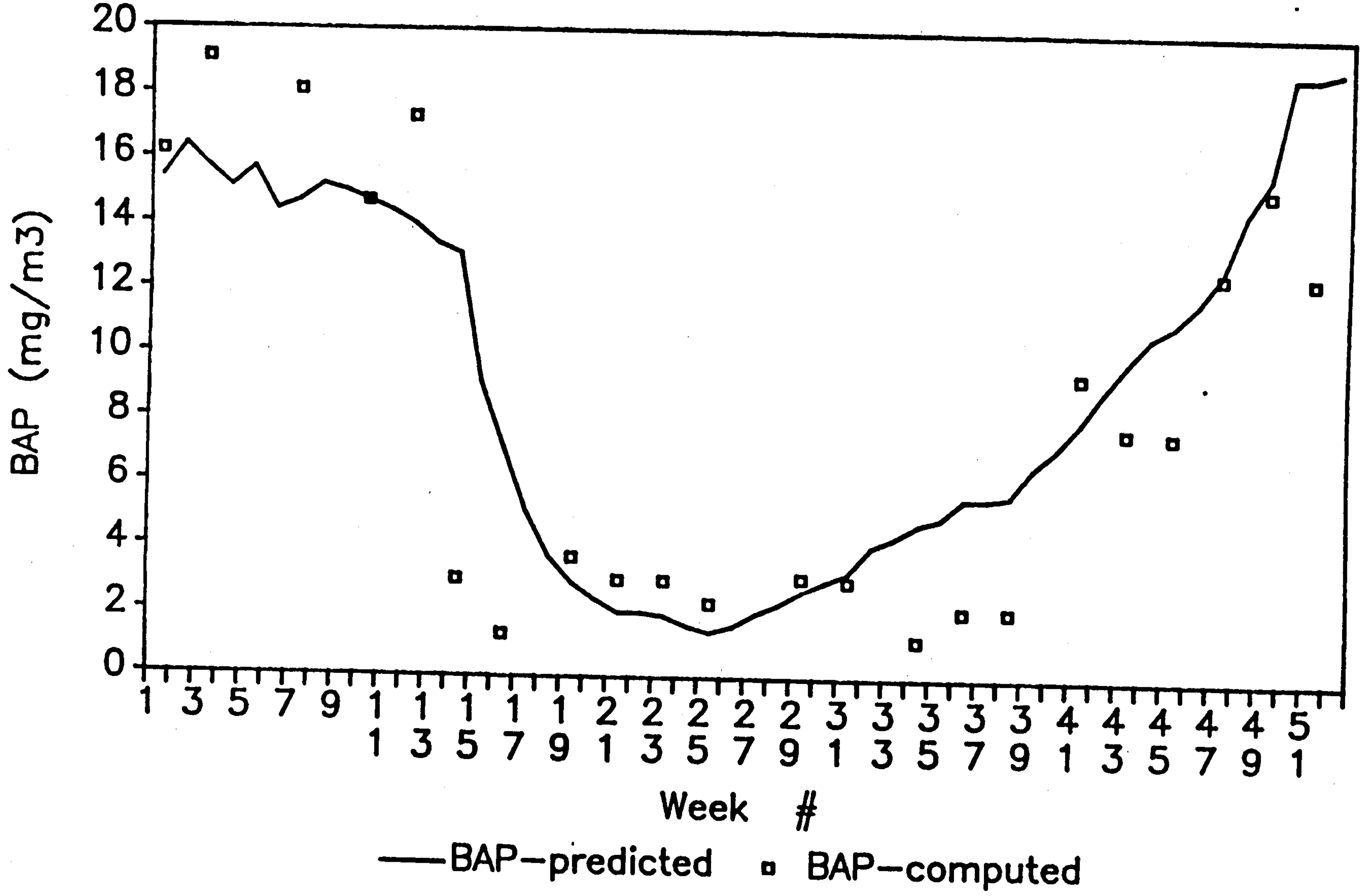
Model Prediction compared to
computed whole lake BAP for 1983–1984
starting the first Sunday in December.



Data used for Model Year 1982-1983

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT (cm/wk)	Computed lake BAP
12/05/82	1	4.55	2.16	16.2
12/12/82	2	4.75	12.75	
12/19/82	3	5.10	3.33	19.1
12/26/82	4	2.56	0.10	
01/02/83	5	14.19	20.35	
01/09/83	6	7.79	2.54	
01/16/83	7	2.74	4.88	18.1
01/23/83	8	2.78	7.01	
01/13/83	9	2.36	1.91	
02/06/83	10	2.28	4.45	14.7
02/13/83	11	2.75	4.52	
02/20/83	12	3.83	5.03	17.3
02/27/83	13	2.98	1.57	
03/06/83	14	5.11	6.81	3.0
03/13/86	15	3.17	0.33	
03/20/83	16	2.21	1.45	1.3
03/27/83	17	3.72	5.46	
04/03/83	18	2.67	0.00	
04/10/83	19	1.96	0.00	3.7
04/17/83	20	1.56	0.00	
04/24/83	21	1.38	0.00	3.0
05/01/83	22	1.27	2.51	
05/08/83	23	1.32	2.84	3.0
05/15/83	24	1.26	0.18	
05/22/83	25	0.78	0.00	2.3
05/29/83	26	0.75	0.94	
06/05/83	27	0.87	3.68	
06/12/83	28	0.83	1.57	
06/19/83	29	1.01	3.33	3.1
06/26/83	30	1.01	2.08	
07/03/83	31	0.85	0.41	3.0
07/10/83	32	1.88	6.32	
07/17/83	33	1.27	0.89	
07/24/83	34	1.02	2.26	1.2
07/31/83	35	0.74	0.00	
08/07/83	36	0.78	3.05	2.1
08/14/83	37	0.62	0.00	
08/21/83	38	0.52	0.03	2.1
08/28/83	39	1.14	4.83	
09/04/83	40	0.89	2.97	
09/11/82	41	1.06	0.74	9.4
09/18/83	42	0.59	1.30	
09/25/83	43	0.77	1.47	7.7
10/02/83	44	0.66	0.23	
10/09/83	45	0.62	0.08	7.6
10/16/83	46	0.72	1.88	
10/23/83	47	0.73	3.28	12.6
10/30/83	48	3.13	9.70	
11/06/83	49	2.31	4.47	15.2
11/13/83	50	5.93	16.41	
11/20/83	51	6.49	4.85	12.5
11/27/83	52	2.44	1.42	

