THE SPOKANE RIVER BASIN:
ALLOWABLE PHOSPHORUS LOADING

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SUMMARY

The Spokane River and its major reservoir, Long Lake, have a long history of water quality problems and associated controversies. One of the more severe water quality deficiencies identified in this system was eutrophication in Long Lake, which previously exhibited very low hypolimnetic dissolved oxygen concentrations and excessive algal growth. Phosphorus removal at the Spokane Advanced Wastewater Treatment Plant, historically the largest point source to the river, was initiated in late 1977 and markedly improved the trophic condition of Long Lake.

Currently (1985), nine municipal and industrial facilities discharge a collective wastewater flow (excluding coolant water) to the Spokane River of 38 million gallons per day (MGD). Most of these facilities are continuing to treat larger quantities of wastewater each year. The present permitted flow of 58 MGD may soon be approached.

In recognition of the potential for degraded water quality in Long Lake as a result of increases in wastewater discharge from the many point sources, the Spokane River Wasteload Allocation process was initiated by court order in 1979. Pursuant to this order, the Washington Department of Ecology (Ecology) in 1981 determined the total maximum daily load (TMDL) for phosphorus from all sources in the river to protect beneficial uses of Long Lake. Subsequent to this determination, additional investigations of both the river system and of Long Lake have been completed. The newer data raised questions regarding the accuracy of key analytical data and modelling assumptions used in previous evaluations. A reassessment and revision of the TMDL methodology was therefore deemed appropriate.

This report includes a synthesis and evaluation of available data collected on the Spokane River system through 1985, for the purpose of updating the Long Lake data base and refining existing water quality models. Quality assurance/quality control information was utilized to verify the accuracy of the available analytical data and to facilitate data adjustments where appropriate.

All data were compiled and accessed through microcomputer files now available through Ecology.

The basic limnology of Long Lake is described, including hydrologic, hydrodynamic, nutrient loading, and trophic response characteristics. Long Lake is characterized by a very rapid flushing rate which varies seasonally. In general, only the lower flow growing season months of June-October need be considered in assessments of trophic response to nutrient loadings. The complex mixing regime characteristic of Long Lake during the summer months creates a situation where inflows are partially separated from lake surface and bottom waters. The rapid flushing and complex hydrodynamics of the lake result in varying or non-steady state relationships between nutrient loading and in-lake water quality conditions.

Both hydrologic and nutrient loading regimes in the Spokane River/Long Lake system have varied considerably over the period of record, and provide an opportunity to evaluate the lake's trophic response to changes in these key controlling parameters. The available data support the hypothesis that nuisance algal populations and hypolimnetic oxygen depletions in Long Lake have been primarily controlled by changes in phosphorus supples. Simple predictive models which are appropriate to the limnology of Long Lake were developed as tools for forthcoming wasteload allocation activities. The uncertainty in each model was addressed.

The response of in-river periphyton communities to changes in nutrient loading characteristics was also assessed using available data. Based on these evaluations, it appears that upper reaches of the river system are predominantly nitrogen-limited with typically low periphytic accumulations. Nitrogen-rich aquifer inputs which enter the river near the Spokane metropolitan area appear to remove this nutrient limitation, resulting in significant increases in periphyton levels. Downstream of the aquifer inputs, phosphorus appears to be the more limiting nutrient to periphyton growth, although supplies of this nutrient may generally be above growth-saturation values. Nuisance growths of periphyton in the middle and lower reaches of the Spokane River appear more apt to be determined by lack of grazing and/or scouring losses than by phosphorus supplies.

By adapting a previously completed model of phosphorus transport through the Spokane River system to reflect the current data base and management framework, a computer model was developed which links point source nutrient loading characteristics with water quality conditions within Long Lake. The model is believed to be adaptable to a sufficiently wide range of hydrologic and nutrient loading conditions for management purposes.

A phosphorus standard for Long Lake is recommended to protect the trophic-related water quality of this reservoir. The proposed standard is a seasonal mean total phosphorus (TP) concentration in the lake's euphotic zone of 25 ug/L, to be applied during the seasonal median river flow condition. The proposed TP standard is generally consistent with other common measures of trophic status such as chlorophyll _a_, biovolume, Secchi disc, and hypolimnetic dissolved oxygen.

The 25 ug/L TP standard is equivalent to a TMDL to Long Lake of 259 +/- 43 kg P/day (571 lbs. P/day) during a median river flow condition. The estimated existing (1985) phosphorus loading to the lake during median river flows is 255 +/- 23 kg P/day (563 lbs. P/day). Existing phosphorus levels in the Spokane River basin, therefore, are equivalent to the recommended TP standard.

Assuming that continued growth within the Spokane River basin may dictate a change in future wastewater quality, several hypothetical wasteload allocation scenarios were evaluated to determine their effect on TP concentrations in Long Lake. These analyses revealed that reductions in future point source nutrient discharges appear to be necessary to achieve the proposed phosphorus standard.

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INTRODUCTION

The Spokane River above Long Lake Dam drains over 6,000 square miles of land in Northeastern Washington and the Idaho panhandle (Figure 1). Approximately 410,000 people now live within the drainage basin, with most residing in the Spokane metropolitan area (278,000) and smaller municipalities such as Coeur d'Alene (20,000)(U.S. Census Bureau, 1980). The river system has a long history of water quality problems and associated controversies. Because the present Spokane River Basin: Allowable Phosphorus Loading study is in many respects a continuation of previous efforts, the history of some pertinent water quality issues is summarized below.

Water quality problems within the Spokane River system have been documented since the 1930's when riverine sludge deposits, low dissolved oxygen levels, and pathogen hazards were linked to raw (combined) sewage discharges from the City of Spokane (Pearse et al., 1933; Harris, 1940). In 1958, the City of Spokane began operation of a sewage collection system and primary treatment plant to alleviate some of these impacts.

Water quality studies conducted during the 1960's revealed two major additional problems within the river system. The first was the discharge of large quantities of metallic waste products (primarily zinc) into the South Fork of the Coeur d'Alene River near Kellogg, Idaho (Mink et al., 1971). Greater than 80 percent of the zinc load carried by the Spokane River has been attributed to sources in the Kellogg region (Schmidt and Crossman, 1973). Impacts from elevated zinc concentrations have been reported as far downstream as Long Lake, some 150 miles from the major source area (Greene et al., 1978).

The metallic discharges had probably been occurring since the late 1800's. During the late 1960's through early 1970's, measures were implemented to reduce the metal loadings by settling and treating the liquid waste streams prior to discharge into the South Fork of the Coeur d'Alene River. Trend analyses of water quality data collected between 1973 and 1978 suggested that these measures reduced zinc concentrations in the Spokane River at Post Falls by at least 50 percent (Yake, 1979). Point source discharges of zinc now

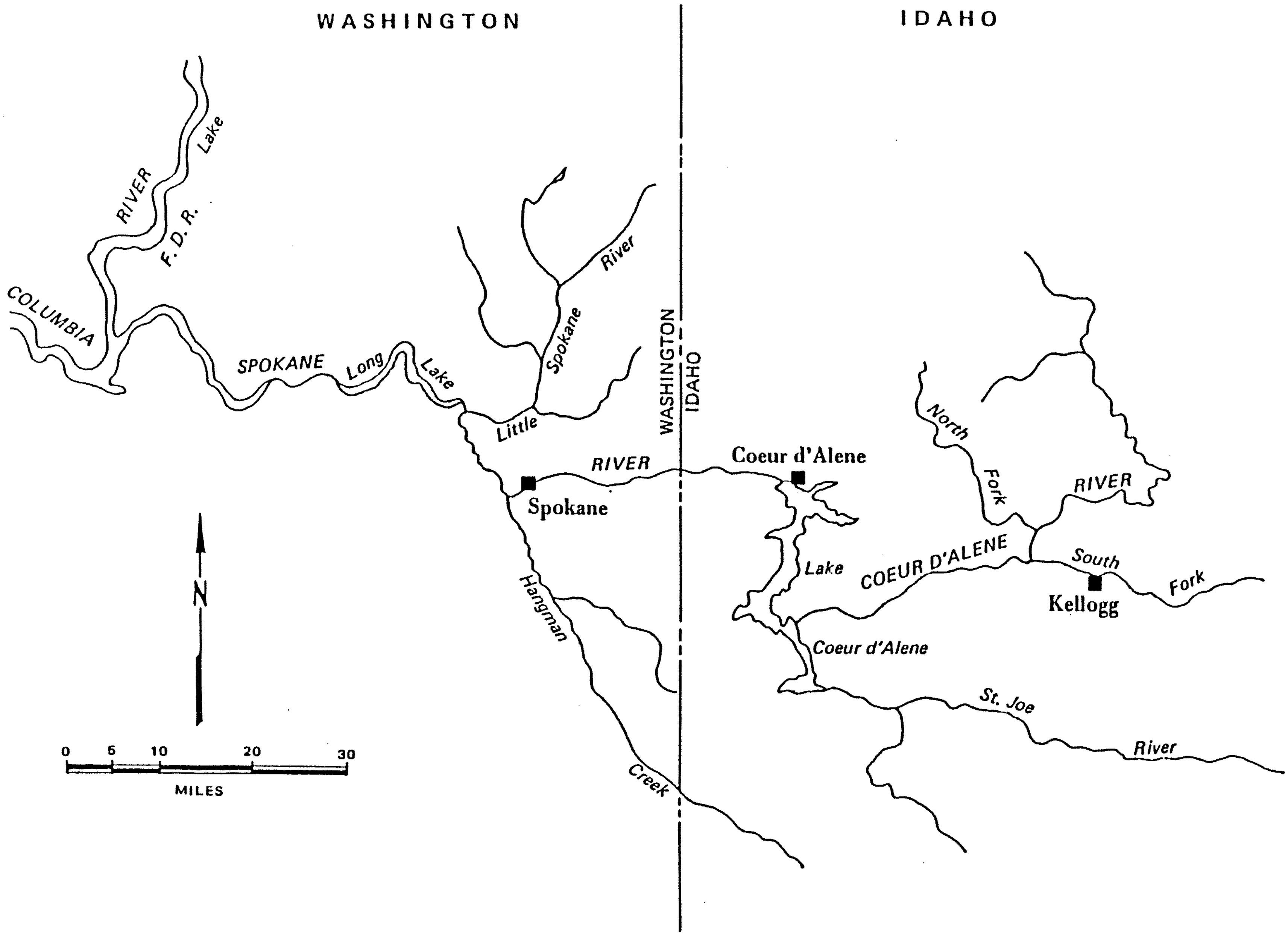


Figure 1. SPOKANE RIVER DRAINAGE SYSTEM

appear to be largely controlled (Smith, 1981); further improvements followed the closure of the Bunker Hill facility. Existing concentrations, though reduced, are still above those in most U.S. waters. (Yake, 1981).

The second water quality problem identified was eutrophication. In 1966, Cunningham and Pine (1969) conducted a water quality study of Long Lake, a man-made hydropower reservoir built in 1915 and the largest of six similar reservoirs along the Spokane River system. Their study revealed extensive anoxia in the lake's bottom waters during the late summer/early fall period, and suggested that algal decomposition within the reservoir may have been the primary cause. Heavy algal growth during summer also reduced the reservoir's recreational value.

Subsequent to the Cunningham and Pine (1969) study, several additional investigations were performed to verify the occurrence of hypolimnetic anoxia and algal blooms, and to examine potential control strategies (Stude, 1971; Bishop and Lee, 1972; Condit, 1972). In 1972, Eastern Washington University (EWU) began an extensive limnological investigation of Long Lake and its major tributaries (Soltero et al., 1973-76; 1978). The EWU studies examined nutrient loading dynamics, algal biomass, and hypolimnetic anoxia in considerably more detail than previous investigations, and the results of their work supported positions of the U.S. Environmental Protection Agency (EPA) and Washington Department of Ecology (Ecology) that phosphorus removal at the City of Spokane Wastewater Treatment Plant would substantially improve water quality conditions in Long Lake. Using a generalized water quality model, Gasperino and Soltero (1977) verified that improvements in in-lake phosphorus, chlorophyll a and hypolimnetic dissolved oxygen levels would occur if phosphorus was removed from the City of Spokane wastewater effluent. The City of Spokane constructed an advanced wastewater treatment (AWT: secondary treatment with 85 percent phosphorus removal) facility, which began phosphorus removal in December 1977. Since the AWT plant came "on-line", Long Lake has improved markedly in terms of algal biomass, transparancy, and hypolimnetic anoxia (Bailey, 1984; Soltero et al., 1979-86).

Although Long Lake had regularly exhibited large algal blooms during the summer/fall months prior to AWT, massive and/or toxic blue-green blooms did not occur in the reservoir until the late summer and fall of 1976, 1977, and 1978, and have subsequently largely disappeared (Soltero and Nichols, 1981; R.A. Soltero, EWU, personal communication). The blooms led several Long Lake homeowners to file a lawsuit against the City of Spokane and Ecology because of a raw sewage bypass during construction of the AWT plant in 1975 and construction of additional plants within the drainage. As a part of the decision, the Superior Court of Spokane County ordered Ecology and EPA to complete a wasteload allocation of phosphorus discharged from all sources into the river system to protect the reservoir from accelerated eutrophication (Spokane County, 1979).

The wasteload allocation process began when URS (1981) reviewed the available water quality data and recommended a methodology for phosphorus limitations. Ecology subsequently established a total maximum daily phosphorus load (TMDL) which could enter Long Lake during the summer/fall growing season (Singleton, 1981). This maximum loading value was set at 248 kg P/day (547 lbs P/day), and applied to the 1-in-20-year seasonal low flow event. The TMDL was based upon maintaining seasonal average chlorophyll _a_ (chl _a_) concentrations in the lake's surface waters of less than 10 ug/L. At that time (1981), the influent load to the Spokane River/Long Lake system was near the TMDL, and was expected to exceed the threshold within ten years unless additional controls were implemented.

Once the maximum influent phosphorus loading value to Long Lake was established, the process moved towards the allocation of this acceptable load among the nine municipal and industrial facilities which presently (1986) discharge effluent into the Spokane River between Lake Coeur d'Alene (RM 111.7) and the Long Lake Dam (RM 33.9)(Patmont et al., 1985; Figure 2). Upstream point sources of phosphorus (e.g. South Fork Coeur d'Alene Sewer District) were not considered because of their relatively small size (Smith, 1981), nutrient retention characteristics of Lake Couer d'Alene, and the mesotrophic character of Lake Couer d'Alene (Funk et al., 1973).

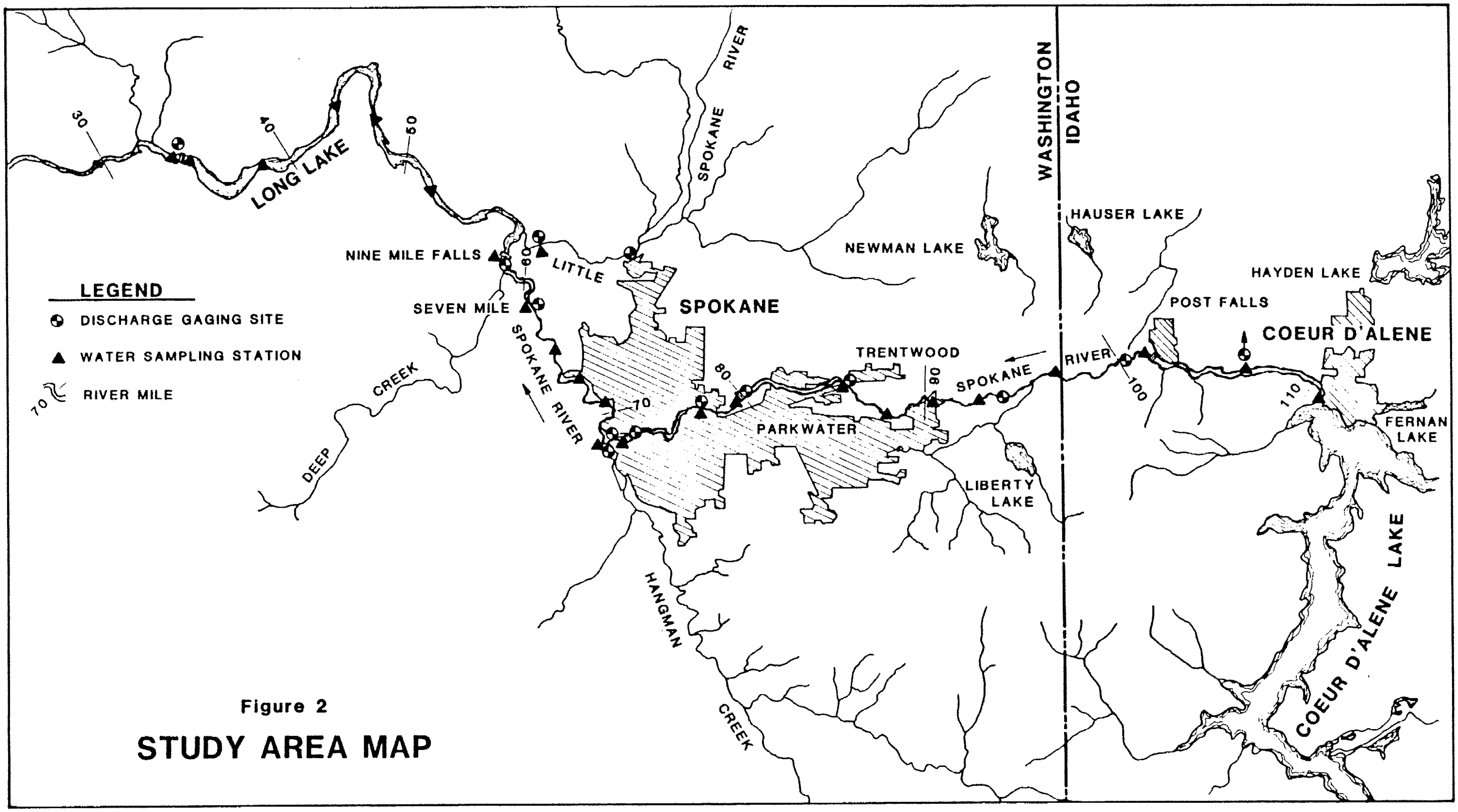


Figure 2

STUDY AREA MAP

The allocation process, however, was complicated when EPA suggested that phosphorus is not transported conservatively through the river system below Coeur d'Alene during the low flow months (Yearsley, 1982). A subsequent detailed study of phosphorus attenuation through the river confirmed that more than 40 percent of the total seasonal influent load was lost during transport (Patmont, et al., 1985). Both in-river removal and aquifer seepage processes were found to be significant loss mechanisms, and the extent of loss of a specific point source discharge depended upon its location in the river system.

The principal product of the attenuation study was a predictive model of phosphorus transport throughout the river system to be used as a tool for wasteload allocation activities (Patmont et al., 1985). This model addressed uncertainties in hydrologic, phosphorus loading, and attenuation processes in the river system, and is generally appropriate for a variety of phosphorus loading scenarios.

The attenuation model can be linked with an appropriate reservoir model describing loading/water quality relationships within Long Lake, thus providing a powerful management tool to evaluate nutrient-related impacts in Long Lake and to assist in the development of an allocation strategy. However, recent evaluations of the Long Lake models used previously by Ecology (Singleton, 1981) and by EWU (Soltero et al., 1986) have raised questions regarding the accuracy of key analytical data and modelling assumptions used in these formulations. Specifically, the results of quality assurance (QA) analyses, possible sampling biases, and the importance of in-lake phosphorus retention had not been critically evaluated. The appropriateness of using average in-lake chl a as the controlling water quality parameter for allocation activities has also been questioned.

Data collected during the phosphorus attenuation study revealed that periphyton accumulations within some reaches of the Spokane River presently exceed a recommended nuisance criterion (Horner et al., 1983; Patmont et al., 1985). The importance of periphyton-related impacts which may occur within the river as a result of nutrient discharges needed to be evaluated since it could affect proper water quality management activities.

Harper-Owes was retained by Ecology to revise and update the Spokane River/ Long Lake data base and water quality models in order to provide a defensible methodology from which to develop appropriate allocation strategies. This study included a synthesis of available water quality data collected within the river system through 1985 (the final year of EWU's limnological monitoring program) and transfered those data onto DBASE III Plus microcomputer files available from Ecology. All nutrient loading, lake water quality, and periphyton data were critically examined and appropriate water quality models developed. A revised TMDL to Long Lake is recommended which would protect beneficial uses of the lake and several example wasteload allocation scenarios are presented.

Although this study was performed largely by Harper-Owes, many of the technical issues were resolved by consensus among Ecology (Lynn Singleton), EWU (Prof. Raymond Soltero), and Harper-Owes, with review provided by the University of Washington (UW, Prof. Eugene Welch). The purpose of this consensus approach was to develop a unified technical foundation among those individuals most familiar with the lower Spokane River data base. Subsequently, the level of water quality and trophic status protection which is appropriate to the management of the Spokane River system was determined by Ecology, since this agency has the principal authority to establish such goals. Any forthcoming wasteload allocation activities involving significant socio-economic issues (which are outside of the scope of this study) are expected to develop directly upon this technical foundation.

METHODOLOGY

The Spokane River Basin: Allowable Phosphorus Loading study basically involved a synthesis and reassessment of data collected previously by other investigators. Additional data were collected during this study on in-river periphyton accumulations, since the existing data on this subject had previously been identified as being deficient (Patmont et al., 1985).

Data Base Sources

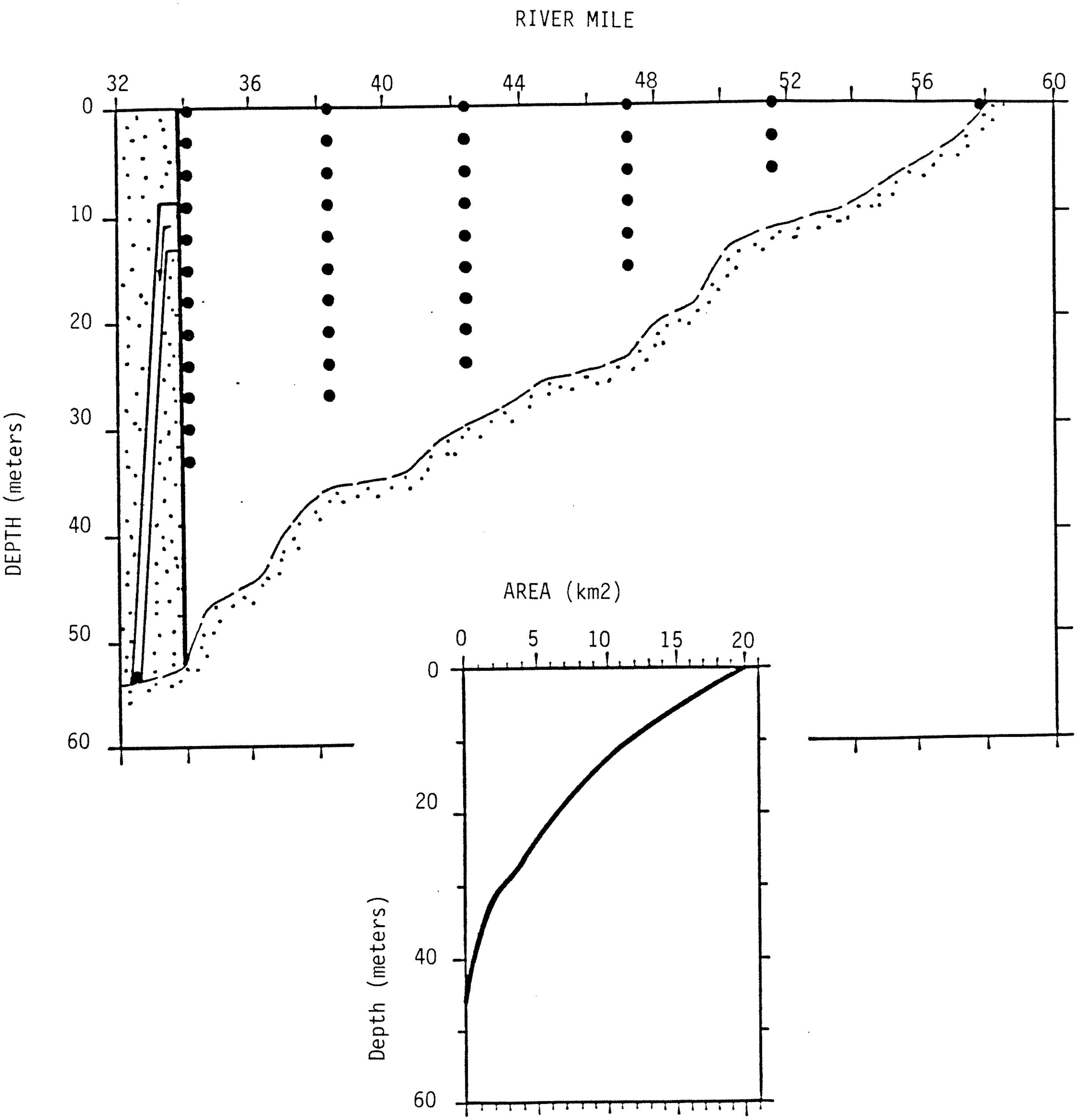
Recent field investigations of water quality characteristics of the Spokane River system have been performed by a large number of public and private organizations, including at least five research and monitoring institutions (EWU, WSU, UW, UI, and USGS), three regulatory agencies (Ecology, EPA, and IDHW), two private firms (Kennedy-Tudor Engineers and Harper-Owes), and many municipal and industrial dischargers (see "References" for a complete listing). Various pieces of the relatively extensive data base have been used by different investigators to assess water quality conditions within the river, but previously no rigorous synthesis of the data had been performed to permit a comprehensive evaluation.

For the purposes of this study, all available data collected from the Spokane River system with adequate QA documentation were gathered and compiled onto a computerized data base. The major portions of this data base which had previously been difficult to obtain in a readily useable format--EWU and Washington State University (WSU) monitoring data--were compiled onto DBASE III Plus microcomputer files and are available through Ecology.

Eastern Washington University

By far the most extensive data set collected on the Spokane River, and the most pertinent to the present investigation, was that collected by EWU (Soltero et al., 1973-76; 1978-86). The EWU limnological studies represented thirteen (13) years of investigation. Sampling sites included five stations within Long Lake at three (3) to twelve (12) depths per station (Figure 3), plus a euphotic zone

Figure 3
LONG LAKE STATIONS AND DEPTHS SAMPLED BY EASTERN WASHINGTON UNIVERSITY



HYPSOGRAPHIC CURVE FOR LONG LAKE
Based on WWP MAP E-26345, Elev. 1535.7

composite. Sampling points also included four stations along the Spokane River (Fort Wright, RM 69.8; Seven Mile, RM 62.0; Nine Mile Dam, RM 58.1; and Long Lake Dam, RM 33.9), two major tributaries (Hangman Creek, RM 72.4, and Little Spokane River, RM 56.3) and the City of Spokane wastewater discharge (RM 67.4) (see Figure 2). Sampling frequency normally ranged from weekly to biweekly during the summer/fall months (June-October), with less sampling during the winter/spring months of high runoff. Eight (8) to nineteen (19) individual parameters were analyzed on each sample collected. In total, the EWU investigations resulted in the collection of over nine thousand (9,000) discrete samples and over one hundred thousand (100,000) analytical determinations.

A summary of most of the analytical determinations performed by EWU is presented in Table 1. Additional parameters were periodically measured on selected samples and dates, and included algal bioassays (performed by EPA, Corvallis) on euphotic zone composites, zooplankton enumeration, and metal determinations. Analytical determinations performed on the EWU samples varied somewhat over the years. For example, in 1981 total phosphorus (TP) was added to the list of parameters analyzed in reservoir samples (river samples, however, had previously been analyzed for TP). Also, beginning in 1981, more sensitive analytical equipment was used to determine chl a levels. The comparability of the EWU data both between years and relative to data from other sources is discussed in the Quality Assurance section below.

The EWU data collected through the 1983 field season were available on unformatted data files stored on Ecology's computer system. These files were accessed and formatted for microcomputer usage through the Ecology facility. Data from the last two years of collection (1984-85) required manual input (by EWU) into DBASE III Plus files for use in this project. All data were checked for entry and formatting errors (see below).

Washington State University

A number of major water quality investigations in the Spokane River system have been conducted by WSU. Nearly all of WSU's monitoring and research activities have taken place upstream of Spokane (RM 72), while EWU's monitoring

TABLE 1

SUMMARY OF ANALYTICAL DETERMINATIONS PERFORMED BY EASTERN WASHINGTON UNIVERSITY, 1972-1985

SAMPLING SITE	PARAMETER	FIELD NAME	METHOD (YEARS)	REPORTED UNITS
LONG LAKE EUPHOTIC ZONE COMPOSITE	EUPHOTIC ZONE DEPTH	EZ_DEP	FIELD 1% INCIDENT LIGHT (ALL)	meters
	EXTINCTION COEFFICIENT	EXTINCT	CALCULATED FROM 1% INCIDENT LIGHT (ALL)	m(-1)
	SECCHI DEPTH	SECCHI	FIELD DISK (ALL)	meters
	TEMPERATURE	TEMP	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	deg. C
	DISSOLVED OXYGEN	DO	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	mgO/l
	pH	PH	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	S.U.
	SPECIFIC CONDUCTANCE	COND	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	umho/cm 25C
	REACTIVE PHOSPHATE	R_PO4	STANNOUS CHLORIDE (ALL)	mgPO4/l
	TOTAL PHOSPHATE	TOT_PO4	PERSULFATE DIGESTION - STANNOUS CHLORIDE (81-85)	mgPO4/l
	NITRATE NITROGEN	NO3_N	CADMIUM REDUCTION (72-73) & CHROMOTROPIC ACID (74-85)	mgN/l
	NITRITE NITROGEN	NO2_N	DIAZOTIZATION (ALL)	mgN/l
	AMMONIA NITROGEN	NH4_N	NESSLER (72-82) & PHENATE (83-85)	mgN/l
	SILICA	SIO2	MOLYBDOSILICATE (ALL)	mgSiO2/l
	TURBIDITY	TURB	JACKSON (72-73) & NEPHELOMETRIC (74-85)	NTU
	TOTAL CHLOROPHYLL A	CHL_A	ACETONE - TRICHROMATIC SPEC 20 (72-84) & DU-8 (81-85)	ug/l
	TOTAL CHLOROPHYLL B	CHL_B	ACETONE - TRICHROMATIC SPEC 20 (72-84) & DU-8 (85)	ug/l
	TOTAL CHLOROPHYLL C	CHL_C	ACETONE - TRICHROMATIC SPEC 20 (72-84) & DU-8 (85)	ug/l
	PHYTOPLANKTON VOLUME	PHY_VOL	SEDIMENTATION - MICROSCOPIC (ALL)	mm3/l
	PHYTOPLANKTON NUMBERS	PHY_NUM	SEDIMENTATION - MICROSCOPIC (ALL)	million/l
LONG LAKE DISCRETE DEPTHS	TEMPERATURE	TEMP	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	deg. C
	DISSOLVED OXYGEN	DO	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	mgO/l
	pH	PH	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	S.U.
	SPECIFIC CONDUCTANCE	COND	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	umho/cm 25C
	REACTIVE PHOSPHATE	R_PO4	STANNOUS CHLORIDE (ALL)	mgPO4/l
	TOTAL PHOSPHATE	TOT_PO4	PERSULFATE DIGESTION - STANNOUS CHLORIDE (81-85)	mgPO4/l
	NITRATE NITROGEN	NO3_N	CADMIUM REDUCTION (72-73) & CHROMOTROPIC ACID (74-85)	mgN/l
	NITRITE NITROGEN	NO2_N	DIAZOTIZATION (ALL)	mgN/l
	AMMONIA NITROGEN	NH4_N	NESSLER (72-82) & PHENATE (83-85)	mgN/l
SPOKANE RIVER, TRIBUTARIES, AND STP EFFLUENT	TEMPERATURE	TEMP	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	deg. C
	DISSOLVED OXYGEN	DO	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	mgO/l
	pH	PH	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	S.U.
	SPECIFIC CONDUCTANCE	COND	FIELD HYDROLAB MODEL 6 (72-77) & 8000 (78-85)	umho/cm 25C
	CALCIUM	CA	EDTA TITRATION (ALL)	meq/l
	MAGNESIUM	MG	HARDNESS CALCULATION (ALL)	meq/l
	BICARBONATE	HCO3	POTENTIOMETRIC TITRATION (ALL)	meq/l
	CHLORIDE	CL	DIPHENYLCARBAZONE (72-75) & MERCURIC NITRATE (77-85)	meq/l
	SULFATE	SO4	BARIUM CHLORIDE (72-75) & TURBIDIMETRIC (77-85)	meq/l
	FILTRABLE REACTIVE PHOSPHATE	FR_PO4	STANNOUS CHLORIDE (ALL)	mgPO4/l
	TOTAL FILTRABLE PHOSPHATE	TF_PO4	PERSULFATE DIGESTION - STANNOUS CHLORIDE (ALL)	mgPO4/l
	TOTAL PHOSPHATE	TOT_PO4	PERSULFATE DIGESTION - STANNOUS CHLORIDE (ALL)	mgPO4/l
	FILTRABLE NITRATE NITROGEN	FNO3_N	CADMIUM REDUCTION (72-73) & CHROMOTROPIC ACID (74-85)	mgN/l
	FILTRABLE NITRITE NITROGEN	FNO2_N	DIAZOTIZATION (ALL)	mgN/l
	FILTRABLE AMMONIA NITROGEN	FNH4_N	NESSLER (72-82) & PHENATE (83-85)	mgN/l
	FILTRABLE KJELDAHL NITROGEN	FK_N	TOTAL KJELDAHL - ELECTRODE (ALL)	mgN/l
	TOTAL KJELDAHL NITROGEN	TK_N	TOTAL KJELDAHL - ELECTRODE (ALL)	mgN/l
	SILICA	SIO2	MOLYBDOSILICATE (ALL)	mgSiO2/l
	TURBIDITY	TURB	JACKSON (72-73) & NEPHELOMETRIC (74-85)	NTU

program has concentrated on the river below this point. Most of the efforts took place between 1971-1974 (Condit, 1972; Funk et al., 1973; Funk et al., 1975) and 1979-82 (Nielsen, 1983; Gibbons et al., 1984). The earlier (1971-74) research episode primarily investigated trophic conditions and metallic contamination in the Coeur d'Alene system, while later activities (1979-82) attempted to evaluate impacts of secondary sewage effluent from the Liberty Lake Wastewater Treatment Plant (RM 92.7), which began discharging into the river in August 1982.

The most recent (1979-82) sampling activities performed by WSU provide a data base characterizing nutrient, metal, and benthic conditions within the upper river system (Gibbons et al., 1984). During this effort, over 400 water samples were collected (representing 10 stations), resulting in over 1,200 determinations. Although the WSU data is quite useful for characterizing recent ambient water quality conditions within the upper river, its primary value to this study was related to periphyton growth investigations. Short-term (typically 60 day) periphyton accumulation experiments were performed repetitively at a number of sites along the upper river. Since ambient water quality data (with QA documentation) were also collected concurrently with the periphyton studies, the WSU data provided an opportunity to examine the relationship between nutrient (especially phosphorus) supplies and attached algal growth within the river. All of the water quality data summarized in Gibbons et al. (1984) were entered onto microcomputer data files (DBASE III Plus) and are available through Ecology.

Other Data Sources

In addition to the EWU and WSU efforts, discharge and water quality monitoring of river and tributary sites within the Spokane River system has been conducted by both Ecology and the U.S. Geological Survey (USGS) since at least the early 1970's. Water quality monitoring at these sites has generally occurred at biweekly to quarterly intervals and has typically included the analysis of a variety of conventional parameters including nutrients. A summary of the combined Ecology/USGS monitoring network is presented in Table 2. All monitoring data (including 1985 and 1986 provisional entries) were transmitted by

Table 2

Historical Summary of Selected Ecology and USGS Monitoring Stations Within the Spokane River

River Mile	Site	Discharge		Water Quality	
		Continuous	Intermittent	USGS	WDOE
106.6*	Rathdrum Canal	1946-present	---	---	---
101.7*	Spokane Valley Canal	1913-1966	---	---	---
100.7	Post Falls	1913-present	---	1973-1980	---
93.6	Harvard Road	1929-1983	---	1959-1971	---
72.9	Spokane	1891-present	---	---	---
72.4*	Hangman Creek	1948-present	---	1973, 77-80	1980-present
66.1	Riverside Park	---	---	1973-1981	1981-present
56.3*	L. Spok. R. - Dartford	1929-32, 46-present	---	---	---
56.3*	L. Spok. R. - Mouth	1913, 48-51	1903-present	1971, 73, 77-80	1980-present
33.9	Long Lake Dam	1939-present	---	1959-present	---

* Denotes either an irrigation withdrawal site from the Spokane River or a major tributary to the river.

Ecology and USGS and processed into microcomputer files. Other existing sources of data which were utilized during this study included historical D.O. observations within Long Lake (Cunningham and Pine, 1969; Bishop and Lee, 1972), algal bioassays and zinc data (Greene et al., 1978), results of the phosphorus attenuation study (Patmont et al., 1985), and recent effluent monitoring conducted by the many municipal and industrial discharges (City of Spokane, Ecology, and IDHW, unpublished records). Most of these data had supporting QA documentation approximately equivalent to those of the other data sets.

Periphyton Sampling

A limited amount of additional sampling and analysis of in-river periphyton levels was performed for this study in an effort to improve the existing data base. On September 3, 1986, five (5) sites along free-flowing sections of the Spokane River were sampled. Sites included: below Upriver Dam (RM 79.7); Spokane at USGS gage (RM 72.9); Fort Wright Bridge (RM 69.8); Riverside State Park (RM 66.2); and the Spokane Gun Club (RM 64.6). Three replicate samples were collected from each station by randomly selecting points across the width of the channel. Periphyton was sampled by scraping all material within a 4.9 cm^2 or 9.6 cm^2 area (enclosed by a plexiglass tube apparatus) and then transferring the material into amber bottles. Samples were stored on ice and delivered to the UW Environmental Engineering and Science laboratory for chl a analysis using the method of Lorenzen (1967). All methods were equivalent to those used previously by Patmont et al. (1985) and Horner et al. (1986).

Quality Assurance

Quality assurance (QA) is a term frequently used to describe a variety of measures which collectively establish the reliability of field and laboratory data. A clear distinction should be made between the terms "precision" and "accuracy" as they are applied to data for a given analytical determination. Precision refers to the reproductibility of a method when it is repeated on a homogenous sample under controlled conditions, regardless of whether or not the observed values deviate from the true value (APHA, 1985). Conversely, accuracy refers to the agreement between the average amount of a constituent measured i the determination and the amount actually present. A given method may be characterized by any combination of accuracy and precision.

A typical analytical quality asurance/quality control program consists of three factors:

- o Use of methods which have been studied collaboratively and found acceptable (e.g. "Standard Methods").
- o Routine calibration and analysis of standard solutions (internal QA).
- o Periodic analysis of reference samples (external QA).

Of the three QA factors, only the first and third were specifically evaluated during this study. The second factor, internal QA, was omitted from consideration primarily due to the difficulty in obtaining these rather voluminous data from each laboratory. However, since explicit internal QA procedures are specified in analytical protocols, such procedures were generally assumed to be acceptable if the method was deemed appropriate.

Currently, there are two organizations which have evaluated alternative analytical methods to determine their reliability for water quality characterization. The first is the American Public Health Association (APHA) which, in cooperation with the American Water Works Association and the Water Pollution Control Federation, periodically reviews and recommends appropriate test procedures. The APHA "Standard Methods" document generally only recommends procedures which have been thoroughly evaluated to assure a minimum level of reliability under a variety of environmental conditions.

The second organization which evaluates analytical techniques is EPA, which periodically updates a list of approved procedures for compliance monitoring activities (EPA, 1985). The EPA's list of procedures is, in general, somewhat more restrictive than that of APHA (1985). Methods characterized by comparatively poor precision or possible analytical interferences are generally excluded from EPA's approved procedures list although, in many cases, the methods may be adequate.

Most of the Spokane River/Long Lake data compiled and utilized in the present study were obtained using procedures approved by both APHA (1985) and EPA (1985). However, the majority of chl a determinations performed by EWU did not conform to the existing (i.e. 1985) approved protocols although they were performed in accordance with previous APHA (1971) recommendations. This occurred because prior to 1985, EWU routinely utilized a spectrophotometer with a rather wide band width (20 nm, versus a recommended band width of less than 2 nm) to determine chl a concentrations (see Table 1). Use of a wide band width typically results in a significant underestimation of the true chl a levels; the approximate magnitude of this underestimation is discussed below. All other aspects of EWU's chl a methodology were generally consistent with current APHA and EPA recommendations.

Although EWU's methods for determining phosphorus (reactive and total), nitrate, and magnesium conformed to APHA (1985) protocols, the methods utilized for these parameters have not been approved by EPA (1985). For example, the phosphorus analysis employed by EWU (stannous chloride method) is not as sensitive as an alternative procedure (ascorbic acid method), which could lead to a reduced precision in the phosphorus analysis (precision and accuracy of these determinations is discussed in detail in Appendix A). Similar potential deficiencies also exist for the nitrate (chromotropic acid) and magnesium (hardness calculation) methods used by EWU. Although potential interferences inherent to these methods can not be wholly dismissed, it is considered doubtful that interferences for these parameters would ever be consequential in the Spokane River/Long Lake samples, given the generally low ambient levels of potentially interfering substances (see also Appendix F).

The third QA factor, analysis of reference samples, is a useful tool for examining the comparability of data available from different sources, particularly when the reference samples are submitted as "unknowns" to the laboratory. In the late 1970's, EPA developed an external QA program for a variety of conventional, nutrient, and algal biomass parameters that has formed the basis for many QA evaluations of eutrophication studies within the U.S. (EPA, 1979). All of the laboratories which have been involved in major elements of previous Spokane River/Long Lake studies have participated in this program to some extent, either by Ecology administration or as a component of their own QA program.

For the purposes of this study, all external QA data available for phosphorus and chl a analyses were compiled for each analytical laboratory for the period of time when Spokane River samples were analyzed. These data formed the basis of evaluations of both the accuracy and relative precision of each method. A detailed summary of these evaluations is presented in Appendix A.

The analyses of relative precision in the TP determinations reveal that most of the laboratories responsible for the existing Spokane River/Long Lake data base for this parameter were capable of reproducing a given TP analysis within approximately 5-15 percent (see Appendix A). EWU-Biology, which generated by far the greatest amount of TP data, appeared to fall within the middle of the range of precision and exhibited an overall coefficient of variation of 10 percent. Generalized precision performance criteria reported by APHA (1985) and EPA for TP analyses (persulfate digestion/ascorbic acid method) typically range from 5-10 percent. Based on this comparison, therefore, the EWU-Biology TP analyses were apparently not characterized by excessive variability, even though the method used (stannous chloride) is generally less sensitive than the EPA-approved ascorbic acid procedure. Overall, only a minor percentage (<10%) of the total sample variance appeared to be due to laboratory precision errors.

The accuracy and comparability of TP determinations performed by various laboratories was assessed with the external QA data (see Appendix A). A Wilcoxan signed-ranks test was used to evaluate whether a significant bias existed between the reported concentrations and the EPA reference values (Sokal and Rohlf, 1969). The initial evaluation detected a significant ($P<.01$) negative bias in the EWU-Biology TP determinations but not in the reactive phosphorus analyses. None of the other laboratories exhibited a significant ($P>.05$) bias and were therefore assumed to have generated TP data comparable to the EPA reference.

The negative bias observed in the EWU-Biology TP analyses was quite consistent both over time (1980-1985) and across a wide concentration range (see Appendix

A). The TP bias determined from 16 reference sample comparisons averaged -12 +/- 4 percent. Linear regression analyses verified that TP levels were underestimated by a constant percentage, since the regression constant (i.e. y-intercept) was not statistiacally significant ($P>.5$), while the regression coefficient (i.e. slope) was significantly ($P<.02$) different from unity. Since no change in analytical TP methods or the degree of bias was apparent over the study period, it was assumed that a constant correction could be applied across all EWU-Biology TP data. Based on these data, the average ratio of reference/ reported TP concentrations formed the basis for the bias correction:

Reference TP = 1.15 * Reported TP

In effect, the external QA determinations were used to perform an a posteriori standardization of the EWU-Biology TP data. The standard error of this correction, based on the 16 available external QA determinations, is equivalent to 3.0 percent of the corrected concentration. A random error of +/- 3.0 percent resulting from bias corection is well within the 5-10 percent generalized performance criteria for TP analyses, and is not considered excessive.

Since nearly all of the chl *a* data utilized in this report were analyzed by EWU Biology, external QA evaluations of chl *a* determinations were limited to include only this facility. The overall precision of the chl *a* analyses appeared to vary with the method and date, and averaged approximately 10 percent over the entire study period. Although published values for the general precision of the chl *a* analysis vary widely, the observed average precision value of 10 percent for the EWU-Biology determinations is within the range of generally accepted performance criteria for this analysis.

The external QA data revealed a considerable negative bias in EWU-Biology chl *a* determinations performed with a Spectronic-20 instrument (-34 +/- 3%; see Appendix A). The bias was believed to be the result of the wide band width of the instrument (20 nm), which cannot resolve the narrow absorbance peak of chl *a*. Wilcoxan signed-ranks analyses indicated that this bias was statistically significant ($P<.02$). Chl *a* data determined with a DU-8 instrument (band width = 0.5 nm) over the period 1981-1984 exhibited a reduced but still significant

(P<.05) negative bias (-10 +/- 8%), possibly as a result of photodegradation during analysis (R.A. Soltero, EWU, personal communication). No bias in 1985-1986 chl a determinations was detected.