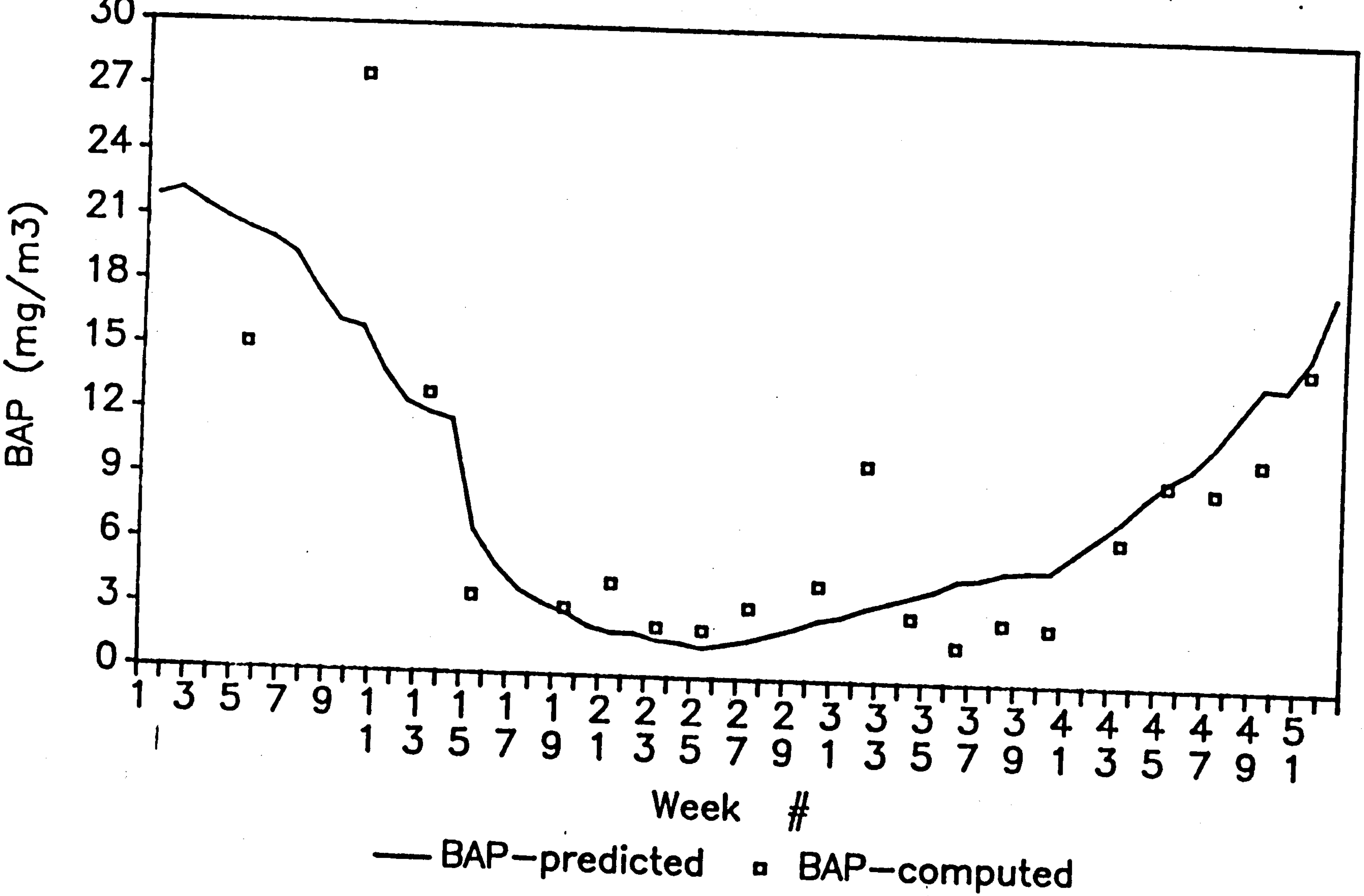
Model Prediction compared to
computed whole lake BAP for 1982–1983
starting the first Sunday in December.



Data used for Model Year 1981-1982

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT (cm/wk)	Computed lake BAP
12/06/81	1	5.14	3.76	
12/13/81	2	5.31	10.62	
12/20/81	3	4.02	4.01	
12/27/81	4	3.29	2.57	
01/03/82	5	2.08	1.68	15.1
01/10/82	6	6.98	7.77	
01/17/82	7	8.27	7.90	
01/24/82	8	11.90	6.25	
01/31/82	9	7.43	2.01	
02/07/82	10	4.72	9.50	27.6
02/14/82	11	18.08	16.05	
02/21/82	12	7.52	1.50	
02/28/82	13	5.00	4.01	12.9
03/07/82	14	6.09	7.95	
03/14/82	15	5.01	0.03	3.6
03/21/82	16	2.53	1.09	
03/28/82	17	2.29	1.32	
04/04/82	18	1.85	1.12	
04/11/82	19	3.06	6.05	3.1
04/18/82	20	2.11	0.00	
04/25/82	21	1.54	0.99	4.3
05/02/82	22	1.40	2.72	
05/09/82	23	1.15	0.00	2.3
05/16/82	24	1.14	1.80	
05/23/82	25	0.96	0.51	2.2
05/30/82	26	0.85	0.64	
06/06/82	27	0.79	0.10	3.3
06/13/82	28	0.68	0.00	
06/20/82	29	0.57	1.09	
06/27/82	30	0.75	3.25	4.4
07/04/82	31	0.72	0.36	
07/11/82	32	0.66	1.50	10.0
07/18/82	33	0.56	0.33	
07/25/82	34	0.50	0.18	3.0
08/01/82	35	0.49	0.48	
08/08/82	36	0.59	2.36	1.7
08/15/82	37	0.50	0.13	
08/22/82	38	0.44	0.91	2.8
08/29/82	39	0.46	0.05	
09/05/82	40	0.61	0.00	2.6
09/12/82	41	0.69	0.00	
09/19/82	42	0.52	0.00	
09/26/82	43	0.82	0.00	6.7
10/03/82	44	0.85	1.40	
10/10/82	45	0.73	2.29	9.4
10/17/82	46	1.04	1.32	
10/24/82	47	1.47	3.81	9.1
10/31/82	48	1.35	5.16	
11/07/82	49	1.13	3.91	10.5
11/14/82	50	3.04	0.13	
11/21/82	51	1.98	5.08	14.8
11/28/82	52	6.02	13.79	

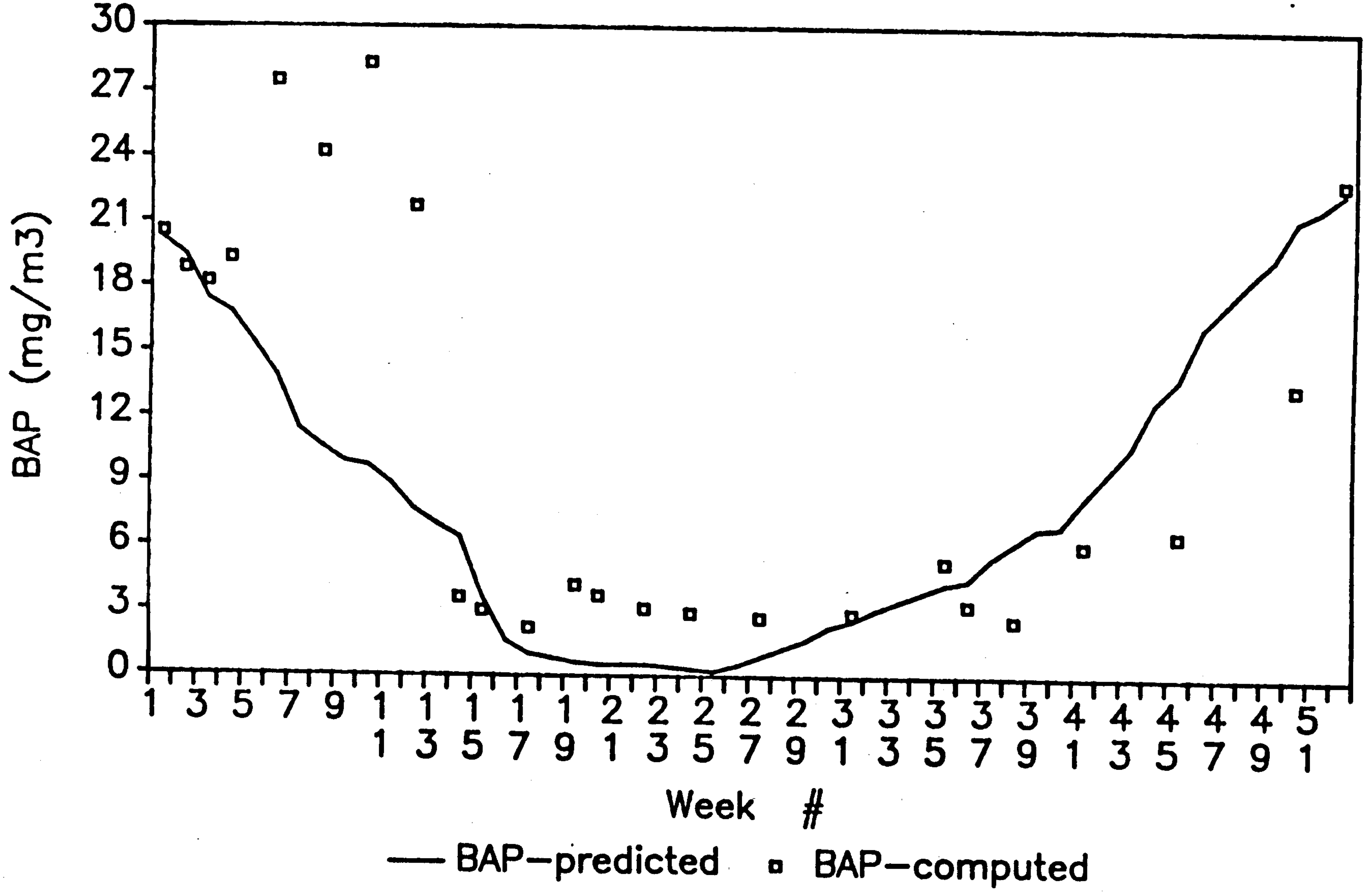
Model Prediction compared to computed whole lake BAP for 1981–1982 starting the first Sunday in December.



Data used for Model Year 1974-1975

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT (cm/wk)	Computed lake BAP
12/04/74	1	2.25	2.79	20.5
12/11/74	2	4.11	2.79	18.8
12/18/74	3	9.52	3.07	18.2
12/25/74	4	7.65	7.29	19.3
01/01/75	5	9.21	3.81	
01/08/75	6	14.36	6.96	27.5
01/15/75	7	17.10	1.98	
01/22/75	8	8.05	2.52	24.2
01/29/75	9	4.23	0.13	
02/05/75	10	3.58	4.34	28.3
02/12/75	11	8.52	3.53	
02/19/75	12	14.65	5.59	21.7
02/26/75	13	10.86	3.94	
03/05/75	14	5.93	0.33	3.6
03/12/75	15	5.57	2.67	3.0
03/19/75	16	7.27	1.04	
03/26/75	17	3.98	0.44	2.2
04/02/75	18	4.45	1.96	
04/09/75	19	3.04	0.53	4.2
04/16/75	20	3.23	1.02	3.7
04/23/75	21	6.50	2.79	
04/30/75	22	4.38	1.55	3.1
05/07/75	23	3.17	0.76	
05/14/75	24	2.68	0.10	2.9
05/21/75	25	2.38	0.46	
05/28/75	26	1.80	0.20	
06/04/75	27	1.51	0.00	2.7
06/11/75	28	1.32	0.76	
06/18/75	29	0.89	1.35	
06/25/75	30	1.13	3.25	
07/02/75	31	0.84	0.18	2.9
07/09/75	32	0.75	0.53	
07/16/75	33	0.71	0.15	
07/23/75	34	0.59	0.56	
07/30/75	35	0.58	0.00	5.3
08/06/75	36	0.57	0.66	3.3
08/13/75	37	0.73	4.27	
08/20/75	38	0.96	3.10	2.6
08/27/75	39	1.36	3.66	
09/03/75	40	0.84	0.00	
09/10/75	41	0.65	0.08	6.1
09/17/75	42	0.57	0.00	
09/24/75	43	0.54	0.00	
10/01/75	44	0.76	5.26	
10/08/75	45	0.75	2.34	6.6
10/15/75	46	1.64	9.86	
10/22/75	47	2.00	4.29	
10/29/75	48	8.76	11.00	
11/04/75	49	4.13	5.21	
11/11/75	50	5.84	10.57	13.5
11/18/75	51	3.85	3.30	
11/25/75	52	5.20	6.17	23.0

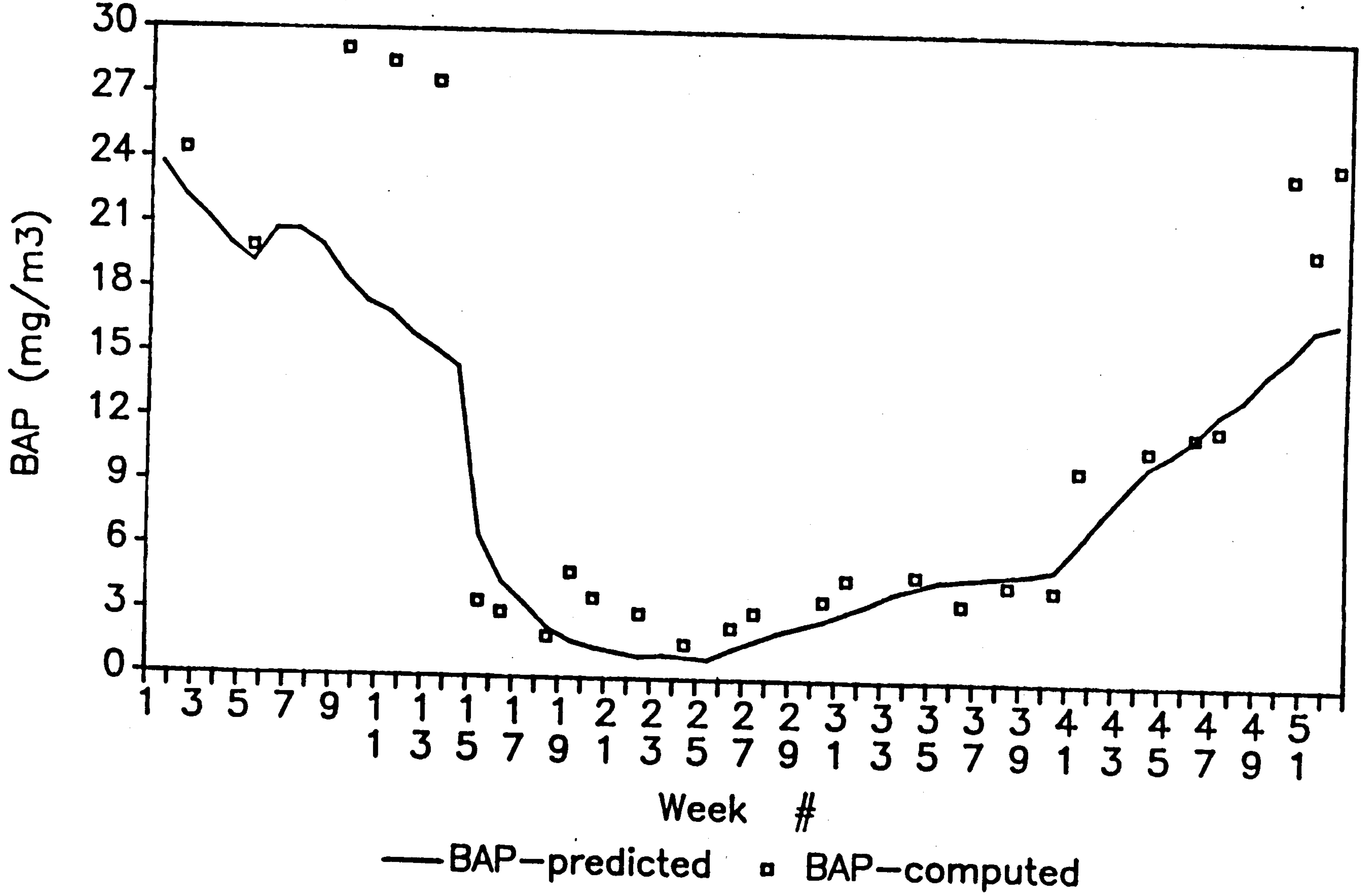
Model Prediction compared to computed whole lake BAP for 1974–1975 starting the first Sunday in December.