Although the previous chl a data could be simply "standardized" using the external QA data (similar to that performed for TP analyses), internal QA information pertaining to the EWU-Biology chl a analyses suggest that such a simple correction may be inappropriate. Based on 179 chl a samples which were run simultaneously using the DU-8 and Spectronic-20 instruments over the period 1981-1984, the relationship between chl a values determined using the two methods does not appear to have been constant. Linear regression analyses, for example, suggested that both the regression coefficient and constant were statistically significant (P>.05), and indicated that the Spectronic-20 negative bias may have been more severe at lower chl a levels. Based on a synthsis of all available internal and external QA data using linear regression methods, the following formulation for bias correction of the Spectronic-20 data was obtained:

Reference chl a (ug/L) = 0.98 + 1.39 * Reported Spec.-20 chl a (ug/L)

The standard error associated with this bias correction is equivalent to 14 percent of the corrected concentration at the average level measured in Long Lake (15 ug/L).

As discussed above, beginning in 1981 most (though not all) chl a extracts quantified using EWU-Bilogy's Spectronic-20 were also analyzed concurrently using a Beckman DU-8. Bias correction of chl a determinations performed with the use of the DU-8 for years prior to 1985 (representing 179 lake samples), were based on the average ratio of reference/reported concentrations:

Reference chl a = 1.11 * Reported DU-8 chl a

The standard error of this bias correction is equivalent to 9.1 percent of the corrected chl a concentration. In instances where both Spectronic-20 and DU-8 data were available for the same lake sample (parts of 1981, 1982, and 1984), the DU-8 (corrected) results were utilized preferentially since both the magnitude and uncertainity of the DU-8 correction was lower.

In 1985, the EWU-Biology DU-8 methodology was improved. External QA information revealed that the new method yielded data comparable to the EPA reference values. No correction of the 1985 chl a data was therefore necessary.

A final aspect of QA/QC performed during this study involved an assessment of data entry errors contained on the EWU and WSU data bases. For the EWU files, 5 percent of the entire data base (representing more than 5,000 records) were randomly selected and compared against the original laboratory results on file at EWU. The comparison suggested that approximately 0.2 percent of the data base records contained some data entry error, although in all cases the magnitude of these errors was small (typically within 10 percent of the true value). A similar result was obtained with the WSU data base, although in this case the records were compared against tabulated values presented in Gibbons et al. (1984) and not against the original data sheets. For the analyses conducted during this study, the minor errors contained on the data bases were considered to be inconsequential.

Uncertainty Analysis

The information value contained within a given estimated or predicted quantity is only as good as the confidence bounds which surround that estimate. Since the water quality models developed in this study are based upon discharge and chemical measurements, and also upon hypothesized relationships between measured parameters, a variety of potential measurement and modelling errors (both systematic and random) can contribute to the total prediction uncertainty. Quantification and propagation of the uncertainty common to each term in the model is necessary in order to determine the degree of confidence which can be placed on the prediction.

Statistical techniques which describe the effects of contributing uncertainties are broadly categorized as error propagation methods. For this report, we have utilized a first-order uncertainty methodology consistent with that used in the previous phosphorus attenuation study (Patmont et al., 1985). The theory and application of first-order uncertainty analysis techniques have been described by Cornell (1973), and Lettenmaier and Richey (1979). Briefly, the technique is based upon the assumption that parameter variations can be propagated about the first derivative (i.e. first order) of a function relative to those variables which make up the function. In general, for any calculated quantity Y which is derived from measured parameters denoted by X,

$$Y = f(X_1, X_2, \ldots\ldots, X_n),$$

the first-order variance of Y can be represented as:

$$\mathrm{Var}\ (Y) = \sum_{i=1}^{n} \left[\frac{\partial Y}{\partial X_i}\right]^2 \mathrm{Var}\ (X_i)$$

The quantity $\left[\frac{\partial Y}{\partial X_i}\right]^2$ describes the first-order relationship between the calculated value and each measured parameter which describes the function. The equation above is only valid when the variances of each measure parameter (i.e. X_i) are independent, and it is therefore necessary to reduce each function to a form which includes only independently measured parameters. An example uncertainty analysis calculation is presented in Appendix B.

LONG LAKE

Hydrology

Summary of Discharges

Annual discharge at Long Lake Dam (RM 33.9) since 1939 has averaged nearly 8,000 cfs (230 m^3/sec) with most of the flow contributed by the Spokane River and nearly all of the remainder by the Little Spokane River (USGS, 1986). Typically, Washington Water Power (WWP), which owns and operates Long Lake Dam, maintains the pool over most of the year at approximately elevation 1,536 ft. MSL (468 m), resulting in an average lake volume of 301 x 10^6 m^3 (244,000 acre-feet) (Table 3). Depending upon river flow conditions and power demands, the elevation of Long Lake may be drawn down as much as 7m (24 ft) over the winter/spring period. Generally, the reservoir is brought to full pool by June 1. The average annual bulk water residence time within Long Lake, assuming the entire reservoir is well mixed (generally only true from November-May; see "Hydrodynamics" section), is approximately 15 days.

Typical of many rivers in the region, flows in the Spokane River generally peak during the months of May and June (Figure 4), as a result of melting of the winter snowpack accumulation. The magnitude of peak snowmelt flows are dampened by storage changes in Lake Coeur d'Alene. During the snowmelt period, discharges at Long Lake Dam commonly exceed 20,000 cfs (600 m^3/ sec; USGS, 1986), and the water residence time within Long Lake falls to less than five days. At least for the duration of the snowmelt, Long Lake is essentially a riverine environment.

Following the snowmelt period, discharges decline rapidly within the river system, reaching minimum flow levels generally by August (Figure 4). Low flows in the Spokane River are maintained in part by the operation of Post Falls Dam (RM 101.7), which generally controls the level of Lake Coeur d'Alene. The current minimum flow at Post Falls established by regulation is 300 cfs (8.5 m^3/sec; WWP, personal communication), although in most years flows are maintained above 1,000 cfs (30 m^3/ sec).

Table 3

Morphometric Data for Long Lake at Normal Pool[a]

Normal Pool Elevation	468.1 m
Length	35.4 km
Maximum Width	1,100 m
Mean Width	568 m
Maximum Depth	52.4 m
Mean Depth	15.0 m
Area	20.11×10^6 m^2
Volume	300.6×10^6 m^3
Shoreline Length	74.3 km

[a]Based on Washington Water Power Map E-26345 (depth soundings conducted September 1974) and Soltero et al. (1986).

[1] Median Flushing Rate (d^{-1}) June - Oct	0.0343
[1] median Residence Time (days) June - Oct	29

[1] Based on median Long Lake Dam discharge of 4,172 cfs

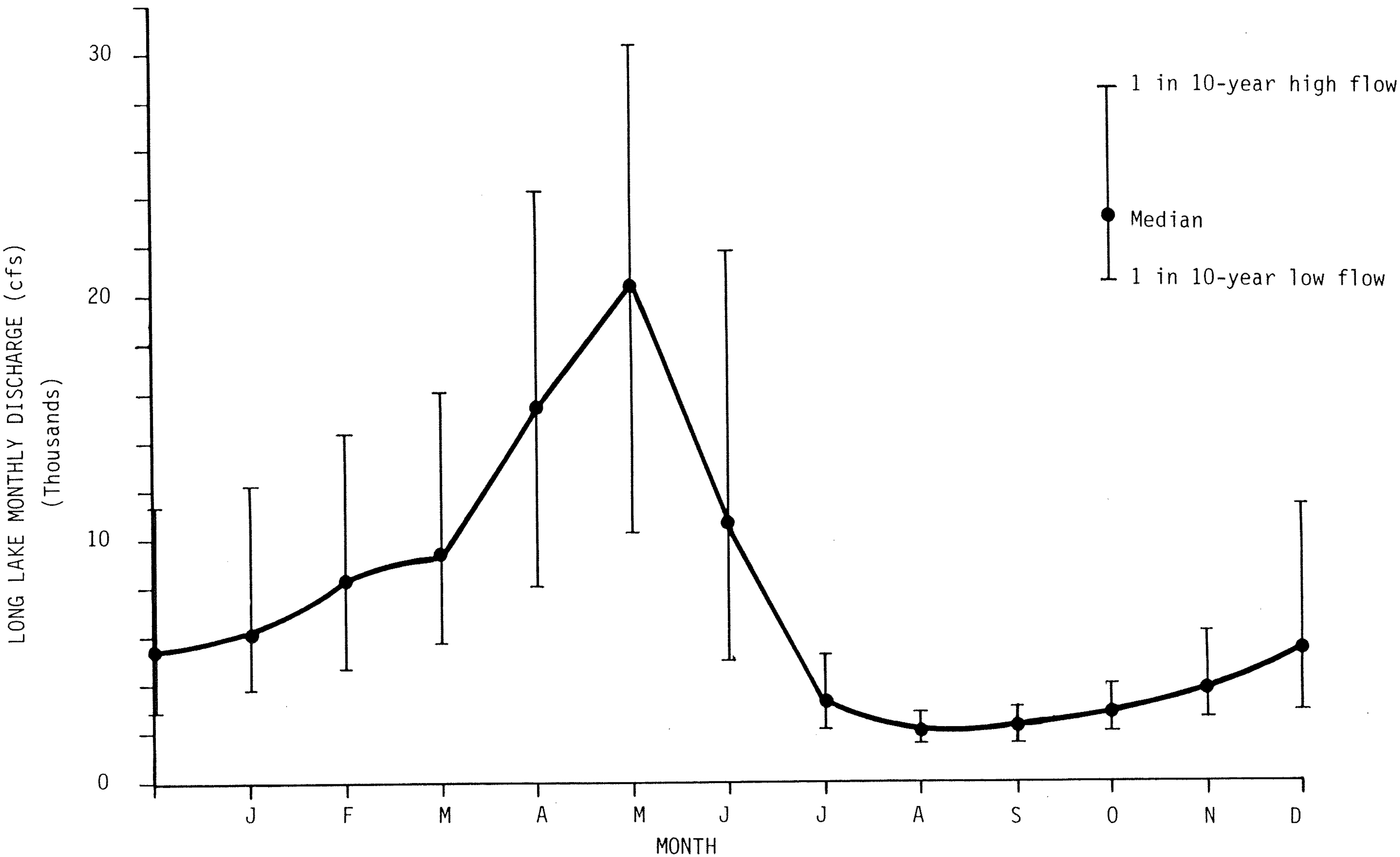


Figure 4

SEASONAL VARIATION IN LONG LAKE FLOWS

Based on Williams and Pearson (1985)

In addition to flow regulation by dams, groundwater inflows also serve to maintain a considerable discharge in the Spokane River during the low flow season. Three major groundwater discharge zones have been identified along the river (near RM 87, RM 79, and Little Spokane River), which combined result in an average summertime net flow increase from Post Falls to Long Lake Dam of more than 1,000 cfs (30 m^3/sec; Patmont et al., 1985).

Regulatory Considerations

For the purpose of applying water quality standards, Ecology defines a reservoir as a "lake" if the bulk water residence time during the 30-day-10-year low flow event exceeds 15 days (WAC 173-201). Based on Long Lake Dam discharge data collected over the period of record (1939-1985), the 30-day-10-year low flow is estimated to be 1,450 cfs (41 m^3/sec). The corresponding bulk water residence time during this flow event is 85 days, which categorized Long Lake as belonging to "Lake Class" relative to water quality standards. The Spokane River above and below Long Lake is presently (1986) categorized as a "Class A" water.

In consideration of the pronounced seasonal cycle of recreational use, lake metabolism, and the very rapid flushing rate during spring snowmelt, URS (1981) and Soltero et al. (1982) suggested that only the months of June-October need be considered when evaluating nutrient loading and trophic response within Long Lake. Ecology has since concurred with these recommendations and has allowed the City of Spokane to restrict AWT to this general period, with allowances made for year-to-year variations in river flow (Soltero et al., 1984; L. Singleton, Ecology, personal communication).

Water Budgets

During the 1972-1986 period when EWU conducted the Long Lake limnological studies, continuous discharge records were collected by USGS at Spokane River at Spokane (RM 72.9), Hangman Creek near its mouth (RM 72.4), Little Spokane River at Dartford (RM 56.3; LSR Mile 11.4), and Spokane River at Long Lake Dam (RM 33.9) (Table 2). These gages formed the basis for characterizing river hydrology during the EWU investigations. However, the mouths of the major tributary inputs to Long Lake--Spokane River at Nine Mile Dam (RM 58.1) and Little Spokane River at its mouth (RM 56.3)-- were not gaged continuously during the EWU investigations. Since these two sites correspond to the principal water quality sampling stations used by EWU to characterize nutrient loading to Long Lake, discharge estimates at these locations were required.

From 1948-1951, USGS maintained a continuous discharge gage at the mouth of the Little Spokane River (see Table 2). Subsequently, USGS performed intermittent discharge measurements at this site, generally several times per year, for the purpose of estimating flow increases due to groundwater inputs between the Dartford gage and the mouth. USGS has previously developed individual linear regression equations for each year to estimate discharge at the mouth as a function of the Dartford flow (Bob Blazs, USGS, personal communication). However, an evaluation of all available data collected during the June-October period revealed that the magnitude of the flow increase between Dartford and the mouth was independent ($P>.05$) of the Dartford discharge and also did not vary significantly ($P>.05$) from year to year (ANOVA). Based on all available seasonal data collected since 1948, and weighting each daily discharge measurement equally, the following formulation for predicting June-October flows at the mouth of the Little Spokane River (LSR) was derived:

$$\text{LSR-Mouth Discharge (cfs)} = 250 + \text{LSR-Dartford Discharge (cfs)}$$

The standard deviation of the discharge increment (250 cfs) is only 14 cfs, or a relative error of less than 6 percent.

The best (least uncertainty) estimate of the seasonal discharge at Nine Mile Dam (RM 58.1) appeared to be that derived from a water balance of the Spokane River between Spokane (RM 72.9) and Long Lake Dam (RM 33.9). A water balance residual within this river reach was calculated based on all gaged or estimated inputs--Spokane River at Spokane, Hangman Creek, Spokane STP effluent, Little Spokane River at its mouth and direct precipitation onto Long Lake--and subtracting outputs--Long Lake Dam, evaporation, and in-lake storage--to obtain the total residual input over the 39 mile reach. Precipitation was based on National Weather Service data from the Spokane International Airport and the

Wellpinit Indian Reservation (NWS, 1948-1986). Evaporation from the surface of Long Lake was assumed to equal 70 percent of pan measurements at the Spokane International Airport (Linsley et al., 1975). Storage change within Long Lake was taken from USGS and WWP records (1948-1986).

The computed June-October residual discharges between Spokane and Long Lake Dam were then compared with similarly calculated residuals between Spokane and Nine Mile Dam for periods when reliable measurements of discharge at Nine Mile were available. This included water years 1948-1949 when USGS maintained a continuous recording gage at the Nine Mile site (Wells, 1955), and low flow months of 1984 when Harper-Owes performed a rating of hydropower turbine efficiency (Patmont et al., 1985). Based on these data, an average of 90 +/- 10 percent of the June-October residual input between Spokane and Long Lake Dam apparently entered the river above Nine Mile Dam. The magnitude of the residual input above Nine Mile Dam was generally greatest during the month of June (median = 342 cfs) and lowest during October (median = 194 cfs); considerable year-to-year variations were also apparent. The source of this residual input was most likely groundwater discharge from the Spokane Aquifer (Broom, 1951; Esvelt, 1978). The least error formulation which estimates the flow increase from Spokane to Nine Mile Dam (excluding measured surface and point source discharges) is:

$$\text{Spokane-to-Nine Mile Monthly Flow Increase} = 0.90 * \text{Spokane-to-Long Lake Monthly Flow Increase}$$

Using first-order uncertainty methods to propagate contributing error terms from all measured and estimated quantities utilized in the above expression, the standard deviation of the estimated monthly Spokane-to-Nine Mile flow increase is approximately 160 cfs. Although this uncertainty is large with respect to the average estimated seasonal flow increase of 220 cfs (CV = 72 percent), this potential error is rather low in comparison to the average estimated June-October discharge at Nine Mile Dam during the EWU study years (4,410 cfs).

The average June-October water budget of Long Lake during the thirteen EWU study years is presented in Table 4. Discharges at Nine Mile Dam represented approximately 91 percent of the total hydraulic input to the lake, with most of the remainder contributed by the Little Spokane River. Local inputs and precipitation were comparatively insignificant. Lake evaporation was also quite small relative to outflow discharges, representing less than 1 percent of the total hydraulic output from Long Lake.

Most of the total variability in the Long Lake water budget appeared to be due to year-to-year fluctuations in the Nine Mile Dam discharge (Table 4). Over the period of Long Lake limnological studies, seasonal (June-October) average flows in the Spokane River at Long Lake Dam have varied considerably, ranging from a low of 2,380 cfs (67.5 m^3/sec) in 1973 to a high of 8,560 cfs (242 m^3/sec) in 1974. This range of flow conditions nearly spans both the high and low extremes measured at Long Lake Dam over the 47-year seasonal period of record, and facilitates an analysis of the effect of hydrologic variations on water quality conditions within the lake (see below). It is also interesting to note that limnological studies of Long Lake have been conducted during three of the five lowest seasonal flow conditions on record (i.e. 1966, 1973, and 1977; see Appendix D). A plot of seasonal discharge fluctuations is presented in Figure 5.

Hydrodynamics

The pronounced thermal stratification of Long Lake during the summer months was first reported by Cunningham and Pine (1969), who suggested that the sharp thermocline at approximately 6-8 meters depth prevented adequate aeration of hypolimnetic waters and contributed to the lake's severe hypolimnetic anoxia. Subsequent investigations performed by EWU (Soltero et al., 1973-76; 1978-86) demonstrated that mixing patterns within the reservoir are very complex. In addition to the seasonal warming and stratification cycle typical of most lakes in the region, Long Lake also exhibits pronounced metalimnetic interflows and hypolimnetic underflows as denser river water enters the reservoir. These density currents are apparent almost throughout the period of thermal stratification (typically June to October). Withdrawal of most of the outlet flows

Table 4

Average Water Budget for Long Lake During the June-October Periods of 1972-1985 (excluding 1976)

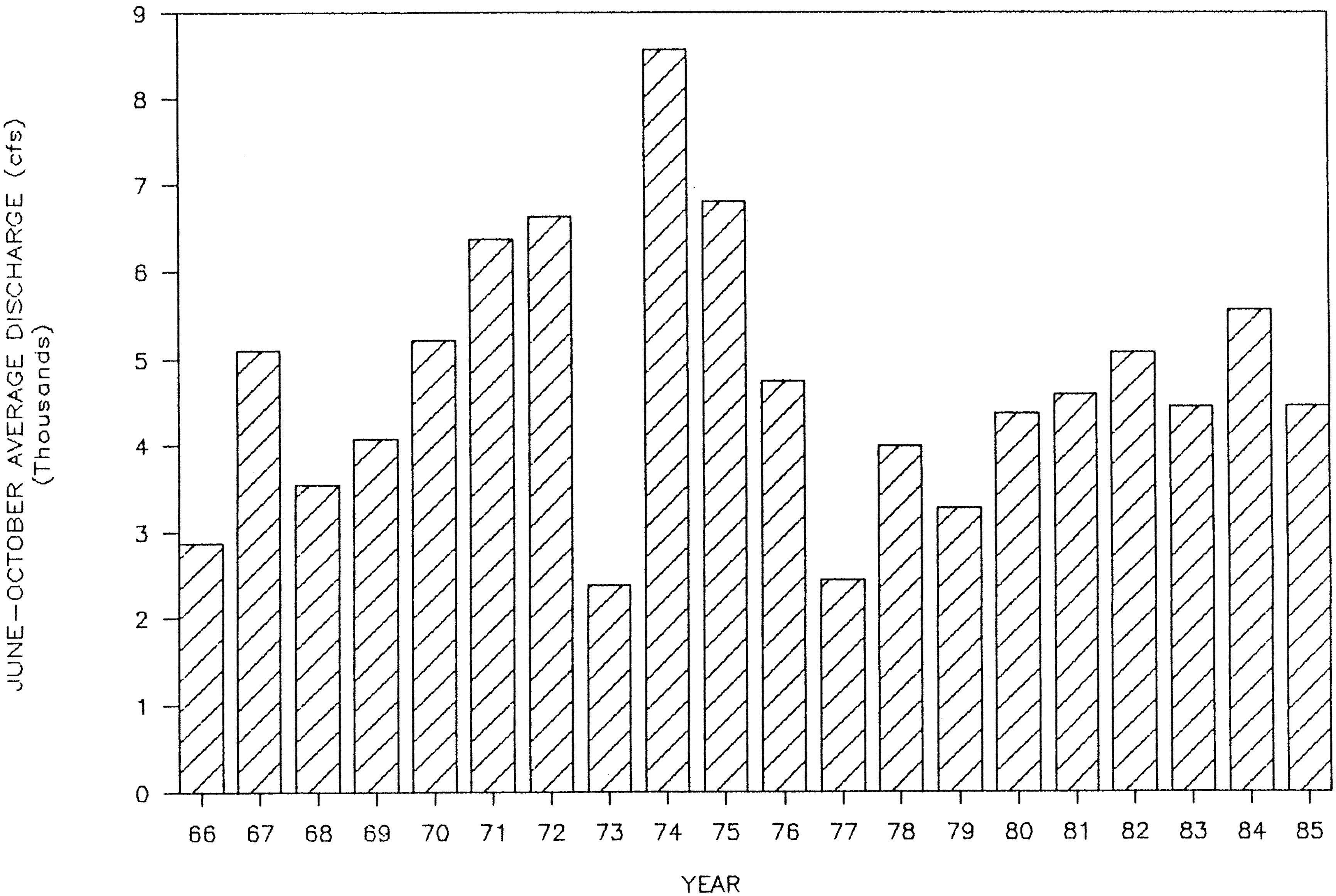
	Discharge (cfs; mean +/- std. dev.)[a]
INPUTS:	
Nine Mile Dam	4,410 +/- 1,750
Little Spokane River (mouth)	418 +/- 46
Local Runoff and Groundwater	24 +/- 18
Direct Precipitation	7 +/- 2
Total Inputs	4,860 +/- 1,750
OUTPUTS:	
Long Lake Dam	4,810 +/- 1,760
Evaporation	39 +/- 11
Total Outputs	4,850 +/- 1,760
STORAGE CHANGE:	+10 +/- 20

[a]The standard deviation includes both measurement uncertainty and year to year variability.

FIGURE 5

FLOW VARIATIONS AT LONG LAKE DAM

JUNE–OCTOBER 1966–1985, USGS DATA



from metalimnetic power penstocks (located at 9-14 m depth; see Figure 3) serves to enhance the metalimnetic currents and further isolate the epilimnion from inflows. Because such a separation of eplimnetic and inflow waters may have significant consequences regarding the relationship between nutrient loading and trophic response within Long Lake, an analysis of reservoir mixing characteristics was conducted.

As discussed above, pronounced thermal stratification within Long Lake typically begins in June and ends in October (Soltero et al., 1973-76; 1978-86). Variations in river flow alter this seasonal cycle to some extent, since high flow conditions (i.e. more than approximately 10,000 cfs) generally prevent, or at least minimize, the development of stratification. Nevertheless, a general picture of the lake's thermal structure can be obtained by averaging all sampling data collected at a specific station and depth during the June-October months over the entire study period. This "typical" temperature contour map is presented in Figure 6. The thermal plot reveals that the average flow-weighted inflow temperature of approximately 15.4 degrees C is considerably cooler than lake surface water temperatures of 19-20 degrees C. If no entrainment were to occur as the inflow progressed along the bottom contours, it would reach equilibrium at a depth of approximately 20 meters, well below the normal thermocline depth of approximately 6 meters. However, considerable entrainment of inflow apparently does occur upon entering Long Lake, resulting in a shallower depth of entrainment than this simple comparison would indicate (see below).

In part because of the rapid change in river flow which occurs between snowmelt and summer low flow (see Figure 4), specific conductance values in the flow-weighted inflow to Long Lake vary substantially over the June-October period. Minimum values of approximately 50-80 umhos/cm generally occur in June as a result of the large, low conductance discharge from Lake Coeur d'Alene. Within two months the inflow conductance increases to 200-250 umhos/cm as higher conductance groundwater flows become a relatively more significant part of the Long Lake inflow. This large change in inflow conductance occurs concurrently with the onset of stratification and, therefore, provides a convenient and generally conservative tracer of the movement and entrainment of summertime inflows through Long Lake.

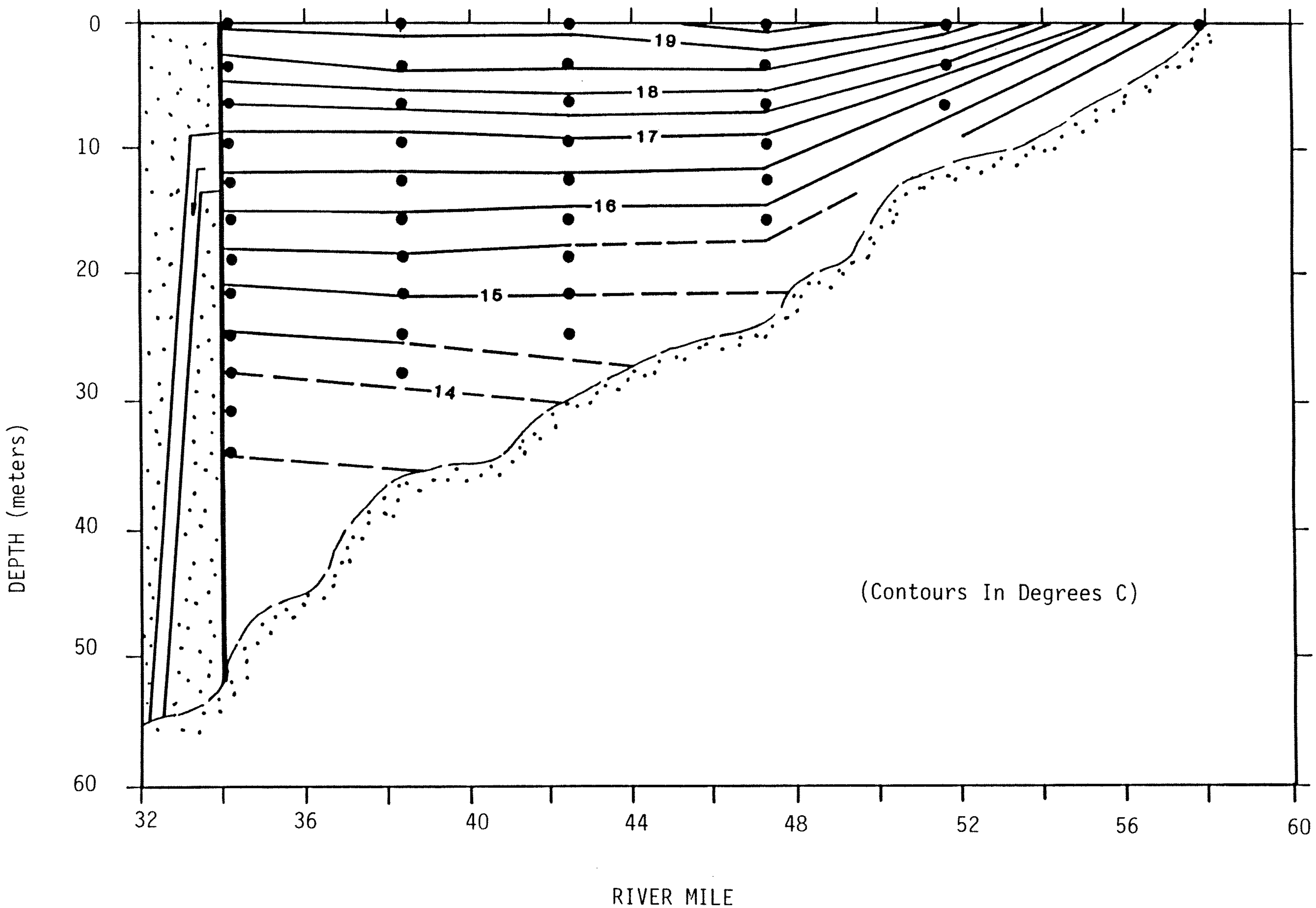


Figure 6

AVERAGE JUNE-OCTOBER TEMPERATURE CONTOURS IN LONG LAKE, 1972 - 1985

A contour map of average June-October specific conductance values is presented in Figure 7. A relatively high conductance "tongue" of water resembling the inflow level is apparent within Long Lake centered at a depth of approximately 10-15 meters, and was similarly described by Soltero et al. (1973). Since this interflow depth also corresponds with the location of the hydropower penstocks, much of the metalimnetic density interflow may simply short-circuit surface and deep waters of the lake directly to the outflow. Similar metalimnetic current patterns have been observed in other reservoir systems, and is often a characteristic feature of moderately well-flushed reservoirs with withdrawal at depth (Fischer, et al., 1979).

The specific conductance data presented in Figure 7 suggest that inflows could be at least partially isolated from surface and bottom waters of Long Lake during the June-October period. Such isolation, if significant, could be an important factor determining the relationship between nutrient loading and trophic response within the lake. In order to estimate the degree of mixing which occurs between inflows and lake waters, mass balances of specific conductance within Long Lake were performed. Briefly, the mass balances utilized temporal and spatial variations of conductance to follow the movement of inflow waters through the lake. The conductance calculations are discussed in more detail in Appendix C.

For the purposes of this study, the euphotic zone (EZ) and hypolimnetic regions of Long Lake were examined using the conductance mass balances. The EZ represents the algal growth environment in Long Lake, and was defined by EWU as those depths containing greater than 1 percent of incident light. The 1 percent light level is generally recognized as the lowest depth at which algal photosyntesis can be maintained (Verduin, 1964; Wetzel, 1975). The June-October EZ depth in Long Lake averaged approximately 7.0 meters over the 1972-85 period, but increased moderately following AWT. The hypolimnion of Long Lake was defined as depths greater than 15 m, although no pronounced demarcation of the hypolimnion was apparent (Figures 6 and 7). Depths below 15 m have historically exhibited the lowest D.O. levels (Figure 8), possibly due to the relative isolation of deeper waters from the surface.

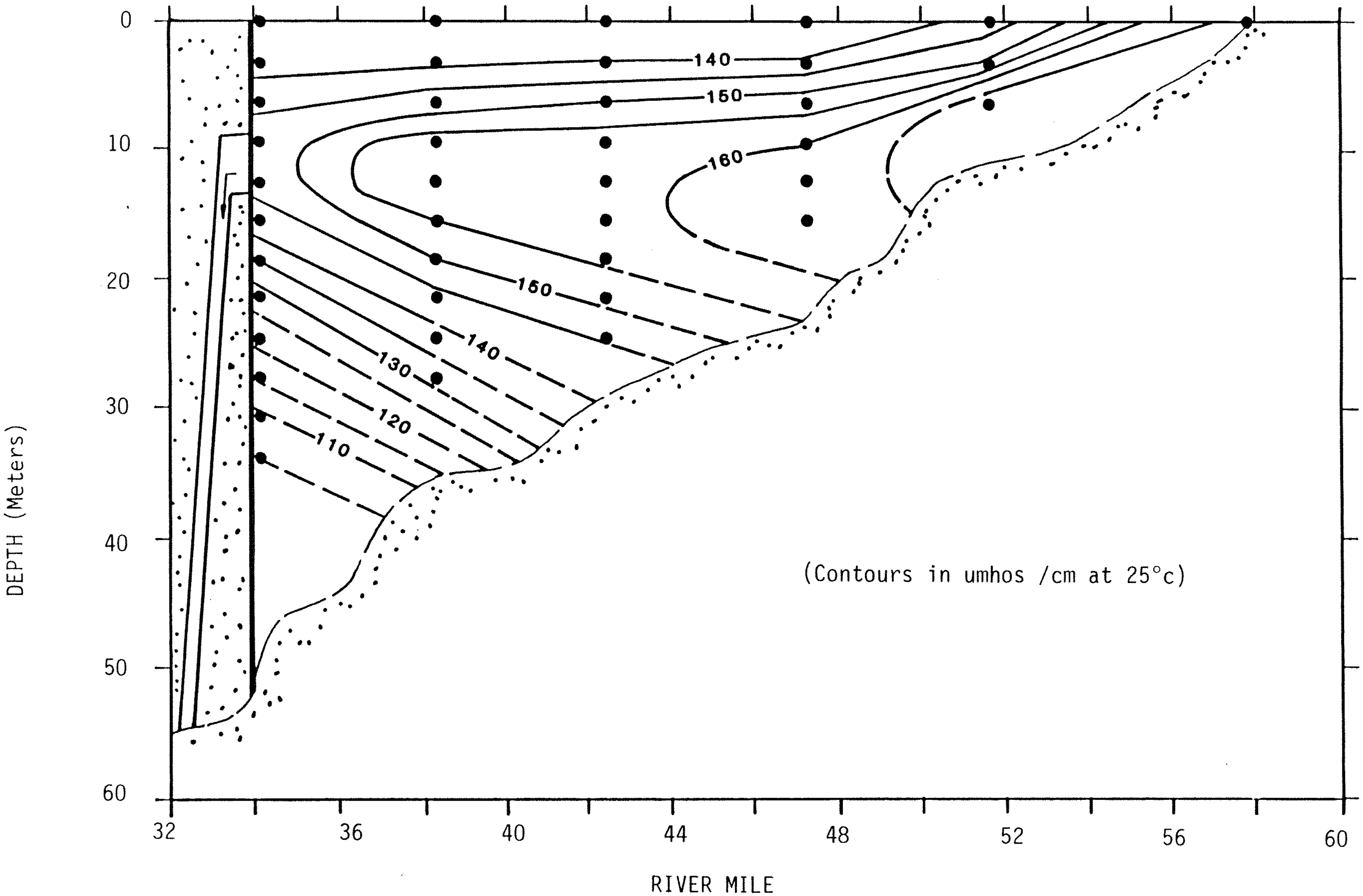


Figure 7

AVERAGE JUNE-OCTOBER SPECIFIC CONDUCTANCE CONTOURS IN LONG LAKE, 1972 - 1985

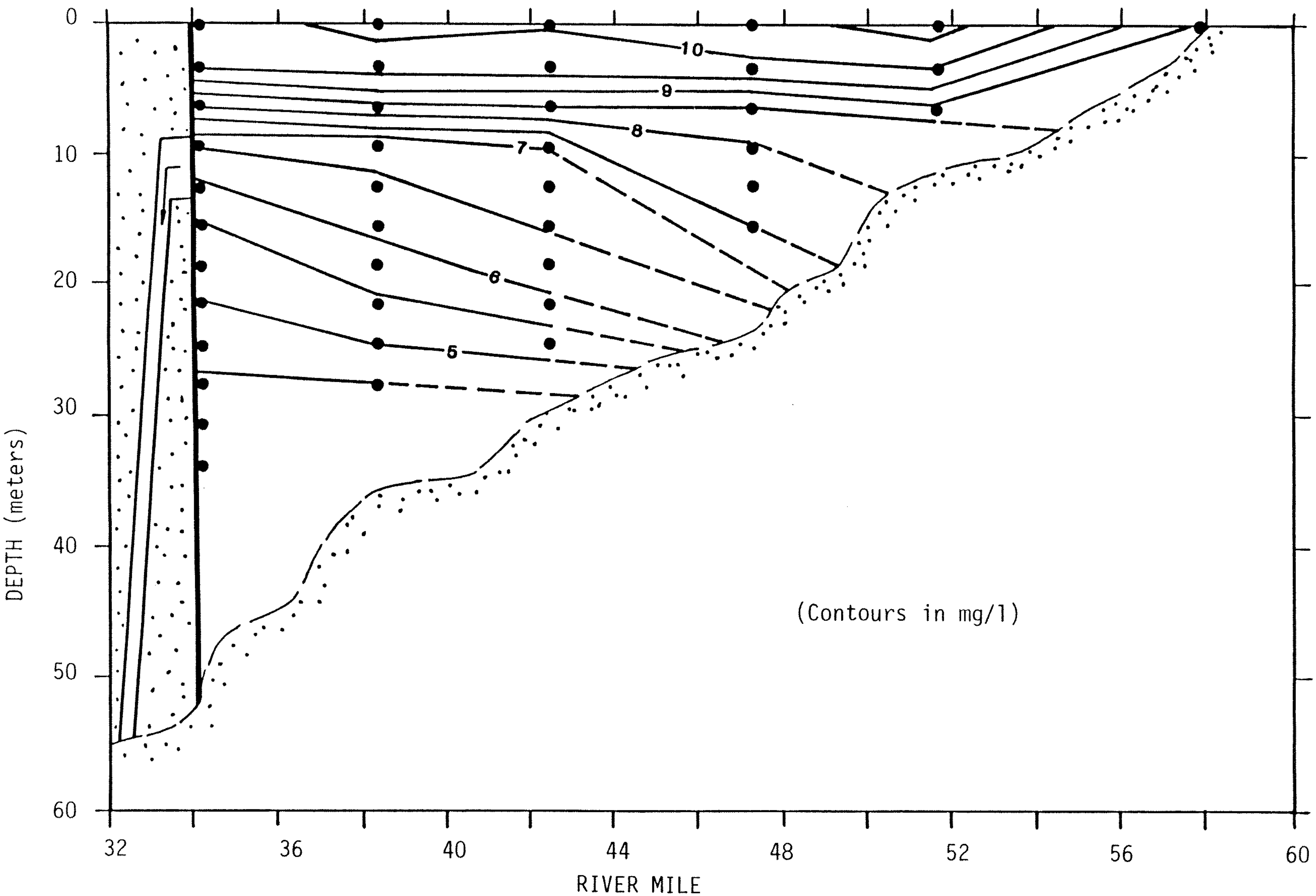


Figure 8

AVERAGE JUNE-OCTOBER DISSOLVED OXYGEN CONTOURS IN LONG LAKE, 1972 -1985

The mass balance data revealed that, on average, the EZ is flushed approximately every 40 days during the June-October period by mixing with inflow water. Most of the calculated residence times ranged between 20-80 days. Turbulence induced by the river flow as it entered the reservoir or by meteorologic forcing may have been the cause(s) of such mixing. These data suggest that the Long Lake euphotic zone could be characterized as being moderately well flushed with inflow waters throughout the June-October growing season. Generally, changes in EZ conductance over the season followed closely those in the inflow (Figure 9). Changes in nutrient concentrations in the inflow would, therefore, be expected to result in similar changes within the lake's EZ. Total phosphorus data collected from the Long Lake EZ (area-weighted) generally support this hypothesis.

The mass balance calculations also suggest that inflow waters penetrate into the lake's hypolimnion. The median hypolimnetic residence time was approximately 60 days, with a normal range between 30 - 150 days. Apparently, the hypolimnion is not stagnant, but is typically slowly to moderately flushed with inflow waters throughout the stratification season.

Nutrient Mass Balances

Loading Estimates

Nutrient (total phosphorus and total nitrogen) loading to Long Lake was calculated for every study year based on a linear regression of instantaneous discharge versus loading at each river and tributary station. Discharge was either measured or estimated using the procedures described previously. Based on the regression statistics, the loading equivalent to the average seasonal flow at each site was estimated. This procedure for calculating loadings generally results in the least amount of loading uncertainty when instantaneous sampling data are extrapolated to the entire range of flow conditions occurring throughout the season (Reckhow, 1980). Uncertainty estimates of each seasonal load were derived directly from the standard errors of the flow estimates and regression statistics propagated using first-order methods (see Appendix B).

Figure 9a

TEMPORAL TRENDS IN CONDUCTANCE, 1981–85

LONG LAKE INFLUENT AND EUPHOTIC ZONE

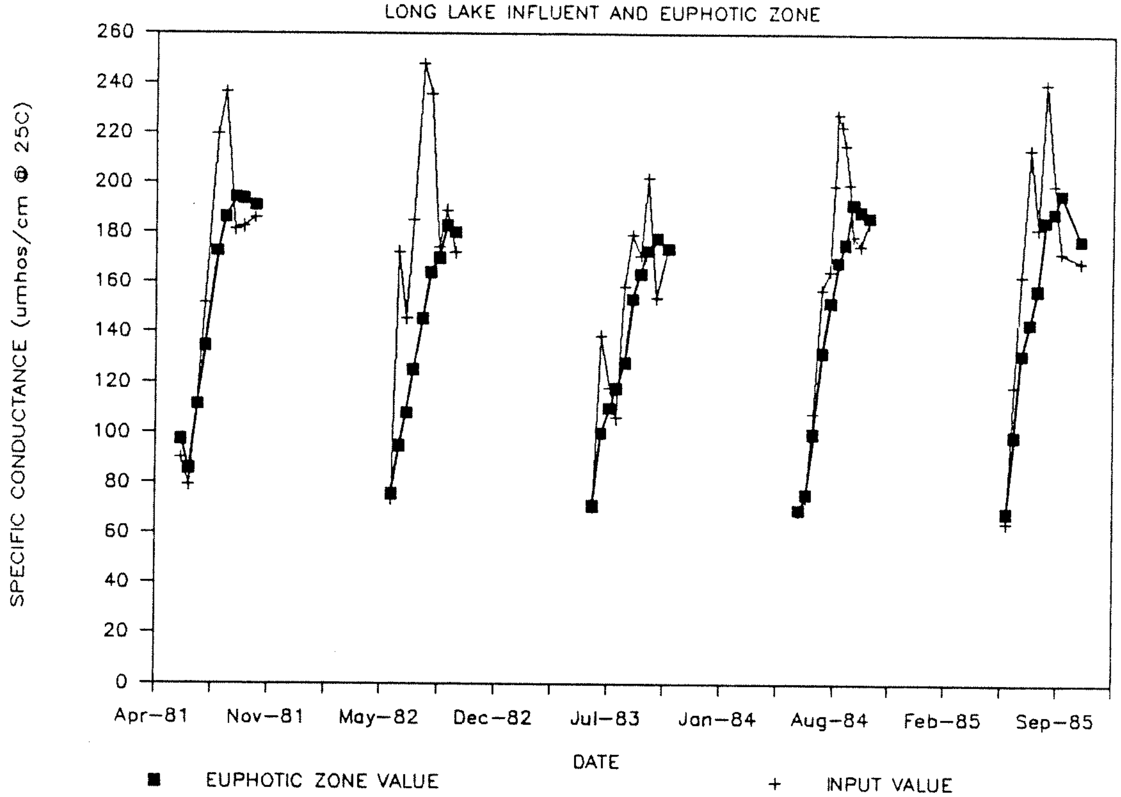
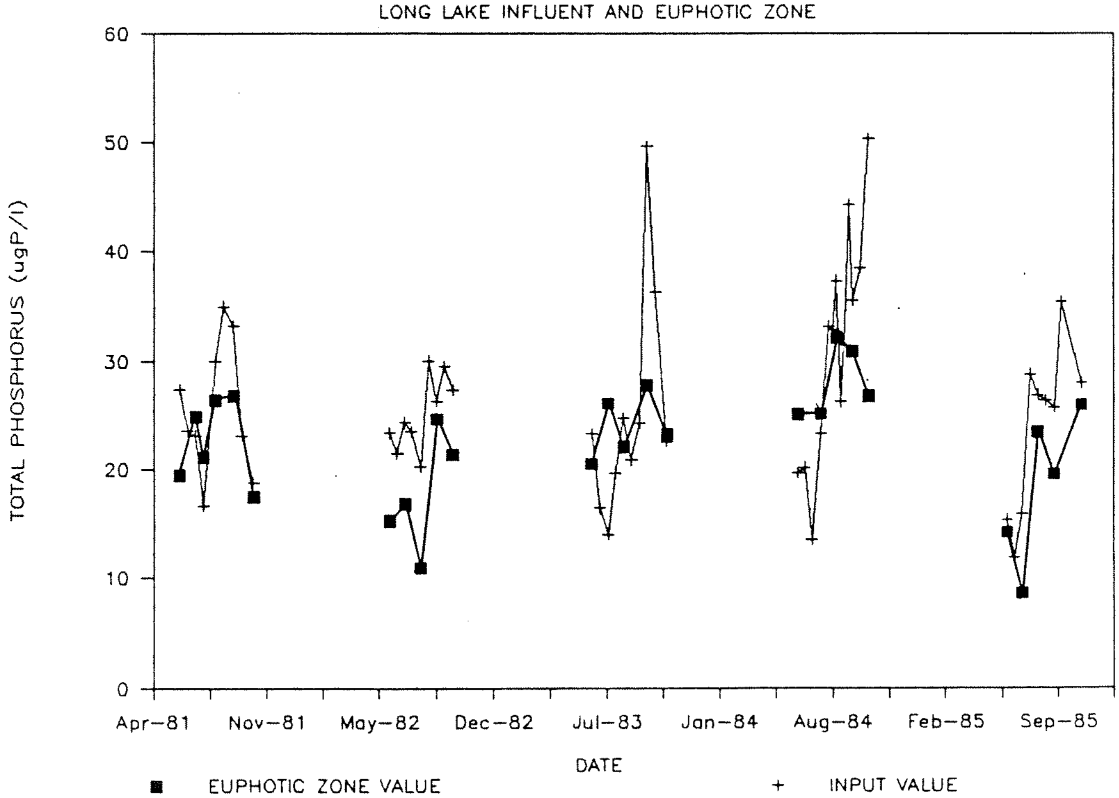


Figure 9b

TEMPORAL TRENDS IN TOTAL P, 1981–85

LONG LAKE INFLUENT AND EUPHOTIC ZONE



Time-of-travel and dispersion data collected during the recent phosphorus attenuation study revealed a pronounced diurnal cycle of phosphorus concentrations at river sites downstream of the Spokane wastewater outfall (RM 67.4), due to a large diurnal variation in wastewater flows (Patmont et al., 1985). Estimates of nutrient loading to Long Lake at Nine Mile Dam (RM 58.1) and Seven Mile Bridge (RM 62.0; Nine Mile was not sampled in 1972) could be biased as a result of this diurnal cycle, since samples were always collected at these sites during the same time of day (early morning; R.A. Soltero, EWU personal communication). In order to evaluate whether a significant bias may have occurred, the phosphorus attenuation model developed by Patmont et al. (1985) was applied to the lower reaches of the Spokane River (Fort Wright, RM 69.8 to Nine Mile, RM 58.1), using daily average wastewater flows and concentrations.