Data used for Model Year 1973-1974

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT (cm/wk)	Computed Lake BAP
12/05/73	1	5.22	7.98	
12/12/73	2	9.23	10.72	24.4
12/19/73	3	6.86	8.15	
12/26/73	4	5.33	2.82	
01/02/74	5	2.14	0.00	19.9
01/09/74	6	4.28	17.22	
01/16/74	7	2.46	6.05	
01/23/74	8	9.29	11.99	
01/30/74	9	10.44	7.95	29.1
02/06/73	10	3.85	0.28	
02/13/74	11	4.17	8.84	28.5
02/20/74	12	5.25	3.68	
02/27/74	13	6.18	10.90	27.6
03/06/74	14	5.85	5.36	
03/13/74	15	7.17	6.20	3.5
03/20/74	16	3.54	1.02	3.0
03/27/74	17	3.70	6.45	
04/03/74	18	4.31	3.33	1.9
04/10/74	19	3.48	1.73	4.9
04/17/74	20	2.51	1.85	3.7
04/24/74	21	2.62	1.80	
05/01/74	22	2.25	0.81	3.0
05/08/74	23	2.38	6.68	
05/15/74	24	2.36	1.70	1.6
05/22/74	25	2.04	2.26	
06/05/74	26	1.72	4.93	2.4
06/05/74	27	2.52	2.59	3.1
06/12/74	28	1.89	0.00	
06/19/74	29	1.27	0.20	
06/26/74	30	1.94	0.43	3.7
07/03/74	31	1.85	0.20	4.7
07/10/74	32	2.07	1.35	
07/17/74	33	2.42	2.29	
07/24/74	34	1.67	0.00	4.9
07/31/74	35	1.46	0.00	
08/07/74	36	1.39	0.00	3.6
08/14/74	37	1.16	0.03	
08/21/74	38	0.93	0.00	4.5
08/22/74	39	0.84	0.00	
09/04/74	40	0.82	0.53	4.3
09/11/74	41	0.80	0.00	9.9
09/18/74	42	0.75	0.00	
09/25/74	43	0.73	0.00	
10/02/74	44	0.76	0.03	10.9
10/09/74	45	0.72	0.10	
10/16/74	46	0.80	1.17	11.6
10/23/74	47	0.82	3.12	11.9
10/30/74	48	0.94	0.99	
11/06/74	49	1.35	2.95	
11/13/74	50	1.34	1.93	23.7
11/20/74	51	5.86	7.62	20.2
11/27/74	52	2.73	0.56	24.2

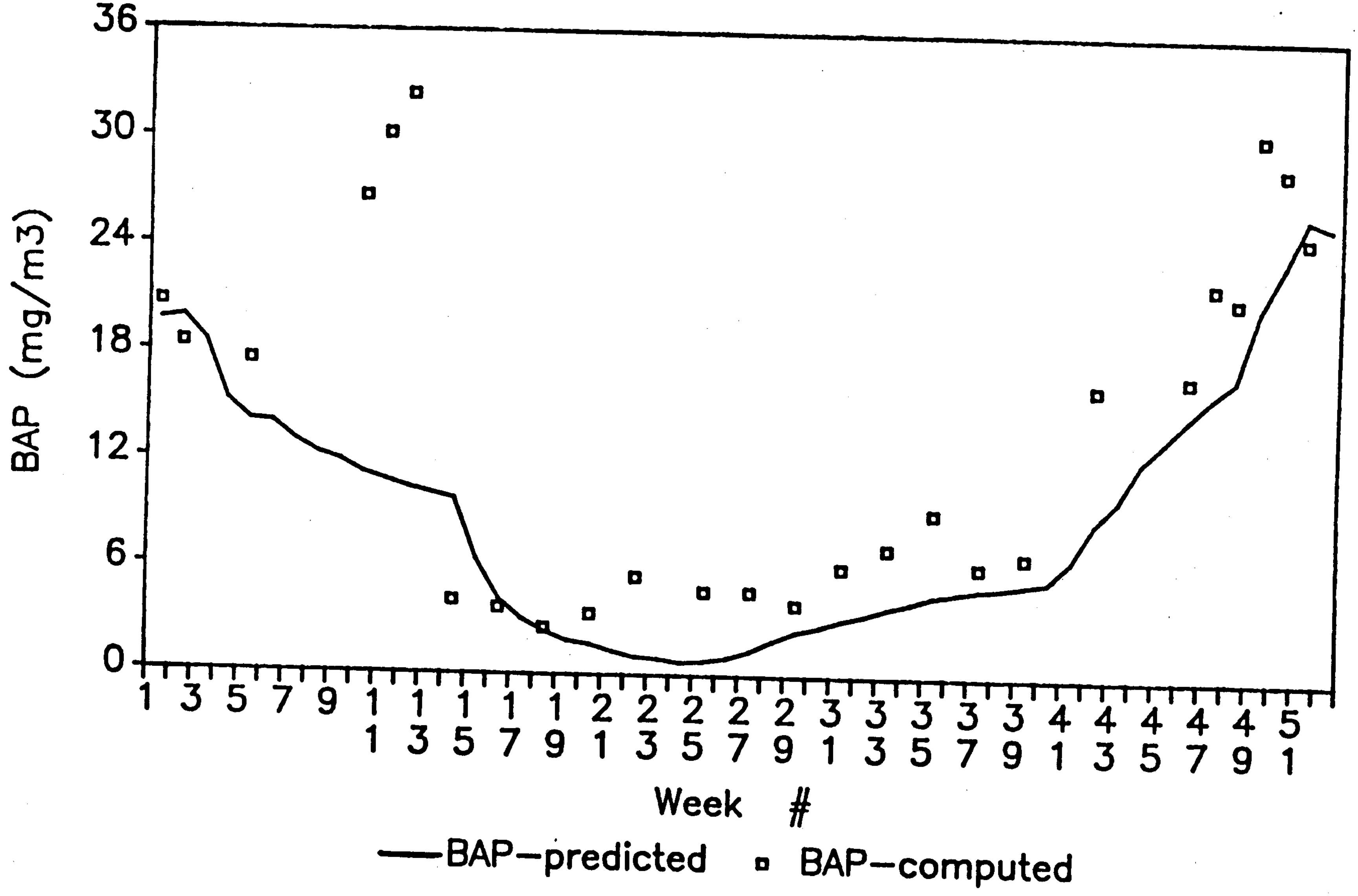
Model Prediction compared to
computed whole lake BAP for 1973–1974
starting the first Sunday in December.



Data used for Model Year 1972-1973

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT (cm/wk)	Computed lake BAF
12/06/72	1	2.91	0.00	20.7
12/13/72	2	1.94	3.81	18.4
12/20/72	3	14.86	9.66	
12/27/72	4	17.61	2.72	
01/03/73	5	5.58	0.71	17.5
01/10/73	6	9.58	6.65	
01/17/73	7	8.06	1.93	
01/24/73	8	4.60	1.09	
01/31/73	9	4.15	1.17	
02/07/73	10	3.34	0.13	26.7
02/14/73	11	2.99	0.58	30.2
02/21/73	12	2.65	1.22	32.4
02/28/73	13	4.18	2.82	
03/07/73	14	3.49	1.75	4.1
03/14/73	15	3.88	1.17	
03/21/73	16	3.71	0.13	3.7
03/28/73	17	2.83	0.58	
04/04/73	18	2.26	0.08	2.6
04/11/73	19	1.82	0.18	
04/18/73	20	3.34	2.67	3.4
04/25/73	21	2.65	0.38	
05/02/73	22	2.06	0.25	5.5
05/09/73	23	2.41	1.42	
05/16/73	24	1.66	0.00	
05/23/73	25	2.02	2.39	4.7
05/30/73	26	1.50	0.00	
06/06/73	27	1.45	0.86	4.7
06/13/73	28	1.83	2.29	
06/20/73	29	2.17	2.16	4.0
06/27/73	30	2.20	1.04	
07/04/73	31	1.43	0.15	6.1
07/11/73	32	1.11	0.00	
07/18/73	33	0.92	0.05	7.2
07/25/73	34	0.82	0.00	
08/01/73	35	0.73	0.18	9.2
08/08/73	36	0.75	0.03	
08/15/73	37	0.77	0.48	6.2
08/22/73	38	0.70	0.00	
08/29/73	39	0.71	0.00	6.8
09/05/73	40	0.70	0.30	
09/12/73	41	0.68	0.10	
09/19/73	42	1.06	3.53	16.3
09/26/73	43	1.03	0.61	
10/03/73	44	0.76	3.96	
10/10/73	45	0.80	2.31	
10/17/73	46	0.71	2.41	16.9
10/24/73	47	0.83	2.36	22.1
10/31/73	48	0.98	1.93	21.3
11/07/73	49	2.65	11.46	30.5
11/14/73	50	4.13	8.43	28.6
11/21/73	51	4.88	10.34	24.8
11/28/73	52	6.03	2.34	

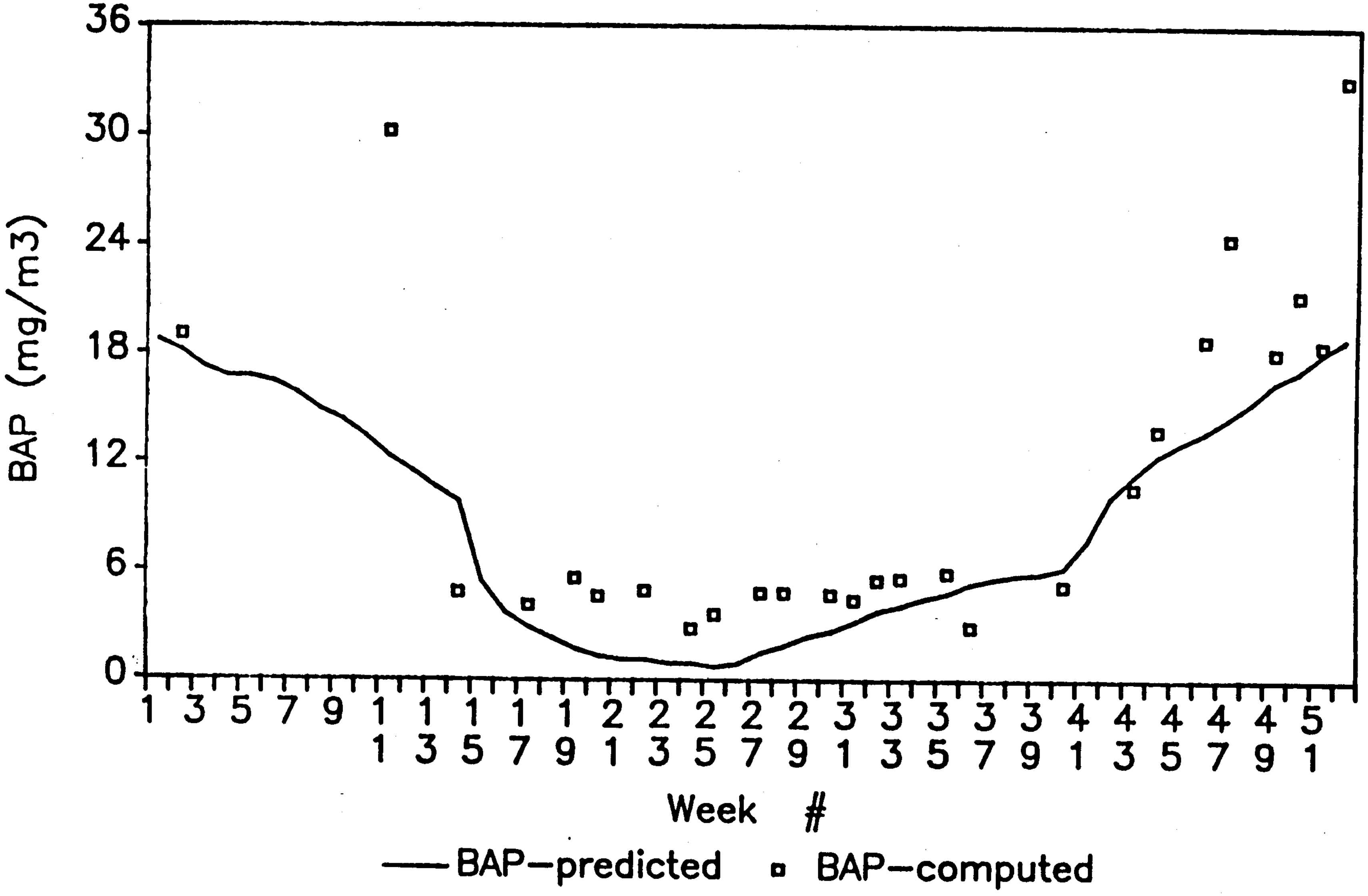
Model Prediction compared to
computed whole lake BAP for 1972–1973
starting the first Sunday in December.