The results of the P-attenuation model runs are presented in Table 5, and revealed that model predictions were generally lower than the observed values. However, in only two years--1972 and 1977--was this difference statistically significant ($P<.05$). The 1972 "observed" values were based on samples collected at Seven Mile Bridge, and may not adequately reflect conditions four miles downstream at Nine Mile Dam (e.g. due to P attenuation). The Spokane wastewater treatment plant was in a transitional period during 1977 as the secondary and AWT systems were being installed. Effluent flow monitoring during this construction period was curtailed for several months, and periodic grab samples of effluent quality may not have been representative of average conditions (D. Arnold, Spokane AWT, personal communication).

All information considered, the observed and predicted phosphorus loadings at Nine Mile Dam generally appear to be equally valid estimates of the true seasonal loading values. Therefore, the observed and predicted estimates were averaged to obtain the "best" estimate of the TP load (Table 5). The difference between the two methods was included in the uncertainty calculations.

The Nine Mile Dam phosphorus loading estimates summarized in Table 5 reveal that the 1980 growing season was characterized by comparatively high and vari-

Table 5

Comparison of Observed and Predicted June-October Total Phosphorus Loading at Nine Mile Dam (1972-1985)
("*" denotes a significant difference at P = .05)

	Nine Mile TP Load (kg/day) (mean +/- std. error)			
Year	Observed		P-Attenuation Model Predictions	Average
Pre-AWT:				
1972	1,246 +/- 86[a]	*	952 +/- 95	1,099 +/- 227
1973	951 +/- 58		686 +/- 138	818 +/- 215
1974	1,167 +/- 72		1,032 +/- 88	1,100 +/- 125
1975	1,046 +/- 76		817 +/- 89	932 +/- 182
1977	689 +/- 49	*	452 +/- 90	570 +/- 183
Post-AWT:				
1978	252 +/- 41		220 +/- 17	236 +/- 39
1979	210 +/- 14		202 +/- 28	206 +/- 23
1980[b]	972 +/- 735		742 +/- 501	857 +/- 650
1981	243 +/- 19		223 +/- 24	233 +/- 26
1982	263 +/- 13		259 +/- 19	261 +/- 17
1983	215 +/- 27		187 +/- 25	201 +/- 33
1984	290 +/- 19		289 +/- 47	290 +/- 36
1985	193 +/- 19		196 +/- 23	194 +/- 21

[a] Based on samples collected at Seven Mile Bridge (RM 62.0); Nine Mile Dam (RM 58.1) was not sampled during 1972.

[b] On May 18, 1980, the Mount St. Helen's volcanic eruption occurred, depositing a large quantity of ash across the watershed. The relatively large and variable TP loads during this year reflect the contribution of particulate P from the ash (Soltero et al., 1981).

able TP loads. This has been attributed to the influence of volcanic ash contributed by the major eruption of Mount St. Helen's on May 18, 1980 (Soltero et al., 1981). Particulate phosphorus loadings in the Spokane River appeared to be extremely large for at least one month following the eruption. However, most of this particulate loading was observed to settle out within Long Lake. Because of the Mount St. Helen's TP input and the highly uncertain nature of river loading estimates during this period, 1980 is recognized as an anomaly to the general nutrient loading/trophic response relationship for Long Lake. The 1980 growing season also appears to have been an anomaly in nearby Moses Lake, again due to the ash inputs (Welch et al., 1986).

In addition to the Nine Mile Dam loading values, estimates of nutrient inputs to Long Lake were also derived for the Little Spokane River at its mouth, local runoff and groundwater, and atmospheric fallout. Little Spokane River nitrogen and phosphorus loads were based on seasonal regression analyses of instantaneous loadings and flows. The quality of local runoff and groundwater to Long Lake was based on samples collected from shallow wells in the vicinity of Nine Mile Dam (TP = 23 +/- 4 ug/L; TN = 2,090 +/- 420 ug/L; Patmont et al., 1985). Loadings were estimated as the product of these concentrations and the local residuals in the Long Lake water balance (Table 4). Atmospheric fallout onto Long Lake was based on measurements at nearby Liberty, Newman, and Williams Lakes during the June-October period (Funk et al., 1976). The estimated seasonal deposition rates obtained from these data were 0.020 +/- 0.009 KgP/km^2-day and 0.30 +/- 0.02 kg N/km^2-day.

A summary of nutrient loading estimates for Long Lake is presented in Table 6. The data have been separated into years prior to AWT at Spokane (1972-1977, excluding 1976) and subsequent to AWT (1978-1985, excluding 1980) in order to examine the impact that P removal at this facility had on the lake's nutrient income. When allowances are made for changes in river discharge between the two periods (average river flows prior to AWT were slightly higher), implementation of AWT at Spokane appeared to have effected a 70 percent reduction in the Long Lake TP load. Changes in plant performance apparently also reduced the total nitrogen (TN) loading to Long Lake by approximately 15 percent,

Table 6

Summary of Average Long Lake Nutrient Loading Characteristics During June-October Periods Before and After Advanced Wastewater Treatment at the City of Spokane (Values in Parenthesis are Standard Errors)

	Discharge (cfs)		TP Loading (kg/day)		TN Loading (kg/day)	
	Pre-AWT	Post-AWT	Pre-AWT	Post-AWT	Pre-AWT	Post-AWT
INPUTS:						
Nine Mile Dam	4,980(1,390)	4,060(300)	904(129)	232(18)	11,100(3,100)	7,640(1,010)
Little Spokane River	418(28)	422(17)	44(11)	34(4)	1,570(200)	1,400(90)
Local Runoff/Groundwater	16(18)	29(18)	1(1)	2(1)	84(95)	150(93)
Atmospheric Fallout	6(1)	8(1)	0(0)	0(0)	6(0)	6(0)
TOTAL	5,410(1,390)	4,520(300)	949(129)	267(18)	12,700(3,100)	9,200(1,020)
OUTPUTS:						
Long Lake Dam	5,360(1,400)	4,480(300)	706(91)	219(22)	9,810(2,560)	7,510(790)
STORAGE CHANGE:	+18(15)	+5(4)	no data	+13(6)[a]	no data	no data
APPARENT SEDIMENTATION LOSS:	--	--	--	29(23)[a]	--	--

[a] 1981-1985 only

probably due to the initiation of secondary treatment in 1977. Influent TN:TP ratios have increased from an average of 13:1 (by weight) before AWT to 34:1 following AWT, which may have contributed to observed qualitative shifts in the Long Lake phytoplankton community (see below).

In the years since AWT at the City of Spokane, approximately 80-90 percent of the seasonal (June-October) TN and TP loadings to Long Lake have been contributed by the Spokane River at Nine Mile Dam (Table 6). These percentages were greater in years prior to AWT. The Little Spokane River contributed most of the remaining input, while local inputs and atmospheric fallout were comparatively insignificant sources.

Sedimentation and EZ-TP

Mass balances of TN and TP within Long Lake revealed that during nearly all study years seasonal inputs exceeded outputs, and the reservoir thus served as a "sink" for these nutrients (Table 6). Although increases in the lake TP content over the season accounted for some of this residual (approximately 30 percent of the 1981-85 Long Lake TP residual can be attributed to in-lake mass changes), most of the nutrient losses appear to have been the result of fluxes out of the system, with the most probable mechanism being in-lake sedimentation. During 1981-85, in-lake losses of TP (i.e. sedimentation) amounted to an average of 11 +/-9 percent of the influent TP load; this value, however, is not statistically significant ($P>.05$).

A variety of investigators have observed that the fraction of the annual influent TP retained or sedimented within a lake is often a function of the bulk water residence time (Larson and Mercier, 1975; Vollenweider, 1976; OECD, 1982). Slowly flushed lakes typically exhibit a greater in-lake retention of TP than more rapidly flushed lakes, presumably because of the greater opportunity for algal uptake and sedimentation of this nutrient. Recently, OECD (1982) suggested that the annual fraction of TP retained within a lake is also a function of the influent concentration, with a greater degree of retention commonly associated with lakes with a higher influent TP level.

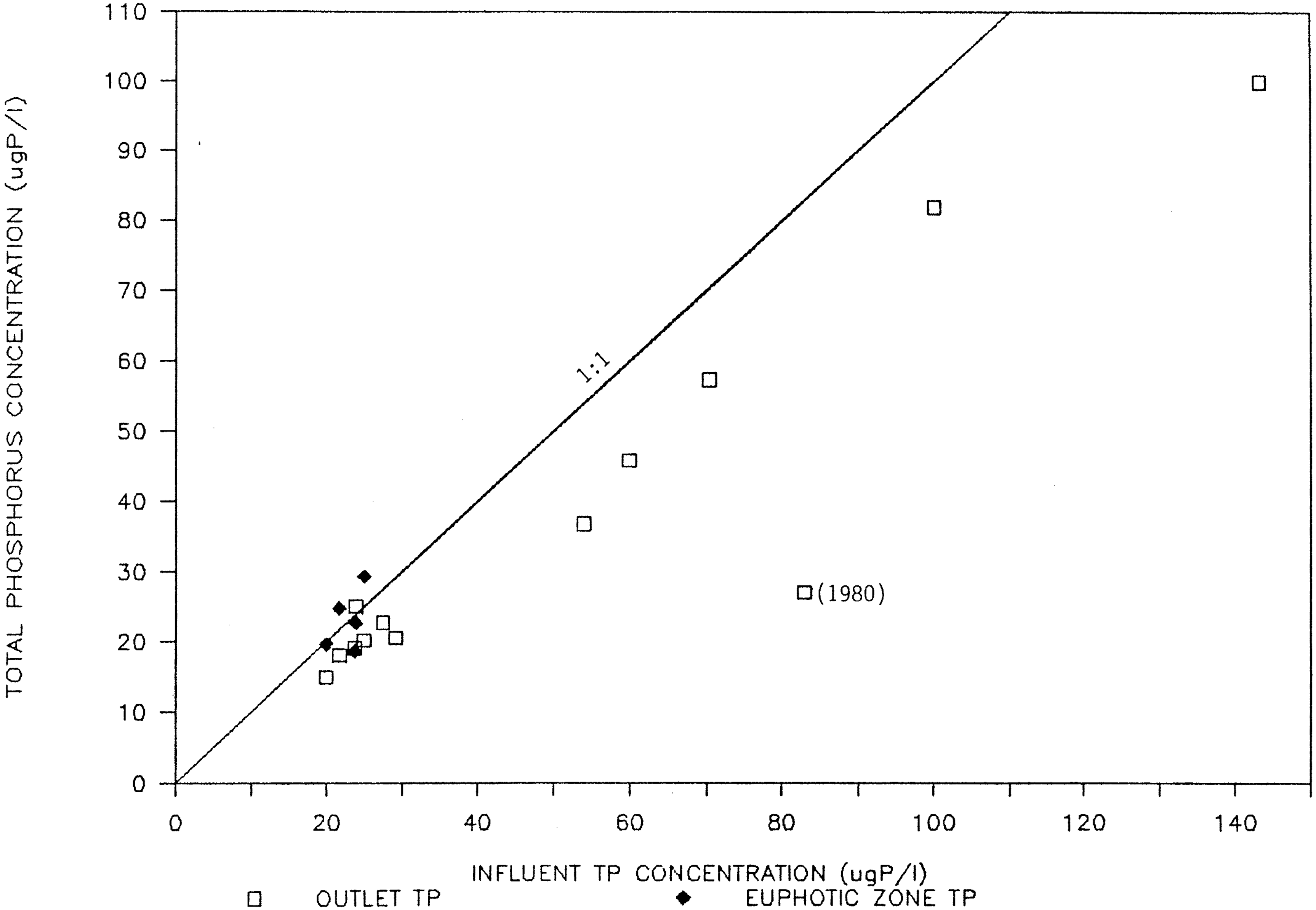
Because sedimentation is a primary factor controlling in-lake TP concentration, which in turn is generally regarded as the primary variable controlling trophic status, the magnitude of retention and its relationship to flushing rate and influent concentration was evaluated using the Long Lake data base. Generalized steady-state models such as those developed by OECD (1982) which predict retention were not deemed directly appropriate to Long Lake, since several key assumptions inherent to these models were not considered valid. These included: 1) the complex hydrodynamics present in Long Lake (e.g. metalimnetic inflows) serve to at least partially separate lake surface waters from inflow and outflow discharges, possibly resulting in significant differences in the relationships between these parameters; 2) Long Lake TP concentrations are not in steady-state (see Figure 9); and 3) the application of annual retention terms to seasonal (i.e. June-October) conditions has not been verified. These generalized retention models also appear to overpredict the seasonal sedimentation in Long Lake. The OECD (1982) model, for example, predicts a TP retention in Long Lake during the June-October periods of 1981-85 of approximately 30 +/- 6 percent, which is considerably greater than the observed value of 11 +/- 9 percent.

As stated previously, data on TP concentrations within Long Lake were only collected between 1981 and 1985. For each June-October period of these years, the time- and area-weighted average TP concentration within the EZ was calculated as the most representative measure of surface water characteristics which vary in both time and space. Comparison of this average EZ-TP concentration with the flow-weighted seasonal influent TP concentration (i.e. the quotient of loading and flow) revealed that these two parameters were statistically equivalent ($P>.05$) (Figure 10). The correspondence of these values, however, may not reflect any lack of in-lake sedimentation, since such a process, though minor, was suggested by the mass balance calculations (see Table 6). Rather, the similarity of the influent-and EZ-TP concentrations is most likely a result of the different averaging procedures used to calculate the non-steady-state concentrations, namely flow versus time weighting. The empirical relationship between influent- and EZ-TP simply expresses a statistical relationship and does not provide information on lake metabolism.

FIGURE 10

INFLUENT TP VS OUTFLOW AND LAKE TP

LONG LAKE JUNE–OCT. MEAN, 1972–1985



Data collected during the 1981-85 period on EZ-TP concentrations span a relatively narrow range of hydrologic and P-loading conditions (see Figure 5 and Table 5). In order to determine whether variations in flushing rate or influent concentrations may alter the empirical inflow EZ-TP relationship discussed above (as suggested by OECD, 1982), TP data from the outflow of Long Lake were evaluated. The outflow-TP data were collected throughout the Long Lake period of record (1972-1985) and span a wide range of hydrologic and P-loading conditions. Outflow-TP (flow-weighted) and EZ-TP generally respond similarly to changes in lake retention characteristics (Larsen and Mercier, 1976; Reckhow, 1979).

Multiple regression analyses did not reveal any significant (P>.05) variation of bulk retention (calculated as 1-[outflow-TP/inflow-TP]) with changes in flushing rate or inflow concentration. Seasonal outflow concentrations were 20 +/- 10 percent below those of the influent concentration throughout the 1972-1985 period of record (Figure 10). Apparently, changes in flushing rate and influent concentrations have less effect on TP retention in Long Lake than in other northern temperate lakes evaluated by OECD (1982), possibly due to the relatively rapid flushing rate and complex hydrodynamics of Long Lake. The rather constant TP retention in Long Lake over time is, however, similar to the 19-year Lake Washington record, which also exhibited a near constant TP retention our a wide range of P loading and flushing conditions (Edmondson and Lehman, 1981).

Based on the evaluations presented above, a simple empirical model was developed which predicts seasonal mean EZ-TP concentrations in Long Lake from the influent concentration:

$$\text{Mean EZ-TP} = 1.005 * \text{Influent-TP}$$

The seasonal standard deviation of this model is equivalent to 16 percent of the predicted EZ-TP concentration.

During 1981-85, observed June-October EZ-TP concentrations averaged 23.0 +/- 4.8 ug/L, which would generally classify Long Lake as mesotrophic (OECD, 1982). Predicted EZ-TP concentrations prior to AWT at Spokane ranged from 54-144 ug/L, indicative of eutrophic conditions. Water quality criteria will be discussed in more detail in a subsequent chapter of this report.

Trophic Response

In addition to the total phosphorus data discussed above, the trophic status of Long Lake was evaluated based on an analysis of chl a concentrations, phytoplankton biovolume, Secchi disc transparency, and hypolimnetic dissolved oxygen levels. All of these parameters have been correlated with the extent of use impairment in a variety of lake environments throughout the world and are commonly utilized in lake classification schemes (OECD, 1982). Historical summaries of these parameters within Long Lake are presented in Figures 11-14. All four trophic status indicators have exhibited significant ($P<.05$) improvements following the implementation of AWT at Spokane (Table 7). Based on these data and using the classification scheme proposed by UNESCO (in press), Long Lake was likely eutrophic prior to AWT and mesotrophic during the years following AWT, which follows the findings of Soltero et al., (1979-86). A similar conclusion was reached based on the EZ-TP data presented above.

Nutrient loading data presented previously in this report reveal that influent TN:TP ratios to Long Lake have increased from an average of 13:1 (by weight) in years prior to AWT (1972-1977) to 34:1 following AWT (1978-1985; Table 6). In many lakes, TN:TP ratios less than 10:1 suggest that nitrogen supplies may control algal growth and biomass, while TN:TP ratios above 15:1 indicate phosphorous limitation (Forsberg, 1980). Intermediate ratios suggest possible nutrient colimitation. Relative to these approximate threshold values, both nitrogen and phosphorus supplies may have determined algal growth prior to AWT, while phosphorous limitation is indicated following AWT.

Because numerous chemical and biological processes can influence the supply and availability of nutrients in lake environments, the characterization of limiting nutrients is generally best evaluated using algal assay techniques

FIGURE 11

EUPHOTIC ZONE CHLOROPHYLL VARIATIONS

LONG LAKE, 1972–1985

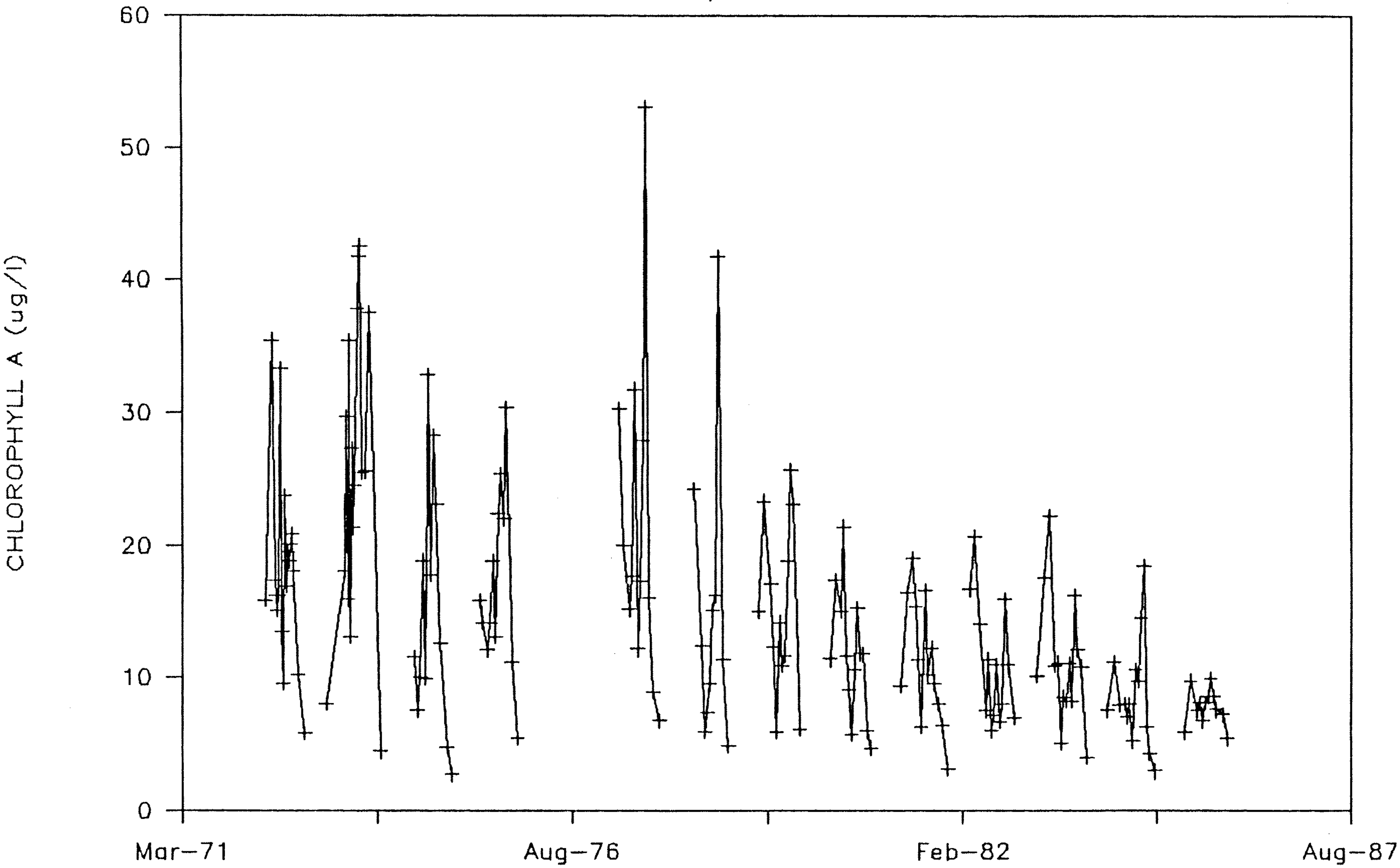


FIGURE 12

EUPHOTIC ZONE BIOVOLUME VARIATIONS

LONG LAKE, 1972–1985

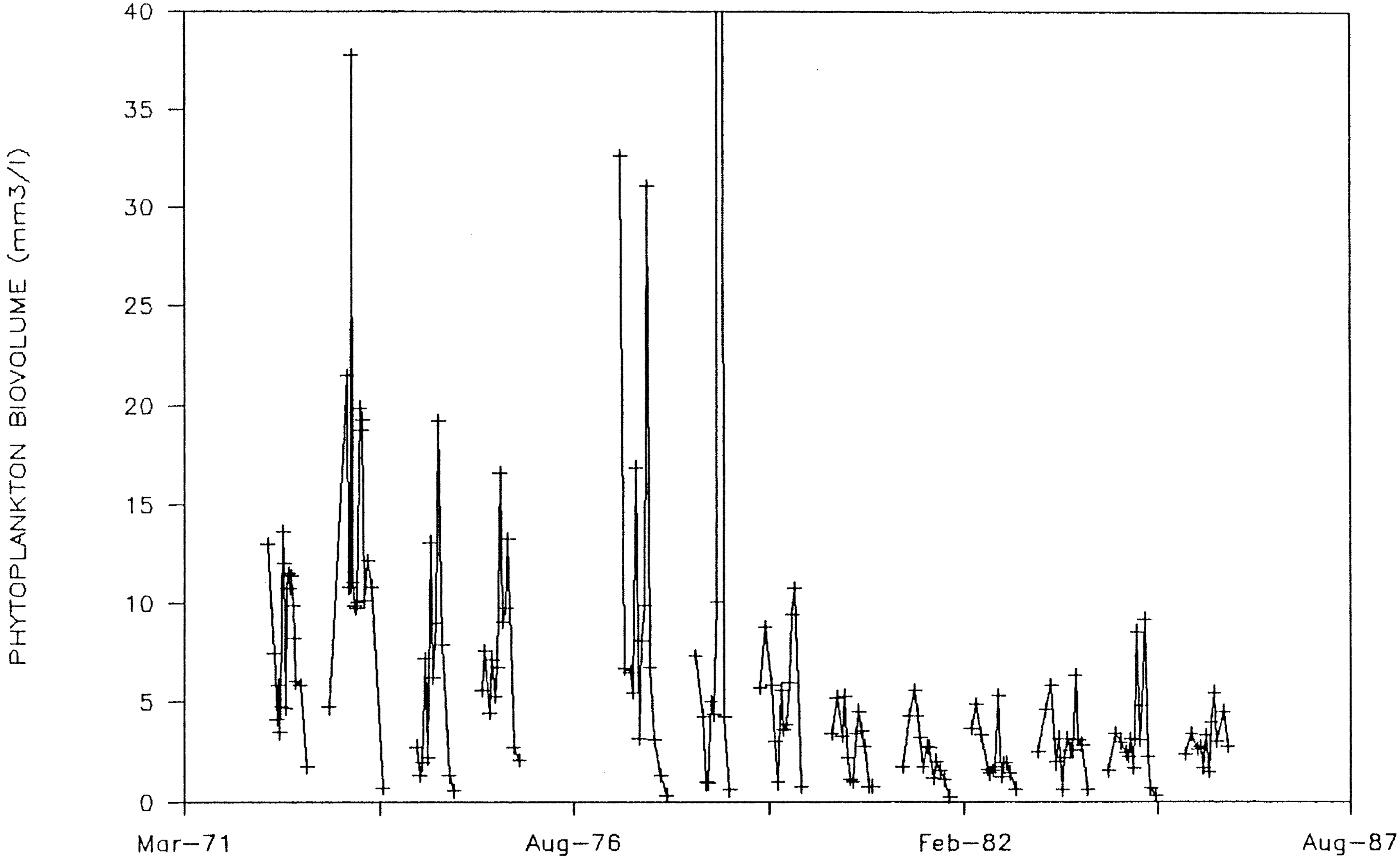


FIGURE 13

SECCHI DISK DEPTH VARIATIONS

LONG LAKE, 1972–1985

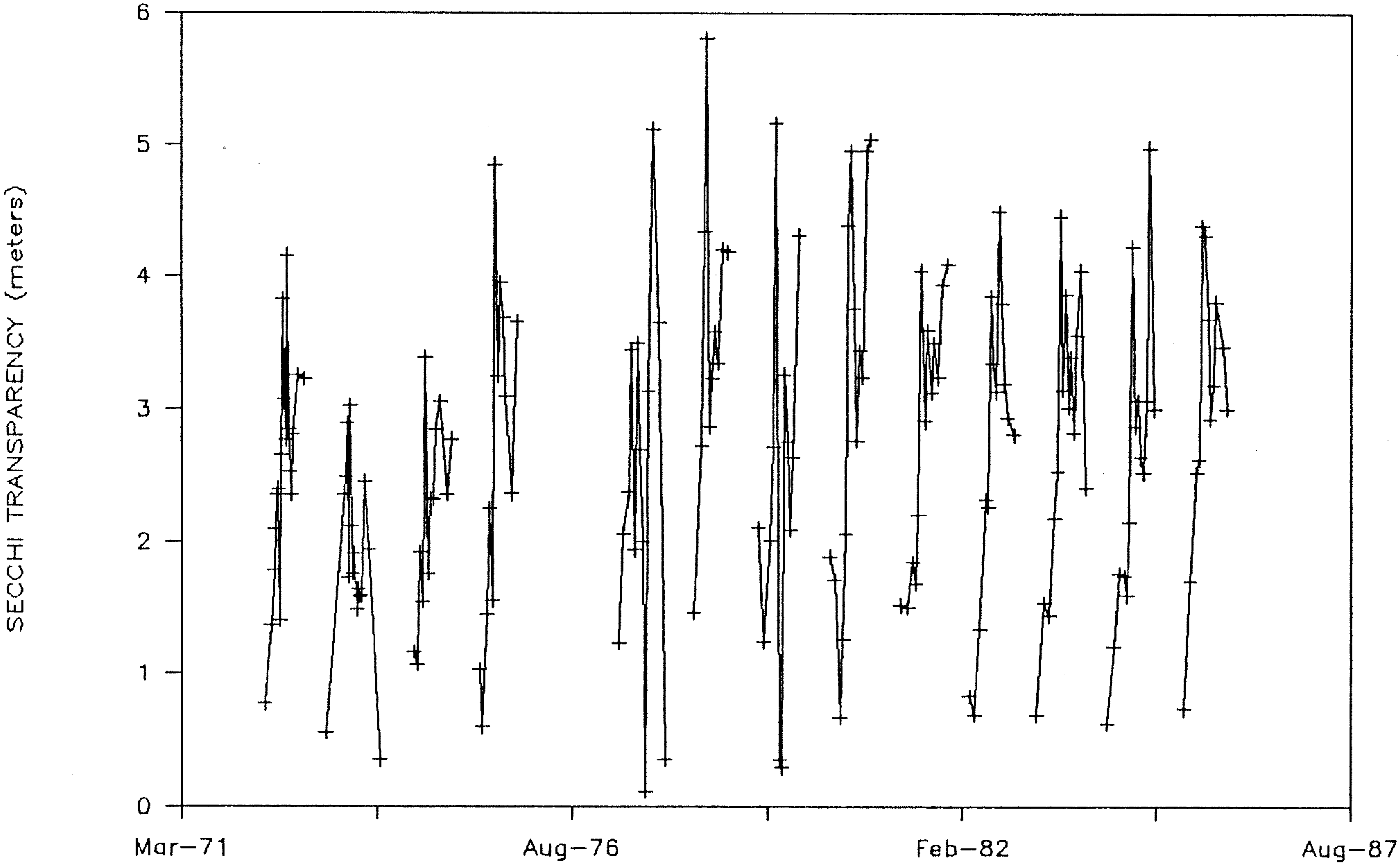


FIGURE 14

HYPOLIMNETIC DISS. OXYGEN VARIATIONS

LONG LAKE, 1966–1985

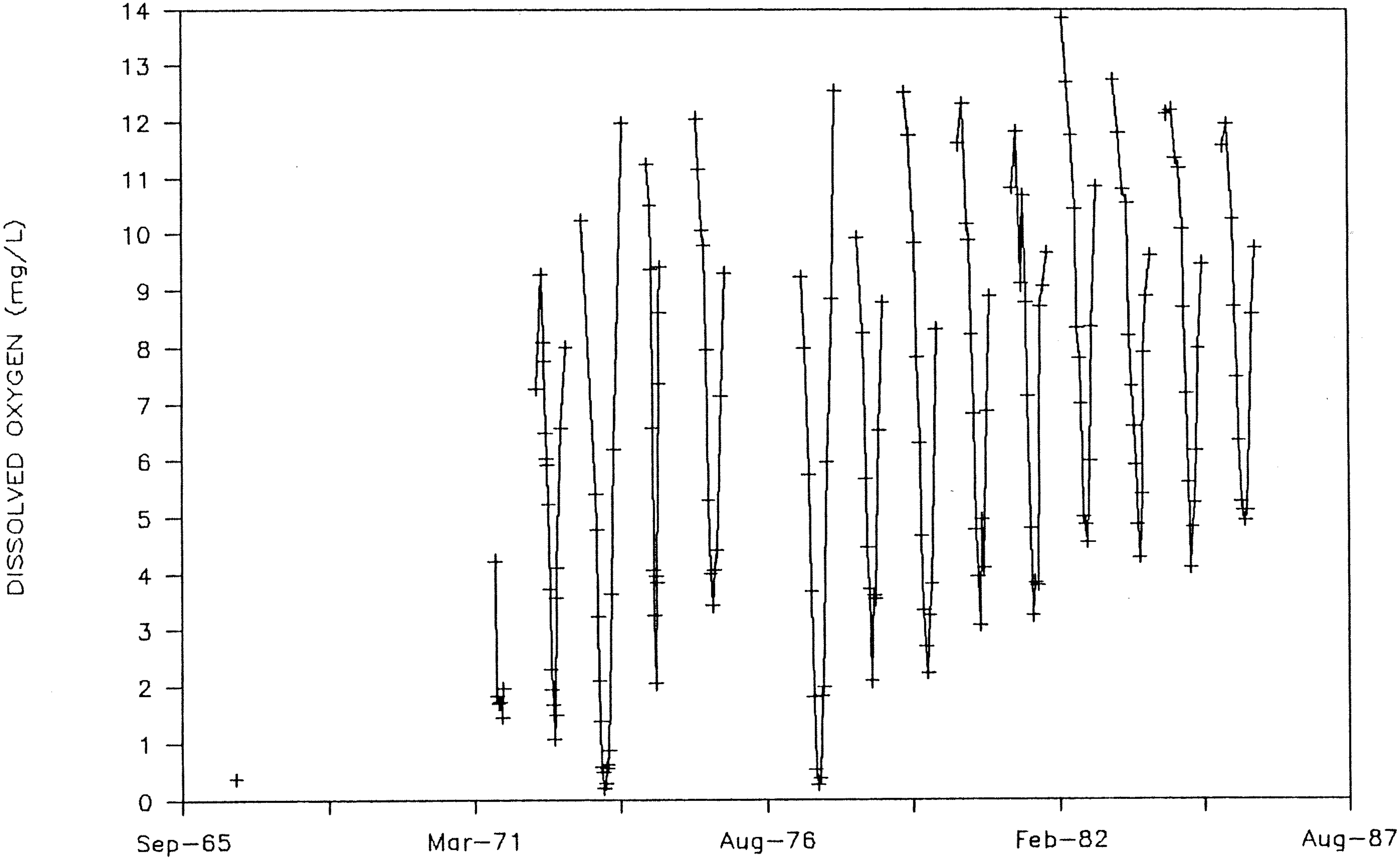


Table 7

Summary of Annual Variations in Long Lake Trophic State Parameters, 1966-1985
(Values in Parentheses are Standard Errors)

Year	Mean June - Oct. EZ-Chl *a* (ug/L)	Median June - Oct. EZ-Biovolume (mm^3/l)	Median July - Oct. Secchi (m)	Minimum Annual Hypolimnetic D.O. (mg/L)
Pre-AWT:				
1966	--	--	--	0.4
1971	--	--	2.4(0.2)	1.4
1972	18.7(3.0)	6.7(0.6)	2.7(0.1)	1.1
1973	27.8(4.7)	12.2(1.4)	1.8(0.1)	0.2
1974	17.0(2.9)	5.0(1.0)	2.2(0.2)	2.0
1975	18.4(3.4)	5.8(0.6)	3.1(0.3)	3.4
1977	20.4(3.8)	5.9(1.4)	2.4(0.2)	0.3
Post-AWT:				
1978	15.0(4.3)	3.4(0.7)	3.5(0.4)	2.1
1979	15.2(2.6)	3.7(0.7)	2.6(0.4)	2.2
1981	11.6(2.0)	2.3(0.3)	3.4(0.2)	3.2
1982	9.4(1.5)	1.5(0.1)	3.7(0.1)	4.6
1983	10.2(1.6)	2.5(0.3)	3.4(0.1)	4.3
1984	8.7(1.1)	2.8(0.4)	3.1(0.2)	4.1
1985	7.9(0.6)	2.5(0.4)	3.7(0.2)	4.9
UNESCO (in press) Criteria:				
Oligo-mesotrophic threshold	3.	1.5	6.6	6.
Meso-eutrophic threshold	10.	5.0	3.1	1.

(Miller et al, 1978). Between 1971 and 1978, EPA conducted numerous algal assay experiments within Long Lake and other areas of the Spokane River basin, primarily to define both nutrient limitation and metal toxicity characteristics within the drainage (Soltero et al, 1975-76; Greene et al., 1978; Shiroyama et al., 1978; J.C. Greene, EPA, unpublished data). The available algal assay information pertaining to Long Lake EZ composite samples are summarized below, along with concurrent nutrient loading data:

Summary of Long Lake Algal Assay and Loading Data
June - October Season

Year	Average Influent TP (ug/L)	Average Influent TN:TP (wt)	EZ Algal Assay Results*: P-Limitation	EZ Algal Assay Results*: N or P	EZ Algal Assay Results*: N-Limitation
1974	54.0	13.1	50%	22%	28%
1975	60.0	15.2	22%	33%	44%
1977	100.1	8.1	11%	56%	33%
1978	27.5	26.3	75%	25%	0

*Nutrient limitation was assessed with Selenastrum capricornutum bioassays in EDTA - spiked samples using methods described in Miller et al, 1978. Between 8-60 algal assays were conducted during each season on Long Lake EZ composite samples.

The algal assay data are consistent with the threshold TN:TP ratios discussed above, and confirm that both nitrogen and phosphorus were co-determinations of algal growth in Long Lake during years prior to AWT at Spokane. Influent N:P ratios to the lake increased markedly as a result of AWT, resulting in a shift to phosphorus as the primary limiting nutrient. Based on the algal assay data, other nutrients besides phosphorus (e.g. certain trace metals) are not believed to be growth limiting in Long Lake (Greene et al., 1978). Potential algal toxins present in the Spokane River (i.e. zinc) appeared to have influenced species-assembledge characteristics of the algal populations, but not overall biomass (see below).

Analyses of variations in trophic status parameters in a wide variety of northern temperate lakes have revealed that chl a concentrations, phytoplankton biovolume, Secchi disc depth, and hypolimnetic D.O. levels are highly correlated with in-lake TP concentrations (OECD, 1982). Linear regression models based on log-transformed data generally result in the best statistical fit between TP and the other trophic parameters. Accordingly, this regression methodology was applied to the Long Lake data base in an effort to further evaluate the significance of TP as a controlling trophic parameter in the reservoir. Because average EZ-TP concentrations within Long Lake appear to be nearly identical to the flow-weighted input concentration, and also because EZ-TP data are only available for recent years (1981-85), the flow-weighted influent TP concentration (log-transformed) was used as the independent variable in the regression analyses.

Algal Blooms

The relationships of influent TP to seasonal average chl *a*, peak chl *a* (defined as the upper 95 percent value), and median biovolume levels within Long Lake's EZ are presented in Figures 15-17. Median biovolume data were utilized instead of arithmetic averages because of a pronounced skew in the data distribution, even after log-transformation. Regression analyses revealed that variations in influent TP explained more than 80 percent of the chl *a* and biovolume variance, and all regression equations were highly significant ($P<.001$). The addition of river discharge as an independent parameter (using multiple regression techniques) did not result in a significant ($P>.05$) improvement in the models, and therefore the influence of flow was not considered further. The formulations for mean chl *a*, peak chl *a*, and median biovolume are presented below:

- Mean chl *a* (ug/L) = EXP (0.662 + 0.537 * ln (Influent TP; ug/L))
  Total Prediction Uncertainty = +/- 20.3 percent

- 95 percentile chl *a* (ug/L) = EXP (1.16 + 0.606 * ln (Influent TP; ug/L))
  Total Prediction Uncertainty = +/- 20.6 percent

- Median Biovolume (mm^3) = EXP (-1.64 + 0.809 * ln (Influent TP; ug/L))
  Total Prediction Uncertainty = +/- 23.6 percent

FIGURE 15

INFLUENT TP VS MEAN EZ-CHLOROPHYLL A

LONG LAKE REGRESSION MODEL AND PREDICTION UNCERTAINTY

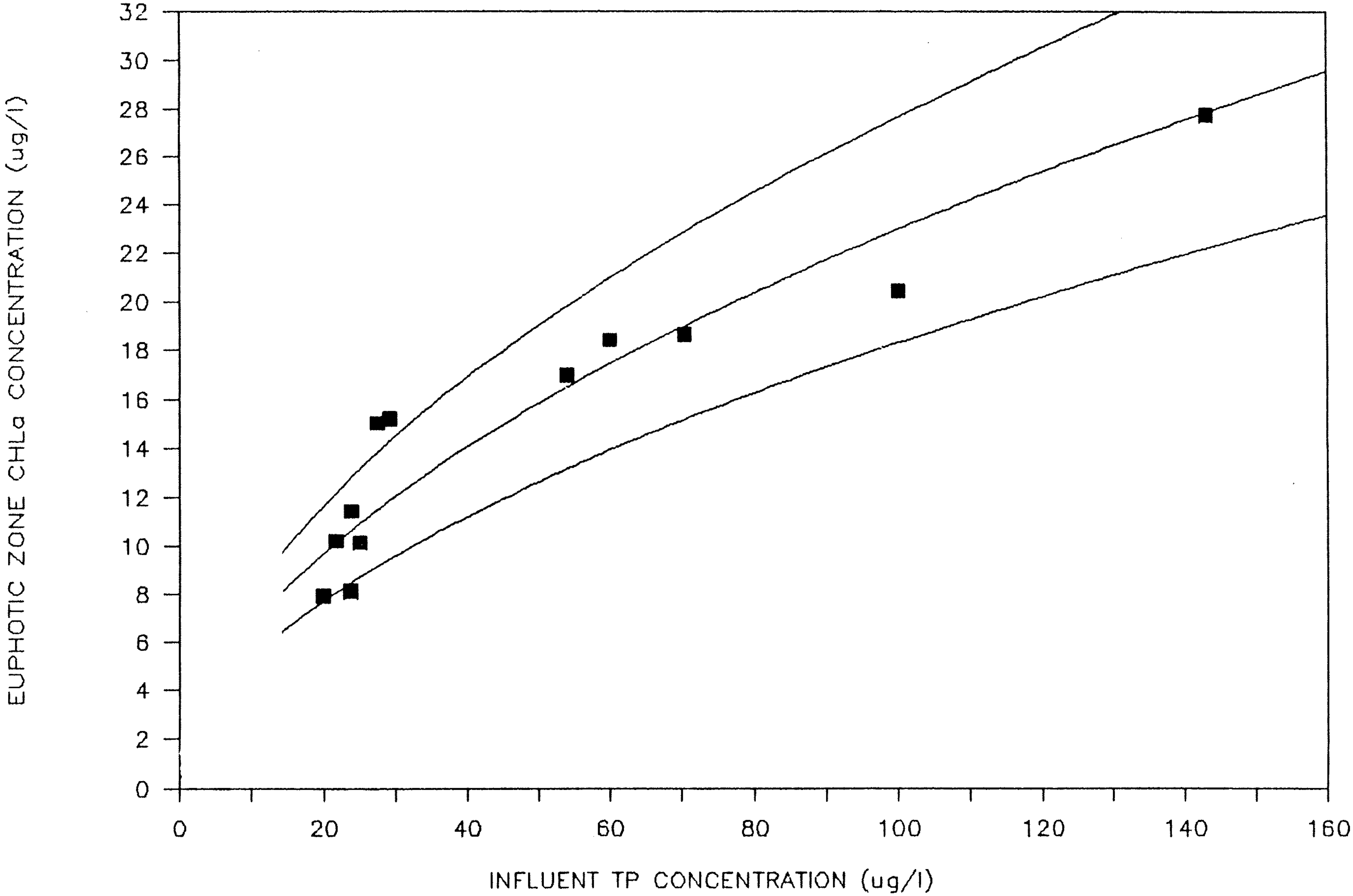


FIGURE 16

INFLUENT TP VS PEAK CHLOROPHYLL A CONC.