Data used for Model Year 1971-1972

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT (cm/wk)	Computed lake BAP
12/08/71	1	6.02	9.91	
12/15/71	2	5.68	7.09	19.0
12/22/71	3	4.92	3.40	
12/29/71	4	3.15	2.59	
01/05/72	5	3.59	7.01	
01/12/72	6	3.73	4.50	
01/19/72	7	15.26	17.48	
01/26/72	8	4.25	0.51	
02/02/72	9	3.84	1.93	
02/09/72	10	6.50	7.37	
02/16/72	11	7.92	5.66	30.2
02/23/72	12	11.99	17.12	
03/01/72	13	13.03	14.33	
03/08/72	14	9.04	6.93	4.8
03/15/72	15	5.22	0.91	
03/22/72	16	3.51	1.63	
03/29/72	17	2.58	2.29	4.1
04/05/72	18	3.92	6.22	
04/12/72	19	4.33	3.91	5.6
04/19/72	20	3.89	3.02	4.6
04/26/72	21	3.31	2.92	
05/03/72	22	2.24	2.13	4.9
05/10/72	23	1.75	0.79	
05/17/75	24	1.82	2.72	2.8
05/24/72	25	1.38	0.00	3.6
05/31/72	26	1.06	0.00	
06/07/72	27	1.28	4.01	4.8
06/14/72	28	1.03	1.24	4.8
06/21/72	29	3.26	5.23	
06/28/72	30	1.73	0.00	4.7
07/05/72	31	1.27	2.62	4.4
07/12/72	32	2.05	3.10	5.5
07/19/72	33	1.01	0.15	5.6
07/26/72	34	0.80	0.00	
08/02/72	35	0.69	0.00	5.9
08/09/72	36	0.62	2.08	2.9
08/16/72	37	0.88	1.68	
08/23/72	38	0.63	0.00	
08/30/72	39	0.55	0.00	
09/06/72	40	0.64	1.45	5.2
09/13/72	41	0.57	1.52	
09/20/72	42	1.67	9.17	
09/27/72	43	0.67	0.00	10.6
10/04/72	44	0.57	0.00	13.8
10/11/72	45	0.55	0.03	
10/18/72	46	0.51	0.25	18.8
10/25/72	47	0.73	1.37	24.4
11/01/72	48	0.85	2.57	
11/08/72	49	1.35	2.62	18.1
11/15/72	50	0.99	0.38	21.3
11/22/72	51	0.98	1.91	18.5
11/29/72	52	2.68	3.43	33.1

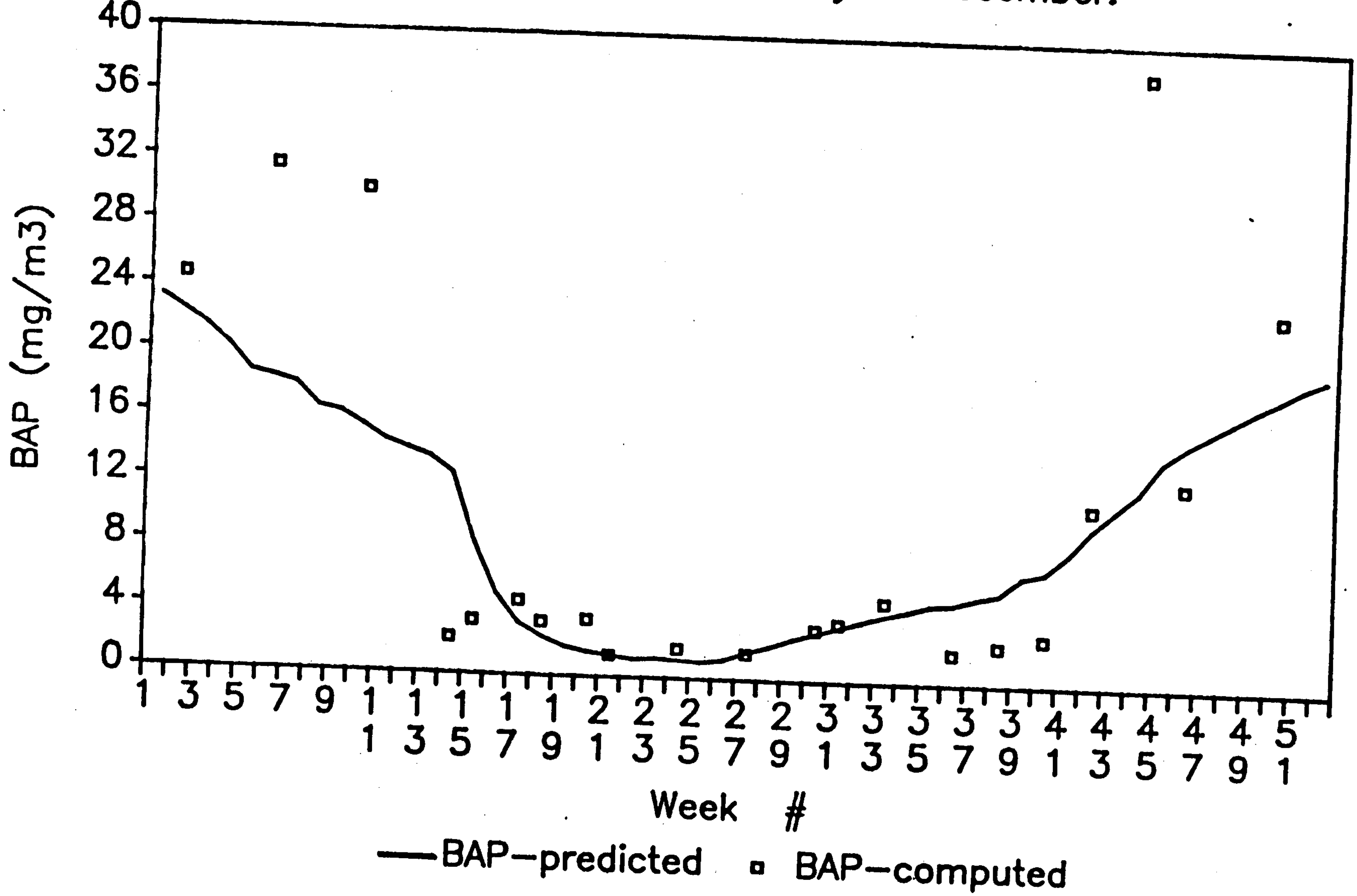
Model Prediction compared to
computed whole lake BAP for 1971–1972
starting the first Sunday in December.



Data used for Model Year 1970-1971

Week Begining	Week #	Issaquah Ck. Flow(m3/wk)	PPT (cm/wk)	Computed lake BAP
12/09/70	1	5.33	3.84	
12/16/70	2	3.60	3.15	24.6
12/23/70	3	4.74	5.18	
12/30/70	4	5.87	4.85	
01/06/71	5	9.30	7.11	
01/13/71	6	6.25	9.50	31.5
01/20/71	7	9.77	13.67	
01/27/71	8	5.53	0.66	
02/03/71	9	3.03	3.35	
02/10/71	10	4.91	5.69	30.1
02/17/71	11	4.66	3.20	
02/24/71	12	3.79	5.05	
03/03/71	13	4.75	7.90	
03/10/71	14	8.70	7.90	2.2
03/17/71	15	3.98	4.57	3.3
03/24/71	16	5.28	6.99	
03/31/71	17	4.09	0.99	4.6
04/07/71	18	4.37	6.48	3.3
04/14/71	19	2.88	0.99	
04/21/71	20	1.98	1.50	3.5
04/28/71	21	1.53	0.10	1.3
05/05/71	22	1.34	0.08	
05/12/71	23	1.76	5.41	
05/19/71	24	2.83	4.80	1.8
05/26/71	25	1.50	1.12	
06/02/71	26	1.43	1.75	
06/09/71	27	1.56	2.79	1.6
06/16/71	28	1.61	1.19	
06/23/71	29	1.65	4.06	
06/30/71	30	1.42	2.01	3.2
07/07/71	31	1.44	2.03	3.6
07/14/71	32	1.00	0.00	
07/21/71	33	0.80	0.03	5.0
07/28/71	34	0.69	0.03	
08/04/71	35	0.61	0.00	
08/11/71	36	0.54	0.00	1.9
08/18/71	37	0.58	1.57	
08/25/71	38	0.53	1.14	2.4
09/01/71	39	1.41	7.37	
09/08/71	40	0.73	0.97	2.9
09/15/71	41	0.49	0.00	
09/22/71	42	0.73	3.10	11.1
09/29/71	43	0.72	0.03	
10/06/71	44	0.54	0.03	38.1
10/13/71	45	1.40	8.71	
10/20/71	46	2.18	4.93	12.6
10/27/71	47	2.54	3.78	
11/03/71	48	5.09	7.72	
11/10/71	49	2.62	3.05	
11/17/71	50	1.85	2.16	23.3
11/24/71	51	3.90	5.00	
12/01/71	52	3.28	3.63	

Model Prediction compared to computed whole lake BAP for 1970–1971 starting the first Sunday in December.



APPENDIX D

Phosphorus Data from Lake Sammamish and Issaquah Creek

Summary of phosphorus forms measured monthly
in Lake Sammamish and Issaquah Creek.
All values are are in μg P/L.

	MAR 1986	APR 1986	MAY 1986	JUN 1986	JUL 1986	AUG 1986
Lake Sammamish 1 meter						
TP	19.2	15.4	16.9	17.7	16.6	12.3
SRP	1.0	1.2	4.9	0.7	2.6	1.8
TSP	8.1	6.4	8.7	0.9	10.7	6.1
Particulate P	11.1	9.0	8.2	16.8	5.9	6.2
NaOH extractable P	0.3	1.6	1.7	4.1	2.6	5.8
Autoclaved TSP	14.8	10.4	9.9	10.6	16.1	11.9
Autoclaved SRP	5.6	4.2	4.7	4.5	3.8	4.4
BAP	2.0	3.1	2.2	2.9	3.8	2.7
BAP/TP (%)	10.4	20.1	13.0	16.4	22.9	22.0
Lake Sammamish 25 meters						
TP	16.1	20.3	18.5	25.0	33.8	31.8
SRP	0.4	3.2	4.5	1.1	7.7	7.5
TSP	11.5	6.9	8.9	4.9	19.9	12.0
Particulate P	4.6	13.4	13.9	20.1	13.9	19.8
NaOH extractable P	0.7	2.7	2.9	7.5	6.7	11.9
Autoclaved TSP	8.8	13.6	13.9	15.6	26.9	15.6
Autoclaved SRP	4.9	6.5	4.5	12.0	14.3	9.1
BAP	3.5	4.7	3.2	7.9	11.2	5.0
BAP/TP (%)	21.7	23.1	17.3	31.6	33.1	15.7
Issaquah Creek						
TP	40.7	57.7	36.6	38.5	55.8	43.9
SRP	14.0	4.8	10.4	10.3	19.4	25.8
TSP	22.7	17.3	21.2	22.2	47.8	33.9
Particulate P	18.0	40.4	15.4	16.3	8.0	10.0
NaOH extractable P	1.3	9.5	3.3	2.6	3.5	6.3
Autoclaved TSP	22.3	37.3	37.2	33.7	46.9	36.3
Autoclaved SRP	20.5	20.5	12.7	14.6	21.9	29.5
BAP	15.4	23.4	10.1	8.0	23.6	33.2
BAP/TP (%)	37.8	40.5	27.6	20.8	42.3	75.6

Summary of phosphorus forms measured monthly
in Lake Sammamish and Issaquah Creek.
All values are in µg P/L.

	SEP 1986	OCT 1986	NOV 1986	DEC 1986	JAN 1987	FEB 1987
Lake Sammamish 1 meter						
TP	8.7	9.2	7.8	27.0	24.1	24.1
SRP	1.9	1.5	1.2	8.9	9.4	7.7
TSP	6.0	3.2	2.5	10.1	14.0	11.7
Particulate P	2.7	6.0	5.3	16.9	10.1	12.4
NaOH extractable P	4.6		2.7	8.7	7.6	4.0
Autoclaved TSP	5.2	9.0	5.8	12.8	15.4	16.6
Autoclaved SRP	2.9		2.8	9.4	13.0	12.7
BAP	5.3	7.3	7.7	18.6	20.5	19.6
BAP/TP (%)	60.9	79.3	98.7	68.9	85.1	81.3
Lake Sammamish 25 meters						
TP	33.6	128.7	191.5	28.4	24.1	50.7
SRP	14.2	93.5	158.7	7.8	10.1	33.0
TSP	13.9	98.2	161.9	8.5	13.3	35.8
Particulate P	19.7	30.5	29.6	19.9	10.8	14.9
NaOH extractable P	11.1	15.0	17.2	9.7	6.5	6.0
Autoclaved TSP	8.0	24.6	23.3	14.1	17.9	39.9
Autoclaved SRP	6.6		19.8	9.4	14.0	37.2
BAP	8.8	19.1	35.2	18.1	22.6	45.8
BAP/TP (%)	26.2	14.8	18.4	63.7	93.8	90.3
Issaquah Creek						
TP	54.4	49.7	39.9	31.2	27.2	74.0
SRP	19.0	34.2	23.5	8.9	10.3	7.7
TSP	25.2	37.2	26.0	12.4	14.6	14.8
Particulate P	29.2	12.5	13.9	22.8	12.6	59.2
NaOH extractable P	8.9		5.0	5.7	5.1	9.6
Autoclaved TSP	32.1	46.9	31.6	15.8	16.8	21.5
Autoclaved SRP	25.3		25.4	9.0	12.9	16.4
BAP	38.1	42.2	38.2	20.8	20.0	24.3
BAP/TP (%)	70.0	84.9	95.7	66.7	73.5	32.8

APPENDIX D cont.

Daily Total Phosphorus Data from Issaquah Creek

Total phosphorus concentration (µg P/L)
measured daily in Issaquah Creek.