LONG LAKE REGRESSION MODEL AND PREDICTION UNCERTAINTY

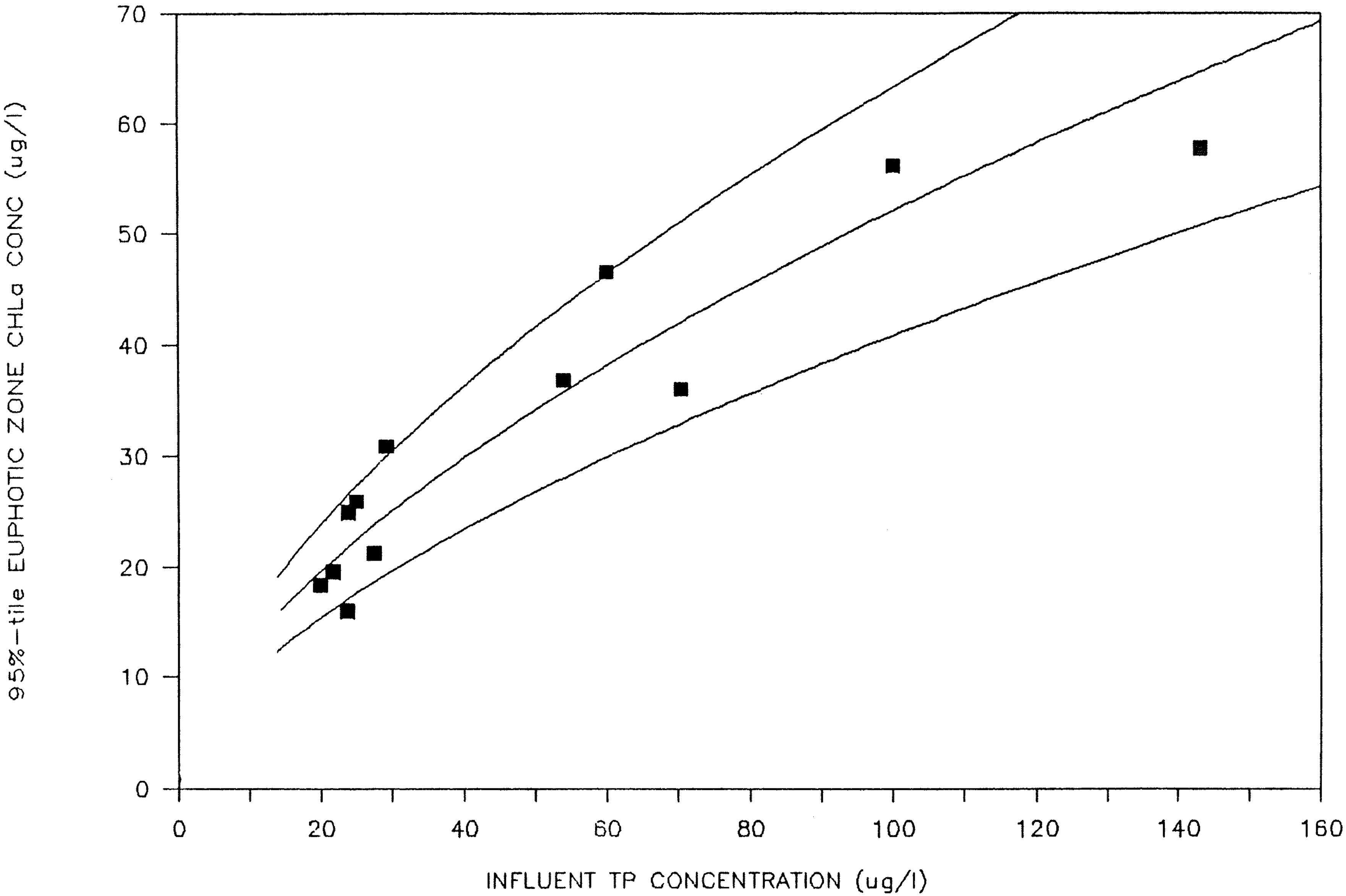
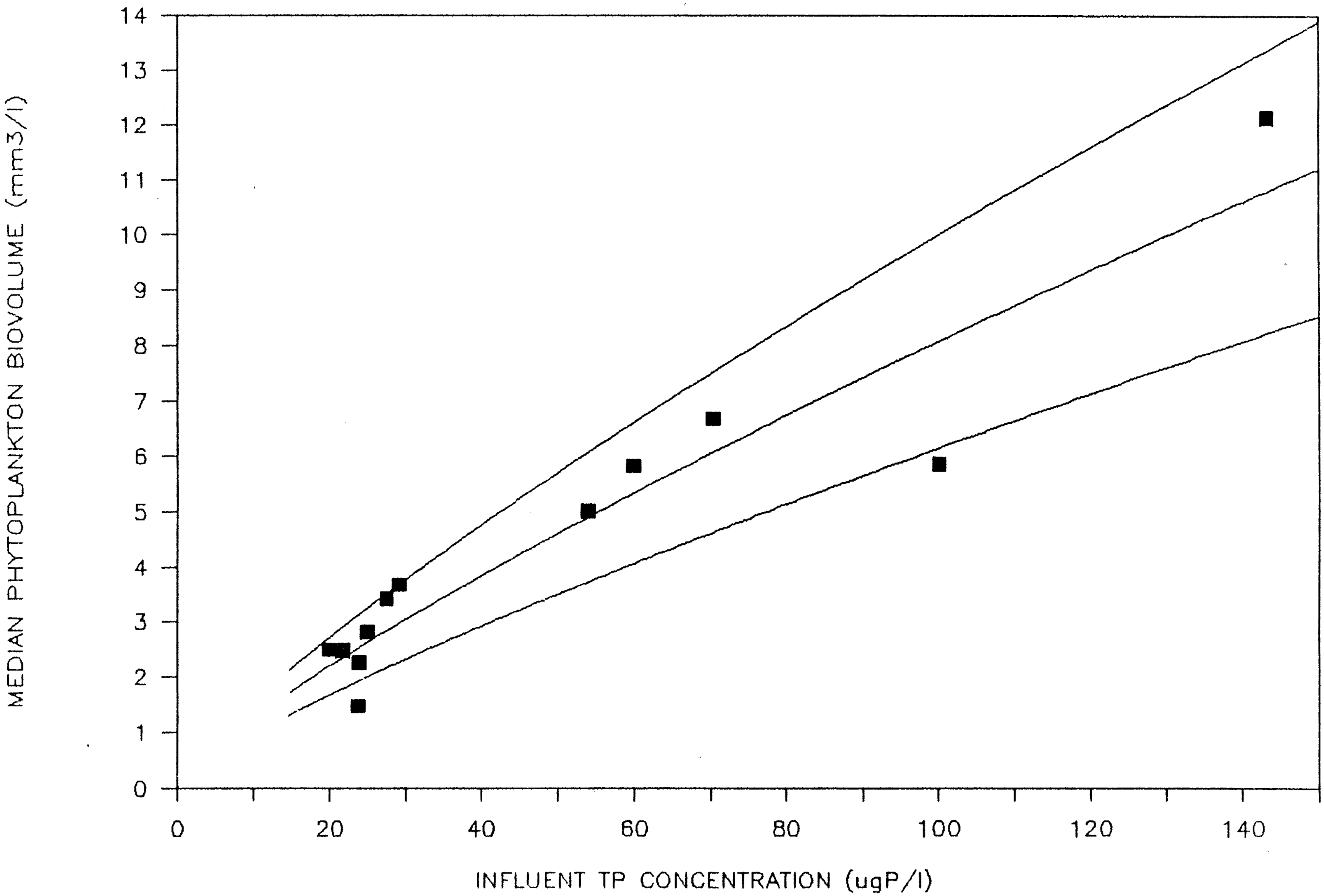


FIGURE 17

INFLUENT TP vs MEDIAN EZ-BIOVOLUME

LONG LAKE REGRESSION MODEL AND PREDICTION UNCERTAINTY



A principal feature of the TP-chl a relationships derived for Long Lake is the pronounced non-linearity of the regression equations (Figures 15-16). Increases in TP concentrations do not lead to proportional increases in chl a, particularly at higher TP levels. This is in contrast to the nearly linear form of the TP-chl a relationship observed in most temperate lakes (e.g. Edmondson, 1972; OECD, 1982) and also differs from the approximately linear relationship between TP and biovolume in Long Lake (Figure 17). A probable cause for the non-linear TP-chl a relationship in Long Lake appears to have been a shift from phosphorus to nitrogen limitation at higher TP levels (see algal assay discussion above). The low influent TN:TP ratios (less than 10:1) and low ambient inorganic nitrogen concentrations (commonly less than 20 ug/L) in Long Lake during several pre-AWT years adds further support to the nitrogen limitation hypothesis.

The importance of nitrogen limitation during pre-AWT years can also be demonstrated with the use of chl a models developed from other lake systems. For example, the widely used relationship between in-lake TP and chl a concentration reported by Dillon and Rigler (1974) for P-limited lakes predicts an average seasonal chl a concentration in Long Lake during 1973 of approxi- mately 98 ug/L. This value is considerably higher than the observed concentration of only 28 ug/L (Table 7). However, the seasonal regression model developed by Smith (1982), incorporating the effects of both N and P limitation, predicts a chl a concentration for the same period of 32 ug/L, which is similar to the observed value. In fact, application of the Smith (1982) model to the Long Lake data results in a predicted curvilinear relationship between seasonal mean TP and chl a which is equivalent to the observed relationship presented in Figure 15. The correspondence of the observed and predicted TP-chl a relationships supports the validity of the models. The agreement between the Long Lake data and the Smith (1982) chl a model also suggests that algal growth in Long Lake responds to nutrient supplies similarly to most other northern temperate lakes.

As stated above, the non-linearity of the Long Lake TP-chl a relationship contrasts with the nearly linear form of the TP-biovolume regression, and implies that EZ biovolume levels may be more closely controlled by phosphorus (and less by nitrogen) than chl _a_. The apparent discrepancy between the chl _a_ and biovolume data is not unique to Long Lake, and has been attributed to variations in cellular chl _a_ production which occur in response to shifts in nutrient and light limitation in a wide variety of lakes (Nichols and Dillon, 1978; Healey and Hendzel, 1980). Possibly because nitrogen is a principal constituent of chlorophyll, algae generally respond to N limitation by synthesizing less chl _a_ per unit of cell biomass. In Long Lake, the chl _a_:biovolume ratio is significantly correlated ($P<.05$) with the influent N:P ratio, a result which is consistent with other lake and experimental studies. These data tend to confirm the importance of phosphorus as the principal limiting nutrient to algal growth in Long Lake, but also point out a potential weakness of using chl _a_ as an index of algal biomass, particularly when TP loading is high.

Transparency

In addition to chl _a_ and biovolume, another commonly used indicator of algal biomass in lakes is the Secchi disc depth, owing to the correlation of biomass and transparency in many lakes (OECD, 1982). In Long Lake, however, abiotic sources of turbidity contribute to reductions in transparency, particularly during snowmelt periods, and result in a pronounced seasonal cycle of low transparency during winter and spring, and comparatively high values during summer and fall (Figure 13). In an effort to separate out this abiotic turbidity from that derived from algal cells, Secchi disc measurements made during the relatively high flow month of June (Figure 4) were not included in the statistical summaries. River discharge was not significantly correlated ($P>.05$) with Secchi disc once the June data were removed.

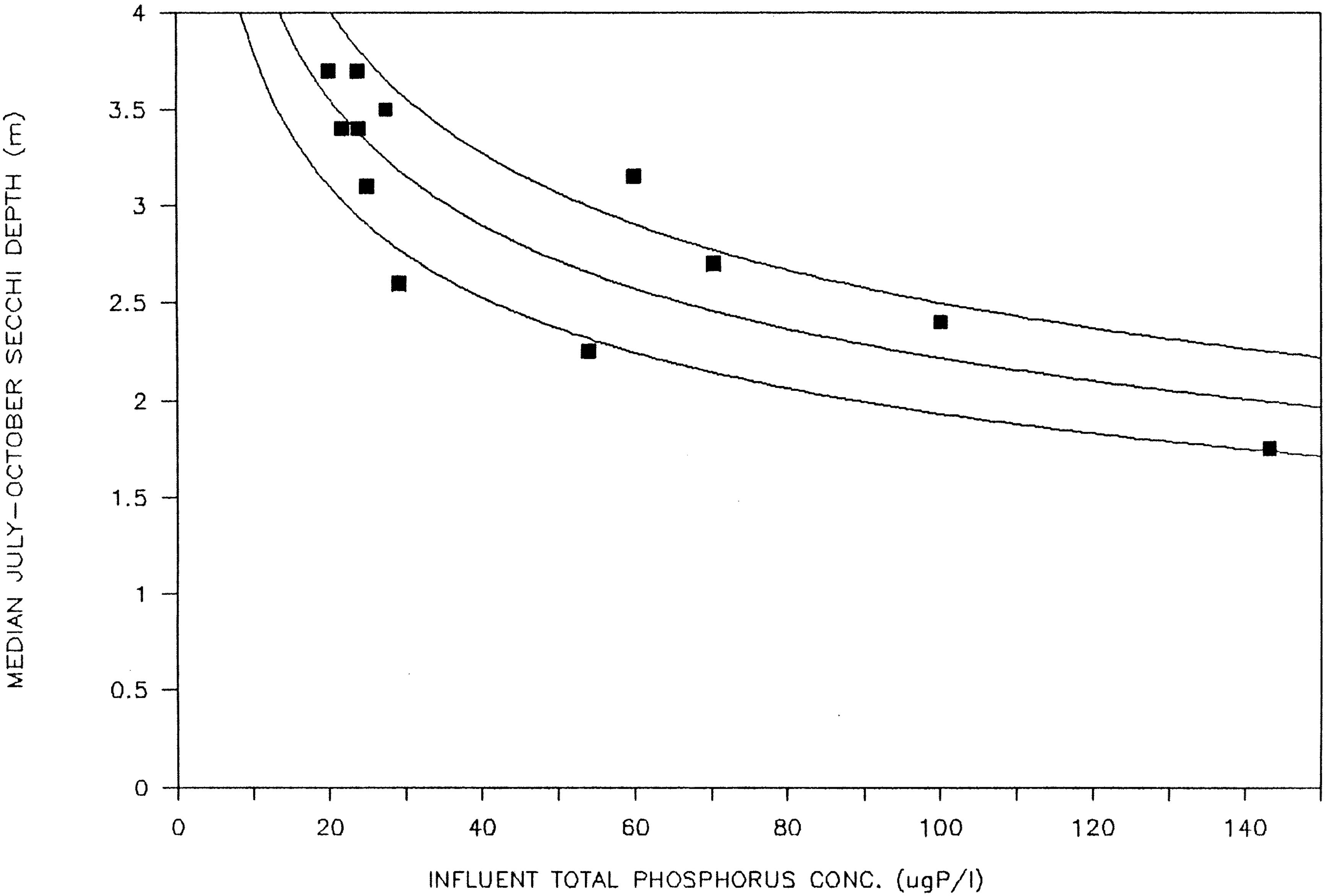
The relationship between influent TP and the median July-October Secchi depth is presented in Figure 18. The regression equation ($P<.05$) was as follows:

Median July-October Secchi Disc Depth (m) =
EXP (2.15 - 0.295 * ln (Influent TP; ug/L))
Total Prediction Uncertainty = +/- 12.8 percent

FIGURE 18

INFLUENT TP vs MEDIAN JULY-OCT. SECCHI

LONG LAKE REGRESSION MODEL AND PREDICTION UNCERTAINTY



Several investigators have suggested that for a given lake, the Secchi disc depth occurs at a certain level of incident light, independent of the magnitude of the Secchi transparency (e.g. Lorenzen, 1980). In Long Lake, however, the light intensity at the Secchi depth is lower when transparency is greater (Figure 19), perhaps reflecting changes in the size of light-scattering particulate matter correlated to the magnitude of the Secchi depth (Edmondson, 1980). This may be caused by the seasonal presence of abiotic turbidity, which periodically clouds Long Lake with relatively large diameter (relative to algal cells) particulates that may not be strongly light absorbing. In any event, the relationship between Secchi depth and light attenuation in Long Lake may be rather complex and these parameters are probably not directly comparable.

Dissolved Oxygen

The final trophic parameter evaluated for this study was the volume-weighted hypolimnetic dissolved oxygen concentration, which periodically reached levels near zero in Long Lake prior to AWT at Spokane (Figure 14; Table 7). During the last four years of study (1982-85), minimum average hypolimnetic D.O. concentrations have exceeded 4 mg/L. Minimum D.O. concentrations always occurred during the period of peak stratification (typically in August).

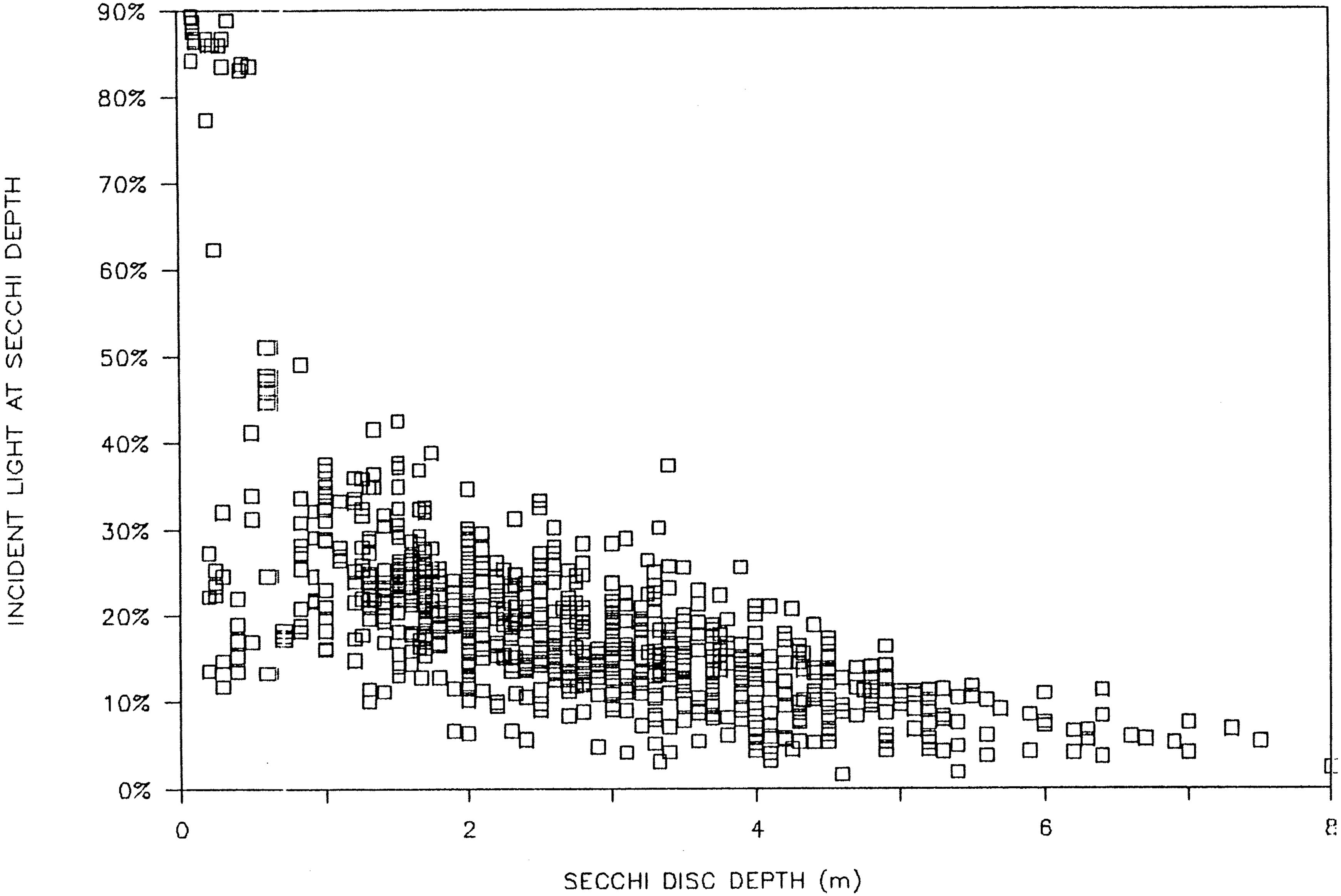
The minimum level of D.O. within the hypolimnion at the height of stratification represents a balance between oxygen supplies and uptake processes. Many investigators have observed that the oxygen uptake rate, when normalized to the area of the hypolimnion (denoted the hypolimnetic oxygen deficit rate; HODR) is correlated with phosphorus loading parameters (Cornett and Rigler, 1979; Welch and Perkins, 1979; OECD, 1982). However, the HODR is also controlled by the depth of the hypolimnion and by water temperature, and generalized values of "acceptable" HODR's (e.g. Mortimer, 1941) are thus not considered appropriate as widely applicable trophic status criteria. Nevertheless, evaluations of the HODR can provide important comparative data between lake environments, and can help describe possible mechanisms contributing to hypolimnetic anoxia.

Estimates of the HODR in Long Lake must not only be based on seasonal reductions in the oxygen content of the reservoir, but must also consider the oxygen

FIGURE 19

SECCHI DEPTH VS LIGHT EXTINCTION

LONG LAKE, 1972–1985



supplied by the mixing of river water into the hypolimnion, since this zone of the reservoir is known to be moderately well flushed, as discussed above. Mass balances of oxygen fluxes in the Long Lake hypolimnion (depth >15m) utilized flow estimates computed from the specific conductance data (see Appendix C).

HODRs calculated from the Long Lake data base ranged from 2.2 to 6.3 gm/m^2-day in years prior to AWT, and 1.8 to 2.6 gm/m^2-day in years after AWT. However, differences between pre- and post-AWT years were not significant ($P>.05$). Based on multiple regression analyses, the most important factor which appeared to determine the HODR in Long Lake was river flow; high flow years exhibited the greatest HODRs. This result implies that allochthonous sources of organic matter, transported into Long Lake during high flow periods (e.g. soil erosion), may contribute substantially to oxygen consumption within the reservoir. However, the flushing rate of the hypolimnion also appeared to be correlated with river flow, and minimum D.O. concentrations were generally less severe during high flow years.

Wagstaff and Soltero (1982) measured sediment oxygen demand (SOD) rates at several locations within Long Lake during the summer/fall period of 1981. Their results suggested that SOD is relatively constant throughout the reservoir, and averaged approximately 1.08 +/- .03 gm/m^2-day (based on 30 observations). This value is approximately 40 percent of the total HODR computed for the same period (2.64 +/- 0.88 gm/m^2-day). Apparently both sediment demand and respiration occurring within the water column may be major pathways of hypolimnetic D.O. depletion. This result is consistent with observations that D.O. often reaches minimum values both within the metalimnion and bottom waters (Soltero et al., 1973-76; 1978-86). Measurements of 5-day biochemical oxygen demand within the water column during 1981 were generally inconclusive, since all influent, reservoir, and outflow values were typically quite low (averaging 2.1 mg/L; Wagstaff and Soltero, 1982).

It is interesting to note that the computed HODRs in Long Lake are among the upper range of deficit rates reported for lakes throughout the northern temperate region (Welch and Perkins, 1979; OECD, 1982). However, for most years (excluding high flows) the observed deficit rates agree reasonably well with predicted values based on a model incorporating the effects of TP loading, hypolimnetic temperature, and depth (Cornett and Rigler, 1979). Models which do not incorporate the effect of hypolimnetic temperature appear to grossly underestimate the observed HODR's in Long Lake (e.g. Welch and Perkins, 1979; OECD, 1982). The rather warm hypolimnetic temperature characteristic of Long Lake (a volume-weighted temperature of ca. 16^{o} C vs. a "typical" lake value of $4\text{-}8^{o}$ C) apparently contributes to the reservoir's susceptibility to hypolimnetic anoxia.

In order to estimate the approximate magnitude of various sources of organic matter (e.g. allochthonous vs. autochthonous) which contribute to hypolimnetic anoxia in Long Lake, an approximate seasonal budget of total organic carbon (TOC) was prepared. The budget was based on available tributary data collected largely by USGS, calculated using a flow versus loading regression methodology. HODR's and Spokane wastewater chemical oxygen demand data were converted to TOC equivalents using conventional stoichiometry. Net ^{14}C- production of phytoplankton in Long Lake was estimated based on a generalized model using chl a and light data (Martin, 1976; Soltero et al., 1986).

The TOC budget is summarized in Table 8. Although the available data are generally too limited and variable to support a detailed characterization of TOC inputs and outputs, a number of conclusions can be inferred from this information:

- Phytoplankton production within the reservoir was the largest identified TOC source to Long Lake, followed in importance by upstream Spokane River inputs;
- Spokane STP/AWT effluent has been a comparatively minor TOC source;
- Very little (typically 10-20 percent) of the TOC input to Long Lake has been decomposed within the hypolimnion, possibly due to the reservoir's complex hydrodynamics.

Because phytoplankton production appears to have been the primary TOC source to Long Lake, and because algal growth has been shown to be determined primarily by phosphorus levels (see above), it is reasonable to expect that the extent of

Table 8

Summary of Long Lake Total Organic Carbon Budgets
June - October 1972-1976 (Pre-AWT) and 1978-85 (Post-AWT)

	TOC Loading (kg/day) (mean +/- std. error)	
	Pre-AWT	Post AWT
INPUTS:		
Spokane STP/AWT (RM 67.4)	8,100 +/- 500	1,200 +/- 200
Spokane River at Riverside Park (RM 66.1)	36,900 +/- 15,900	17,800 +/- 5,300
Little Spokane River at Mouth	3,800 +/- 2,500	3,900 +/- 2,600
Phytoplankton Production	45,300 +/- 24,200	28,600 +/- 14,600
TOTAL INPUTS	86,000 +/- 29,100	50,300 +/- 15,800
OUTPUTS:		
Hypolimnetic Respiration	11,400 +/- 3,800	6,900 +/- 2,200
Long Lake Outflow	151,000 +/- 62,300	24,700 +/- 6,400
TOTAL OUTPUTS	162,000 +/- 62,400	31,600 +/- 6,800

D.O. depletion in Long Lake may be related to phosphorus supplies. Regression analyses confirm that the influent TP concentration is a significant ($P<.05$) determinant of the minimum mean hypolimnetic D.O. level (Figure 20). However, river discharge also appeared to be an equally significant determinant, and the combined predictive formulation (based on a stepwise multiple regression model) was as follows:

FIGURE 20a

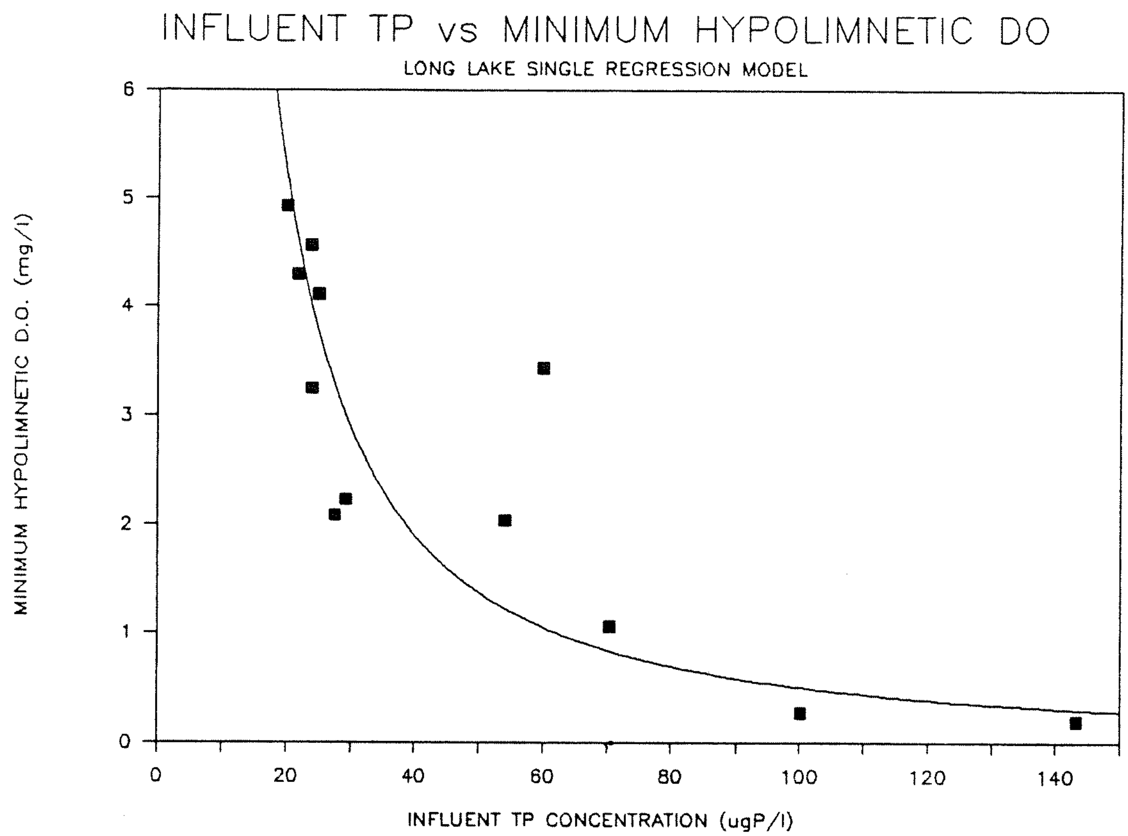
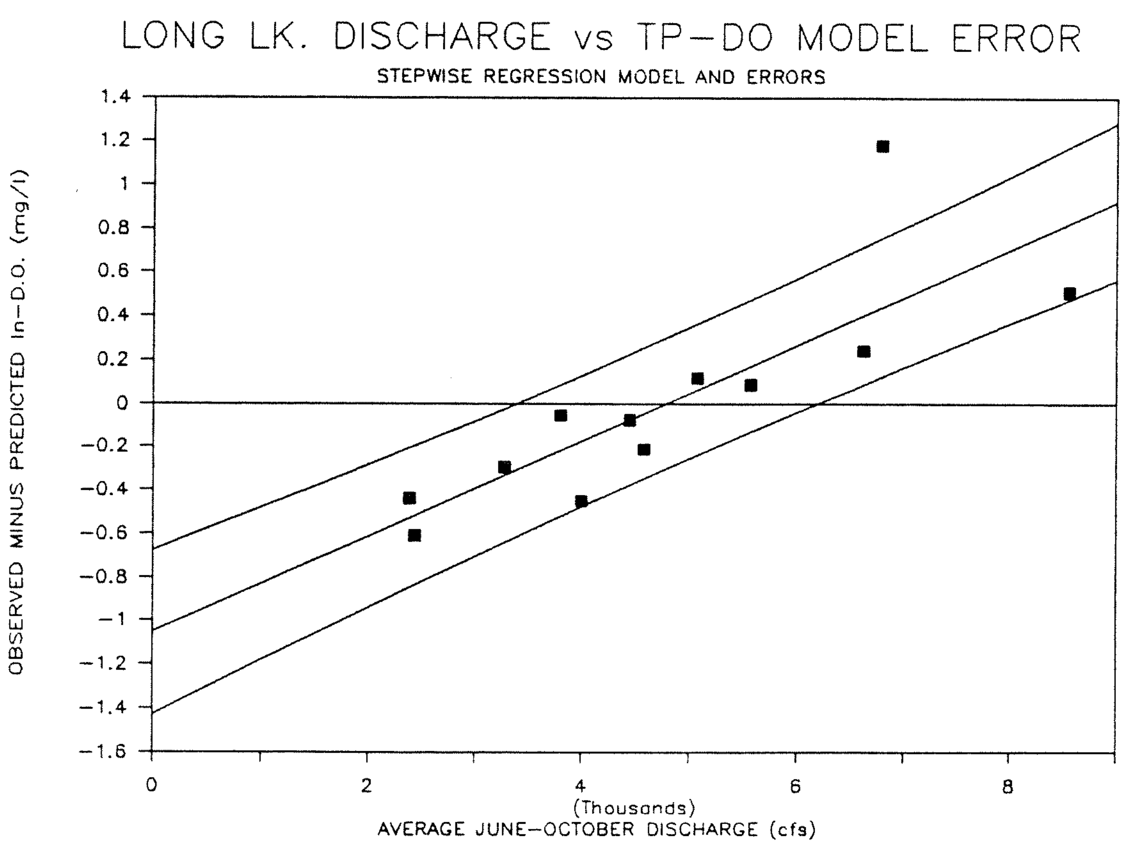


FIGURE 20b



$$\text{Minimum Hypo. D.O. (mg/l)} = \text{EXP}\,(4.96 - 1.46 * \ln\,(\text{Influent TP; ug/L}) + 2.19\text{e-}4 * (\text{Outflow Q; cfs}))$$

Total Prediction Uncertainty = +/- 29.5 percent

Regression analyses also revealed that the seasonal average hypolimnetic temperature in Long Lake is correlated with river flow ($P<.05$). Low flow years were associated with a cooler hypolimnion (and thus reduced HODR), perhaps because of the greater importance of comparatively cold groundwater inputs to the river system during low flows (Patmont et al., 1985). Clearly the fundamental relationships between minimum D.O., HODR, TP levels, river flow, and temperature are quite complex. The empirical multiple regression model presented above only attempts to describe the net result of these processes in simple statistical terms.

Zinc Inhibition

Zinc discharges into the South Fork of the Coeur d'Alene River are well documented and were largely curtailed in the early 1970's. The effects of zinc discharges appear to have been most severe at points closest to the source, but have been documented as far downstream as Long Lake (Greene et al., 1978). The zinc content of reservoir waters was identified as a principal growth-limiting factor to a non-endemic test alga, *Selenastrum capricornutum*, and also to an important Long Lake species, *Anabaena flos-aquae*. However, an indigenous algal species isolated from Long Lake, *Sphaerocystis schroeteri*, appeared to be relatively insensitive to ambient concentrations of heavy metals in the reservoir. These data suggest that elevated zinc concentrations in Long Lake may not necessarily result in quantitative reductions in the total algal biomass present in Long Lake, but could lead to qualitative shifts in the endemic phytoplankton community.

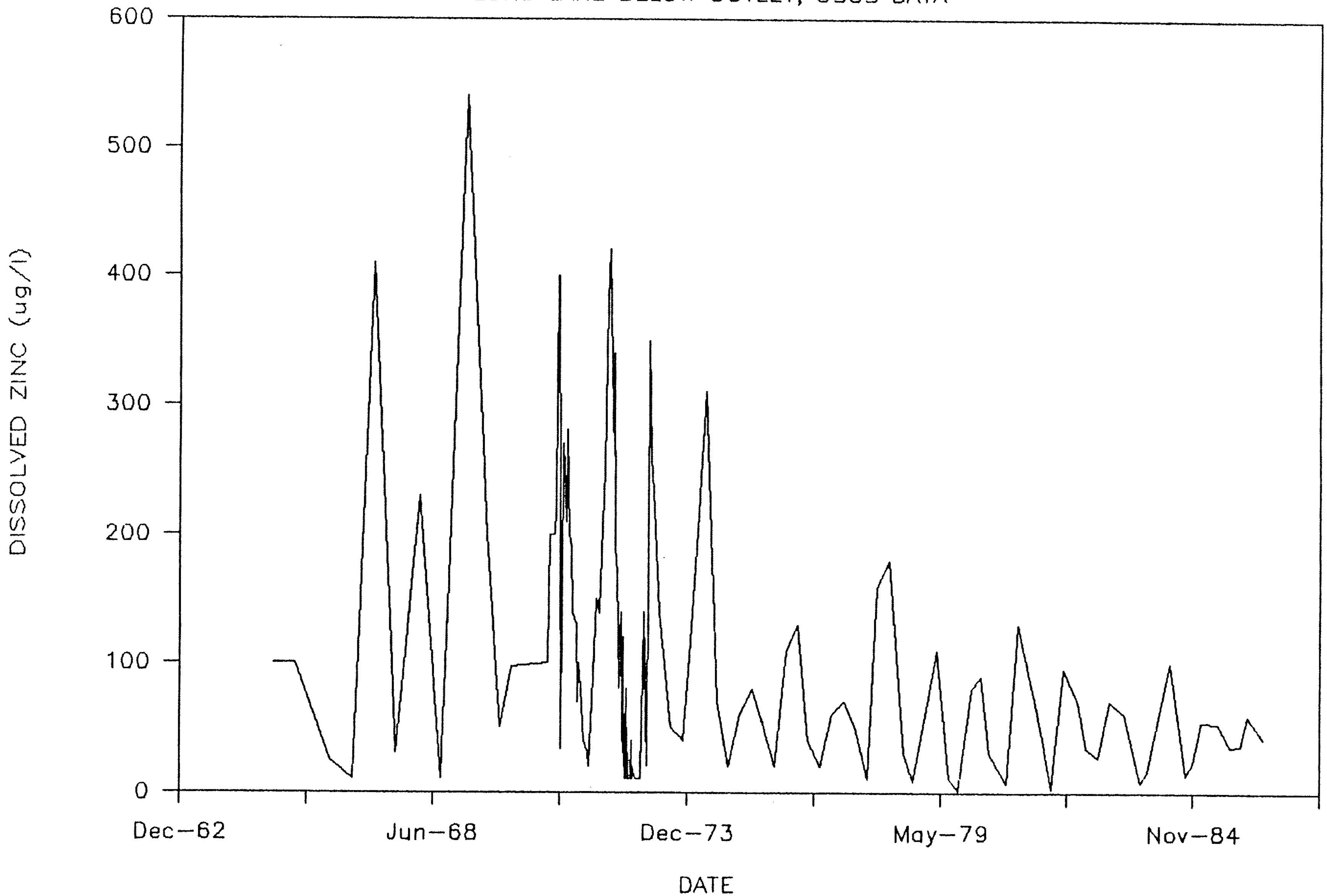
Aside from being of general ecological concern throughout the river system (e.g. Funk et al., 1975), elevated zinc concentrations in Long Lake may have contributed to the notable lack of blue-green algae in the reservoir during early study years (1972-1975), even though environmental conditions in the reservoir during low flow periods (i.e. high P, low N:P) may otherwise have been suitable for abundant growth (Soltero and Nichols, 1981). The phytoplankton assembledge during these earlier years (pre-1975) was dominated by a variety of diatoms, cryptophytes, and green algae. The sudden appearance of toxic blooms of Anabaena flos-aquae in Long Lake in 1976 and 1977 correlates with the general timing of zinc discharge controls implemented near Kellogg, Idaho, and also with the observed reduction of zinc concentrations at Long Lake Dam (Figure 21). Dissolved zinc concentrations during earlier years rarely fell below 20-40 ug/L, which corresponds to the approximate threshold range of zinc toxicity to Anabaena (Figure 22). In more recent years, however, dissolved zinc concentrations at Long Lake Dam during the summer/fall low flow period have frequently been observed at trace levels (<5-10 ug/L) associated with little inhibition (USGS, 1961-85; Shiroyama et al., 1976).

Following the implementation of AWT at Spokane (December 1977), Long Lake TP concentrations are predicted to have dropped to relatively low levels, concurrent with a large increase in N:P ratios and ambient nitrogen concentrations. These conditions are generally not favorable to the growth of nitrogen-fixing blue-green algae such as Anabaena, since other species appear to be more competitive (Welch, 1980). Thus, it is not surprising that Anabaena blooms have not reappeared in Long Lake since 1977 (Soltero and Nichols, 1981; Soltero et al., 1986). However, in 1978, a relatively large bloom did occur of the blue-green alga Microcystis aeruginosa, which does not fix atmospheric nitrogen and, thus, requires ambient nitrogen for growth. The 1978 Microcystis bloom, which has not yet recurred in Long Lake, may possibly have been a carryover from previous years, since vegetative colonies of Microcystis are known to survive through winter on bottom sediments (Reynolds and Walsby, 1975). Nevertheless, because the cause of the 1978 Microcystics bloom can not be fully established, future blooms of this alga in Long Lake--even with the existing loading regime--must be considered a possibility.

FIGURE 21

DISSOLVED ZINC TRENDS; 1964–1986

LONG LAKE BELOW OUTLET, USGS DATA



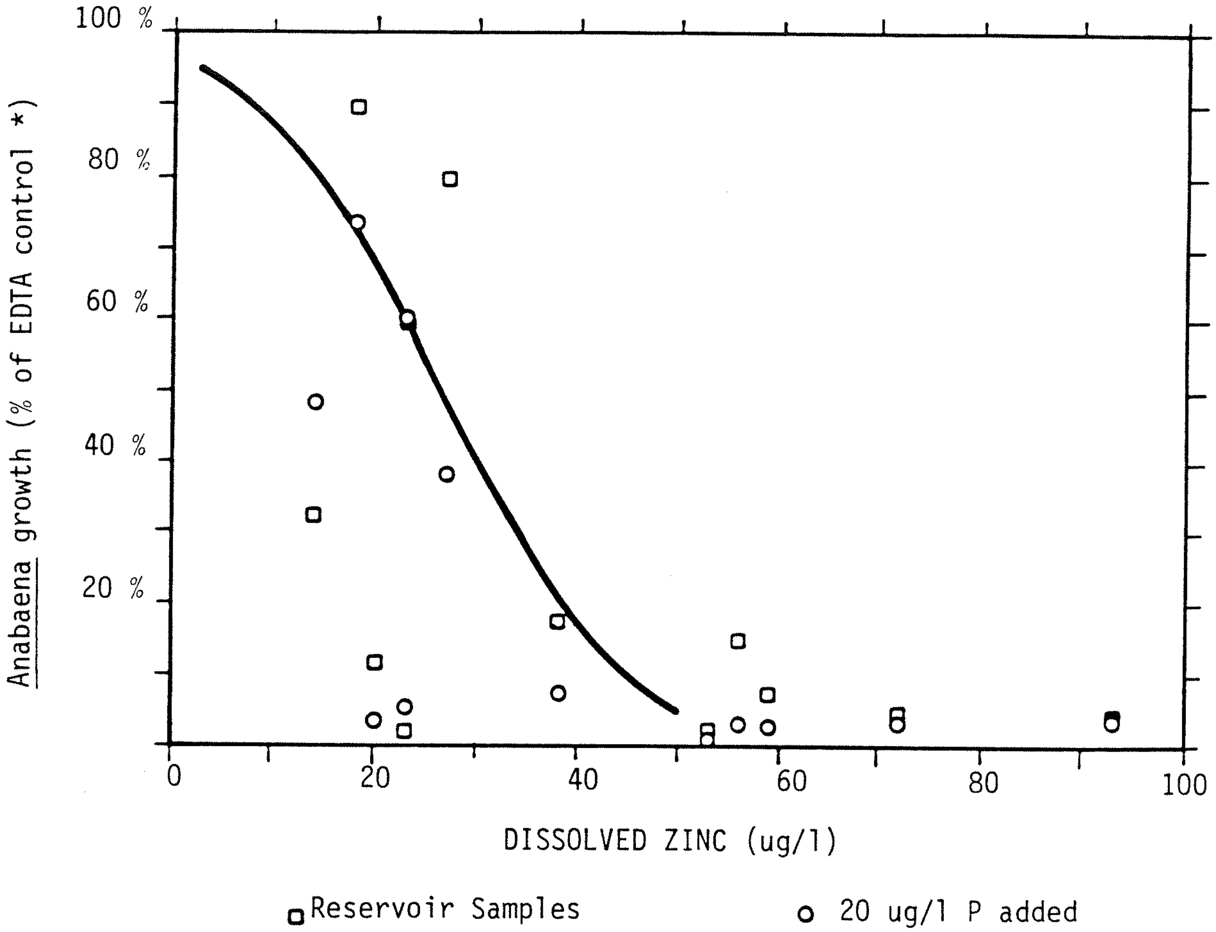


Figure 22

LONG LAKE ALGAL ASSAYS, ANABAENA FLOS-AQUAE

(Adapted from Shiroyoma et al, 1976)

* Defined as the growth of Anabaena flos-aquae in reservoir samples, expressed as a percentage of the growth obtained in duplicate samples receiving 1 mg/l EDTA to remove metal toxicity. Zinc is believed to have been the most toxic metal present in the Spokane River.

SPOKANE RIVER PERIPHYTON

Compared to the extensive limnological studies of Long Lake, investigations of the development and biomass of attached algal communities in the Spokane River have been quite limited. Studies which have been completed include a variety of relatively short-term (typically 2-8 week) periphyton accrual experiments on both natural and artificial substrates (Williams and Soltero, 1978; Nielsen, 1983; Gibbons et al., 1984). Comparatively few observations of in-river periphyton biomass have been performed (Patmont et al., 1985, and this study).

River Biomass

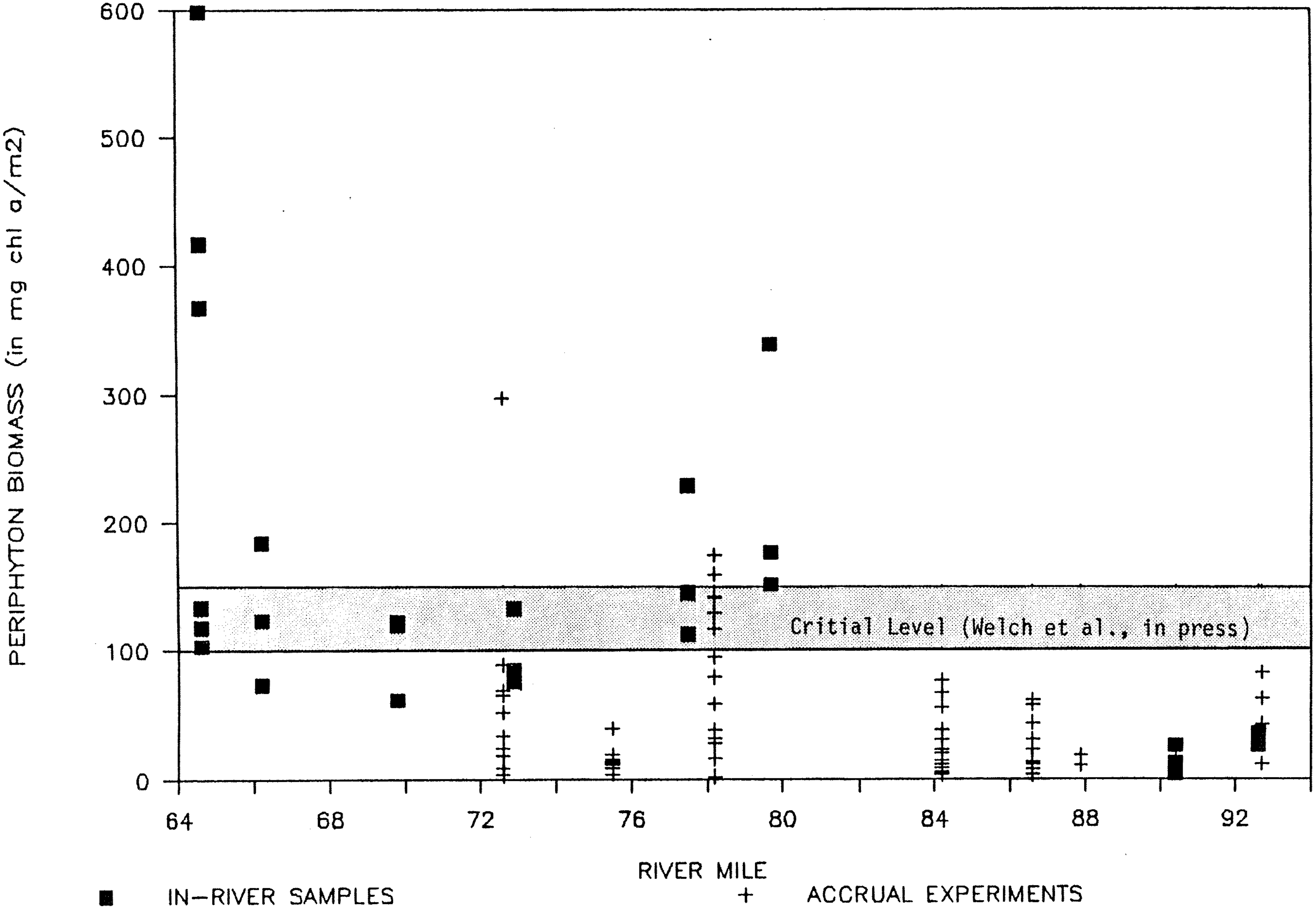
From 1984 to 1986, 26 samples of the summer in-river periphyton standing crop (expressed as chl a) were collected, representing eight free-flowing reaches of the river with similar depth and velocity characteristics (Patmont et al., 1985 and this study). A summary of these data is presented in Figure 23. Periphyton chl a levels in upper reaches (RM 90-94) of the river ranged from 3-34 mg chl a/m^2 (based on 5 samples). Biomass in more downstream reaches of the Spokane River appeared to be considerably higher, with values ranging from 61-600 mg chl a/m^2 (based on 21 samples).

Patmont et al. (1985) suggested that free-flowing reaches of the Spokane River could generally be separated into three regions on the basis of nitrogen and phosphorus levels. Upper reaches of the river (RM 87-102) exhibited very low ambient inorganic nitrogen levels (<10 ug/L) and moderate soluble reactive phosphorus (SRP) concentrations (5-15 ug/L). Based on analyses of periphyton tissue, growth in these areas appeared to be controlled primarily by nitrogen supplies. Middle and lower reaches of the river exhibited much greater nitrogen concentrations (100-1,000 ug/L) as a result of aquifer inputs rich in nitrate. Ambient and tissue N:P ratios suggested that phosphorus was the more limiting nutrient in these areas. However, middle reaches of the river (RM 68-86) commonly exhibited low to moderate SRP concentrations (generally less than 10 ug/L) while lower reaches (RM 62-67) contained higher SRP levels (greater than 20 ug/L) as a result of wastewater discharges from the Spokane AWT facility.