Day	APR 1986	MAY 1986	JUN 1986	JUL 1986	AUG 1986	SEP 1986
1	25.5	30.2	41.3	94.8	54.0	45.8
2	26.7	24.4	66.0	74.2	58.7	74.2
3	23.1	25.3	43.4	70.9	56.6	51.3
4	25.3	28.2	45.7	60.8	57.1	61.7
5	30.6	31.1	50.0	45.3	55.6	51.4
6	29.5	34.1	45.3	43.6	59.5	26.5
7	28.5	28.3	40.6	52.5	56.0	33.2
8	32.7	29.5	42.0	52.5	63.8	29.8
9	150.1	78.5	43.4	54.4	56.0	29.8
10	30.8	34.5	37.4	64.5	61.1	36.7
11	28.9	34.1	34.8	63.1	52.4	35.0
12	27.0	36.0	34.0	56.8	61.3	29.3
13	25.2	168.3	34.0	54.9	55.1	31.7
14	27.5	52.5	33.2	55.9	57.1	27.1
15	36.4	42.3	35.8	59.1	52.2	29.0
16	31.3	49.0	29.4	66.9	64.4	29.1
17	48.4	51.1	28.0	70.2	50.7	30.3
18	23.9	51.1	29.9	62.7	50.9	45.5
19	23.6	53.3	31.8	53.9	51.1	38.6
20	27.8	60.1	32.5	61.3	59.8	31.7
21	22.5	59.9	50.9	63.6	49.6	31.0
22	17.3	58.9	56.8	69.5	58.4	48.5
23	22.1	55.1	61.0	53.0	54.4	48.1
24	26.9	52.2	65.2	46.2	50.4	52.8
25	28.3	49.3	58.2	48.3	45.8	27.7
26	33.0	56.5	64.2	50.0	58.4	29.7
27	37.8	76.5	66.5	43.6	56.9	32.0
28	36.8	39.6	70.4	42.5	53.8	34.0
29	37.8	35.2	69.1	47.1	50.2	57.6
30	25.6	40.1	76.3	43.4	46.5	43.4
31		40.7		54.7	49.3	

Total phosphorus concentration (µg P/L)
measured daily in Issaquah Creek.

Day	OCT 1986	NOV 1986	DEC 1986	JAN 1987	FEB 1987	MAR 1987
1	36.7	29.6	42.1	23.0	73.7	37.0
2	32.0	33.7	43.6	25.2	82.5	40.7
3	30.8	33.7	32.7	23.9	38.6	78.4
4	39.2	39.1	32.0	24.2	33.4	109.0
5	38.1	95.2	32.4	17.0	28.2	46.6
6	48.3	47.2	22.7	14.9	19.7	38.8
7	55.3	35.6	22.5	19.4	20.0	22.8
8	64.4	26.9	15.8	17.3	14.7	19.1
9	51.2	23.1	18.1	15.8	15.2	19.1
10	46.1	22.9	21.7	17.3	15.4	17.6
11	46.7	36.5	21.1	64.9	67.3	19.7
12	49.4	34.3	19.9	78.7	21.3	21.3
13	48.0	31.5	25.7	28.4	17.5	21.0
14	48.3	40.8	26.6	28.9	23.4	19.7
15	49.3	45.8	20.9	21.7	18.1	19.4
16	55.0	43.0	18.8	18.8	12.8	17.9
17	55.5	38.5	17.2	17.8	12.7	22.1
18	53.4	38.3	17.8	15.4	10.6	18.1
19	52.1	37.3	22.2	15.4	16.2	20.4
20	52.9	232.3	22.2	15.4	18.7	18.7
21	55.2	54.3	26.5	12.9	15.2	18.1
22	55.8	51.3	24.5	14.1	14.6	17.5
23	62.8	367.4	43.0	14.2	12.0	18.1
24	58.2	488.0	33.8	39.0	12.3	19.9
25	72.8	533.5	31.5	42.6	13.7	16.3
26	119.5	127.4	29.1	22.3	13.7	19.1
27	125.2	99.2	30.1	25.0	15.1	17.8
28	67.8	61.1	87.4	29.8	13.5	17.9
29	41.0	68.9	88.9	16.5		15.4
30	38.7	42.8	48.5	17.1		15.1
31	41.8		23.9	20.5		15.5

APPENDIX D cont.

Phosphorus Data from Additional Lakes Sampled

Summary of phosphorus forms measured in
the additional lakes surveyed.
All values are in µg P/L.

Lake Name	Date Sampled	SRP	ASRP	NaOH ext.P	TSP	ATSP	TP	BAP
Angle	8-09-86	0.5	2.7	4.5	5.5	15.8	18.1	3.1
Beaver	8-01-86	1.1	4.0	2.2	8.7	20.8	27.6	4.9
Deep	8-02-86	0.7	2.5	5.1	7.7	23.7	25.5	4.8
Desire	8-02-86	1.4	5.3	3.9	15.5	37.6	43.4	8.3
Dolloff	8-09-86	3.3	12.3	10.0	25.0	61.0	54.3	12.6
Fenwick	8-09-86	1.5	4.7	7.6	12.6	16.8	29.7	5.5
Fivemile	8-09-86	3.7	9.6	7.3	14.0	44.1	37.5	8.6
Geneva	8-09-86	1.1	3.5	4.7	6.8	21.5	23.9	5.8
Green	9-01-86	4.8	11.1	5.6	19.4	25.3	31.0	11.1
Long	9-02-86	3.4	13.3	15.9	14.3	32.4	45.9	23.5
Lucerne	8-31-86	1.1	2.9	7.2	3.4	8.2	9.7	3.7
Meridian	8-02-86	0.5	2.4	2.5	5.9	16.1	19.5	4.2
Morton	8-02-86	0.2	1.4	2.7	5.6	16.5	15.5	2.6
Moses-St.7	7-29-86	7.2	6.5	5.1	22.0	27.9	39.9	7.7
Moses-St.9	7-29-86	2.4	3.2	4.3	13.3	20.1	42.7	5.2
North	8-09-86	1.4	4.3	3.3	9.0	30.7	23.1	6.9
No. Twelve	8-02-86	0.2	1.4	2.3	6.3	15.8	19.8	4.5
Panther	8-31-86	4.8	16.6	9.0	14.5	35.7	48.8	17.3
Pine	8-01-86	0.8	4.3	2.4	9.2	25.3	26.6	7.0
Pipe	8-31-86	1.2	2.6	5.1	3.7	10.1	11.4	4.4
Sawyer	8-02-86	0.9	2.0	4.0	6.4	28.4	21.6	4.1
Shadow	8-31-86	1.5	3.9	4.1	2.4	8.5	14.3	6.0
Shady	8-02-86	1.1	2.4	4.0	9.0	22.6	31.2	5.9
Silver	9-17-86	1.6	3.4	7.2	0.5	5.2	9.8	6.1
Spring	8-31-86	2.9	5.2	5.9	9.5	18.6	13.2	5.4
Star	8-09-86	0.5	2.0	5.1	5.5	14.3	16.8	3.6
Steel	8-09-86	1.2	5.5	4.5	5.0	20.3	24.0	5.8
Wilderness	8-02-86	0.4	2.8	2.6	5.8	19.2	27.3	5.5
Angle	12-27-86	1.4	3.0	1.9	3.8	7.9	15.1	4.4
Fivemile	12-27-86	5.8	11.7	6.0	13.1	23.0	33.9	18.8
Pine	12-27-86	21.0	23.2	7.0	25.5	29.3	35.6	36.3
Wilderness	12-27-86	2.2	7.0	5.7	6.6	20.0	26.5	13.0
Moses-St.9	12-27-86	4.4	2.1	3.4	12.7	12.4	38.6	4.0