FIGURE 23

PERIPHYTON BIOMASS IN THE SPOKANE RIVER

JUNE–OCTOBER SAMPLES, 1980–1986



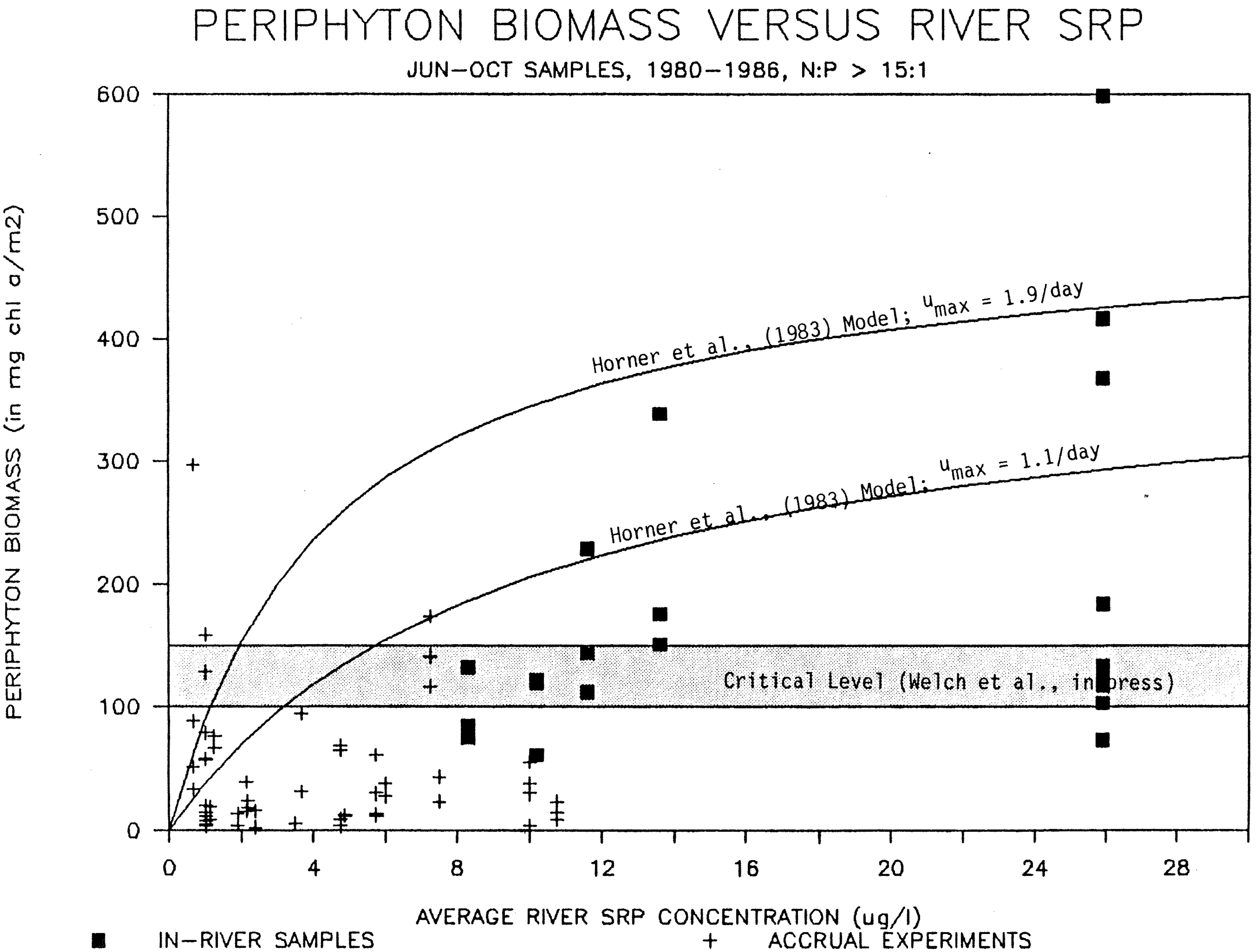
Analysis of variance (ANOVA) tests were performed with the in-river periphyton data to determine if significant differences in biomass levels existed between these three river regions. The ANOVA results revealed that upper reaches of the river contained significantly less ($P<.02$) chl a than the middle and lower reaches; differences between the middle and lower reaches were not significant ($P>.20$). These results appear to confirm the importance of nitrogen as a significant factor controlling periphyton chl a in the Spokane River. The possible influence of phosphorus, however, was not apparent in these data. Regression analysis of measured chl a levels versus average in-stream SRP concentrations in high N:P reaches also failed to show a statistically significant ($P>.05$) phosphorus relationship (Figure 24). This may have occurred because ambient SRP concentrations throughout the river were generally high compared to periphyton growth saturation values of approximately 3-7 ug/L (Bothwell, 1985; Seeley, 1986). Grazing by macroinvertebrates may also be a significant factor complicating the phosphorus-periphyton relationship (Jacoby, 1986). The influence of phosphorus on periphytic growth will be discussed in more detail in the "Growth Experiments" section below.

Periphyton standing crop levels above a critical range of 100-150 mg chl a/m^2 are generally considered indicative of nuisance conditions, since values above this approximate threshold are correlated with a high areal coverage of algae on the stream bottom and a high proportion of more undesirable filamentous forms (Horner et al., 1983; Welch et al., in press). Within the Spokane River, values in excess of 100-150 mg/m^2 have been observed throughout the middle and lower reaches (Figure 23). Seventeen of the 21 observations (81 percent) in this area have exceeded 100 mg chl a/m^2, while eight (38 percent) have exceeded 150 mg/m^2. Compared to these criteria, and also relative to other similar rivers in the Pacific Northwest, periphyton biomass levels in the middle and lower Spokane River appeared to be rather high. Standing crop levels in the N-limited upper region of the river, however, appeared to be lower than the nuisance threshold.

Growth Experiments

Although it is generally more important from a management standpoint to be able

FIGURE 24


PERIPHYTON BIOMASS VERSUS RIVER SRP
JUN–OCT SAMPLES, 1980–1986, N:P > 15:1
PERIPHYTON BIOMASS (in mg chl a/m2)
AVERAGE RIVER SRP CONCENTRATION (ug/l)
Horner et al., (1983) Model; umax = 1.9/day
Horner et al., (1983) Model; umax = 1.1/day
Critical Level (Welch et al., in press)
■ IN–RIVER SAMPLES
+ ACCRUAL EXPERIMENTS

to predict the maximum or seasonal periphyton biomass which may develop on the stream bottom in relation to changes in nutrient supply, in practice such predictions have been shown to be very uncertain (Welch et al., in press). Possible explanations for the large uncertainty inherent to existing models include macroinvertebrate grazing, light limitation, velocity and substrate variability, the effects of which are often difficult to describe. For these reasons, many investigators examining periphyton levels have performed relatively short-term biomass accrual experiments using artificial substrates or bare rock surfaces. A variety of physical and biological factors can be somewhat controlled in these experiments, allowing the effects of changes in nutrient supply to be observed more clearly. The results of these growth experiments generally provide information on potential biomass which could be produced within the stream, since *in situ* biomass is nearly always lower than that obtained in the accrual experiments. Experiments conducted in the upper Spokane River (RM 91-93) during the summer of 1982, for example, revealed that chl *a* levels typically peaked within two weeks on bare natural substrates (Nielsen, 1983). Similarly, Jacoby (1986) observed large reductions in biomass in grazed versus ungrazed areas of the Raging River, Washington.

Short-term (less than two-week) accrual experiments in artificial laboratory channels and natural streams have demonstrated that periphyton growth responds to both the SRP concentration and to stream velocity (Horner and Welch, 1981; Horner et al., 1983; Seeley, 1986). Growth appears to saturate at SRP levels greater than approximately 7 ug/L. Velocity enhances accrual between a range of 5-25 cm/sec. These studies revealed that periphyton communities do respond to increases in nutrient supply in a similar fashion as planktonic forms and that phosphorus could be a limiting nutrient to periphyton if ambient SRP concentrations were sufficiently low.

Accrual experiments conducted in the Spokane River provide an additional test of the hypothesized relationship between nutrient supply and periphyton growth. For the purposes of this study, only data collected during the principal growing season months of June-October were considered. Furthermore, only measurements made during relatively low flow conditions (<5,000 cfs) were evaluated, in order to provide a characterization of conditions appropriate to the design flow event.

The available seasonal accrual experiment data are presented in Figure 23. The mean growing period for the substrates was 56 days, and ranged from 18 to 117 days. In general, the data appeared consistent with the in-river observations for the same river reach, although differences in river characteristics (e.g. velocity and SRP levels) between the two data sets render such comparisons tenuous (see below).

For a two-week period prior to each accrual measurement, the average river velocity, inorganic nitrogen, SRP and TP concentrations were estimated for each sampling site. Velocity was based on USGS discharge data, assumed groundwater interactions and the discharge/velocity relationships presented in Patmont et al. (1985), adjusted for reported site characteristics. Nitrogen and phosphorus concentrations were estimated based on concurrent water sampling data (e.g. see Gibbons et al., 1984).

The importance of velocity, nitrogen, and phosphorus concentrations as determinants of periphyton chl a accrual (dependent variable) was evaluated using a multiple regression analysis of log-transformed variables. The results of this analysis, which was based on 90 observations, suggested that both average river velocity (range: 5-80 cm/sec) and inorganic nitrogen concentrations (range: 5-900 ug/L) were significantly ($P<.05$) correlated with chl a accrual. SRP concentrations (range: 1-14 ug/L) were not significant ($P>.2$) determinants; TP levels exhibited even less correlation ($P>.4$.). Accrual data collected in reaches of the river believed to be P limited (based on N:P ratios exceeding 15:1) are plotted against the ambient SRP concentration in Figure 24. In general, SRP levels encountered during the 1980-82 accrual experiments were lower than those observed during the 1984 P-attenuation sampling (Patmont et al., 1985).

The Spokane River accrual data confirmed that nitrogen is a critical parameter controlling periphyton growth, and that differences in river biomass levels between the upper and middle/lower reaches of the river are the result of shifts in N limitation. The observation that velocity also controls periphyton accrual is consistent with experimental results (Horner and Welch, 1981; Horner et al., 1983; Horner et al., 1986). Phosphorus supplies did not appear to be a major factor limiting periphyton growth, possibly because ambient levels of SRP in the Spokane River were sufficiently high to be growth saturating.

As a further evaluation of the possible relationship between periphyton accrual and phosphorus supplies, the model developed by Horner et al. (1983) was applied to the Spokane River below the possible influence of nitrogen limitation (RM 62-86). The model predicts the maximum potential biomass of periphytic algae based upon the formulation:

$$B = [B_{max} - K_2 V^{\theta} / K_1 \mu L \; (k_f + k_{f_0})] \;\; [1 - e^{-K_1 \mu L (k_f + K_{f_0}) t}]$$

where: B is chl a concentration (mg/m^2), B_{max} is 560 mg chl a/m^2, K_2 is the scour coefficient 0.3 mg chl a/m^2-day, V is velocity, u is the P uptake rate (1/day) based on Michaelis-Menton kinetics, L is the dimensionless light factor 0.755, k_f is the turbulent mass transfer coefficient (D = 1.5×10^{-5} cm^2/sec; l = 1 cm), k_{fo} is the non-turbulent mass transfer coefficient 0.0094 cm/sec, t is time, and θ and K_1 are empirical coefficients set equal to 0.45 and 1.2, respectively.

This model has been calibrated against periphyton growth in laboratory channels with variable velocity and SRP content at temperatures similar to the Spokane river during summer (15-18^{o}; Horner and Welch, 1981; Horner et al., 1983; Horner et al., 1986). There was no loss due to grazing in the channels and minimal loss due to scouring. Scouring has been shown to be important only when velocity is abruptly increased and/or when suspended sediment is increased (Seeley, 1986). Those conditions would be expected to be stable in the Spokane River during summer low flow.

The half saturation constant for SRP was taken as 8 ug/L, based on an evaluation of uptake kinetics in laboratory channels (Horner et al., 1986; Seeley, 1986). This half saturation value may be high, since other investigators have suggested that P uptake is saturated at considerably lower SRP values (2-3 ug/L;

Bothwell, 1985). However, Bothwell's (1985) results are for a relatively thin covering of diatoms. The laboratory results of Horner et al. (1986) and Seeley 1986) were obtained with thicker substrate coverings of filamentous green algae, which could logically require higher saturating concentrations. Lower reaches of the Spokane River, which exhibited the greatest chl a levels, were dominated by relatively thick mats of filamentous green and blue-green algae (Patmont et al., 1985).

The resulting relationship between SRP concentration and maximum potential biomass was derived using a typical riffle velocity during summer low flow of 40 cm/sec (1.3 ft/sec; Patmont et al., 1985), and an assumed growing period of 60 days. Depending upon the method of estimation, the maximum P uptake rate could vary from 1.1-1.9/day in the Spokane River during summer low flow, and this range of uptake rates was applied in the model. Uncertainties in the maximum uptake rate and half saturation value appear to be the principal limitations of the existing maximum periphyton accrual model (E.B. Welch, UW, personal communication).

The results of the model are presented in Figure 24. Model predictions of maximum potential biomass appear generally representative of Spokane River conditions, since most of the in-river samples and accrual experiment data fall below both the 1.1/day and 1.9/day u_{max} predictions. This model suggests that, barring significant loss rates from scouring or grazing, biomass could exceed the critical level for nuisance conditions at a SRP level as low as 2-5 ug/L. The "critical" SRP concentration could be even lower if the half saturation level in the Spokane River is similar to the 2-3 ug/L value reported by Bothwell (1985). Clearly, a critical phosphorus concentration that determines excessive biomass levels may be quite low, which presents a difficult management problem. Nuisance levels of periphyton appear more apt to be determined by lack of grazing and/or scouring in the Spokane River than by phosphorus increases.

Based on the information available to date, it appears that free-flowing reaches of the Spokane River currently limited by nitrogen (above approximately RM 87) will likely continue to exhibit low periphyton biomass levels regardless of changes in phosphorus loading. Nitrogen loading associated with wastewater discharges into this region of the river could result in localized increases in periphyton biomass, although the magnitude of this effect can not be predicted at the present time.

Conversely, the middle and lower reaches of the Spokane River characterized by higher N:P ratios are likely to continue to experience similar and potentially nuisance level periphyton accumulations unless the existing P loading regime is substantially reduced. This conclusion is based on the low P saturation values suggested in the literature and is somewhat supported by an analysis of Spokane River data. In addition, results from the recent phosphorus attenuation study suggest that SRP is recycled somewhat within riffle reaches of the river (Patmont et al., 1985), which could tend to maintain ambient SRP concentrations above saturation values. Such recycling was not considered in the periphyton model (i.e. Figure 24). Clearly, additional research in this area would be required before a defensible model of phosphorus-periphyton relationships could be developed. In particular, the influence of macroinvertebrate grazing, which may be a principal factor presently controlling in-river biomass levels, should be examined if periphyton reductions are considered desirable.

Due to the relatively low growth saturating concentrations of SRP in running water, it is considered unlikely that periphyton biomass at any stream point could be controlled by controlling ambient phosphorus levels. However, the stream distance adversely affected below a nutrient source (somewhat analagous to a "mixing zone") is a logical option to be managed, since in-stream uptake (i.e. attenuation) may ultimately reduce ambient SRP levels to limiting values. Additional work in these areas would be necessary before nuisance periphyton levels in the Spokane River could be related to phosphorus inputs. For these reasons, control of periphyton was not condiered in the development of a wasteload allocation strategy described in the next two sections.

SPOKANE RIVER/LONG LAKE MODEL

The attenuation model developed previously to describe phosphorus transport through the Spokane River (Patmont et al., 1985) formed the basis for the Spokane River/Long Lake model developed for this study. River flow conditions between the median and 1-in-10-year low June-October seasonal discharge were to be considered for the management of Long Lake (L. Singleton, Ecology, personal communication). Since the previous phosphorus attenuation model was developed for the 1-in-20-year June-November discharge event, hydrologic and phosphorus loading components of the model were modified to reflect the new flow condition. Phosphorus loading to the river from several non-point sources (e.g. stormwater and combined sewer overflows) were also revised to incorporate more recent data. In addition, mathematical expressions describing the relationships between the influent phosphorus concentration to Long Lake with a variety of trophic status parameters were adapted to the new model to permit an evaluation of water quality conditions within the reservoir resulting from alternative management strategies. Major features of the revised Spokane River/Long Lake model are described below; example model output is discussed in the subsequent chapter.

Model Structure

Phosphorus transport through the Spokane River was simulated with a mass balance which incorporates inputs, outputs, and channel uptake within sixteen reaches of the river from Lake Coeur d'Alene to Nine Mile Dam (Patmont et al., 1985). Briefly, the model begins with a flow balance within each reach and assumes that all surface inputs and outputs enter or leave at the top of the reach. Groundwater inputs and outputs are assumed to be linear across the length of the reach.

Phosphorus attenuation within the river channel was assumed to be predominantly benthic and proportional to the in-river phosphorus concentration (i.e. first-order) (Patmont et al., 1985). Nitrogen was assumed to limit P uptake in upper reaches of the river (by controlling periphyton growth); a Michaelis-Menten formulation was used to describe this effect. All attenuation constants were developed based on results of field sampling during 1984. The interested reader is referred to the P-attenuation report for additional documentation.

The interactive phosphorus transport component of the model, which was programmed using Microsoft QuickBASIC^{R}, allows the user to vary a variety of hydrologic and loading conditions throughout the river system to determine their influence on Long Lake. The model output consists of seasonal (June-October) steady-state concentrations and loadings of phosphorus throughout the river system. Seasonal predictions of water quality characteristics of Long Lake are also included. Uncertainties in each term of the Spokane River/Long Lake model are propagated through the model using first-order techniques. A complete program listing is presented in Appendix E. A user's manual and diskette containing the model are available through Ecology.

Hydrology

The USGS has maintained stream gaging stations at various sites along the Spokane River for more than 100 years. The principal gaging stations have been located at Post Falls, Harvard Road, Spokane, and Long Lake Dam. Surface water inputs to the river from Hangman Creek and the Little Spokane River have also been monitored, as well as irrigation withdrawals in the vicinity of Post Falls. These data provide a basis to describe annual variations in discharge within the river system and are summarized for the June to October period in Appendix D.

Because of the many sources which discharge into the river throughout the system, the flow condition applicable to the management of Long Lake is evaluated at the outlet of Lake Coeur d'Alene (RM 111.7), which marks the upstream boundary of the project area. All other flows in the system are basically tied to this discharge. Since the Lake Coeur d'Alene discharge has not been routinely measured, it was calculated based on data collected at the USGS gage below Post Falls (RM 100.7), corrected for irrigation withdrawals and minor point source inputs occurring within the 11-mile reach. Groundwater influence has been determined to be nearly negligible in this area, possibly due to the presence of relatively impervious bedrock close to the ground surface (Seitz and Jones, 1981; Patmont et al., 1985).

The probability distribution of calculated June-October average discharges from Lake Coeur d'Alene over the period of record (1913-1985) is presented in Figure 25. Based on linear interpolation of this non-normally (i.e. non-Gaussian) distributed data, the 1-in-10-year seasonal low flow is estimated to be 1,537 cfs. The median June-October discharge is 2,970 cfs. For comparison, the previously estimated 1-in-20-year June-November discharge at Lake Coeur d'Alene was 1,500 cfs; the median flow for the June-November time period was 2,900 cfs (Patmont et al., 1985).

Correlation analyses between the Lake Coeur d'Alene seasonal discharge (independent variable) and other surface water and groundwater discharges influencing the flow of the Spokane River above Long Lake revealed that many of the hydrologic inputs and outputs exhibited a significant ($P<.05$) dependence upon the upstream boundary flow. Accordingly, regression statistics were used to estimate the magnitude and uncertainty of the correlated input-output flows for specified Lake Coeur d'Alene discharge conditions. If no significant correlation was observed, the predicted flows were based on the mean and standard deviation of discharges measured over the period of record. The results of these analyses were incorporated into the hydrologic modelling framework developed previously, in order to permit characterization of the range of seasonal discharge conditions between the 1-in-10-year low flow and median flow at Lake Coeur d'Alene. A summary of estimated flows throughout the Spokane River system is presented in Table 9.

Analysis of year-to-year variations in discharge throughout the entire project area revealed that most (ca. 90 percent) of the June-October flow variations at Long Lake Dam were due to fluctuations in the Lake Coeur d'Alene discharge (based on first-order methods). Although groundwater influences represented a substantial portion of the seasonal Spokane River water budget, particularly during low flow years, these groundwater flows did not exhibit a large variability (Table 9). Setting the phosphorus management design flow at the Lake Coeur d'Alene outlet, therefore, accounts for nearly all of the flow variability in the project area.

FIGURE 25

CUMULATIVE PROBABILITY DISTRIBUTION

JUN—OCT LK COEUR d'ALENE FLOWS, 1913—85

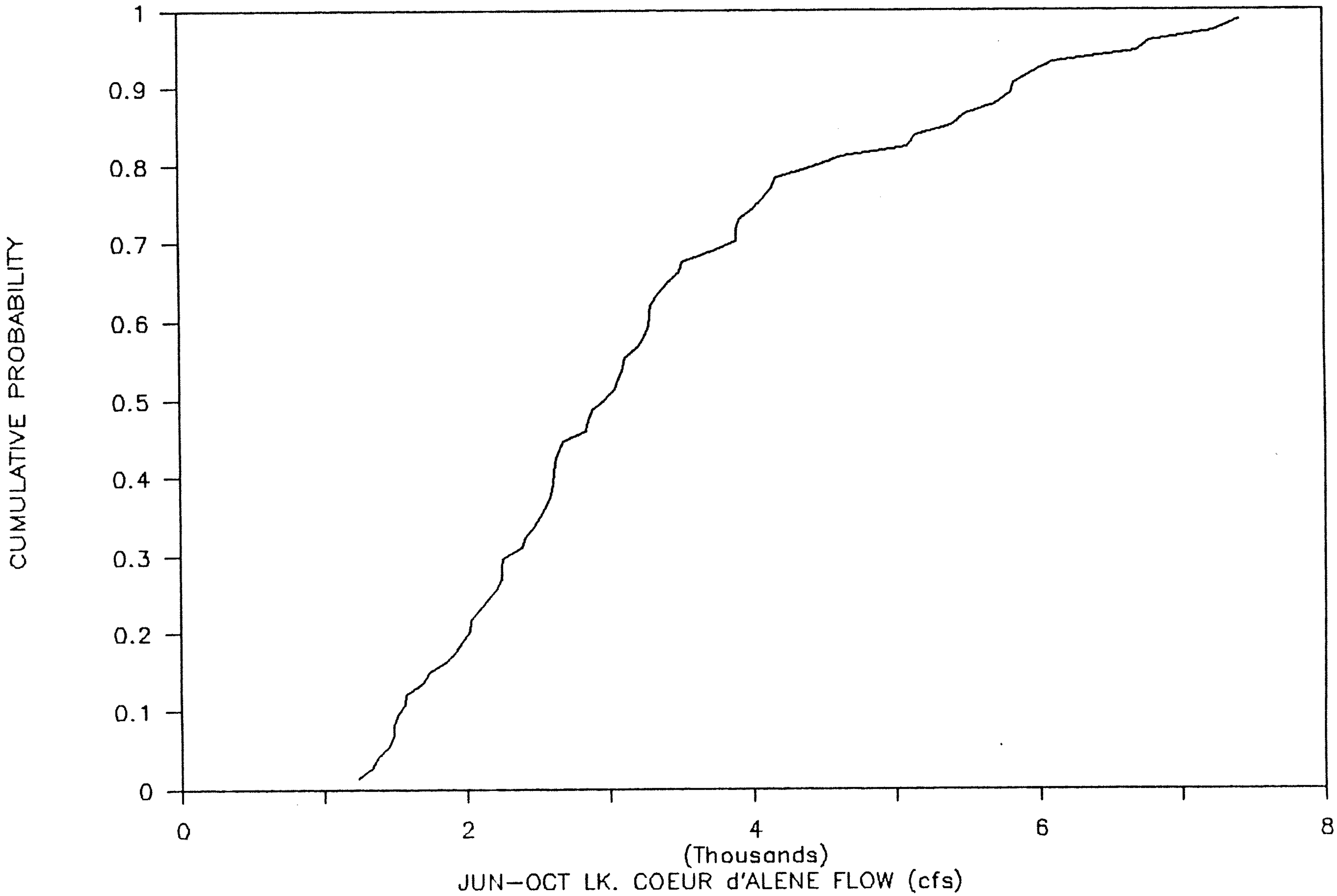


TABLE 9

SUMMARY OF SELECTED HYDROLOGIC CONDITIONS UTILIZED IN THE SPOKANE RIVER/LONG LAKE MODEL (EXCLUDING POINT SOURCES)

INPUT/OUTPUT LOCATION (RM)	JUN-OCT DISCHARGE (CFS): 1-IN-10-YEAR LOW FLOW MEAN +/- STD DEV	JUN-OCT DISCHARGE (CFS): MEDIAN CONDITION MEAN +/- STD DEV
Lake Coeur D'Alene (111.7)	1537	2970
Rathdrum Canal (106.6)	-32.1 +/- 4.8	-32.1 +/- 4.8
Seepage Loss (101.7-96.0)	-10.8 +/- 54.2	-55.7 +/- 54.2
Seepage Loss (96.0-93.6)	-4.5 +/- 22.8	-23.5 +/- 22.8
Aquifer Input (87.8-85.3)	363.0 +/- 121.8	432.0 +/- 121.8
Seepage Loss (82.6-79.8)	-256.2 +/- 65.0	-256.2 +/- 65.0
Aquifer Input (79.8-78.0)	425.3 +/- 144.9	506.1 +/- 144.9
Seepage Loss (78.0-74.1)	-179.7 +/- 84.0	-179.7 +/- 84.0
Aquifer Input (74.1-69.8)	154.8 +/- 44.8	172.8 +/- 44.8
Hangman Creek (72.4)	36.7 +/- 18.2	70.9 +/- 18.2
Aquifer Input (69.8-67.6)	42.8 +/- 23.0	42.8 +/- 23.0
Aquifer Input (67.6-64.6)	58.3 +/- 31.3	58.3 +/- 31.3
Aquifer Input (64.6-62.0)	50.5 +/- 27.2	50.5 +/- 27.2
Little SPokane River (56.3)	389.5 +/- 35.9	416.0 +/- 35.9
Local Long Lake Input (58.1-33.9)	23.3 +/- 67.1	23.3 +/- 67.1
Long Lake Precipitation	6.9 +/- 2.1	6.9 +/- 2.1
Long Lake Evaporation	-38.6 +/- 10.6	-38.6 +/- 10.6
Long Lake Storage Change	10.2 +/- 20.2	10.2 +/- 20.2

Nutrient Loading

Lake Coeur d' Alene

Phosphorus and nitrogen concentrations in the Lake Coeur d'Alene outflow were based upon samples collected during the June-October period of 1984 (Patmont et al. 1985). The average TP concentration in Lake Coeur d'Alene during the 1984 study (8.7 +/- 2.4 ug/L) is very similar to levels reported by other investigators (Yearsley, 1980; Seitz and Jones, 1981; Falter and Mitchell, 1982). The seasonal Coeur d'Alene discharge during all study periods ranged from approximately 2,000-4,000 cfs. Because the river is to be managed for 2,970 cfs (see below), which represents the median flow event at Lake Coeur d"Alene, available data are believed to be adequate.

Based on a constant TP concentration of 8.7 +/- 2.4 ug/L, the seasonal average loadings from Lake Couer d'Alene under the 1-in-10 year low flow and median flow conditions are as follows:

	TP Loading (kg/day) (mean +/- std.dev.)	
	10-year low flow event	Median Flow Event
Lake Couer d'Alene	32.6 +/- 3.0	63.1 +/- 5.9

Because the average seasonal Lake Coeur d'Alene outflow TP concentration of 8.7 ug/L is quiet low and indicative of oligotrophic (unproductive) conditions (OECD, 1982; see also Table 10 below), the phosphorus input to the Spokane River from this source is believed to approximate the natural condition.

Hangman Creek and Little Spokane River

Nutrient loadings from Hangman Creek and the Little Spokane River at their respective tributary input locations to the Spokane River were estimated using the instantaneous flow versus loading regression methodology described previously. Based on samples collected during the June-October months over the period of record (1971-1985), average loadings (and variances) appropriate to seasonal average discharge conditions were calculated from the regression statistics, and are summarized below:

	TP Loading (kg/day)(mean +/- std. dev.)	
	10-year low flow event*	Median Flow Event*
Hangman Creek	3.2 +/- 6.8	5.6 +/- 6.8
Little Spokane River	31.4 +/- 13.6	35.7 +/- 13.6

*Evaluated at Lake Coeur d'Alene

The flow-weighted seasonal TP concentration in both Hangman Creek and the Little Spokane River averaged approximately 32-35 ug/L. Because these values are somewhat greater than the average groundwater TP level of approximately 10-15 ug/L, (see below), it is probable that non-point surface sources of phosphorus (e.g. agriculture inputs), have contributed to the observed loading values. However, sufficient data are not presently available to reliably separate natural versus non-point phosphorus contributions to the Spokane River from these drainage areas.

Groundwater

Phosphorus and nitrogen concentrations in groundwater inputs to the Spokane River were based upon samples collected during the June-October period of 1984 (Patmont et. al., 1985; S. Miller, Spokane County, unpublished data). The total phosphorus loading from the six aquifer input reaches (see Table 9) is summarized below:

	TP Loading (kg/day) (mean +/- std. dev.)	
	10-year low flow event*	Median Flow Event*
Total Aquifer Input	32.2 +/- 7.5	37.0 +/- 7.9

*Evaluated at Lake Coeur d'Alene

Combined Sewer Overflows

Previous estimates of the average annual CSO discharge into the Spokane River were based on an assumption that the average capacity of the City of Spokane wastewater collection system was equal to twice the dry weather flow (Esvelt et al., 1972). Inputs to the collection system in excess of this capacity were assumed to overflow the system into the river. URS (1981) computed an average seasonal CSO discharge to the river by multiplying this annual overflow volume estimate by the fraction of annual precipitation which occurs during the season. Using this procedure, the estimated average June-October CSO discharge to the Spokane River was 1.4 cfs (0.04 m^3/sec). The uncertainty in this estimate was not reported but could be on the order of at least +/- 50 percent.

Because of the reported significance of existing CSO discharges to the river prior to CSO control activities (initiated in 1982; see below) and the large uncertainty of the present overflow estimate, it was deemed appropriate to confirm the CSO discharge estimate using an independent method. This was accomplished by taking the difference between the estimated stormwater flow influent to the wastewater collection system and the observed infiltration/inflow (I/I) discharge at the Spokane AWT facility. Influent flow was calculated using the following expression:

$$Q_{INF} = PPT * RO * AREA$$

where: PPT = incident June-October precipitation at the Spokane Airport (4.3 +/- 1.5 inches), RO = estimated runoff coefficient (0.70 +/- 0.10; Corps of Engineers, 1976), and AREA = impervious area in the CSO watershed area (5.2 +/- 1.8 square miles; URS, 1981). The average seasonal stormwater influent flow to the wastewater collection system was thus 2.7 +/- 1.0 cfs.

The seasonal I/I discharge at the Spokane treatment plant was based on a linear regression of daily precipitation (independent variable) and influent flow to the plant during the June-October months of 1978-1985. The regression equation (significant at P<.001) suggested that for every inch of incident precipitation, plant flow increased by an average of 23 +/- 2 million gallons, for a seasonal average I/I discharge of 1.2 +/- 0.2 cfs. No significant (P>.05) change in this I/I estimate was observed between earlier (1978-79) and later (1984-85) years.

The difference between the estimated influent flow to the collection system (2.7 +/- 1.0 cfs) and the observed I/I discharge (1.2 +/- 0.2 cfs) represents an apparent overflow discharge of 1.6 +/- 1.1 cfs. This average value is similar to the previous estimate of 1.4 cfs from URS (1981), and reinforces the validity of the assumed CSO discharge. The large variance term (CV = 70 percent) is believed to reflect the rather large year-to-year fluctuations in CSO discharge.

Although the Spokane AWT facility presently receives an estimated 1.2 +/- 0.2 cfs of I/I discharges during the June-October period, not all of this flow can be treated at the plant. Average influent flows above the plant capacity of 60 MGD, for example, are routed around the secondary treatment and phosphorus removal systems and are chlorinated prior to discharge (i.e primary treatment). These "excess flows" averaged 0.2 +/- 0.2 cfs during the 1978-85 seasonal period.

Chemical data for CSO's in the Spokane area are limited to eight observations of TP concentration during 1981-82 from two major overflow locations (City of Spokane, unpublished data). The average TP concentration in these samples was 3,180 +/- 550 ug/L. This average value is nearly identical to the mean TP concentration measured in primary effluent during eleven excess flow events at the treatment plant (3,120 +/- 140 ug/L).

Because of similarities in both the TP concentrations and discharge locations of CSO's and excess plant flows, these two sources were combined in the present Spokane River/Long Lake model. A single input location at RM 67.4 was assumed to represent the combined input, since 85 percent of CSO's discharge above this point and 15 percent below (Esvelt et al., 1972). The resultant average existing TP load of 13 +/- 9 kg/day (29 lbs P/day) from the combined input is similar in magnitude to many of the wastewater discharges along the river such as the Inland Empire Paper Co. (RM 82.6; Patmont et al., 1985).

In 1982, the City of Spokane initiated a large-scale program to separate stormwater inputs from the wastewater collection system and thus reduce the volume and frequency of CSO's and excess plant flows receiving only primary treatment. The present goal of the CSO control program is to achieve an 81 percent reduction in the CSO-contributing area by 1989 (P. Williams, City of Spokane, personal communication). For the purposes of this analysis, a similar 81 percent reduction in the combined CSO excess flow input was assumed for the future condition, with no change in chemical composition of the discharges. Both existing (i.e. pre-1982) and future (post-1989) conditions were programmed into the model, with selection specified during input.

Stormwater

Currently, an estimated 8.7 +/- 2.1 square miles of impervious area in the Spokane metropolitan area drain into the Spokane River via stormwater collection systems and river outfalls (Corps of Engineers, 1976; URS, 1981). Approximately two-thirds of this separated area is in the City of Spokane, with the remainder in the Spokane Valley east of the city. Stormwater discharges from the North Spokane area (1.3 +/- 0.8 square miles of impervious area) which drain into the Little Spokane River were not considered in this evaluation since existing inputs have been previously accounted for in the Little Spokane River loading estimate. Using the method previously described for calculating surface runoff quantities (i.e. PPT * RO * AREA), existing seasonal average stormwater discharges from separated areas of the City of Spokane and the Spokane Valley were estimated to be 2.9 +/- 1.1 cfs and 1.6 +/- 0.6 cfs, respectively. The Spokane Valley seasonal flow estimate--1.6 cfs-- may be somewhat high, due to the prevalence of dry well injection facilities for stormwater disposal (S. Miller, Spokane County, personal communication).

The average TP concentration in stormwater runoff in the Spokane metropolitan area was based on data reported by Miller (1984), who summarized chemical results by land use type. These data were weighted by reported land use activity in the contributing impervious areas--70 percent residential, 18 percent commercial, and 12 percent industrial--to obtain an overall average stormwater TP concentration of approximately 350 +/- 84 ug/L (S. Miller, Spokane County, personal communication). Based on these data, the existing seasonal average stormwater TP load from the City of Spokane and the Spokane Valley were computed to be 2.5 +/- 1.1 kg P/day (5.5 lbs. P/day) and 1.4 +/- 0.6 kg P/day, (3.1 lbs P/day), respectively. Future stormwater TP loading from the City of Spokane is estimated to increase to 4.4 +/- 1.7 kg P/day (9.7 lbs P/day), following completion of the CSO control project (assuming 81 percent of the CSO influent discharge is diverted directly to the river).

A summary of estimated total CSO and stormwater TP loadings to the Spokane River before and after the CSO control project is presented below:

	TP Loading (kg/day) (mean +/- std. dev.)	
	Existing	After CSO Control
CSO's and Excess Flows	13.0 +/- 9.5	2.5 +/- 4.1
Stormwater	3.9 +/- 1.3	5.8 +/- 1.8
TOTAL	16.9 +/- 9.6	8.3 +/- 4.4

Because no significant correlation (P>.05) between the seasonal Lake Coeur d'Alene discharge and Spokane precipitation was observed, CSO and stormwater loadings were not assumed to vary with the river discharge condition.

Based on the distribution of stormwater outfalls to the Spokane River, the Spokane Valley stormwater TP load was assumed to be represented by a single input location at RM 85.3 (URS, 1981). The City of Spokane input was assumed to occur at RM 67.4. Like the CSO inputs, the selection of existing or future (i.e. post-CSO control) conditions is specified during input in the Spokane River/Long Lake model.

Growth projections for the Spokane metropolitan area indicate that a considerable amount of new development is likely to occur within the Spokane Valley east of Spokane (Washington Department of Revenue, 1986). However, stormwater discharges associated with this new development may not result in a significant increase in P loading to the Spokane River since most new stormwater collection systems are expected to use dry well injection facilities for disposal (S. Miller, Spokane County, personal communication). Such injection systems have been shown to remove the majority of stormwater-derived contaminants from the water (Miller, 1984). Nevertheless, the "future" storm-water loadings incorporated in the existing model should be considered only as rough estimates of likely future conditions in the year 1990. These stormwater loading estimates should be periodically revised to reflect more current data and updated forecasts.

In addition to addressing permitted point sources and the non-point discharges discussed above, the present Spokane River/Long Lake model also incorporates minor inputs to Long Lake arising from local runoff and atmospheric deposition. The magnitude of these inputs was estimated based on the Long Lake nutrient budgets presented earlier in this report. Seasonal TP loading from local runoff averaged 1.3 +/- 0.6 kg P/day (2.9 lbs P/day); atmospheric TP loading averaged 0.4 +/- 0.2 kg P/day (0.9 lbs P/day).

Long Lake

The regression equations presented in the Long Lake: Trophic Status section of this report describe the relationships between the June-October flow-weighted influent TP concentration and a variety of pertinent water quality parameters in Long Lake. These parameters include the EZ-TP level, EZ-chl a concentration, EZ-phytoplankton biovolume, Secchi disc depth, and the minimum hypolimnetic D.O. concentration. Prediction of all of these trophic status parameters only requires information on the seasonal influent TP concentration to Long Lake and the outflow discharge.

The phosphorus attenuation model developed by Patmont et al. (1985)--with modifications as discussed above--provides an estimate of the seasonal discharge and flow-weighted TP concentration in the Spokane River at Nine Mile Dam (RM 58.1) based on variable loading scenarios. The uncertainty associated with a given seasonal average value is also estimated in the model. These data were then pooled with other identified external inputs to Long Lake (Little Spokane River, local runoff, atmospheric fallout) to provide an estimate of the mean and variance of the seasonal inflow and flow-weighted influent TP concentration entering the reservoir. Minor precipitation, evaporation, and typical storage change terms in the Long Lake water balance were also included to estimate lake outflow.

The regression equations which predict the various trophic state indicators were linked to the combined discharge and phosphorus influent data as the final output of the Spokane River/Long Lake model, since ultimately one or more of these in-lake water quality parameters shall define the permissible wasteload to the system (see next chapter). The uncertainty inherent to each prediction was calculated by propagating all identified measurement and modelling uncertainties throughout the entire model. In this way, the confidence in each prediction can be assessed.

TOTAL MAXIMUM DAILY PHOSPHORUS LOADING

Previous chapters have described a hydrologic and phosphorus transport model of the Spokane River which generates predictions of key water quality parameters in Long Lake. The uncertainty associated with these predictions was also addressed. The next task which must be completed prior to any wasteload allocation, therefore, is selection of an appropriate trophic-related water quality standard(s) for Long Lake. The section below describes the rationale for development of a water quality standard(s) for Long Lake, and examples of possible wasteload allocations relative to this standard are then presented.

Water Quality Criteria

The management goal for Long Lake defined in the 1979 court order which required the development of a wasteload allocation mechanism was to slow the eutrophication process within Long Lake (Spokane County, 1979). The undesirable eutrophic character of Long Lake prior to and shortly after the implementation of AWT at Spokane was recognized (e.g. *Anabaena* and *Microcystis* blooms), and achievement of a more desirable mesotrophic condition in Long Lake was set as a primary objective of wasteload allocation activities (Singleton, 1981; URS, 1981).

Trophic Status

Although trophic descriptions (e.g. eutrophic, mesotrophic) have no absolute meaning, they are generally used by many lake investigators and managers either to denote the nutrient "status" of a waterbody, or to describe the effects of nutrients on water quality conditions within that waterbody (OECD, 1982). Consequently, several attempts have been made to relate descriptive trophic terms to specific boundary values for key water quality parameters. The most rigorous attempt at such a classification scheme was presented by OECD (1982), based on a probabilistic evaluation of an extensive limnological data base collected from lakes and reservoirs throughout the northern temperate zone. An example of the resultant probability distribution of trophic status based on the most highly correlated parameter--in-lake TP--is presented in Figure 26.

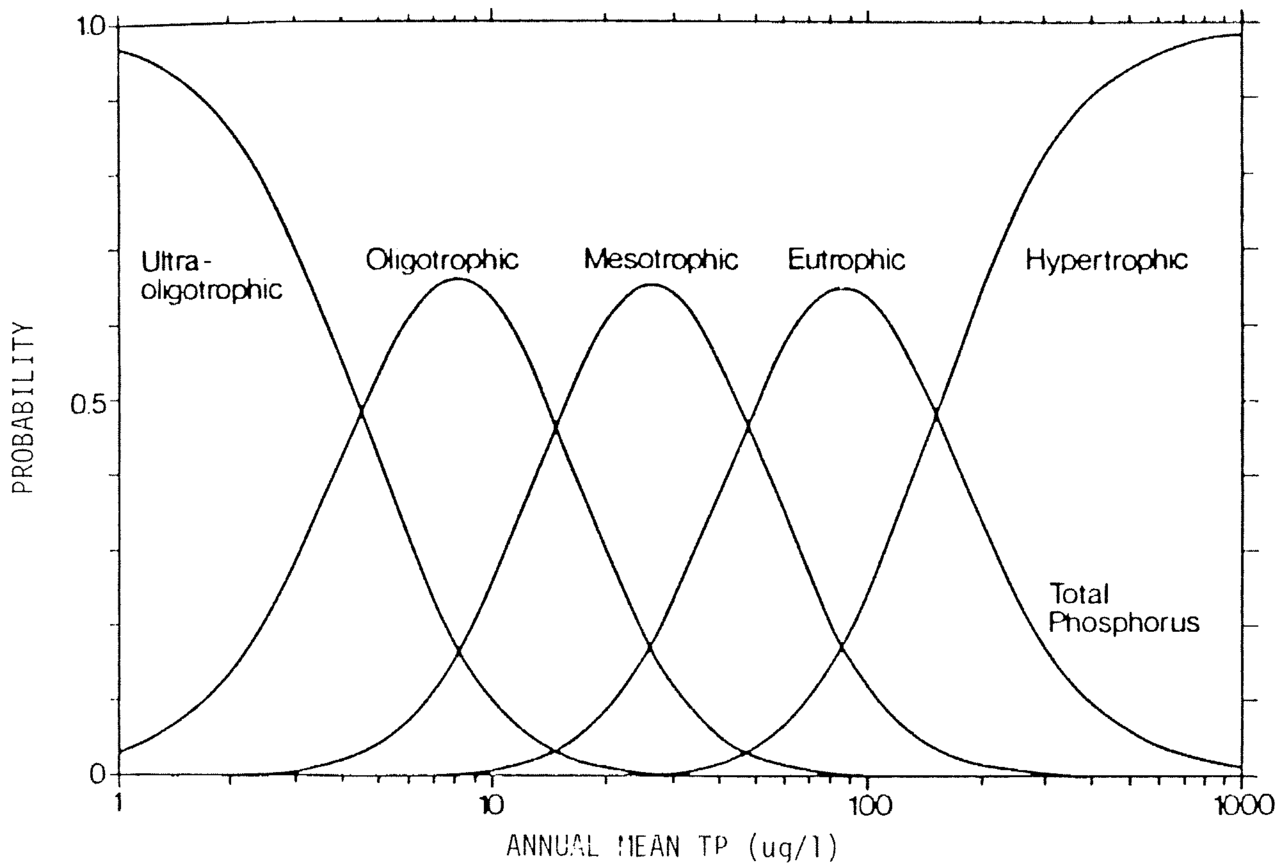


Figure 26

PROBABILITY DISTRIBUTION OF TROPHIC CATEGORIES RELATIVE TO AVERAGE PHOSPHORUS CONCENTRATIONS

Based on OECD (1982)

The overlap between trophic categories is substantial, and attests to the subjective nature of trophic classification schemes. A summary of OECD boundary values is presented in Table 10.

The OECD (1982) probabilistic criteria for determining trophic status considered only five water quality parameters: annual mean TP, TN, chl a and Secchi disc, and peak annual chl a (Table 10). Chl a concentrations were evaluated at the surface, all other values were whole-lake means. Of these parameters, only the peak chl a criterion is directly applicable to Long Lake, since the seasonal (June-October) condition specified for the management of Long Lake can not be readily compared with annual average conditions in other lakes.

Other investigators have utilized summer average concentrations of key water quality parameters to define trophic status, since the biological activity expressed in the trophic descriptions usually develops during growing season months. A recent summary of such boundary values was prepared by UNESCO (in press), and is presented in Table 10. These trophic criteria basically represent a synthesis of values which had been used previously (e.g. EPA, 1974; Wetzel, 1977; Welch, 1980; GDR, 1982). The seasonal trophic criteria are also more applicable to the Long Lake growing season condition.

With the boundary values listed in Table 10, the approximate water quality conditions which define a particular trophic category or transition zone between adjacent categories can be determined. As a practical management goal, OECD (1982) and UNESCO (in press) recommended that for water uses which do not require high purity conditions (e.g. drinking water), achievement of a mid-mesotrophic condition should generally provide adequate protection against impacts to important water uses as recreation and fisheries production. EPA (1986) reached a similar conclusion in recommending that in-lake TP concentrations less than 25 ug/L should generally protect against undesirable water quality conditions associated with eutrophy (compare with the Table 10 value of 27 ug/L).

TABLE 10

SUMMARY OF GENERALIZED OECD (1982) AND UNESCO (in press) BOUNDARY VALUES FOR PROBABILISTIC LAKE TROPHIC CLASSIFICATION

TROPHIC CLASSIFICATION	ANNUAL MEAN TP (ug/l)	SUMMER MEAN TP (ug/l)	ANNUAL MEAN CHLa (ug/l)	SUMMER MEAN CHLa (ug/l)	ANNUAL PEAK CHLa (ug/l)	SUMMER MEAN BIOVOLUME (mm3/l)	ANNUAL MEAN SECCHI (m)	SUMMER MEAN SECCHI (m)	ANNUAL MINIMUM D.O. (mg/l)
ULTRA-OLIGOTROPHIC THRESHOLD	4.5	-	1.0	-	-	-	14.	-	-
OLIGOTROPHIC (max. likelihood)	8.0	-	1.7	-	4.2	-	9.9	-	-
OLIGO-MESOTROPHIC THRESHOLD	14.	15.	3.2	3.	8.2	1.5	6.6	6	6.
MESOTROPHIC (max. likelihood)	27.	-	4.7	-	16.	-	4.2	-	-
MESO-EUTROPHIC THRESHOLD	48.	40.	7.1	10.	24.	5.	3.1	3	1.
EUTROPHIC (max. likelihood)	84.	-	14.	-	43.	-	2.4	-	-
EU-HYPERTROPHIC THRESHOLD	150.	300.	24.	40.	85.	20.	1.8	-	-
LONG LAKE EXISTING CONDITIONS JUNE-OCTOBER MEAN, 1981-85	-	23.	-	9.6	21.	2.3	-	3.5	4.2

Dissolved Oxygen

The trophic state criteria presented in Table 10 suggest that minimum hypolimnetic D.O. concentrations between 1-6 mg/L are typically associated with mesotrophic conditions. However, in order to provide for maximum protection and growth of aquatic life residing within these waters, D.O. levels should be maintained at levels considerably greater than this mesotrophic "boundary" range (Doudoroff and Shumway, 1967). Maximum production of both warm and cold water fish species may only occur at oxygen levels close to atmospheric saturation.

EPA (1986) has recently revised the ambient water quality criteria for D.O. concentrations which provide for the protection of aquatic life. The new criteria reflect the varying D.O. requirements of both coldwater and warmwater fish, depending upon such critical factors as the life stage and the ambient concentration/duration relationship. It should be noted that the EPA criteria do not necessarily represent a no-impact condition, but rather refer to a level of production impairment which that agency has found to be acceptable. The warmwater criteria applicable to Long Lake are summarized below (the Washington Department of Game classifies Long Lake as a spiny-ray fishery):

	D.O. Criterion (mg/L)	
Time Period	Early Life Stages	Other Life Stages
30 Day Mean	---	5.5
7 Day Mean	6.0	---
7 Day Mean Minimum	---	4.0
1 Day Minimum	5.0	3.0

The early life stages include all embryonic and larval stages and all juvenile forms to 30 days following hatching (EPA, 1986). Because such early life forms of fish presently inhabiting Long Lake are not expected to enter hypolimnetic waters during the critical summer stratification season (Scott and Crossman, 1973; Anderson and Soltero, 1984), the more appropriate criteria for Long Lake hypolimnetic waters fall under the "Other Life Stages" category. Based on these criteria, and considering that minimum D.O. concentrations in Long Lake were determined based on weekly or biweekly sampling, a reasonable criterion applicable to the predicted minimum volume-weighted hypolimnetic D.O. concentration would be approximately 4 mg/L. At this average volume-weighted hypolimnetic concentration (which represents approximately one-third of the volume of Long Lake), deeper waters may be nearly devoid of oxygen, although refuge areas with ample D.O. levels should be present within other areas of the hypolimnion (see Figure 8).

Water Quality Standard

Aside from the general provisions of Chapter 173-201 WAC which state that "Lake Class" waters must meet qualitative nuisance requirements, Ecology water quality standards applicable to Long Lake do not specify any numeric water quality parameter value or trophic category which should be maintained to prevent the occurrence of undesirable symptoms of accelerated eutrophication. The Lake Class D.O. standard, for example, requires that D.O. concentrations must not be degraded below natural conditions, a condition which is often difficult to define in a regulated riverine environment such as Long Lake. An enforceable eutrophication-related water quality standard(s) for Long Lake, however, is desirable if future wasteload allocation efforts throughout the project area are to be implemented.

The logical water quality parameter which should first be considered as a candidate for a Long Lake water quality standard is in-lake TP, since this variable is known to be most correlated with lake trophic status (OECD, 1982). The importance of phosphorus as the primary determinant of trophic conditions within Long Lake is also well supported by the available data (see Long Lake: Trophic Response section above). Cause-effect relationships between phosphorus supplies and both EZ algal growth and hypolimnetic oxygen depletion within the lake have been adequately demonstrated. In addition, EPA (1986) has suggested that in-lake TP is, in general, a good indicator of lake trophic conditions, and an approximate impact threshold value of 25 ug/L was recommended. The 25 ug/L value is similar to the mid-mesotrophic delineation (27 ug TP/L) suggested by OECD as a reasonable management goal (Table 10). In Long Lake, the June-October EZ-TP concentration, which represents the time- and area-weighted average within the algal growth environment, can also be modeled with the least amount of predictive uncertainty relative to the other key trophic status variables (e.g. chl a). It should be noted that recent (1981-1985) EZ-TP concentrations in Long Lake have averaged 23.0 +/- 4.8 ug/L, and have apparently been associated with acceptable lake quality conditions (R. Soltero, EWU, personal communication). River discharge during this five-year period has been somewhat greater than normal (see Figure 5 and Appendix D).

Based on the observed relationship between flow and EZ-TP concentration in Long Lake, an in-lake concentration of 25 ug/L would result from a flow-weighted influent-TP concentration of 24.9 +/- 3.9 ug/L. This influent value, in turn, can then be used to predict the average concentration of other key water quality parameters in Long Lake, in order to determine if the 25 ug/L EZ-TP value is consistent with related trophic status and water quality criteria. A summary of predicted water quality characteristics associated with the 25 ug/L TP criterion is summarized below:

Parameter (units)	Approximate Criteria (see Table 10 and page 96)	Predicted Value At EZ-TP = 25 ug/L (mean +/- std. dev.)
June-Oct. Mean EZ-Chl a (ug/L)	3-10	10.9 +/- 2.4
June-Oct. Peak EZ-Chl a (ug/L)	<16.	22.4 +/- 5.1
June-Oct. Median EZ-Biovolume (mm^3/L)	1.5-5.0	2.6 +/- 0.7
July-Oct. Median Secchi Disc (m)	3-6	3.3 +/- 0.4
Minimum Mean Hypolimnetic D.O. (mg/L):		
Median Flow	>4.0	3.3 +/- 1.3
1-in-10-year low flow	>4.0	2.4 +/- 1.0

These data suggest that both seasonal mean and peak EZ-chl a concentrations associated with the 25 ug/L TP value may exceed the general mesotrophic boundary values. However, biovolume and Secchi disc, which are also estimates of algal biomass, would be expected to fall within the mesotrophic range. Given that the predicted trophic state indicators are not significantly different ($P>.05$) from the mesotrophic criteria and, also, that many investigators pool the various trophic parameters to obtain a composite index of lake trophic status (e.g. Carlson, 1977), the 25 ug/L EZ-TP value appears to be a reasonable index of mesotrophic conditions within Long Lake.

The D.O. concentrations within Long Lake's hypolimnion are not likely to be maintained above the 4 mg/L suggested aquatic life criterion when TP concentrations approach 25 ug/L. Oxygen levels probably would be lowest during low flow years. These data suggest that some production impairment of the fisheries might occur at this TP level as a result of the relatively low D.O. concentrations, although fish mortality is considered unlikely (EPA, 1986). As discussed previously, Long Lake appears to be particularly susceptible to hypolimnetic oxygen depletion, probably due to warm hypolimnetic temperatures. However, the 25 ug/L TP value should still protect Long Lake from recurrence of critical anoxia (<0.5 mg/L) which was frequently observed in the lake prior to AWT (Table 7).

The 25 ug/L EZ-TP value does not include any "safety factor" component to reflect the uncertainty in trophic delineations and resultant water quality impacts. For example, at this TP concentration, there exists a nearly 20 percent probability that the lake would exhibit undesirable water quality characteristics associated with eutrophy (but also a similar probability of being oligotrophic; see Figure 26). In Long Lake, a 25 ug/L EZ-TP level may lead to some minor aquatic life impacts associated with low hypolimnetic D.O. levels, particularly during low flow years. Furthermore, the observation that a nuisance bloom of *Microcystis* occurred during 1978 with a predicted EZ-TP concentration of approximately 28 +/- 6 ug/L (based on influent TP data) attests to the potential trophic variability in Long Lake, particularly since the cause of this bloom could not be established. TP levels of 25 ug/L thus may not totally prevent such blooms from occurring. These potential trophic-related risks, however, are generally regarded as somewhat typical of the inherent variability of biological systems present in lake environments. The 25 ug/L EZ-TP value, therefore, represents an approximate threshold level above which the risk of adverse water quality effects becomes "unreasonably" great.

In this case, "reasonableness" has been defined by collective opinion of a variety of researchers (e.g. OECD, 1982) and also by EPA (1986).

The characteristic goal for Lake Class water is that "water quality of this class shall meet or exceed the requirements for all or substantially all uses" similar to Class A water (Chapter 173-201 WAC). In recognition of these water quality goals and the fact that a zero risk condition is simply not possible given the inherent variations in receiving water processes and analytical data, Ecology has the responsibility to define an "acceptable" level of protection for Long Lake. Based on these considerations, Ecology determined that the 25 ug/L seasonal mean EZ-TP value is an appropriate water quality standard for Long Lake, since it best represents mesotrophic conditions within the lake (L. Singleton, Ecology, personal communication). Ecology's determination was also based on a consideration of antidegradation policies (existing TP loads to the Spokane River result in median seasonal EZ-TP concentrations of 24.8 +/- 4.3 ug/L; see below). A TP standard will likely be adopted as a special condition under WAC 173-201-070.

The water quality standard is to be used to set the total maximum daily phosphorus load (TMDL) to Long Lake from all sources. The TMDL, in turn, may be a basis for setting future effluent loading limitations within the Spokane River basin. The TMDL determination, however, requires that a specific river flow condition applicable to the management of Long Lake be established, since the phosphorus load to the lake which will result in a 25 ug/L EZ-TP value varies proportionately with river discharge (see Long Lake: Nutrient Mass Balances section above).

River discharge conditions which have been considered in previous evaluations of the appropriate TMDL for Long Lake have ranged from the 1-in-20-year seasonal low flow to the median seasonal flow condition (Singleton, 1981; URS, 1981; Soltero et al., 1981-1986; Patmont et al., 1985; L. Singleton, Ecology, personal communication). Although the 1-in-20-year recurrence interval condition would offer the most protection from eutrophication in Long Lake, Ecology recognized that the choice of the appropriate design flow condition for phosphorus management would ultimately represent a judgement regarding environmental benefits and additional treatment costs. Within the existing management framework for Long Lake, environmental benefits are defined as a reduced probability that the lake would exhibit undesirable lake quality characteristics associated with eutrophy.

By combining the Spokane River/Long Lake model with the probabilistic lake classification scheme developed by OECD (1982) (i.e. Figure 26), the probability that Long Lake would be eutrophic under alternative design flow conditions can be estimated. This procedure is briefly described below.

First, the design flow event and EZ-TP standard determine the TMDL to Long Lake from all sources. The TMDL is then apportioned among existing point sources throughout the basin by allocating phosphorus loads on the basis of attenuation characteristics (i.e. equal impact per unit influent phosphorus load at each source; see "Allocation Scenarios" section below for a more detailed description of this strategy). With the point source loadings thus established to meet the 25 ug/L EZ-TP standard, the seasonal average EZ-TP concentration (and uncertainty) within Long Lake over the entire range of river flow conditions can be estimated from the model. Using first-order uncertainty analysis methods, the model output is then combined with the OECD (1982) probabilistic criteria to estimate the overall, long-term probability that Long Lake would be eutrophic. This procedure is consistent with the probabilistic lake classification methodology discussed by Reckhow (1979). Output from the model runs is summarized below:

	Design Flow Event		
	1-in-20-year Low Flow	1-in-10-year Low Flow	1-in-2-year Median Flow
Lk. Coeur d'Alene Flow (cfs)	1,428	1,537	2,970
Long Lake TP Load (kg/day):			
Existing (1985) Conditions	191	197	255
TMDL to Achieve 25 ug/L EZ-TP	154	163	259

	20-yr-Low Flow	10-yr-Low Flow	Median Flow
Oligotrophic	28%	28%	19%
Mesotropic	55%	55%	58%
Eutrophic	17%	17%	23%

The model results reveal that managing Long Lake for the 1-in-20-year or 1-in-10-year design flow conditions would result in a long-term, overall 17 percent probability that the lake would be eutrophic. Setting the TMDL based on the median flow event would increase this probability only slightly to an estimated 23 percent, even though the TMDL and allowable point source loadings are considerably greater under the median flow management condition. Much of the relative stability in Long Lake trophic characteristics suggested by these analyses appears to have been due to phosphorus attenuation processes in the river, which somewhat dampen the effects of changes in phosphorus loading to the Spokane River (Patmont et al., 1985).

The model output presented above also reveals that existing (1985) phosphorus loads to the Spokane River (based on effluent monitoring data; see below) will substantially exceed the TMDL if the design flow event was set at the 1-in-20-year or 1-in-10-year recurrence interval. Immediate phosphorus reductions would therefore be necessary if either of these flow conditions formed the basis for lake management activities. Existing (1985) loading to the river would be approximately equal to the TMDL if the median seasonal flow condition was used for design purposes.

In consideration of the potential environmental benefits and additional treatment costs associated with alternative design flow conditions, Ecology determined that the proposed 25 ug/L EZ-TP standard should be applied to the median flow event. The marginal benefits of reduced eutrophic probability in Long Lake were felt to be outweighed by the large treatment costs which would have resulted from either the 1-in-20-year or 1-in-10-year design flow conditions. The median TMDL for Long Lake from all sources was therefore set at have resulted from either the 1-in-20-year or 1-in-10-year design flow conditions. The median TMDL for Long Lake from all sources was therefore set at

259 +/- 43 kg P/day (571 lbs P/day), based on the hydrologic data presented in Table 9 and the existing total point source discharge of 58 cfs. In consideration of the 1979 court order (Spokane County, 1979), Ecology determined that the 259 kg/day TMDL represents the "total maximum daily load of phosphorus from all sources which can safely be assimilated into the system."

Example Allocation Scenarios

The Spokane River/Long Lake model was used to evaluate several example wasteload allocation strategies within the basin. Each scenario was compared with the proposed water quality standard and TMDL for median flows to Long Lake. The 1-in-10-year low flow condition is presented for comparison. Forthcoming management activities are expected to develop directly upon this modelling framework and TMDL, but may or may not be similar to the examples presented below.

The wasteload allocation examples presented herein only address the control of point source discharges. Although non-point sources of phosphorus occur within the Spokane River basin, the magnitude of such inputs is presently minor in comparison to point source discharges. For example, based on data presented previously, total existing non-point inputs are estimated at roughly 40 kg P/day. The ongoing Spokane CSO control project is estimated to reduce this non-point total by approximately 9 kg P/day. For comparison, the total point source load to the river is approximately 170 kg P/day (see below). Under existing NPDES permits, the point source input could increase to 380 kg P/day, representing 90-95 percent of the total cultural input. For these reasons, and also because the point source management framework is well established under the NPDES program, Ecology determined that point source controls should be the principal focus of initial wasteload allocation measures. Additional non-point controls may be evaluated further in the future.

Existing Conditions

The first management condition evaluated with the Spokane River/Long Lake model was the current point source loading regime. Flow data for each discharge were taken from June-October 1985 discharge monitoring reports available from Ecology and IDHW. Because most of the dischargers except the Spokane AWT have analyzed nutrient concentrations only infrequently (typically <1-4 per month), all data from June-October periods of 1984-85 were pooled to determine average effluent concentrations (Ecology and IDHW records; Patmont et al., 1985). Effluent concentrations at Spokane AWT were taken directly from 1985 plant records (City of Spokane, unpublished data). Point source data are summarized in Table 11. Current CSO and stormwater loadings, which do not reflect reductions due to the ongoing CSO control project, were assumed.

A summary of the model run is presented in Table 12. At current discharge levels, seasonal Long Lake EZ-TP concentrations are expected to average 24.8 +/- 4.3 ug/L during the median flow event. These values are equivalent to the proposed water quality standard of 25 ug/L. For comparison, the 1-in-10-year low flow prediction is 30.5 +/- 5.5 ug/L.

Data presented in Table 12 reveal that point sources presently contribute an estimated 51 percent of the total non-attenuated system load during the design condition, with the two largest inputs - Coeur d'Alene and Spokane - amounting to nearly 77 percent of the point source total. However, the relative impact of each point source discharge on Long Lake is influenced by its position within the river, since upstream sources are attenuated to a greater degree than downstream inputs (Patmont et al., 1985).

The magnitude of the varying attenuation response was evaluated using sensitivity analysis techniques (Chapra and Rechkow, 1983), and is summarized in Table 13 for the existing discharge/design flow event. These data reveal that the Spokane AWT discharge is the most significant point source presently (1985) contributing to the Long Lake EZ-TP concentration, and represents nearly 26 percent of the "effective" input during the median flow condition. This occurs in spite of the fact that the AWT plant presently removes nearly 89 percent of the TP from the influent wastewater (see Table 11). The Coeur d'Alene STP discharge is the next most significant point source, contributing approximately 14 percent of the "effective" input. All seven other point sources combined total approximately the same amount (12 percent).

TABLE 11

SUMMARY OF EXISTING POINT SOURCE LOADING IN THE SPOKANE RIVER

POINT SOURCE	RIVER MILE	1985 AVERAGE JUNE-OCTOBER DISCHARGE (MGD)	1987 PERMITTED DISCHARGE (MGD)	1984-85 AVERAGE JUNE-OCTOBER TP CONCENTRATION (ugP/l)		1984-85 AVERAGE PERCENT TP REMOVAL	ESTIMATED EFFLUENT TP LOADING (kgP/day)	
				INFLUENT	EFFLUENT		1985 LEVELS	PERMITTED LEVELS
Coeur d'Alene STP	111.0	2.216	6.000	8,430	7,375	12.5%	61.9	167.5
Hayden Lake Regional STP	106.6 E	0.000	0.750	N/A	6,738 E	-	0.0	19.1
Post Falls STP	101.6	0.116	1.500	N/A	6,100	-	2.7	34.6
Liberty Lake STP	92.7	0.261	1.000	6,948	6,701	3.5%	6.6	3.9 (23.6)!
Spokane Ind. Park WTP	87.1	0.460	0.750	2,784	2,320	16.7%	4.0	6.6
Kaiser WTP and Coolant	86.0	23.000	33.000	N/A	N/A	-	5.1	5.1 @
Inland Empire WTP	82.6	2.390	3.500	N/A	1,668	-	15.1	15.1 @
Millwood STP	82.3	0.018	0.015	N/A	4,875	-	0.3	0.3
Spokane AWT	67.4	31.632	44.000	5,052 #	568 #	88.8% #	68.0	126.2 (757.2)!
Northwest Terrace STP	64.3	0.178	0.000 *	N/A	9,048	-	6.1	0.0 *
							169.8	378.5 (1,029.1)!

LEGEND:

- E Denotes an estimated value.
- # Value based on 1985 data only.
- ! The existing discharge permits for both the Liberty Lake and Spokane plants require 85% TP removal at the permitted flow level. Numbers in parentheses refer to the estimated effluent TP load assuming only conventional secondary treatment (i.e. 10% TP removal).
- @ Based on the nature of the industrial processes at Kaiser and Inland Empire Paper Co., phosphorus loading from these facilities is not expected to increase with additional flows.
- * Wastewater in the present Northwest Terrace STP service area is to be connected to the Spokane AWT system in 1987.

TABLE 12

SUMMARY OF PHOSPHORUS LOADING CHARACTERISTICS
BASED ON THE SPOKANE RIVER/LONG LAKE MODEL

CONDITION: 1985 POINT SOURCE DISCHARGES
AND TP CONCENTRATIONS

SOURCE	1985 DISCHARGE (MGD)	TOTAL PHOSPHORUS LOADING (kg/day) 1-in-10-Year Low Flow Event	TOTAL PHOSPHORUS LOADING (kg/day) Median Flow Event	
Lake Coeur d'Alene Outlet		32.6	63.1	
Coeur d'Alene STP	2.2	61.9	61.9	
Hayden Lake Regional STP	0	0.0	0.0	
Post Falls STP	0.16	2.7	2.7	
Liberty Lake STP	0.26	6.6	6.6	
Spokane Ind. Park WTP	0.46	4.0	4.0	
Kaiser WTP and Coolant	23. (gross)	5.1	5.1	
Spokane Valley Stormwater		1.4	1.4	
Inland Empire WTP	2.4	15.1	15.1	
Millwood STP	0.02	0.3	0.3	
Total Aquifer Input		32.2	37.0	
Hangman Creek		3.2	5.6	
Spokane AWT	32.	68.0	68.0	
CSO's and Stormwater		15.5	15.5	
Northwest Terrace STP	0.18	6.1	6.1	
Little Spokane River		31.4	35.7	
Local Long Lake Inputs		1.7	1.7	
TOTAL LOADING		288.0	329.9	
TOTAL ATTENUATION		31.8%	22.6%	
ATTENUATED LONG LAKE INPUTS		196.5	255.3	(TMDL= 259 kg/day)
RESULTANT EZ-TP CONCENTRATION		30.5 +/- 5.5 ug/L	24.8 +/- 4.3 ug/L	(STANDARD= 25 ug/L)

TABLE 13

SUMMARY OF PHOSPHORUS ATTENUATION CHARACTERISTICS
UNDER EXISTING MEDIAN FLOW CONDITIONS

SOURCE	SOURCE TP LOADING (kg P/day)	SPOKANE RIVER TP ATTENUATION (%)	"EFFECTIVE" LONG LAKE TP LOADING (kg P/day)	PERCENT OF "EFFECTIVE" TOTAL
Lake Coeur d'Alene Outlet	63.1	41.9%	36.7	14.4%
Coeur d'Alene STP	61.9	41.9%	36.0	14.1%
Hayden Lake Regional STP	0.0	38.8%	0.0	0.0%
Post Falls STP	2.7	35.4%	1.7	0.7%
Liberty Lake STP	6.6	31.2%	4.6	1.8%
Spokane Ind. Park WTP	4.0	29.6%	2.8	1.1%
Kaiser WTP and Coolant	5.1	29.6%	3.6	1.4%
Spokane Valley Stormwater	1.4	28.1%	1.0	0.4%
Inland Empire WTP	15.1	26.3%	11.1	4.3%
Millwood STP	0.3	26.3%	0.3	0.1%
Total Aquifer Input	37.0	23.7%	28.2	11.1%
Hangman Creek	5.6	8.8%	5.1	2.0%
Spokane AWT	68.0	3.2%	65.8	25.8%
CSO's and Stormwater	15.5	3.2%	15.0	5.9%
Northwest Terrace STP	6.1	2.7%	5.9	2.3%
Little Spokane River	35.7	0.0%	35.7	14.0%
Local Long Lake Inputs	1.7	0.0%	1.7	0.7%
TOTAL LOADING	329.9			
TOTAL ATTENUATION		22.6%		
ATTENUATED LONG LAKE INPUTS			255.3	100.0%

Permitted Discharges

Many of the point sources which discharge into the Spokane River are operating at levels well below the limitation specified in their National Pollutant Discharge Elimination System (NPDES) permit. Because discharge at the NPDES permit level could occur within the near future at many of these plants, it was considered desirable to assess the combined impact of these higher flows on water quality conditions within Long Lake. Accordingly, the current (1987) permitted discharge from each facility was entered into the model (based on information furnished by Ecology and IDHW). It should be noted that the point source flow conditions assumed for this simulation of permitted discharges do not necessarily reflect a determination of reasonable future maximum flows from the facilities. Rather, these discharge levels simply reflect current (1987) NPDES permit conditions and are presented here only to illustrate a possible outcome of allowing point source phosphorus loadings to increase.

Effluent concentrations were assumed to equal existing levels or set equal to the permitted value where appropriate (i.e. 85% P removal at Spokane AWT and also at Liberty Lake STP/AWT when flows exceed 0.9 MGD). A representative TP value of 6,740 ug/L was applied to the future Hayden Lake flow, since this facility is not yet operational. Because the permitted discharge scenario represents a possible future (vs. existing) condition, CSO and stormwater conditions after completion of the control project (est. 1989) were assumed.

The model runs for permitted discharge conditions are presented in Table 14. During the median design flow event, EZ-TP concentrations may average 36.2 +/- 6.0 ug/L, which is above the proposed TP standard of 25 ug/L. Low-flow EZ-TP levels are estimated to be 43.4 +/- 7.5 ug/L. Clearly, some additional form of wasteload management would be required if the TP standard is to be met.

Uniform Phosphorus Treatment

For the purposes of this report, a hypothetical allocation scenario was evaluated which would require all permitted discharges to remove 85 percent of the influent phosphorus. In order to calculate representative influent TP

TABLE 14

SUMMARY OF PHOSPHORUS LOADING CHARACTERISTICS
BASED ON THE SPOKANE RIVER/LONG LAKE MODEL

CONDITION: FUTURE PERMITTED DISCHARGES

SOURCE	1987 PERMITTED DISCHARGE (MGD)	TOTAL PHOSPHORUS LOADING (kg/day) 1-in-10-Year Low Flow Event	Median Flow Event	
Lake Coeur d'Alene Outlet		32.6	63.1	
Coeur d'Alene STP	6.	167.5	167.5	
Hayden Lake Regional STP	0.75	19.1	19.1	
Post Falls STP	1.5	34.6	34.6	
Liberty Lake STP	1.	3.9	3.9	
Spokane Ind. Park WTP	0.75	6.6	6.6	
Kaiser WTP and Coolant	33. (gross)	5.1	5.1	
Spokane Valley Stormwater		1.4	1.4	
Inland Empire WTP	3.5	15.1	15.1	
Millwood STP	0.015	0.3	0.3	
Total Aquifer Input		32.2	37.0	
Hangman Creek		3.2	5.6	
Spokane AWT	44.	126.7	126.7	
CSO's and Stormwater		6.8	6.8	
Northwest Terrace STP	0.	0.0	0.0	
Little Spokane River		31.4	35.7	
Local Long Lake Inputs		1.7	1.7	
TOTAL LOADING		488.4	530.3	
TOTAL ATTENUATION		42.0%	29.3%	
ATTENUATED LONG LAKE INPUTS		283.2	375.2	(TMDL= 259 kg/day)
RESULTANT EZ-TP CONCENTRATION		43.4 +/- 7.5 ug/L	36.2 +/- 6.0 ug/L	(STANDARD= 25 ug/L)

concentrations for those facilities which have not routinely monitored influent wastewater quality, it was assumed that conventional secondary treatment presently removes 10 percent of the influent TP (see Table 11). All other aspects of this model run were similar to the "Permitted Discharge" condition discussed above (i.e. NPDES permit flows, future CSO conditions).

The results of this model run, which represents a vigorous management strategy, are summarized in Table 15. During the median flow design event, Long Lake EZ-TP concentrations are predicted to average 25.2 +/- 4.2 ug/L, which represents a 30 percent reduction relative to conditions without additional treatment requirements (see Table 14). The predicted value is similar to the proposed TP standard of 25 ug/L. Under low-flow conditions the predicted EZ-TP concentration is 32.3 +/- 5.6 ug/L.

Attenuation Based P Removal

An alternative to uniform phosphorus removal throughout the Spokane River basin would be to base the level of treatement required at each facility upon a constant water quality impact per unit of influent phosphorus loading. This strategy accounts for differences in attenuation characteristics throughout the river system, essentially giving each discharger credit for removal processes which occur within the river. The total system treatment (plant removal plus river attenuation) would be equivalent for all dischargers, resulting in greater in-plant treatment requirements at more downstream locations.

The major elements and assumptions of this strategy are listed below.

- The total phosphorus load from all sources to Long Lake during a median flow even was set equal to the recommended TMDL of 259 kg/day.

- Influent phosphorus loads to each wastewater treatment plant were based on 1987 permit flows and average 1984-85 influent TP concentrations. If sufficient data were not available to characterize influent TP, levels were estimated using effluent data and an assumed

TABLE 15

SUMMARY OF PHOSPHORUS LOADING CHARACTERISTICS
BASED ON THE SPOKANE RIVER/LONG LAKE MODEL

CONDITION: FUTURE PERMITTED DISCHARGES
w/ 85% P REMOVAL AT ALL POINT SOURCES

SOURCE	1987 PERMITTED DISCHARGE (MGD)	TOTAL PHOSPHORUS LOADING (kg/day) 1-in-10-Year Low Flow Event	Median Flow Event	
Lake Coeur d'Alene Outlet		32.6	63.1	
Coeur d'Alene STP	6.	28.7	28.7	
Hayden Lake Regional STP	0.75	3.2	3.2	
Post Falls STP	1.5	5.8	5.8	
Liberty Lake STP	1.	3.9	3.9	
Spokane Ind. Park WTP	0.75	1.2	1.2	
Kaiser WTP and Coolant	33. (gross)	0.8	0.8	
Spokane Valley Stormwater		1.4	1.4	
Inland Empire WTP	3.5	2.5	2.5	
Millwood STP	0.015	0.0	0.0	
Total Aquifer Input		32.2	37.0	
Hangman Creek		3.2	5.6	
Spokane AWT	44.	126.7	126.7	
CSO's and Stormwater		6.8	6.8	
Northwest Terrace STP	0.	0.0	0.0	
Little Spokane River		31.4	35.7	
Local Long Lake Inputs		1.7	1.7	
TOTAL LOADING		282.4	324.3	
TOTAL ATTENUATION		25.4%	19.7%	
ATTENUATED LONG LAKE INPUTS		210.6	260.4	(TMDL= 259 kg/day)
RESULTANT EZ-TP CONCENTRATION		32.3 +/- 5.6 ug/L	25.2 +/- 4.2 ug/L	(STANDARD= 25 ug/L)

P removal of 10 percent.

- Only point source loads were considered as variables in this phosphorus control strategy. CSO and stormwater loadings after completion of the control project were assumed.

- The fraction of the influent phosphorus load to each facility which can be discharged into the Spokane River was inversely proportional to the fraction of phosphorus transported through the river system (i.e. 1-attenuation fraction; see formulation below). This strategy basically results in a constant water quality impact to Long Lake from every kilogram of influent TP within the basin.

- River attenuation values for each location were not constant, but varied somewhat depending upon the river's phosphorus loading regime.

The methodology used to develop this allocation strategy can be represented by the expression:

$$PR_{(i)} = 100 \quad 1- \left[\frac{K}{TPTRANS_{(i,k)}} \right]$$

Where: $PR_{(i)}$ = phosphorus removal required at facility (i) (%);

K = The basin-wide fraction of phosphorus influent to each facility which can be transported to Long Lake (i.e. accounting for both in-plant removal and river attenuation) in order to achieve the EZ-TP standard (unitless);

$TPTRANS_{(i,k)}$ = the fraction of phosphorus discharged from facility (i) which is transported to Long Lake (i.e. 1-attenuation fraction) (unitless).

The expression was evaluated iteratively until the 25 ug/L EZ-TP standard was met during the median flow condition. All other aspects of this model run were similar to the uniform treatment scenario discussed above (i.e. permitted flows, future CSO's and estimated influent TP levels).

TABLE 16

SUMMARY OF PHOSPHORUS LOADING CHARACTERISTICS
BASED ON THE SPOKANE RIVER/LONG LAKE MODEL

CONDITION: FUTURE PERMITTED DISCHARGES
w/ ATTENUATION-BASED P ALLOCATION (see text)

SOURCE	1987 PERMITTED DISCHARGE (MGD)	REQUIRED PHOSPHORUS REMOVAL	TOTAL PHOSPHORUS LOADING (kg/day) 1-in-10-Year Low Flow Event	Median Flow Event	
Lake Coeur d'Alene Outlet			32.6	63.1	
Coeur d'Alene STP	6.	74.8%	48.2	48.2	
Hayden Lake Regional STP	0.75	77.1%	4.9	4.9	
Post Falls STP	1.5	79.2%	8.0	8.0	
Liberty Lake STP	1.	81.0%	5.0	5.0	
Spokane Ind. Park WTP	0.75	81.8%	1.4	1.4	
Kaiser WTP and Coolant	33. (gross)	81.8%	1.0	1.0	
Spokane Valley Stormwater			1.4	1.4	
Inland Empire WTP	3.5	82.7%	2.9	2.9	
Millwood STP	0.015	82.7%	0.1	0.1	
Total Aquifer Input			32.2	37.0	
Hangman Creek			3.2	5.6	
Spokane AWT	44.	86.8%	111.2	111.2	
CSO's and Stormwater			6.8	6.8	
Northwest Terrace STP	0.		0.0	0.0	
Little Spokane River			31.4	35.7	
Local Long Lake Inputs			1.7	1.7	
TOTAL LOADING			292.2	334.1	
TOTAL ATTENUATION			30.3%	22.5%	
ATTENUATED LONG LAKE INPUTS			203.8	258.9	(TMDL= 259 kg/day)
RESULTANT EZ-TP CONCENTRATION			31.2 +/- 5.4 ug/L	25.0 +/- 4.2 ug/L	(STANDARD= 25 ug/L)

Under either a uniform treatment or attenuation-based wasteload allocation strategy, it may be feasible for individual dischargers to purchase phosphorus loading credits from one another in exchange for additional treatment. In this way, smaller facilities could possibly waive treatment of their own effluent by arranging for another facility to provide treatment over and above their own permitted level. Under the attenuation-based wasteload allocation strategy, phosphorus loading credits may have to be discounted based on variations in attenuation characteristics (see Table 13).

The information presented above reveals that achievement of the proposed TP standard in Long Lake during the design flow condition will present a difficult management task as point source discharges increase. Major changes in existing treatment and/or disposal methods may become necessary in order to meet the TP goal for Long Lake. The models developed during this study provide powerful tools to evaluate the effectiveness of a variety of different control options, and ultimately to determine an appropriate allocation strategy.

Recommended Initiation/Termination Dates for P Removal

Under the current management framework established by Ecology, the "critical" growing season in Long Lake extends from June through October (URS, 1981; Soltero et al., 1981-86; L. Singleton, Ecology, personal communication). The TMDL to Long Lake is designed to maintain acceptable water quality conditions within the reservoir during this critical season, as discussed in the section above. The TMDL is then used as a basis for determining the percent TP removal required at facilities throughout the basin, at least for the duration of the June-October period.

In their evaluations of the efficacy of seasonal phosphorus removal within the Spokane River basin, URS (1981) pointed out that reductions in wastewater phosphorus levels may need to be initiated prior to June 1 to adequately protect Long Lake from eutrophication. A finite time interval between the initiation date of phosphorus removal and the beginning of the critical season, called the reduction period, appeared to be necessary to allow in-lake TP concentrations to reach acceptable levels by June 1. Based in part on the URS analyses, in 1981 Ecology revised Spokane's previous requirement for year-round AWT and permitted the plant to initiate seasonal phosphorus removal by April 1 and terminate AWT after October 31. Seasonal phosphorus removal has apparently provided a considerable cost savings to the City of Spokane.

Subsequent to the URS (1981) study, EWU developed methodologies for varying the initiation and termination dates for phosphorus removal at Spokane AWT, based primarily upon forecasted river flow conditions and a time-response modelling framework (Mires and Soltero, 1983; Mires et al. 1983). The EWU methodology for estimating the AWT initiation date differed somewhat from the previous URS approach, and was based on a reduction period sufficient to flush over 95 percent of pre-AWT effluent out of Long Lake by June 1. The termination date was based on maintaining in-lake TP concentrations of less than 25 ug/L through October 31. Although a number of conceptual and technical deficiencies in the EWU models were recognized (Singleton, 1984), Ecology accepted the variable initiation and termination date approaches in 1984. Application of the EWU methodologies presently allows Spokane to begin AWT in late April/early May during median flow years, and in early April during the 1-in-10-year low flow condition. The EWU methods generally permit phosphorus removal at Spokane AWT to terminate less than one week prior to the end of October under most flow conditions.

In order to assess whether the EWU initiation date methodology may generally be consistent with the proposed 25 ug/L TP standard, daily in-lake phosphorus concentrations during the spring months were simulated for three recent years which approximate the median flow condition (1980, 1983, and 1985; see Appendix D). Two low flow years (1973 and 1977) were also examined for comparative purposes. For each year, the daily Long Lake inflow from March through June was calculated from available USGS and WWP data based on a water budget analysis (see Long Lake: Hydrology section above). Typical flow variations are presented in Figure 27.

The AWT initiation date required for in-lake TP concentrations to reach 25 ug/L by June 1 during the three "median" flow years was estimated using a time-response modelling framework with a daily time step. The structure of the simulation model was basically equivalent to that described by URS (1981). Key assumptions of the model include:

- o Phosphorus is not attenuated or retained within the river system or Long Lake during the spring months;
- o Total point source loading prior to AWT was set equal to the 1986 permitted secondary treatment level of 1,029 kg/day (Table 11). P removal was evaluated using the attenuation-based scenario, for a total point source load of 183 kg/day (Table 16);
- o The flow-weighted tributary and groundwater TP concentration during spring was assumed to equal 10 ug/L, based on an analysis of available data (Yearsley, 1980; Seitz and Jones, 1981; Falter and Mitchell, 1982; Gibbons et al., 1984; Patmont et al., 1985; USGS, 1961-85).

Based on the simulation model results for 1980, 1983, and 1985, the required initiation date for P removal during median flow years may range from approximately May 14 to May 27. These dates are considerably later than the forecasted initiation dates of April 17 to May 7 using the EWU methodology (Mires and Soltero, 1983; Soltero et al., 1984-86). Apparently, the EWU initiation date forecasts may typically be conservatively early.

On the basis of the three "median" flow years examined, an initiation date for P removal during normal seasonal conditions could be set at approximately May 15. However, it does not appear desirable at this point to apply a fixed initiation date across all flow conditions. For example, if basin-wide AWT was not initiated until May 15 during the 1977 flow year (which approximates the 1-in-10-year low flow condition at Long Lake), EZ-TP levels on June 1 are predicted to exceed 55 ug/L (Figure 27). The risk of eutrophic conditions with such an elevated TP level are considerably greater than those suggested based on a steady-state analysis of phosphorus loads (see Table 16). The steady-state analysis, however, did not explicitly consider the reduction period necessary for the lake to reach equilibrium.

FIGURE 27a

SPRING VARIATIONS IN DISCHARGE

LONG LAKE INFLUENT: 1977 & 1980

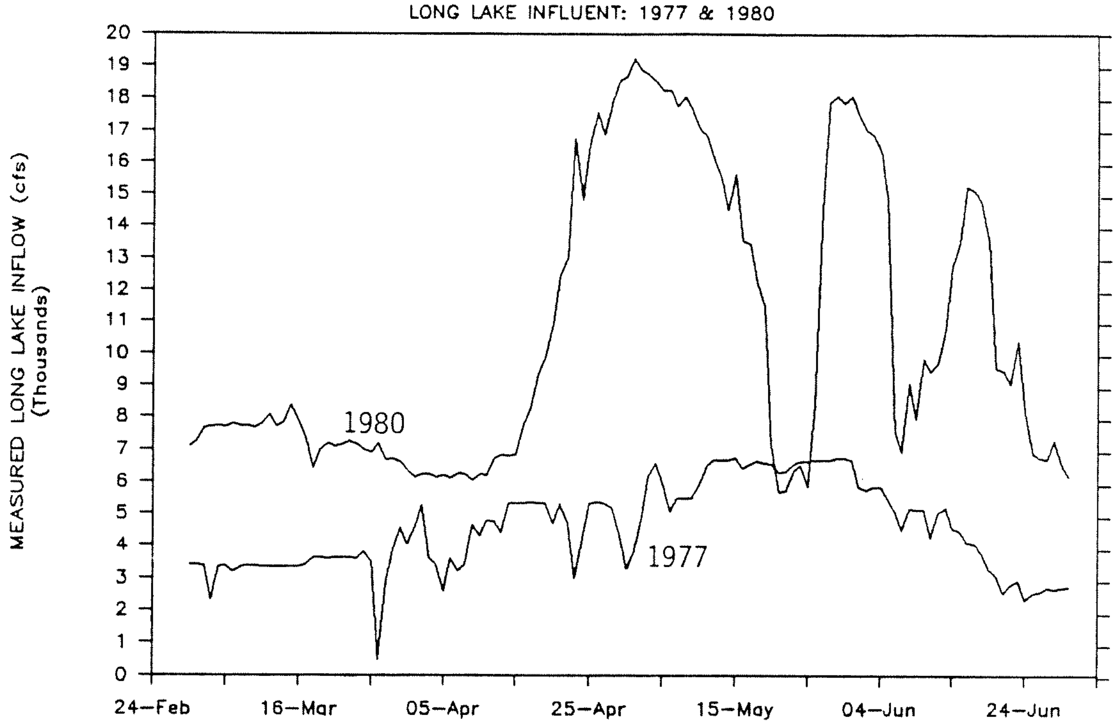
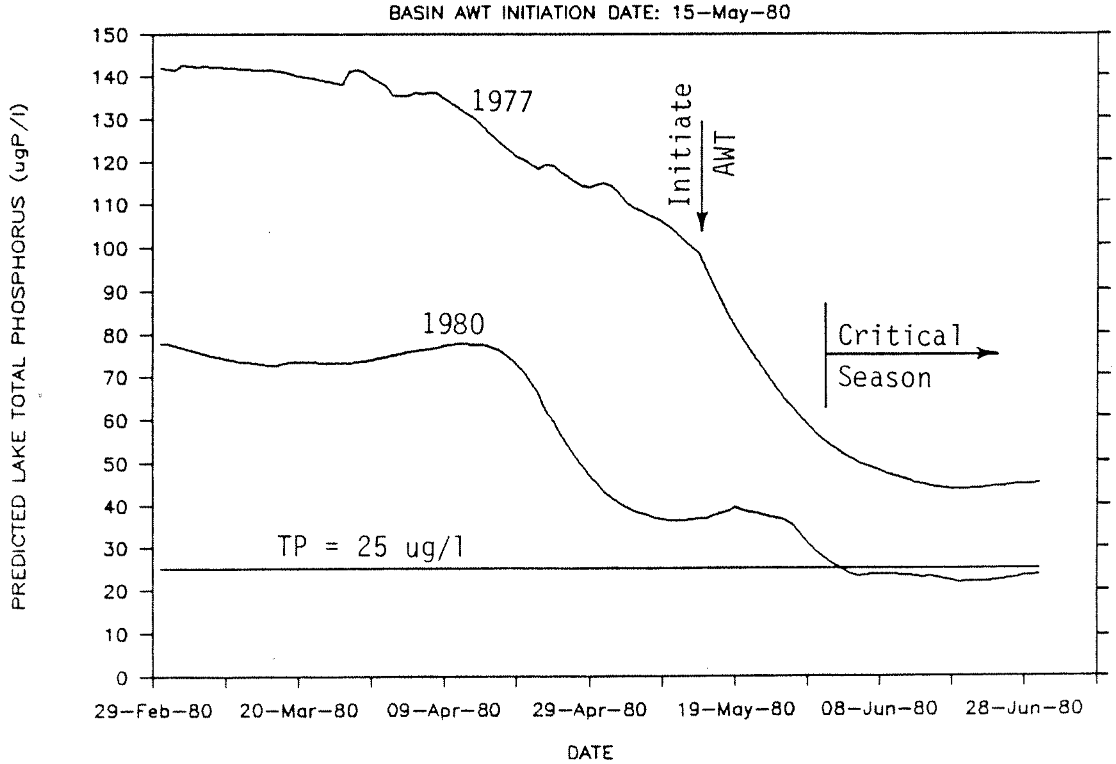


FIGURE 27b

PREDICTED IN-LAKE TP CONCENTRATION

BASIN AWT INITIATION DATE: 15-May-80



Output of the steady-state Spokane River/Long Lake model suggests that maintaining an EZ-TP concentration of 25 ug/L during the median flow condition may generally lead to average levels of approximately 31 ug/L during the 1-10-year low flow event (Table 16). Since the 1973 and 1977 flow years are generally representative (i.e. within 10 percent) of the 1-in-10-year seasonal low flow condition, a reasonable target concentration for June 1 during these years required initiation dates ranging from approximately March 1 to April 1. Again, these dates are later than forecasts using the EWU methodology (Singleton, 1984).

On the basis of the preceding discussion, we recommend that the initiation date methodology developed by EWU (Mires and Soltero, 1983) continue to be used as a basis for determining basin-wide AWT initiation dates. However, the EWU model, which appears to be somewhat conservative, could be refined to better reflect the current management framework for Long Lake. The refinement should include correlations of river flow forecasts (available from 1963 through the Soil Conservation Service) with initiation dates determined using actual daily flow measurements and time-response simulation models. The benefits of reduced treatment costs resulting from a seasonal removal methodology (versus a fixed initiation date of April 1) appear to exceed the costs of is implementation. Conversely, because the potential benefits of the existing variable termination date methodology appear to be only marginal, a fixed basin-wide termination date of October 31 for phosphorus removal is recommended.

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APPENDIX A

QUALITY ASSURANCE RESULTS:

PRECISION AND ACCURACY

APPENDIX A

QUALITY ASSURANCE RESULTS: PRECISION AND ACCURACY

A clear distinction should be made between the terms "precision" and "accuracy" as they are applied to quality assurance (QA) data for a given analytical determination. Precision refers to the reproducibility of a method when it is repeated on a homogenous sample under controlled conditions, regardless of whether or not the observed values deviate from the true value (APHA, 1985). Conversely, accuracy refers to the agreement between the average amount of a constituent measured in the determination and the amount actually present. A given method may be characterized by any combination of accuracy and precision.

As stated in the text of this report, a typical analytical quality assurance/ quality control program consists of three factors:

- o Use of methods which have been studied collaboratively and found acceptable (e.g. "Standard Methods");
- o Routine calibration, analysis of standard solutions, and evaluation of the precision of analytical duplicates (internal QA);
- o Periodic analysis of reference samples (external QA).

Of the three QA factors, only the first and third were specifically evaluated during this study. The second factor, internal QA, was omitted from consideration primarily due to the difficulty in obtaining these rather voluminous data from each laboratory. However, since explicit internal QA procedures are specified in analytical protocols, such procedures were generally assumed to be acceptable if the method was deemed appropriate.

Analytical precision can be estimated by determining the reproducibility of external QA reference sample analyses performed regularly over the conduct of these studies. Precision determined from these data incorporates the additional variability associated with calibration, standardization, and other analytical procedures which may vary over time. Since this temporal variation is not included in more typical assessments of precision, an evaluation of external QA results would generally result in an overestimate of the actual method variability (i.e. reduced precision) compared to that determined solely from internal QA data. In the context of the rather long-term data base developed for the Spokane River/Long Lake system, external QA-based precision is felt to be a more meaningful parameter to assess the laboratories' component of the observed data variability. External QA data also allows an assessment of accuracy and comparability between different laboratory results.

For the purposes of this study and to be consistent with other published studies of method precision and accuracy, all external QA data have been summarized to determine both the relative standard deviation (i.e. precision) and relative error (i.e. accuracy) of the methods utilized by each laboratory.

The relative standard deviation (or population coefficient of variation) is defined as the standard deviation of the difference between the true and reported values divided by the true value:

$$\text{Coefficient of Variation (CV; \%)} = 100 \times \left[\frac{\sum_{i=1}^{n} ((d_i/R_i)-\overline{(d/R)})^2}{n}\right]^{0.5}$$

where d_i = difference between measured and true values for reference sample i

R_i = reference concentration in sample i

$\overline{(d/R)}$ = average ratio of the difference (d) to reference (R) concentration

n = number of reference sample comparisons

The relative error (or bias) expresses the average difference between the measured and the actual values, also as a percentage of the mean:

$$\text{Bias (B; \%)} = \overline{(d/R)} * 100$$

Further, the random error associated with this bias can be computed as:

$$\text{Bias Error (BE; \%)} = CV/\sqrt{n-1}$$

Total Phosphorus

The available external QA data for total phosphorus (TP) determinations performed over the study period are presented in Table A-1. A statistical summary of these data using the above equations for low- and high-level EPA reference samples is presented below:

Laboratory	Method	Comparisons [n]	TP Level [$\overline{R}$(ug/L]	Overall Precision [CV]	Overall Accuracy [B+/-BE]
EWU-Biology	Pers.-Stannous	8	114.	9.7%	-9.3+/-3.7% *
		8	1,040.	10.7%	-14.3+/-4.0% *
	Subtotal	16		10.5%	-11.8+/-4.0% *
Ecology	Pers.-Ascorbic	4	114.	16.1%	16.8+/-9.3%
		8	1,770.	10.0%	-3.6+/-3.8%
	Subtotal	12		15.7%	3.2+/-4.7%
Spokane AWT	Pers.-Ascorbic	3	113.	22.5%	20.8+/-15.9%
		6	2,090.	6.8%	5.6+/- 3.0%
	Subtotal	9		15.8%	10.7+/- 5.6%

Because only two low- and two high-level external QA determinations of TP were available from WSU and EWU-Turnbull for the study period (i.e. corresponding to Gibbons et al., 1984, and Patmont et al., 1985, respectively), these data were not presented here. All of these reported TP values, however, were within

TABLE A-1

SUMMARY OF AVAILABLE QA DATA FOR TOTAL PHOSPHORUS DETERMINATIONS

DATE	TP CONCENTRATION (ugP/1) REFERENCE VALUE (EPA)	EWU	SPOKANE AWT	ECOLOGY
8/80	140	120		
8/80	59	49	90	80
8/80	1,060	786	1,250	1,050
1/81	930	690		
3/81	140	110	144	140
3/81	930	710	900	930
9/81	59	50		60
9/81	1,060	1,070	1,120	1,110
7/82	515			540
7/82	911			940
8/82	140	140		
8/82	930	820		
2/83	140	120	150	
2/83	1,040	810	1,030	
6/83	2,320		2,500	1,900
6/83	3,370			2,600
9/84	100	100		
9/84	1,370	1,330		
11/84	200			260
11/84	4,000			4,000
7/85	7,100		7,545	
11/85	130	140		
11/85	1,030	1,000		

SUMMARY OF AVAILABLE CHLOROPHYLL A QA DATA; EWU

DATE	SOURCE/CONTROL	CHLOROPHYLL A CONCENTRATION (ug/1) REFERENCE VALUE	MEASURED SPEC-20	MEASURED DU-8
Jul-81	NBS/EWU	750	573	851
Aug-81	EPA/WDOE	8,400	5,600	
Oct-81	EPA/WDOE	8,400	3,740	4,420
Jun-82	EPA/WDOE	8,110	5,280	7,410
Jul-82	EPA/WDOE	8,110	5,290	7,600
May-83	EPA/EWU	7,550	5,110	7,270
Nov-83	EPA/EWU	7,760	5,160	7,290
Jan-86	EPA/EWU	1,990		1,970
Jan-86	EPA/EWU	1,990		1,980
Jan-86	NBS/EWU	750	557	797
Feb-86	EPA/EWU	7,940		7,930
Feb-86	EPA/EWU	7,940		7,920
Feb-86	EPA/EWU	1,990		2,000
Feb-86	EPA/EWU	1,990		2,010

10 percent of the EPA reference concentrations and also well within EPA's "warning" and "acceptance" limits for the individual reference samples. Based on analytical duplicate data, the overall precision in the WSU TP determinations was estimated to range from 5-10 percent (H.L. Gibbons, KCM, personal communication). Similarly, the average coefficient of variation obtained from 134 analytical duplicates of Spokane River TP samples (mean TP = 23 ug/L) analyzed by EWU-Turnbull was 8.5 percent (Patmont et al., 1985).

The analyses of precision in the TP determinations reveal that most of the laboratories responsible for the existing Spokane River/Long Lake data base for this parameter were capable of reproducing a given TP analysis within approximately 5-15 percent. EWU-Biology, which generated by far the greatest amount of TP data, appeared to fall within the middle of the range of precision and exhibited an overall coefficient of variation of 10 percent. Generalized precision performance criteria reported by APHA (1985) and EPA for TP analyses (persulfate digestion/ascorbic acid method) typically range from 5-10 percent. Based on this comparison, therefore, the EWU-Biology TP analyses were apparently not characterized by excessive variability, even though the method used (stannous chloride) is generally less sensitive than the EPA-approved ascorbic acid procedure.

The random precision error discussed above can generally be compensated for by performing a large number of determinations over time. In effect, this was accomplished during the EWU-Biology investigations by performing more than 150 TP determinations at each major sampling location on the river system over the 13-year study period. The extensive sampling effort also minimized the effect of random sampling-related variability. During the P-attenuation study, for example, nearly 80 percent of the total variance in repetitive sampling of TP in the Spokane River was attributable to sampling-related variability (Patmont et al., 1985). This sampling-related variance corresponded to a coefficient of variation of approximately 16 percent (based on 788 sampling replicates). A similar amount of variability was attributed to longer-term temporal changes in the seasonal river TP concentration. Overall, only a minor percentage (<10%) of the total sample variance appeared to be due to laboratory precision errors. A similar condition of comparatively minor precision errors likely applied to the EWU-Biology TP data as well.

The accuracy and comparability of TP determinations performed by various laboratories was assessed with the external QA data. A Wilcoxan signed-ranks test was used to evaluate whether a significant bias existed between the reported concentrations and the EPA reference values (Sokal and Rohlf, 1969). The initial evaluation detected a significant ($P<.01$) negative bias in the EWU-Biology TP determinations but not in the reactive phosphorus analyses. None of the other laboratories exhibited a significant ($P>.05$) bias and were therefore assumed to have generated TP data comparable to the EPA reference.

Because the observed negative bias in the EWU-Biology TP determinations contrasts with results for reactive P, it is likely that the bias was caused by sample loss during the persulfate digestion procedure, possibly due to a malfunctioning autoclave (R.A. Soltero, EWU, personal communication). In any event, the negative TP bias was quite consistent both over time (1980-1985) and across a wide concentration range (see TP QA summary above). Linear regression analyses verified that TP levels were underestimated by a constant percentage, since the regression constant (i.e. y-intercept) was not statistically significant (P>.5), while the regression coefficient (i.e. slope) was significantly (P<.02) different from unity. Since no change in analytical TP methods or the degree of bias was apparent over the study period, it was assumed that a constant correction could be applied across all EWU-Biology TP data. Based on these data, the average ratio of reference/reported TP concentrations formed the basis for the bias correction:

Reference TP = 1.15 * Reported TP

In effect, the external QA determinations were used to perform an *a posteriori* standardization of the EWU-Biology TP data. The standard error of this correction, based on the 16 available external QA determinations, is equivalent to 3.0 percent of the corrected concentration. A random error of +/- 3.0 percent resulting from bias correction is well within the 5-10 percent generalized performance criteria for TP analyses, and is not considered excessive.

Chlorophyll *a*

The available external QA data for chlorophyll *a* (chl *a*) determinations performed by EWU-Biology over the study period are presented in Table A-1. Since nearly all of the chl *a* data utilized in this report were analyzed by EWU-Biology, external QA evaluations were limited to include only this facility. A statistical summary of the available external QA data for the various methodologies employed by EWU-Biology is presented below.

Method	Years	Comparisons [n]	Overall Precision [CV]	Overall Accuracy [B+/-BE]
Spectronic-20	1981-86	8	9.0%	-34.2+/-3.4%
DU-8	1981-83	6	18.3%	- 9.8+/-8.2%
DU-8	1986	7	2.3%	0.8+/-0.9%

These data suggest that the overall precision of the chl *a* analysis appeared to vary with the method and date, and averaged approximately 10 percent over the entire study period. Although published values for the general precision of the chl *a* analysis vary widely, the observed average value of 10 percent for the EWU-Biology determinations is within the range of generally accepted performance criteria for this analysis.

The external QA data presented above reveal a considerable negative bias in EWU-Biology chl *a* determinations performed with a Spectronic-20 instrument. The bias is believed to be the result of the wide band width of the instrument (20 nm), which cannot resolve the narrow absorbance peak of chl *a*. Wilcoxan signed-ranks analyses indicated that this bias was statistically significant (P<.02). Chl *a* data determined with a DU-8 instrument (band width - 0.5 nm) over the period 1981-1983 exhibited a reduced but still significant (P<.05) negative bias, possibly as a result of photodegradation during analysis (R.A. Soltero, EWU, personal communication). No bias in 1986 chl *a* determinations were detected.

Although the previous chl a data could be simply "standardized" using the external QA data (similar to that performed for TP analyses), internal QA information pertaining to the EWU-Biology chl a analyses suggest that such a simple correction may be inappropriate. Based on 179 chl a samples which were run simultaneously using the DU-8 and Spectronic-20 instruments over the period 1981-1984, the relationship between chl a values determined using the two methods does not appear to have been constant. Linear regression analyses, for example, suggested that both the regression coefficient and constant were statistically significant (P>.05), and indicated that the Spectronic-20 negative bias may have been more severe at lower chl a levels. Based on a synthesis of all available internal and external QA data using linear regression methods, the following formulation for bias correction of the Spectronic-20 data was obtained:

Reference chl a (ug/L) = 0.98 + 1.39 * Reported Spec.-20 chl a (ug/L)

The standard error associated with this bias correction is equivalent to 14 percent of the corrected concentration at the average level measured in Long Lake (15 ug/L).

As discussed above, beginning in 1981 most (though not all) chl a extracts quantified using EWU-Biology's Spectronic-20 were also analyzed concurrently using a Beckman DU-8. Bias correction of chl a determinations performed with the use of the DU-8 for years prior to 1985 (representing 179 lake samples), were based on the average ratio of reference/reported concentrations:

Reference chl a = 1.11 * Reported DU-8 chl a

The standard error of this bias correction is equivalent to 9.1 percent of the corrected chl a concentration. In instances where both Spectronic-20 and DU-8 data were available for the same lake sample (parts of 1981, 1982, and 1984), the DU-8 (corrected) results were utilized preferentially since both the magnitude and uncertainty of the DU-8 correction was lower.

In 1985, the EWU-Biology DU-8 methodology was improved. External QA information revealed that the new method yielded data comparable to the EPA reference values. No correction of the 1985 chl a data was therefore necessary.

APPENDIX B

EXAMPLE UNCERTAINTY CALCULATION

APPENDIX B

EXAMPLE UNCERTAINTY CALCULATION

The information value contained within a given estimated or predicted quantity is only as good as the confidence bounds which surround that estimate. Since the water quality models developed in this study are based upon discharge and chemical measurements, and also upon hypothesized relationships between measured parameters, a variety of potential measurement and modelling errors can contribute to the total prediction uncertainty. Quantification and propagation of the uncertainty common to each term in the model is necessary in order to determine the degree of confidence which can be placed on the prediction.

Statistical techniques which describe the effects of contributing uncertainties are broadly categorized as error propagation methods. For this report, we have utilized a first-order uncertainty methodology consistent with that used in the previous phosphorus attenuation study (Patmont et al., 1985). The theory and application of first-order uncertainty analysis techniques have been described by Cornell (1973), and Lettenmaier and Richey (1979). Briefly, the technique is based upon the assumption that parameter variations can be propagated about the first derivative (i.e. first order) of a function relative to those variables which make up the function. In general, for any calculated quantity Y which is derived from measured parameters denoted by X,

$$Y = f(X_1,\ X_2, \ldots\ldots, X_n),$$

the first-order variance of Y can be represented as:

$$\mathrm{Var}\ (Y) = \sum_{i=1}^{n} \left(\frac{\partial Y}{\partial X_i}\right)^2 \ \mathrm{Var}\ (X_i)$$

The quantity $\frac{\partial Y}{\partial X_i}$ describes the first-order relationship between the calculated value and each measured parameter which describes the function. The equation above is only valid when the variances of each measure parameter (i.e. X_i) are independent, and it is therefore necessary to reduce each function to a form which includes only independently measured parameters.

In order to provide a better understanding of the uncertainty analysis methods utilized in this study, a relatively simple example uncertainty propagation sequence is presented. The example calculation refers to the estimated 1984 seasonal (June-October) total phosphorus (TP) load at Nine Mile Dam, since this calculation includes an assortment of hydrologic, sampling, quality assurance (QA) and modelling uncertainties. More complicated first-order uncertainty calculations used in this study utilized the same basic principles presented below, but involved more complex calculus.

The first element of the example loading calculation was the estimation of the seasonal average discharge at Nine Mile Dam. Based on published discharge records and uncertainties (Patmont et al., 1985, USGS, 1985) and other estimations as described in this report, the following seasonal summary was produced.

Spokane to Nine Mile Dam
1984 Seasonal Discharge (cfs)

Spokane River at Spokane	4,728 +/- 118
Hangman Creek	61 +/- 5
Spokane AWT	48 +/- 2
Groundwater	256 +/- 170
Spokane River at Nine Mile	5,094 +/- 207

The groundwater discharge from the City of Spokane to Nine Mile Dam was calculated based on the assumption that 90 percent (std. deviation = 10%) of the entire water balance residual between the City of Spokane and the Long Lake Dam enters the river above Nine Mile Dam. Uncertainties in all terms of the water balance (e.g. Spokane discharge, evaporation, etc.) were propagated by summing component variances. Based on this procedure, the estimated Spokane to Long Lake residual for the 1984 seasonal period was 285 +/- 186 cfs.

The algebraic function which describes the groundwater residual between Spokane and Nine Mile Dam may be written as:

$$Y_1 = X_1 \cdot X_2$$

where

Y_1 = Groundwater residual from Spokane to Nine Mile Dam

X_1 = Fraction of total residual above Nine Mile Dam = 0.90

X_2 = Groundwater residual from Spokane to Long Lake Dam = 285 cfs

The first derivitatives of the Nine Mile Dam residual with respect to each component are therefore:

$$\frac{\partial Y_1}{\partial X_1} = X_2$$

$$\frac{\partial Y_1}{\partial X_2} = X_1$$

Therefore, the first order error propagation formula to compute the variance of the ground water residual from Spokane to Nine Mile Dam (Var (Y)) is stated as:

$$\mathrm{Var}\ (Y_1) = \left(\frac{\partial Y_1}{\partial X_1}\right)^2 \mathrm{Var}\ (X_1) + \left(\frac{\partial Y_1}{\partial X_2}\right)^2 \mathrm{Var}\ (X_2)$$

$$= X_2{}^2\ \mathrm{Var}\ (X_1) + X_1{}^2\ \mathrm{Var}\ (X_2)$$

Since:

Variance of $X_1 = 0.10^2$

$$\text{Variance of } X_2 = 186^2 \text{ cfs}^2$$

$$\text{Var }(Y_1) = (285)^2 (0.10)^2 + (0.9)^2 (186)^2 = 28{,}835 \text{ cfs}^2$$

which corresponds to a standard deviation of 170 cfs. The groundwater input between the City of Spokane and Nine Mile Dam was therefore estimated at 256 +/- 170 cfs.

By adding the individual discharge terms together and summing component variances, the 1984 seasonal discharge at Nine Mile Dam was estimated at 5,094 +/- 207 cfs.

During the June-October period of 1984, a total of 19 samples collected from the Spokane River immediately downstream of Nine Mile Dam were analyzed for TP. Most of the chemical analyses were performed by EWU. The original EWU analyses were multiplied by 1.15 in accordance with the results of external QA data. The uncertainty in this QA correction (+/- 3.0% of the corrected concentration) will be discussed below.

The average daily discharge at Nine Mile Dam which corresponded to each sampling event was estimated as the sum of daily flows at the Spokane River at Spokane, Hangman Creek and Spokane AWT and computed monthly average groundwater flows. The product of these estimated daily flows and measured TP concentrations were then used to derive instantaneous estimates of TP loading at Nine Mile Dam.

A linear regression methodology was used to determine the random variation in instantaneous loading values which could not be attributed to changes in river flow. A summary of confidence and prediction limits of the regression is presented in Figure B-1. Based on the regression statistics, the average seasonal TP loading at Nine Mile Dam at a discharge of 5,094 cfs was estimated to be 290 kg/day. The regression standard error of this estimate (which does not yet include QA and discharge uncertainties) was +/- 15 kg/day. When the 3.0 percent uncertainty in the QA correction to the EWU data was added, the standard error increased slightly to +/- 17 kg/day.

The additional variance in the TP loading estimate which was due to discharge uncertainties was approximated as follows. The total load may be expressed as:

$$Y_2 = A\ X_3 + B$$

where:

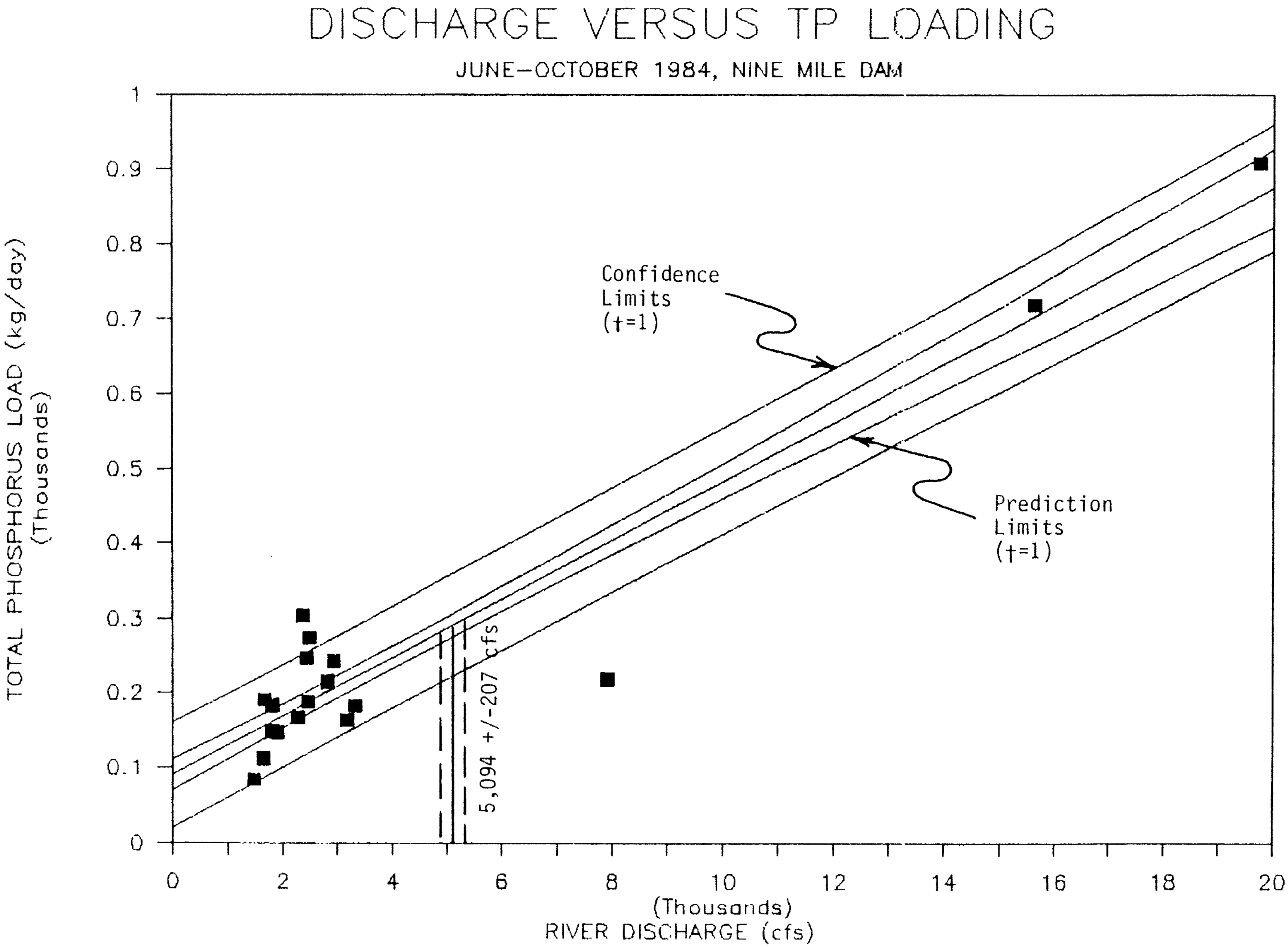
Y_2 = Nine Mile Dam TP load (kg/day)

A = Linear regression coefficient (0.0392 kg/day/cfs)

X_3 = Total flow of Spokane River at Nine Mile Dam (5,094 cfs)

B = Linear regression constant (90.5 kg/day)

Figure B-1



DISCHARGE VERSUS TP LOADING
JUNE—OCTOBER 1984, NINE MILE DAM
TOTAL PHOSPHORUS LOAD (kg/day)
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Confidence
Limits
(t=1)
Prediction
Limits
(t=1)
5,094 +/-207 cfs
0
2
4
6
8
10
12
14
16
18
20
(Thousands)
RIVER DISCHARGE (cfs)

The first derivative of Nine Mile Dam TP load with respect to discharge is therefore:

$$\frac{Y_2}{X_3} = A$$

The additional variance in the TP load due to discharge uncertainties is thus:

$$\text{Var } (Y_2) = A^2 \text{ Var } (X_3)$$

Since Variance of $X_3 = 207^2 \text{ cfs}^2$

$$\text{Var } (Y_2) = (0.0392)^2 \ (207)^2 = 65.8 \ (\text{kg/d})^2$$

which corresponds to a standard deviation of 8 kg/d. Therefore the total uncertainty in TP loading at Nine Mile Dam, including regression error, QA error and discharge error, may be expressed as a standard deviation of:

$$[(17)^2 + (8)^2]^{0.5} = +/- \ 19 \text{ kg/day.}$$

APPENDIX C

HYDRODYNAMICS

APPENDIX C

HYDRODYNAMICS

In an effort to determine the degree of mixing which occurs between inflows and epilimnetic waters of Long Lake during the June-October period, mass balances of conductance in the euphotic zone (EZ) and hypolimnion were performed. The mass balances were attempted to explain the seasonal increase in conductance which occurs within these and other regions of Long Lake (Figures C-1 abd C-2), since such an increase could only occur as a result of mixing with higher conductance inflow waters. The mass balance can be approximated as follows:

$$Q_{EZ} = \frac{V_{EZ} * \quad C_{EZ}}{t * (C_{IN} - C_{EZ})}$$

where: Q_{EZ} = discharge of river water into the EZ
V_{EZ} = volume of the EZ
C_{EZ} = change in EZ conductance over t
t = time period between successive samplings
C_{IN} = average inflow conductance over t
C_{EZ} = average EZ conductance over t

All terms on the right side of the above equation were measured. The discharge of river water into the EZ (i.e. Q_{EZ}) was calculated for each period between successive sampling trips. This value was then compared to the actual river flow measured for the period (primarily Nine Mile + LSR) to determine that fraction of the inflow which entered the EZ.

For the 13-year period of Long Lake record (1972-1985, excluding 1976), a median of 61 percent (normal range: 30-100 percent) of the river inflow was calculated to have entered the EZ during the June-October stratification period. Although several assumptions inherent to the mass balance model may be overly simplistic in the case of Long Lake (e.g. the EZ is rarely a discrete "box"), the conclusion nevertheless remains that a considerable proportion of the river inflow typically mixed into the EZ. Turbulence induced by the river flow as it entered the reservoir or by meteorologic forcing may have been the cause(s) of such mixing. Other more sophisticated modelling techniques which describe the dispersion process may provide a better characterization of mixing processes in Long Lake (Chapra and Reckhow, 1983), but were not considered necessary for this study.

The mass balance described above also provides an estimate of the normal water residence time within the euphotic zone (i.e. V_{EZ}/Q_{EZ}) during the June-October period. The median value obtained for the period of record was 40 days, with most of the calculated residence times ranging between 20-80 days. The calculations presented above suggest that the Long Lake euphotic zone could be characterized as being moderately well flushed with inflow waters throughout the June-October growing season. Changes in nutrient concentrations in the inflow would, therefore, be expected to result in similar changes within the lake's EZ.

FIGURE C-1

EUPHOTIC ZONE CONDUCTANCE VARIATIONS

LONG LAKE, 1972–1985

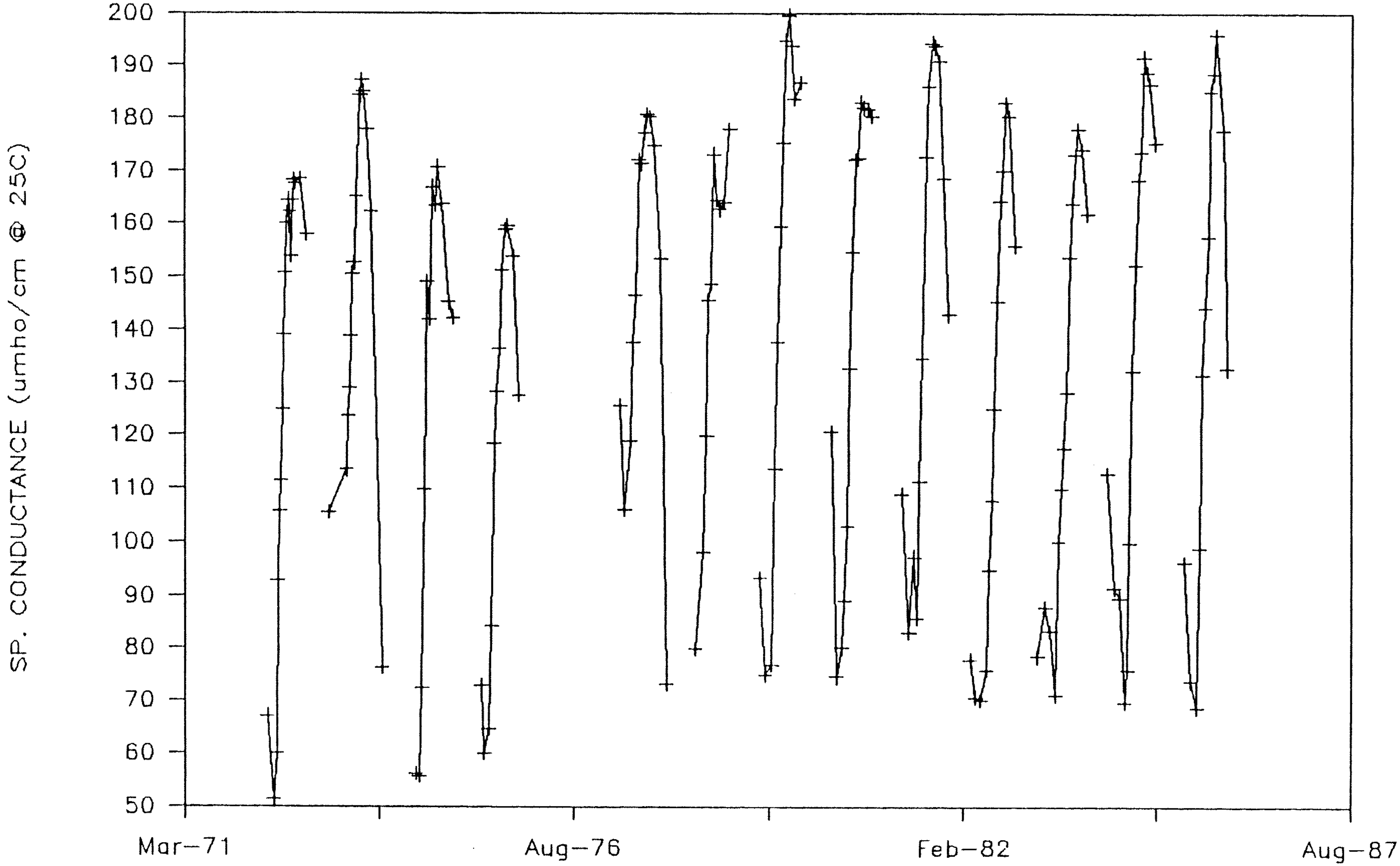
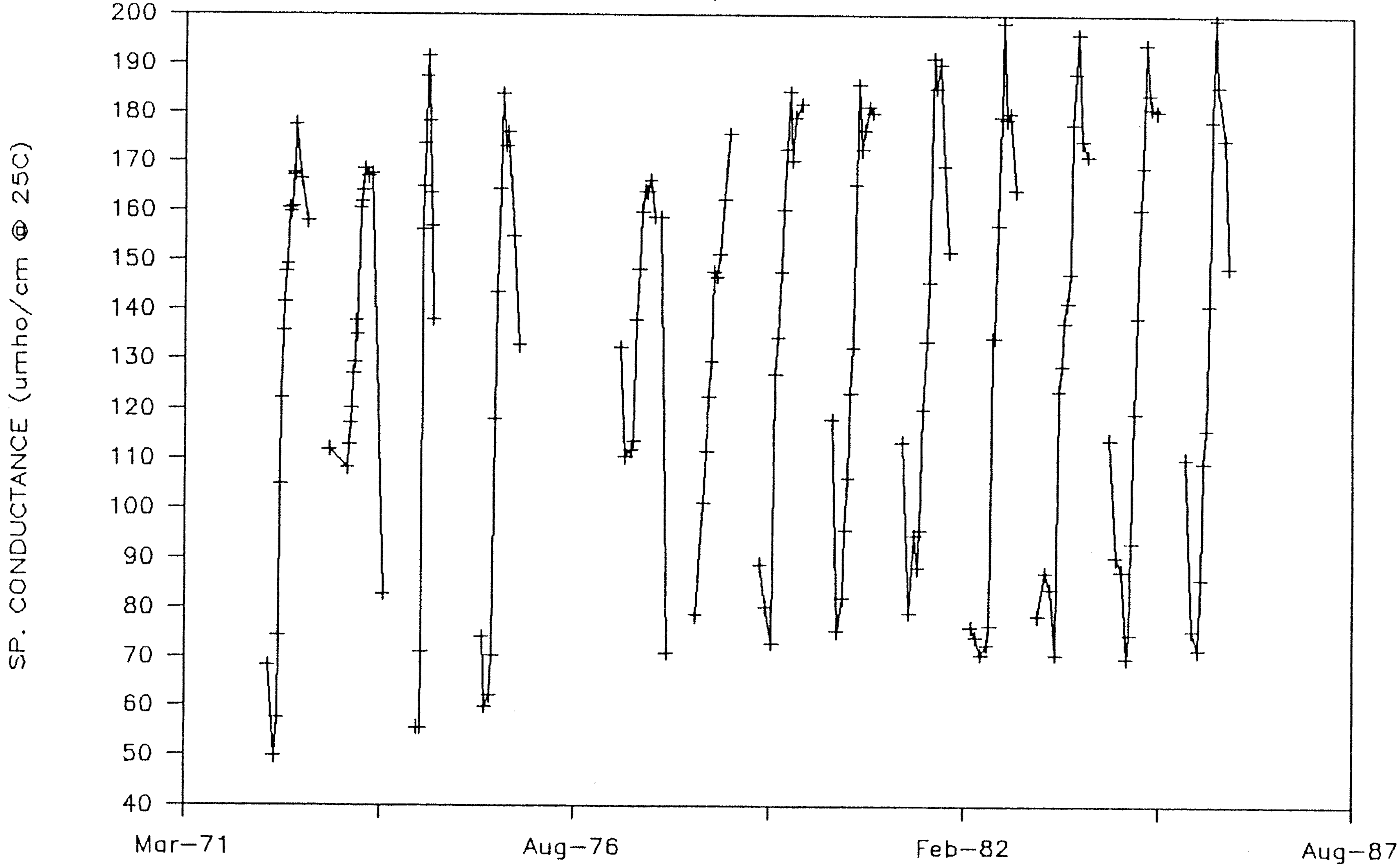


FIGURE C-2

HYPOLIMNETIC CONDUCTANCE VARIATIONS

LONG LAKE, 1972–1985



This result has important implications regarding the relationship between nutrient loading and trophic response in Long Lake.

One of the more critical water quality deficiencies identified in Long Lake prior to the implementation of AWT at Spokane was hypolimnetic anoxia. Temperature and specific conductance contours suggest that depths below approximately 15 meters may be relatively isolated from surface and metalimnetic currents and thus could be comparatively stagnant (see Figures 6-7). These deeper waters have also exhibited the lowest D.O. levels (Figure 8). However, temporal plots of specific conductance within the hypolimnion (defined as depths below 15 m) reveal a seasonal increase indicative of the mixing of inflow waters to depth (Figure C-2). Mass balance calculations equivalent to those performed for the EZ suggested that this conductance increase could be explained by the mixing of 10-50 percent (median = 30 percent) of the input flow. This calculated flow would result in a median hypolimnetic residence time of approximately 60 days. Although the same limitations of the "box" model identified for the EZ apply as well to the hypolimnion (deeper waters appear to be defined by a gradient of densities and not by a single mixed unit), it is nevertheless apparent that the hypolimnion is not stagnant, but is typically slowly to moderately flushed with inflow waters throughout the stratification season.

APPENDIX D

SUMMARY OF HISTORICAL FLOW DATA

APPENDIX D

SUMMARY OF AVERAGE JUNE-OCTOBER DISCHARGES IN THE SPOKANE RIVER, 1913-1985

Year	Rathdrum Canal Diversion (111.7)	Spokane Farm Co. Diversion (101.7)	Post Falls (100.7)	Harvard Road (93.6)	Spokane (72.9)	Hangman Creek (72.4)	Little Spokane River Dartford (56.3)	Long Lake Dam (33.9)
1913	0	69	6045		6549			
1914	0	72	1956		2420			
1915	0	80	2162		2541			
1916	0	89	6693		7151			
1917	0	86	7332		7871			
1918	0	92	2511		2990			
1919	0	98	2522		3013			
1920	0	97	2873		3391			
1921	0	111	2934		3732			
1922	0	112	3182		3976			
1923	0	142	3772		4508			
1924	0	157	1330		1854			
1925	0	159	2721		3439			
1926	0	160	1357		1861			
1927	0	163	5675		6343			
1928	0	167	2444		3274			
1929	0	128	1896	1912	2450		118	
1930	0	149	1540	1589	2022		92	
1931	0	169	1209	1198	1617		83	
1932	0	176	3321	3428	4192			
1933	0	166	5807	5400	6417			
1934	0	174	1068	1067	1807			
1935	0	187	2879	2859	3774			
1936	0	181	1965	1916	2760			
1937	0	179	2384		3043			
1938	0	188	2331	2242	2986			
1939	0	185	1671	1651	2236			2963
1940	0	181	1268	1268	1871			2628
1941	0	168	1762		2284			2996
1942	0	176	2067	1996	2596			3340
1943	0	179	3712		4484			5285
1944	0	174	1307	1232	1818			2465
1945	0	173	2075	2036	2758			3506
1946	22	171	2446	2436	3220			4040
1947	32	182	2265		2954		139	3759
1948	30	160	5518		6356	111	316	7595
1949	38	171	1875	1797	2823	19	166	3476
1950	33	181	6489	6217	7541	49	214	8204
1951	38	184	2191	1966	2937	28	199	3783
1952	37	173	2179	2077	2917	27	210	3671
1953	36	171	3523	3379	4152	36	206	5041
1954	31	155	4451	4338	5098	27	183	5802
1955	35	182	4871	4767	5577	14	179	6066
1956	32	183	3959	3865	4861	32	220	5667
1957	31	179	3069	3116	3981	47	185	4719
1958	34	175	1764	1726	2627	20	174	3337
1959	34	170	4214	4093	4881	29	211	5756

SUMMARY OF AVERAGE JUNE-OCTOBER DISCHARGES IN THE SPOKANE RIVER, 1913-1985

Year	Rathdrum Canal Diversion (111.7)	Spokane Farm Co. Diversion (101.7)	Post Falls (100.7)	Harvard Road (93.6)	Spokane (72.9)	Hangman Creek (72.4)	Little Spokane River Dartford (56.3)	Long Lake Dam (33.9)
1960	34	173	2903	2864	3738	16	228	4460
1961	40	176	3029	2967	3887	16	209	4613
1962	37	172	2472	2425	3248	17	184	3898
1963	40	179	1117	1090	1822	16	158	2332
1964	27	165	5618	5542	6358	18	174	7008
1965	32	163	2901	2893	3733	28	170	4428
1966	37	80	1620	1626	2163	11	135	2870
1967	37	0	3857	3816	4304	25	160	5098
1968	34	0	2557	2479	2826	7	130	3549
1969	35	0	2816	2675	3283	27	182	4075
1970	38	0	3978	3837	4440	24	168	5206
1971	31	0	5119	4840	5590	78	182	6361
1972	33	0	5465	5198	6037	20	161	6618
1973	36	0	1536	1445	1812	3	113	2385
1974	35	0	7207	6948	8084	36	221	8558
1975	31	0	5369	5223	6016	43	227	6793
1976	30	0	3390	3305	3930	25	185	4744
1977	33	0	1534	1450	1837	9	116	2430
1978	26	0	2814	2770	3177	24	160	3991
1979	27	0	2182	2151	2557	13	119	3267
1980	25	0	3257	3173	3545	48	148	4356
1981	25	0	3485	3299	3770	30	170	4580
1982	27	0	4053	3760	4378	23	161	5072
1983	20	0	3188		3707	36	202	4446
1984	26	0	4111		4728	61	242	5562
1985	26	0	3329		3738	28	148	4453

APPENDIX E

SPOKANE RIVER/LONG LAKE

MODEL PROGRAM CODE

"SPOKTP.BAS"

Microsoft Quick Basic[R]

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10 '**********************************************************************
20 '**********************************************************************
30 '
40 '          SPOKANE RIVER/LONG LAKE TOTAL PHOSPHORUS (TP) ATTENUATION MODEL
50 '                   MICROSOFT QuickBASIC PROGRAM SPOKTP.BAS
51 '                          HARPER-OWES, SEATTLE, WA
52 '
60 '**********************************************************************
70 '**********************************************************************
90 '
100 ' Model originally developed by Harper-Owes using MICROSOFT BASIC, and modified by
101 ' Ecology to run with COMPAQ or IBM BASIC  [W.Kendra, 11/85].  The present version
102 ' was again updated in QuickBASIC by Harper-Owes to reflect 1985 conditions, Long
103 ' Lake predictions and several allocation scenarios [C. PATMONT and G. PELLETIER, 9/87].
120 '
130 '-------------------------------------------------------------------------
140 '        DIMENSION STATEMENTS FOR PROGRAM ARRAYS (lines 170-560)
150 '-------------------------------------------------------------------------
160 '
170 'ONE-DIMENSIONAL ARRAYS: SUBSCRIPTS (I) DENOTE REACHES AS DEFINED IN PROGRAM LINES 1760 THROUGH 2070
180 '
190 'TWO-DIMENSIONAL ARRAYS: SUBSCRIPTS (I,J) DENOTE REACH (I) AND SURFACE WATER SOURCE (J) AS DEFINED
195 'IN PROGRAM LINES 2210 THROUGH 2460
200 '
201 'NAME ARRAY FOR SURFACE WATER SOURCES
202 DIM A$(17,9),AA$(17,9)
203 '
210 'UPSTREAM NODE, DOWNSTREAM NODE, AND AVERAGE DISCHARGE OF REACH (I), UNITS IN CFS
220 DIM QINIT(19),QFINAL(19),QAVG(19)
230 'UPSTREAM NODE TP AND DIN CONCENTRATION OF REACH (I), UNITS IN ug/L
240 DIM TPINIT(17),DININIT(17)
250 'DOWNSTREAM NODE TP AND DIN CONCENTRATION OF REACH (I), UNITS IN ug/L
260 DIM TPFINAL(17),DINFINAL(17)
270 'AVERAGE TP AND DIN CONCENTRATION OF REACH (I), UNITS IN ug/L
280 DIM TPAVG(17),DINAVG(17)
290 'SURFACE WATER SOURCE DISCHARGE, TP CONCENTRATION, AND DIN CONCENTRATION TO REACH (I) FROM SOURCE (J)
295 'UNITS IN ug/L
300 DIM QSW(17,9),QEX(17,9),QPERMIT(17,9),TPSW(17,9),DINSW(17,9)
302 'POINT SOURCE INFLUENT TP CONCENTRATIONS AND REMOVAL EFFICIENCIES
304 DIM TPINSW(17,9),TPEX(17,9),TPREMOVE(17,9),TPEXREM(17,9)
310 'SUM OF SURFACE WATER DISCHARGES TO REACH (I), UNITS IN CFS
320 DIM QSWTOT(17)
330 'AVERAGE SURFACE WATER TP AND DIN CONCENTRATIONS TO REACH (I) FROM ALL SOURCES, UNITS IN ug/L
340 DIM TPSWTOT(17),DINSWTOT(17)
350 'TOTAL TP AND DIN LOADS TO REACH (I) FROM ALL SURFACE WATER SOURCES, UNITS IN (ug/L)*CFS
360 DIM SWTPLOAD(17),TPLOADSUM(17),SWDINLOAD(17)
370 'GROUND WATER DISCHARGE, TP CONCENTRATION, AND DIN CONCENTRATION OF REACH (I), CFS, ug/L, AND ug/L
380 DIM QGW(17),TPGW(17),DINGW(17)
390 'NUMBER OF SURFACE WATER SOURCES DISCHARGING TO REACH (I)
400 DIM SOURCECNT(17)
410 'MASS BALANCE MODEL PARAMETERS FOR REACH (I)
420 DIM K2(17),K2MAX(17)
430 'COMPUTED CHANGE IN TP AND DIN CONCENTRATION BETWEEN UPSTREAM AND DOWNSTREAM NODE OF REACH (I), ug/L
440 DIM DELTP(17),DELDIN(17)
450 'SURFACE AREA OF REACH (I)
460 DIM AREA(17)
470 'RIVER MILE OF DOWNSTREAM NODE OF REACH (I)
480 DIM RM(18)
490 'INTERMEDIATE VARIABLES FOR VARIANCE COMPUTATIONS
500 DIM VARY1(18),VARY2(18),VARY3(18),VARY4(18),VARY5(18),VARY6(18)
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510 DIM VARY7(18),VARY8(18),VARX1(18),VARX2(18),VARX3(18),VARX4(18)
520 DIM VARX5(18),VARX6(18),VARX7(18),VARX8(18),VARX9(18)
530 'ESTIMATED VARIANCE FOR DOWNSTREAM NODE TP AND DIN CONCENTRATION FOR REACH (I), UNITS OF ug/L SQUARED
540 DIM VARTPFINAL(18),VARDIN(18)
550 'ESTIMATED STANDARD DEVIATION OF DOWNSTREAM NODE TP CONCENTRATION OF REACH (I), ug/L
560 DIM DEVTPFINAL(18),TPVAR(18)
565 'ATTENUATION PARAMETERS FOR ALLOCATION SCENARIOS
570 DIM TPTRANS(19)
575 'UPSTREAM AND DOWNSTREAM TP LOADINGS, UNITS IN kg P/day
578 DIM UPSTREAM(17),DOWNSTREAM(17)
580 '
590 '--------------------------------------------------------------------------
600 '            INITIALIZATION OF VARIABLES (lines 630-1240)
610 '--------------------------------------------------------------------------
620 '
621 'CONVERSION FACTORS
622 CF1=(1000000!/(7.4805195#*24*60*60))          ' CONVERT MGD TO CFS
623 CF2=(1E+09/(28.31605#*24*60*60))              ' CONVERT KG/D TO (ug/L)(CFS)
625 CF3=5.9857318E+06                             ' CONVERT CFS^2 TO CMD^2
628 CF4=2.2046226#                                ' CONVERT KILOGRAMS TO POUNDS
629 '
638 'EXISTING AND PERMITTED POINT SOURCE DISCHARGES (CFS)
640 QEX(1,1)=2.2163*CF1      : QPERMIT(1,1)=6*CF1          ' COUER D'ALENE
642 QEX(2,1)=0*CF1           : QPERMIT(2,1)=0.75*CF1       ' HAYDEN LAKE
650 QEX(3,1)=.11574*CF1      : QPERMIT(3,1)=1.5*CF1        ' POST FALLS
660 QEX(5,1)=.26146*CF1      : QPERMIT(5,1)=1*CF1          ' LIBERTY LAKE
670 QEX(7,1)=.45952*CF1      : QPERMIT(7,1)=.75*CF1        ' SP. IND. PARK
675 QEX(7,2)=.23*CF1                                       ' KAISER
680 QEX(9,1)=2.3901*CF1      : QPERMIT(9,1)=3.5*CF1        ' IN. EMP. PAPER
690 QEX(9,2)=.018405*CF1     : QPERMIT(9,2)=.015*CF1       ' MILLWOOD
710 QEX(14,1)=31.632*CF1     : QPERMIT(14,1)=44*CF1        ' SPOKANE AWT
720 QEX(15,1)=.178418*CF1    : QPERMIT(15,1)=0*CF1         ' NW TERRACE
722 '
724 'EXISTING TP REMOVAL EFFICIENCIES FOR POINT SOURCES
725 '
726 TPEXREM(1,1)=.125
727 TPEXREM(2,1)=.1
728 TPEXREM(3,1)=.1
729 TPEXREM(5,1)=.035
730 TPEXREM(7,1)=.167
731 TPEXREM(7,2)=.1
732 TPEXREM(9,1)=.1
733 TPEXREM(9,2)=.1
734 TPEXREM(14,1)=.888
735 TPEXREM(15,1)=.1
736 '
740 'INFLUENT TP VALUES IN ug P /l FOR POINT SOURCES
742 '
750 TPEX(1,1)=7375/(1-TPEXREM(1,1))
752 TPEX(2,1)=((6100+7375)/2)/(1-TPEXREM(2,1))                 ' ESTIMATED
760 TPEX(3,1)=6100/(1-TPEXREM(3,1))
770 TPEX(5,1)=6701/(1-TPEXREM(5,1))
780 TPEX(7,1)=2320/(1-TPEXREM(7,1))
790 TPEX(9,1)=1668/(1-TPEXREM(9,1))
800 TPEX(9,2)=4875/(1-TPEXREM(9,2))
820 TPEX(14,1)=568/(1-TPEXREM(14,1))
830 TPEX(15,1)=9048/(1-TPEXREM(15,1))
840 '
850 'INITIAL DIN VALUES IN ug N /l FOR POINT SOURCES
860 DINSW(1,1)=13500
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```
862 DINSW(2,1)=(13500#+27401#)/2863#              ' ESTIMATED
870 DINSW(3,1)=27401
880 DINSW(5,1)=18800
890 DINSW(7,1)=3760
900 DINSW(9,1)=624
910 DINSW(9,2)=9700
920 DINSW(12,1)=995
930 DINSW(14,1)=11500
940 DINSW(15,1)=19100
950 '
960 'NET TP AND DIN LOAD FROM KAISER WTP IN Kg /day
970 K6KAISERTP=5.1
980 K6KAISERDIN=22.3
982 'NET TP AND DIN LOAD FROM INLAND EMP. PAPER CO. IN Kg/day
984 K6IEPCTP=15.09083
986 K6IEPCDIN=5.65
990 '
1000 'INITIAL GROUNDWATER TP (ug P /l) AND DIN (ug N /l)
1040 TPGW(7)=6.91
1050 DINGW(7)=1075
1080 TPGW(10)=15.4
1090 DINGW(10)=757
1120 TPGW(12)=12.2
1130 DINGW(12)=2865
1150 TPGW(13)=10.5
1160 DINGW(13)=1305
1180 TPGW(14)=10.6
1190 DINGW(14)=1560
1210 TPGW(15)=23.1
1220 DINGW(15)=2400
1230 EDIT$="N" : ATTEN$="N" : ALLOC$="N"
1240 'REACH (0)=LAKE COEUR D'ALENE
1260 '
1270 '*********************************************************************
1280 '*********************************************************************
1290 '
1300 '                    INPUT SECTION (lines 1350-3850)
1310 '
1320 '*********************************************************************
1330 '*********************************************************************
1340 '
1350 'Q (cfs), TP (ug P/L), AND DIN (ug N/L)
1360 FOR I=1 TO 25
1370 PRINT
1380 NEXT I
1390 PRINT "SPOKANE RIVER PHOSPHORUS LOADING/ATTENUATION MODEL FROM COEUR"
1400 PRINT "D'ALENE, IDAHO TO LONG LAKE, WASHINGTON  (HARPER-OWES, 9/87)"
1402 PRINT "INCLUDING WATER QUALITY PREDICTIONS FOR LONG LAKE"
1410 PRINT:PRINT
1420 PRINT "ENTER THE DISCHARGE (CFS) YOU WOULD LIKE TO EVALUATE AT THE
1430 PRINT "OUTLET OF LAKE COUER D'ALENE. THE LIKELY CHOICES ARE:
1440 PRINT "         10-YEAR LOW FLOW = 1537 CFS
1450 PRINT "              MEDIAN FLOW = 2970 CFS
1452 INPUT QFINAL(0)
1454 IF QFINAL(0)<700 OR QFINAL(0)>4000 THEN PRINT:PRINT "WARNING: NOT CALIBRATED AND/OR VERIFIED BELOW 700 OR ABOVE 4000 CFS"
1455 IF QFINAL(0)<700 OR QFINAL(0)>4000 THEN PRINT "MODEL RUNS OUTSIDE OF THIS RANGE ARE NOT RECOMMENDED."
1456 IF QFINAL(0)<700 OR QFINAL(0)>4000 THEN PRINT:PRINT "PRESS RETURN TO CONTINUE OR ENTER ANY OTHER KEY TO RESTART"
1457 IF QFINAL(0)<700 OR QFINAL(0)>4000 THEN INPUT NOTHING$ ELSE GOTO 1459:IF NOTHING$="" THEN GOTO 1459 ELSE GOTO 1360
1458 'GROUNDWATER INFLOW OR OUTFLOW TO EACH REACH (CFS)
1459 QGW(3)=37.46-(.031367*QFINAL(0))
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1460 QGW(4)=15.77-(.013207*QFINAL(0))
1462 QGW(7)=288.97+(.048167*QFINAL(0))
1464 QGW(9)=-256.2
1466 QGW(10)=338.54+(.056428*QFINAL(0))
1468 QGW(11)=-179.7
1470 QGW(12)=135.53+(.012548*QFINAL(0))
1472 QGW(13)=42.75
1474 QGW(14)=58.3
1476 QGW(15)=50.53
1478 'TP AND DIN CONCENTRATIONS AT THE COEUR D'ALENE OUTFLOW (RM 111.7), UNITS OF ug/L
1480 TPFINAL(0)=8.68
1482 DINFINAL(0)=10
1483 FOR I=1 TO 25 :PRINT: NEXT I
1484 PRINT "ENTER THE CONDITIONS FOR STORMWATER SEPARATION THAT YOU "
1485 PRINT "WOULD LIKE TO EVALUATE FOR THE CITY OF SPOKANE"
1486 PRINT "The estimated future separation of CSO's is 81%"
1487 PRINT "CHOOSE CSO CONDITIONS (E=1982 Existing, S=81% Separation)"
1488 INPUT SEPARATE$
1489 IF SEPARATE$<>"E" AND SEPARATE$<>"S" THEN GOTO 1488
1490 '
1491 'COMBINED SEWER OVERFLOWS, SPOKANE AWT BYPASSES AND SEPARATED STORMWATER FLOWS: ADD TO REACH 14. DISCHARGE CFS, CONC ug/L
1492 '
1494 IF SEPARATE$="E" THEN QBYPASS=.18 : VARQBYPASS=.22^2 : QCSO=1.49 : VARQCSO=1.17^2 : QSEPARATE=2.94 : VARQSEPARATE=1.13^2
1496 IF SEPARATE$="S" THEN QBYPASS=.03 : VARQBYPASS=.1^2 : QCSO=.28 : VARQCSO=.51^2 : QSEPARATE=5.16 : VARQSEPARATE=1.48^2
1498 TPBYPASS=3125 : VARTPBYPASS=141^2           'AWT BYPASS TP ug/L
1499 DINBYPASS=5800 : VARDINBYPASS=2900^2
1500 TPCSO=3185 : VARTPCSO=546^2                 'CSO TP CONC ug/L
1501 DINCSO=5800 : VARDINCSO=2900^2
1502 TPSEPARATE=350 : VARTPSEPARATE=84^2         'SEPERATE STORMWATER TP ug/L
1503 DINSEPARATE=790 : VARDINSEPARATE=320^2
1512 '
1513 'SPOKANE VALLEY SEPARATED STORMWATER: ADD TO REACH 8
1514 '
1515 IF EDIT$="Y" THEN GOTO 1524
1516 QSW(8,1)=1.63 : VARQVALLEY=.63^2            'CFS, CFS^2
1518 TPSW(8,1)=350 : VARTPVALLEY=84^2            'ug/L, ug/L ^2
1519 DINSW(8,1)=790 : VARDINVALLEY=320^2         'ug/L, ug/L ^2
1520 '
1521 'CALCULATION OF POOLED BYPASS, CSO, AND SEP. STORMWATER TO REACH 14
1522 '
1524 BYPASSTPLOAD=QBYPASS*TPBYPASS                                     '(ug/L)(CFS)
1525 BYPASSDINLOAD=QBYPASS*DINBYPASS                                   '(ug/L)(CFS)
1526 VARBYPASSTPLOAD=TPBYPASS^2*VARQBYPASS+QBYPASS^2*VARTPBYPASS       '(ug/L)(CFS) ^2
1527 VARBYPASSDINLOAD=DINBYPASS^2*VARQBYPASS+QBYPASS^2*VARDINBYPASS    '(ug/L)(CFS) ^2
1528 CSOTPLOAD=QCSO*TPCSO                                              '(ug/L)(CFS)
1529 CSODINLOAD=QCSO*DINCSO                                            '(ug/L)(CFS)
1530 VARCSOTPLOAD=TPCSO^2*VARQCSO+QCSO^2*VARTPCSO                      '(ug/L)(CFS) ^2
1531 VARCSODINLOAD=DINCSO^2*VARQCSO+QCSO^2*VARDINCSO                   '(ug/L)(CFS) ^2
1532 SEPARATETPLOAD=QSEPARATE*TPSEPARATE                               '(ug/L)(CFS)
1533 SEPARATEDINLOAD=QSEPARATE*DINSEPARATE                             '(ug/L)(CFS)
1534 VARSEPARATETPLOAD=TPSEPARATE^2*VARQSEPARATE+QSEPARATE^2*VARTPSEPARATE    '(ug/L)(CFS) ^2
1535 VARSEPARATEDINLOAD=DINSEPARATE^2*VARQSEPARATE+QSEPARATE^2*VARDINSEPARATE '(ug/L)(CFS) ^2
1536 STORMTPLOAD14=BYPASSTPLOAD+CSOTPLOAD+SEPARATETPLOAD               '(ug/L)(CFS)
1537 STORMDINLOAD14=BYPASSDINLOAD+CSODINLOAD+SEPARATEDINLOAD           '(ug/L)(CFS)
1538 VARSTORMTPLOAD14=VARBYPASSTPLOAD+VARCSOTPLOAD+VARSEPARATETPLOAD
1539 VARSTORMDINLOAD14=VARBYPASSDINLOAD+VARCSODINLOAD+VARSEPARATEDINLOAD
1540 IF EDIT$="Y" THEN GOTO 1545
1541 QSW(14,2)=QBYPASS+QCSO+QSEPARATE                           'CFS
1542 VARQSTORM14=VARQBYPASS+VARQCSO+VARQSEPARATE
1543 'POOLED TP CONC TO REACH 14 FROM BYPASS, CSO AND SEPARATE STORMWATER
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1544 TPSW(14,2)=STORMTPLOAD14/QSW(14,2)                          'ug/L
1545 DINSW(14,2)=STORMDINLOAD14/QSW(14,2)                        'ug/L
1546 VARTPSTORM14=(VARSTORMTPLOAD14-(TPSW(14,2)^2*VARQSTORM14))/QSW(14,2)^2
1547 VARDINSTORM14=(VARSTORMDINLOAD14-(DINSW(14,2)^2*VARQSTORM14))/QSW(14,2)^2
1654 '
1656 'RIVER MILE OF DOWNSTREAM NODE OF REACH (I)
1658 RM(0)=111.7
1660 RM(1)=106.6
1662 RM(2)=101.7
1664 RM(3)=96!
1666 RM(4)=93!
1668 RM(5)=90.4
1670 RM(6)=87.8
1672 RM(7)=85.3
1674 RM(8)=82.6
1676 RM(9)=79.8
1678 RM(10)=78!
1680 RM(11)=74.1
1682 RM(12)=69.8
1684 RM(13)=67.6
1686 RM(14)=64.6
1688 RM(15)=62!
1690 RM(16)=58.1
1695 RM(17)=33.9
1700 '
1710 'THE FOLLOWING FOR/NEXT LOOP (FOR I=1 TO 16) CONTROLS THE INPUT OF DATA
1712 'FOR DISCHARGE, TP CONCENTRATION, AND DIN CONCENTRATION FROM SURFACE WATER
1714 'SOURCES IN EACH REACH I (lines 1720-3810)
1720 IF EDIT$="Y" THEN GOTO 2490
1725 FOR I=1 TO 16
1730 SOURCECNT(I)=0
1740 '
1750 'SEGMENT BOUNDARIES -- RIVER MILE AND VERBAL DESCRIPTION
1751 IF I=1 THEN R1$="RM 111.7 TO 106.6"
1752 IF I=1 THEN R2$="LAKE COEUR D'ALENE TO HARBOR ISLAND"
1753 IF I=2 THEN R1$="RM 106.6 TO 101.7"
1754 IF I=2 THEN R2$="HARBOR ISLAND TO POST FALLS DAM"
1755 IF I=3 THEN R1$="RM 101.7 TO 96.0"
1756 IF I=3 THEN R2$="POST FALLS DAM TO STATELINE"
1757 IF I=4 THEN R1$="RM 96.0 TO 93.0"
1758 IF I=4 THEN R2$="STATELINE TO HARVARD ROAD"
1759 IF I=5 THEN R1$="RM 93.0 TO 90.4"
1760 IF I=5 THEN R2$="HARVARD ROAD TO BARKER ROAD"
1761 IF I=6 THEN R1$="RM 90.4 TO 87.8"
1762 IF I=6 THEN R2$="BARKER ROAD TO SULLIVAN ROAD"
1880 IF I=7 THEN R1$="RM 87.8 TO 85.3"
1890 IF I=7 THEN R2$="SULLIVAN ROAD TO TRENT ROAD"
1900 IF I=8 THEN R1$="RM 85.3 TO 82.6"
1910 IF I=8 THEN R2$="TRENT ROAD TO ARGONNE ROAD"
1920 IF I=9 THEN R1$="RM 82.6 TO 79.8"
1930 IF I=9 THEN R2$="ARGONNE ROAD TO UPRIVER DAM"
1940 IF I=10 THEN R1$="RM 79.8 TO 78.0"
1950 IF I=10 THEN R2$="UPRIVER DAM TO GREEN STREET"
1960 IF I=11 THEN R1$="RM 78.0 TO 74.1"
1970 IF I=11 THEN R2$="GREEN STREET TO POST STREET"
1980 IF I=12 THEN R1$="RM 74.1 TO 69.8"
1990 IF I=12 THEN R2$="POST STREET TO FORT WRIGHT BRIDGE"
2000 IF I=13 THEN R1$="RM 69.8 TO 67.6"
2010 IF I=13 THEN R2$="FORT WRIGHT BRIDGE TO SPOKANE AWT"
2020 IF I=14 THEN R1$="RM 67.6 TO 64.6"
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2030 IF I=14 THEN R2$="SPOKANE AWT TO GUN CLUB"
2040 IF I=15 THEN R1$="RM 64.6 TO 62.0"
2050 IF I=15 THEN R2$="GUN CLUB TO SEVEN MILE BRIDGE"
2060 IF I=16 THEN R1$="RM 62.0 TO 58.1"
2070 IF I=16 THEN R2$="SEVEN MILE BRIDGE TO NINE MILE DAM"
2080 '
2090 FOR J=1 TO 25
2100 PRINT
2110 NEXT J
2120 PRINT "REACH ",I
2130 PRINT R1$
2140 PRINT R2$
2150 '
2160 'THE FOLLOWING FOR/NEXT LOOP (FOR J=1 TO 5) CONTROLS THE INPUT OF DATA FOR SURFACE WATER SOURCES
2162 'WITHIN EACH REACH I (lines 2170-3450)
2170 FOR J=1 TO 9
2180 '
2190 'SURFACE WATER SOURCES DEFINED: A$(I,J) IDENTIFIES SOURCE (J) IN REACH (I)
2200 A$(I,J)="0"
2205 IF I=0 THEN IF J=1 THEN A$(I,J)="LAKE COEUR D'ALENE OUTLET  " : AA$(I,J)="LAKE CDA"
2210 IF I=1 THEN IF J=1 THEN A$(I,J)="COEUR D'ALENE STP          " : AA$(I,J)="CDA STP "
2212 IF I=2 THEN IF J=1 THEN A$(I,J)="HAYDEN LAKE/REGIONAL STP   " : AA$(I,J)="HAYDEN L"
2220 IF I=3 THEN IF J=1 THEN A$(I,J)="POST FALLS STP             " : AA$(I,J)="POST FAL"
2230 IF I=5 THEN IF J=1 THEN A$(I,J)="LIBERTY LAKE STP           " : AA$(I,J)="LIBERTY "
2240 IF I=7 THEN IF J=1 THEN A$(I,J)="SPOKANE INDUSTRIAL PARK WTP" : AA$(I,J)="SIP WTP "
2250 IF I=7 THEN IF J=2 THEN A$(I,J)="KAISER WTP                 " : AA$(I,J)="KAISER  "
2255 IF I=8 THEN IF J=1 THEN A$(I,J)="SPOKANE VALLEY STORMWATER  " : AA$(I,J)="STORMWAT"
2260 IF I=9 THEN IF J=1 THEN A$(I,J)="INLAND EMPIRE WTP          " : AA$(I,J)="INLAND E"
2270 IF I=9 THEN IF J=2 THEN A$(I,J)="MILLWOOD STP               " : AA$(I,J)="MILLWOOD"
2280 IF I=12 THEN IF J=1 THEN A$(I,J)="HANGMAN CREEK              " : AA$(I,J)="HANGMAN "
2290 IF I=14 THEN IF J=1 THEN A$(I,J)="SPOKANE AWT                " : AA$(I,J)="SPOKANE "
2295 IF I=14 THEN IF J=2 THEN A$(I,J)="CITY OF SPOKANE CSO & STORM" : AA$(I,J)="CSO/STRM"
2300 IF I=15 THEN IF J=1 THEN A$(I,J)="NORTHWEST TERRACE STP      " : AA$(I,J)="NW TERR "
2305 IF I=17 THEN IF J=1 THEN A$(I,J)="LITTLE SPOKANE RIVER       " : AA$(I,J)="L SPOK R"
2310 IF I=1 THEN IF J=2 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2320 IF I=2 THEN IF J=2 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2330 IF I=3 THEN IF J=2 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2340 IF I=4 THEN IF J=1 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2350 IF I=5 THEN IF J=2 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2360 IF I=6 THEN IF J=1 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2370 IF I=7 THEN IF J=3 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2380 IF I=8 THEN IF J=2 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2390 IF I=9 THEN IF J=3 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2400 IF I=10 THEN IF J=1 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2410 IF I=11 THEN IF J=1 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2420 IF I=12 THEN IF J=2 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2430 IF I=13 THEN IF J=1 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2440 IF I=14 THEN IF J=3 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2450 IF I=15 THEN IF J=2 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2460 IF I=16 THEN IF J=1 THEN A$(I,J)="MISCELLANEOUS SOURCES"
2470 '
2480 'CALCULATION OF HANGMAN CREEK DISCHARGE AND TOTAL P (NOT INTERACTIVE)
2482 '
2490 IF I=12 THEN GOTO 2500 ELSE GOTO 2560
2500 IF J=1 THEN GOTO 2520 ELSE GOTO 2560
2520 QSW(12,1)=3.3+(.007237*QFINAL(0))                        ' CFS
2522 VARQHC=18.24^2                                           ' CFS ^2
2523 IF EDIT$="Y" THEN GOTO 2526
2524 KGHCTPLOAD=-.145581+(.23322*QSW(12,1))                   ' Kg/day
2526 VARKGHCTPLOAD=1.43696^2+(KGHCTPLOAD^2/QSW(12,1)^2)*VARQHC  ' Kg/day ^2
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2528 HCTPLOAD=K6HCTPLOAD*CF2                                          ' (ug/L)(CFS)
2530 VARHCTPLOAD=VARK6HCTPLOAD*(CF2^2)                                ' (ug/L)(CFS) ^2
2532 TPSW(12,1)=HCTPLOAD/QSW(12,1)                                    ' ug/L
2534 VARTPHC=(VARHCTPLOAD-(TPSW(12,1)^2)*VARQHC)/(QSW(12,1)^2)        ' ug/L ^2
2536 IF EDIT$="Y" THEN GOTO 3470
2538 SOURCECNT(I)=SOURCECNT(I)+1
2540 GOTO 3450
2550 '
2560 IF A$(I,J)="MISCELLANEOUS SOURCES" THEN GOTO 3260
2570 '
2820 '
2830 '------------------------------------------------------------------------
2840 '                    INPUT FOR SURFACE WATER SOURCES
2850 '------------------------------------------------------------------------
2860 '
2861 'INTERACTIVE INPUT OF POINT SOURCE FLOW AND TP DATA
2862 '
2863 'NET RIVER DISCHARGE INPUT (i.e. excluding recirculated coolant water)
2864 '
2865 IF(I=14 AND J=2) OR (I=8 AND J=1) THEN GOTO 3013
2866 PRINT:PRINT:PRINT A$(I,J):PRINT
2867 IF I=7 AND J=2 THEN GOTO 2877
2868 PRINT "Existing (1985) Discharge =";QEX(I,J)/CF1;"MGD"
2869 PRINT:PRINT "Permitted Discharge =";QPERMIT(I,J)/CF1;"MGD"
2870 PRINT:PRINT "CHOOSE DISCHARGE (E=Existing, P=Permit, O=Other)"
2871 INPUT D$
2872 IF D$<>"E" AND D$<>"P" AND D$<>"O" THEN GOTO 2871
2873 IF D$="E" THEN QSW(I,J)=QEX(I,J) : GOTO 1772
2874 IF D$="P" THEN QSW(I,J)=QPERMIT(I,J) : GOTO 1772
2875 IF D$="O" THEN PRINT "ENTER THE DESIRED DISCHARGE IN MGD"
2876 INPUT X# : QSW(I,J)=X#*CF1 : GOTO 1772                    ' CFS
2877 PRINT "Total Existing (1985) Discharge (incl. coolant water) = 23 MGD"
2878 PRINT:PRINT "Permitted Total Discharge = 33 MGD"
2879 PRINT:PRINT "Net Estimated Existing (1985) Wastewater Discharge =";QEX(I,J)/CF1;"MGD"
2880 PRINT:PRINT "CHOOSE NET DISCHARGE (E=Existing, O=Other)"
2882 INPUT P$
2884 IF P$<>"E" AND P$<>"O" THEN GOTO 2882
2886 IF P$="E" THEN QSW(I,J)=QEX(I,J) : GOTO 1772
2888 IF P$="O" THEN PRINT "ENTER THE DESIRED NET DISCHARGE IN MGD"
2890 INPUT X# : QSW(I,J)=X#*CF1                                ' CFS
2891 DINSW(7,2)=K6KAISERDIN*CF2/(QSW(7,2)*CF1)
1770 'INFLUENT TP CONCENTRATIONS AT EACH TREATMENT PLANT
1771 '
1772 PRINT:PRINT:PRINT A$(I,J):PRINT
1773 IF (I=7 AND J=2) OR (I=9 AND J=1) THEN GOTO 1791
1774 IF I=1 OR I=5 OR I=7 OR I=14 THEN GOTO 1775 ELSE GOTO 1784
1775 PRINT "Existing (1984-85) Influent TP Concentration =";TPEX(I,J);"ug P/L"
1777 PRINT:PRINT "CHOOSE TP CONCENTRATION (E=Existing, O=Other)"
1778 INPUT D$
1779 IF D$<>"E" AND D$<>"O" THEN GOTO 1778
1780 IF D$="E" THEN TPINSW(I,J)=TPEX(I,J) : GOTO 2896
1782 IF D$="O" THEN PRINT "ENTER THE DESIRED INFLUENT TP CONCENTRATION IN ug P/L"
1783 INPUT TPINSW(I,J) : GOTO 2896
1784 PRINT "Estimated (1984-85) Influent TP Concentration =";TPEX(I,J);"ug P/L"
1785 PRINT:PRINT "CHOOSE TP CONCENTRATION (E=Existing, O=Other)"
1786 INPUT D$
1787 IF D$<>"E" AND D$<>"O" THEN GOTO 1786
1788 IF D$="E" THEN TPINSW(I,J)=TPEX(I,J) : GOTO 2896
1789 IF D$="O" THEN PRINT "ENTER THE DESIRED INFLUENT TP CONCENTRATION IN ug P/L"
1790 INPUT TPINSW(I,J) : GOTO 2896
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1791 IF (I=7 AND J=2) THEN K6TPLOAD=K6KAISERTP : K6DINLOAD=K6KAISERDIN
1792 IF (I=9 AND J=1) THEN K6TPLOAD=K6IEPCTP : K6DINLOAD=K6IEPCDIN
1793 PRINT "TP Loading At This Facility Is Not Proportional To Flow"
1794 PRINT:PRINT "Estimated Existing (1984-85) Net Influent TP Load ="K6TPLOAD/(1-TPEXREM(I,J));"Kg P /day"
1795 PRINT:PRINT "CHOOSE INFLUENT TP LOADING (E=Existing, O=Other)"
1796 INPUT D$
1797 IF D$<>"E" AND D$<>"O" THEN GOTO 1796
1798 IF D$="E" THEN TPINSW(I,J)=(K6TPLOAD/(1-TPEXREM(I,J)))*CF2/QSW(I,J) : GOTO 2896
1799 IF D$="O" THEN PRINT "ENTER THE DESIRED INFLUENT TP LOAD IN kg P/day"
1800 INPUT INTPLOAD# : TPINSW(I,J)=INTPLOAD#*CF2/QSW(I,J) : GOTO 2896
2892 '
2894 'TOTAL PHOSPHORUS REMOVAL EFFICIENCIES AT EACH TREATMENT PLANT'
2895 '
2896 IF I=1 OR I=5 OR I=7 OR I=14 THEN GOTO 2913
2898 PRINT:PRINT:PRINT A$(I,J):PRINT
2900 PRINT:PRINT "Estimated Existing (1984-85) TP Removal Efficiency =";100*TPEXREM(I,J);"%"
2902 PRINT:PRINT "CHOOSE TP REMOVAL EFFICIENCY (E=Estimated, O=Other)"
2904 INPUT P$
2906 IF P$<>"E" AND P$<>"O" THEN GOTO 2904
2908 IF P$="E" THEN TPREMOVE(I,J)=TPEXREM(I,J) : GOTO 2954
2910 IF P$="O" THEN PRINT "ENTER THE DESIRED TP REMOVAL EFFICIENCY IN PERCENT"
2912 INPUT EFF# : TPREMOVE(I,J)=.01#*EFF# : GOTO 2954
2913 IF J=2 THEN GOTO 2898
2914 PRINT:PRINT "Existing TP Removal Efficiency =";100*TPEXREM(I,J);"%"
2916 IF I=5 OR I=14 THEN GOTO 2930
2918 PRINT:PRINT "CHOOSE TP REMOVAL EFFICIENCY (E=Existing, O=Other)"
2920 INPUT P$
2922 IF P$<>"E" AND P$<>"O" THEN GOTO 2920
2924 IF P$="E" THEN TPREMOVE(I,J)=TPEXREM(I,J) : GOTO 2954
2926 IF P$="O" THEN PRINT "ENTER THE DESIRED TP REMOVAL EFFICIENCY IN PERCENT"
2928 INPUT EFF# : TPREMOVE(I,J)=.01#*EFF# : GOTO 2954
2930 IF I=5 AND QSW(I,J)<.89*CF1 THEN GOTO 2918
2932 PRINT:PRINT "Permitted TP Removal Efficiency At This Flow Is 85 %"
2934 PRINT:PRINT "CHOOSE TP REMOVAL EFFICIENCY (E=Existing, P=Permitted, O=Other)"
2936 INPUT P$
2938 IF P$<>"E" AND P$<>"P" AND P$<>"O" THEN GOTO 2936
2940 IF P$="E" THEN TPREMOVE(I,J)=TPEXREM(I,J) : GOTO 2954
2942 IF P$="P" THEN TPREMOVE(I,J)=.85 : GOTO 2954
2944 IF P$="O" THEN PRINT "ENTER THE DESIRED TP REMOVAL EFFICIENCY IN PERCENT"
2946 INPUT EFF : TPREMOVE(I,J)=.01#*EFF
2948 '
2950 'EFFLUENT TOTAL PHOSPHORUS LOADINGS FROM EACH TREATMENT PLANT"
2952 '
2954 PRINT:PRINT:PRINT A$(I,J):PRINT
2956 IF (I=7 AND J=2) OR (I=9 AND J=1) THEN GOTO 2988
2958 PRINT "Given An Effluent Discharge =";QSW(I,J)/CF1;"MGD,"
2960 PRINT:PRINT "An Estimated 1984-85 Influent TP Concentration =";TPINSW(I,J);"ug/L,"
2962 PRINT:PRINT "And a TP Removal Efficiency =";100*TPREMOVE(I,J);"%,"
2964 PRINT:PRINT "The Estimated TP Loading To The Spokane River =";(QSW(I,J)*TPINSW(I,J)*(1-TPREMOVE(I,J)))/CF2;"Kg P/day"
2966 PRINT:PRINT "CHOOSE TP LOADING (E=Estimated, O=Other)"
2968 INPUT P$
2970 IF P$<>"E" AND P$<>"O" THEN GOTO 2968
2972 IF P$="E" THEN TPSW(I,J)=TPINSW(I,J)*(1-TPREMOVE(I,J)) : GOTO 3013
2974 IF P$="O" THEN PRINT "ENTER THE DESIRED TP LOADING IN Kg P/day"
2976 INPUT X# : TPSW(I,J)=(X#*CF2)/QSW(I,J) : TPREMOVE(I,J)=1-TPSW(I,J)/TPINSW(I,J)
2977 PRINT "This Loading Value Corresponds To A TP Removal Efficiency =";100*TPREMOVE(I,J);"%"
2978 PRINT "IS THIS CORRECT? (Y/N)"
2979 INPUT P$
2980 IF P$<>"Y" AND P$<>"N" THEN GOTO 2979
2981 IF P$="Y" THEN GOTO 3013
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2982 IF P$="N" THEN PRINT "REDO INPUT LOOP" : GOTO 2865
2983 '
2984 'INPUT OF KAISER AND INLAND EMP. PAPER CO. TP LOADS
2985 '
2988 PRINT "TP Loading From This Facility Is Not Proportional To Flow"
2990 PRINT:PRINT "Given An Estimated Existing (1984-85) Net Influent TP Load =";QSW(I,J)*TPINSW(I,J)/CF2;"Kg P /day"
2992 PRINT:PRINT "And a TP Removal Efficiency =";100*TPREMOVE(I,J);"%,"
2994 PRINT:PRINT "The Estimated Effluent TP Loading To The Spokane River =";QSW(I,J)*TPINSW(I,J)*(1-TPREMOVE(I,J))/CF2;"Kg P/day"
2996 PRINT:PRINT "CHOOSE TP LOADING (E=Estimated, O=Other)"
2998 INPUT P$
3000 IF P$<>"E" AND P$<>"O" THEN GOTO 2998
3001 IF P$="E" THEN TPSW(I,J)=TPINSW(I,J)*(1-TPREMOVE(I,J)) : GOTO 3010
3002 IF P$="O" THEN PRINT "ENTER THE DESIRED TOTAL P LOAD IN Kg P/day"
3003 INPUT X# : TPSW(I,J)=(X#*CF2)/QSW(I,J) : TPREMOVE(I,J)=1-TPSW(I,J)/TPINSW(I,J)
3004 PRINT "This Loading Value Corresponds To A TP Removal Efficiency =";100*TPREMOVE(I,J);"%"
3005 PRINT "IS THIS CORRECT? (Y/N)"
3006 INPUT P$
3007 IF P$<>"Y" AND P$<>"N" THEN GOTO 3006
3008 IF P$="Y" THEN GOTO 3013
3009 IF P$="N" THEN PRINT "REDO INPUT LOOP" : GOTO 2865
3010 '
3013 IF EDIT$="Y" THEN GOTO 3470
3014 SOURCECNT(I)=SOURCECNT(I)+1
3015 GOTO 3450
3215 '
3220 '-------------------------------------------------------------------------
3230 '                    INPUT OF MISCELLANEOUS SOURCES
3240 '-------------------------------------------------------------------------
3250 '
3260 PRINT:PRINT
3270 PRINT "MISCELLANEOUS SOURCES"
3275 IF EDIT$="Y" THEN GOTO 3298
3280 PRINT
3290 PRINT "Existing (1985) Discharge =";QSW(I,J)/CF1;"MGD"
3292 PRINT:PRINT "CHOOSE DISCHARGE (E=Existing, O=Other)"
3294 INPUT D$
3295 IF D$<>"E" AND D$<>"O" THEN GOTO 3294
3296 IF D$="E" THEN GOTO 3470
3297 AA$(I,J)="MISC.   "
3298 PRINT:PRINT "ENTER THE DISCHARGE IN MGD"
3299 INPUT X# : QSW(I,J)=X#*CF1                        ' CFS
3308 PRINT:PRINT "ENTER THE DESIRED INFLUENT TOTAL P CONCENTRATION IN ug P/L"
3310 INPUT TPINSW(I,J)
3312 PRINT:PRINT "ENTER TP REMOVAL EFFICIENCY IN PERCENT"
3314 INPUT X# : TPREMOVE(I,J)=.01#*X#
3316 PRINT:PRINT "ENTER THE DESIRED EFFLUENT DIN CONCENTRATION IN ug N/L"
3318 INPUT DINSW(I,J)
3320 PRINT:PRINT "The Estimated TP Loading To The Spokane River =";(QSW(I,J)*TPINSW(I,J)*(1-TPREMOVE(I,J)))/CF2;"Kg P/day"
3321 PRINT:PRINT "CHOOSE TP LOADING (E=Estimated, O=Other)"
3322 INPUT P$
3323 IF P$<>"E" AND P$<>"O" THEN GOTO 3322
3324 IF P$="E" THEN TPSW(I,J)=TPINSW(I,J)*(1-TPREMOVE(I,J)) : GOTO 3334
3325 IF P$="O" THEN PRINT "ENTER THE DESIRED TOTAL P LOAD IN Kg P/day"
3326 INPUT X# : TPSW(I,J)=(X#*CF2)/QSW(I,J) : TPREMOVE(I,J)=1-TPSW(I,J)/TPINSW(I,J)
3327 PRINT "This Loading Value Corresponds To A TP Removal Efficiency =";100*TPREMOVE(I,J);"%"
3328 PRINT "IS THIS CORRECT? (Y/N)"
3329 INPUT P$
3330 IF P$<>"Y" AND P$<>"N" THEN GOTO 3329
3331 IF P$="Y" THEN GOTO 3334
3332 IF P$="N" THEN PRINT "REDO INPUT LOOP" : GOTO 3298
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3333 '
3334 IF EDIT$="Y" THEN GOTO 3470 ELSE SOURCECNT(I)=SOURCECNT(I)+1
3335 J=J+1
3336 PRINT:PRINT:PRINT "ARE THERE ANY MORE MISCELLANEOUS SOURCES IN THIS REACH ? (Y/N)"
3338 INPUT M$
3340 IF M$<>"Y" AND M$<>"N" THEN GOTO 3338
3342 IF M$="N" THEN GOTO 3470
3344 IF SOURCECNT(I)=9 THEN PRINT:PRINT "THIS IS THE LAST SOURCE ALLOWED IN THE ARRAY FOR THIS REACH!"
3348 IF M$="Y" THEN GOTO 3298
3349 '
3450 NEXT J
3460 '
3470 SUMQ=0
3480 SUMTP=0
3490 SUMDIN=0
3500 IF SOURCECNT(I)=0 THEN GOTO 3810
3510 '
3590 '-----------------------------------------------------------------------
3600 '    THE FOLLOWING FOR/NEXT LOOP CALCULATES Q, TP LOAD, AND DIN LOAD SUMS FOR EACH REACH I (lines 3630-3790)
3610 '-----------------------------------------------------------------------
3620 '
3630 FOR J=1 TO SOURCECNT(I)
3640 SUMQ=SUMQ+QSW(I,J)
3660 SUMTP=SUMTP+(TPSW(I,J)*QSW(I,J))
3670 SUMDIN=SUMDIN+(DINSW(I,J)*QSW(I,J))
3680 GOTO 3720
3710 'SUM OF SURFACE WATER DISCHARGES TO REACH (I), CFS
3720 QSWTOT(I)=SUMQ
3730 'FLOW-WEIGHTED AVERAGE SURFACE WATER TP AND DIN LOADS FOR SOURCES DISCHARGED TO REACH (I), ug/L*CFS
3740 SWTPLOAD(I)=SUMTP
3750 SWDINLOAD(I)=SUMDIN
3755 IF SUMQ=0 THEN GOTO 3790
3760 'FLOW-WEIGHTED AVERAGE SURFACE WATER TP AND DIN CONCENTRATIONS FOR SOURCES DISCHARGED TO REACH (I), ug/L
3770 TPSWTOT(I)=SUMTP/SUMQ
3780 DINSWTOT(I)=SUMDIN/SUMQ
3790 NEXT J
3800 '
3810 IF EDIT$="Y" THEN GOTO 3830
3815 NEXT I
3820 '
3830 FOR K=1 TO 25
3840 PRINT
3850 NEXT K
3870 '
3890 '************************************************************************
3900 '
3910 '                COMPUTATION SECTION (lines 3960-6600)
3920 '
3930 '************************************************************************
3950 '
3960 PRINT "COMPUTING" : FOR I=1 TO 12:PRINT:NEXT I
3970 '
3980 'THE FOLLOWING FOR/NEXT LOOP (FOR I=1 TO 16) CONTROLS MASS BALANCE AND VARIANCE COMPUTATIONS
3985 'FOR EACH REACH I (lines 3990-6600)
3990 TOTSWTPLOAD=0 : TOTGWTPLOAD=0
3995 FOR I=1 TO 16
4000 '
4010 '-----------------------------------------------------------------------
4020 '   MASS BALANCE AND TP ATTENUATION RATE EQUATIONS (lines 4050-4550)
4030 '-----------------------------------------------------------------------
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4040 '
4042 TOTSWTPLOAD=TOTSWTPLOAD+SWTPLOAD(I)                      '(ug/L)(CFS)
4044 IF QGW(I)<0 THEN GOTO 4050 ELSE GOTO 4046
4046 TOTGWTPLOAD=TOTGWTPLOAD+(QGW(I)*TPGW(I))                 '(ug/L)(CFS)
4050 DELTP(I)=0
4060 DELDIN(I)=0
4070 TESTDELTP=DELTP(I)
4080 TESTDELDIN=DELDIN(I)
4090 QINIT(I)=QFINAL(I-1)+QSWTOT(I)
4100 IF I=2 THEN QINIT(I)=QINIT(I)-32.12
4110 QFINAL(I)=QINIT(I)+QGW(I)
4120 QAVG(I)=(QINIT(I)+QFINAL(I))/2
4130 '
4140 'CALCULATION OF SURFACE AREAS FOR EACH REACH (I), SQUARE METERS
4150 AREA(1)=5.1*1609*182
4160 AREA(2)=4.9*1609*188
4170 AREA(3)=5.7*1609*22.093*(QAVG(3)^.1252)
4180 AREA(4)=3!*1609*22.093*(QAVG(4)^.1252)
4190 AREA(5)=2.6*1609*22.093*(QAVG(5)^.1252)
4200 AREA(6)=2.6*1609*22.093*(QAVG(6)^.1252)
4210 AREA(7)=2.5*1609*22.093*(QAVG(7)^.1252)
4220 AREA(8)=2.7*1609*65
4230 AREA(9)=2.8*1609*97
4240 AREA(10)=1.8*1609*22.093*(QAVG(10)^.1252)
4250 AREA(11)=3.9*1609*71
4260 AREA(12)=4.3*1609*22.093*(QAVG(12)^.1252)
4270 AREA(13)=2.2*1609*22.093*(QAVG(13)^.1252)
4280 AREA(14)=3!*1609*22.093*(QAVG(14)^.1252)
4290 AREA(15)=2.6*1609*79
4300 AREA(16)=3.9*1609*181
4310 '
4320 'MASS BALANCE EQUATIONS FOR UPSTREAM AND DOWNSTREAM NODE TP AND DIN CONCENTRATIONS FOR EACH REACH (I)
4325 TPLOADSUM(I)=SWTPLOAD(I)
4326 IF ATTEN$="Y" THEN IF K=I THEN TPLOADSUM(I)=SWTPLOAD(I)+CF2
4330 TPINIT(I)=((QFINAL(I-1)*TPFINAL(I-1))+TPLOADSUM(I))/QINIT(I)
4340 TPFINAL(I)=(((QFINAL(I-1)*TPFINAL(I-1))+TPLOADSUM(I)+(QGW(I)*TPGW(I)))/QFINAL(I))-DELTP(I)
4350 DININIT(I)=((QFINAL(I-1)*DINFINAL(I-1))+SWDINLOAD(I))/QINIT(I)
4360 DINFINAL(I)=(((QFINAL(I-1)*DINFINAL(I-1))+SWDINLOAD(I)+(QGW(I)*DINGW(I)))/QFINAL(I))-DELDIN(I)
4370 IF QGW(I)<0 THEN TPFINAL(I)=TPINIT(I)-DELTP(I):DINFINAL(I)=DININIT(I)-DELDIN(I)
4380 IF DININIT(I)<10 THEN DININIT(I)=10
4390 IF DINFINAL(I)<10 THEN DINFINAL(I)=10
4400 TPAVG(I)=(TPINIT(I)+TPFINAL(I))/2
4410 DINAVG(I)=(DININIT(I)+DINFINAL(I))/2
4420 'ATTENUATION MODEL K2MAX IN UNITS OF METERS/DAY
4430 K2MAX(I)=.835
4440 'K2MAX DOWNSTREAM OF AWT
4450 IF I>13 THEN IF TPREMOVE(14,1)>.1 THEN K2MAX(I)=.178
4460 'K2MAX OF REACH 10 --UPRIVER DAM TO GREEN ST-- ASSUMED EQUAL TO ZERO          (I.E. NO ATTENUATION)
4470 K2MAX(10)=9.999999E-21
4480 'MICHAELIS MENTEN FORMULATION FOR MODEL K2
4490 K2(I)=(K2MAX(I)*DINAVG(I))/(DINAVG(I)+29)
4500 'COMPUTED CHANGES IN TP CONCENTRATION BASED ON FIRST ORDER ATTENUATION          MODEL
4510 DELTP(I)=(K2(I)*TPAVG(I)*AREA(I))/(QAVG(I)*2446.58)
4520 'RATIO OF DIN:TP SET EQUAL TO 3.9
4530 DELDIN(I)=DELTP(I)*3.9
4540 'ITERATIVE CALCULATION CRITERIA
4550 IF .01<(ABS(TESTDELTP-DELTP(I))/DELTP(I)) THEN IF .05<(ABS(TESTDELDIN-DELDIN(I))/DELDIN(I)) THEN GOTO 4070
4570 '
4580 '------------------------------------------------------------------------
4590 '    FIRST-ORDER UNCERTAINTY ANALYSIS TO ESTIMATE VARIANCE OF TP CONCENTRATION
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4595 '    AT THE DOWNSTREAM NODE OF EACH REACH I (lines 4620-6580)
4600 '---------------------------------------------------------------------------
4610 '
4615 IF ATTEN$="Y" OR ALLOC$="Y" THEN GOTO 6600
4620 Y1=QFINAL(I-1)*(CF3^.5)
4630 Y2=TPFINAL(I-1)
4640 Y3=QSWTOT(I)*(CF3^.5)
4650 Y4=TPSWTOT(I)
4660 Y5=QGW(I)*(CF3^.5)
4670 Y6=TPGW(I)
4680 Y7=K2(I)
4690 Y8=AREA(I)
4730 VARY1(0)=0       ' COUER D'ALENE OUTFLOW DISCHARGE VARIANCE ASSUMED ZERO
4740 VARY3(0)=0
4750 VARY5(0)=0
4760 'COEUR D'ALENE LAKE: TP CONCENTRATION VARIANCE = 0.6529 (ug/L) SQUARED; DIN CONC. VARIANCE = 25 (ug/L) SQUARED
4770 VARTPFINAL(0)=.6529
4780 VARDIN(0)=25
4790 VARY1(I)=VARY1(I-1)+VARY3(I-1)+VARY5(I-1)
4800 VARX1(I)=VARY1(I)
4810 VARY2(I)=VARTPFINAL(I-1)
4820 VARX2(I)=VARDIN(I-1)
4830 'VARY3 = SURFACE WATER DISCHARGE VARIANCE, (CU.METERS/DAY) SQUARED
4840 'VARY4 = SURFACE WATER TOTAL P VARIANCE, (ug/L) SQUARED
4850 'VARX4 = SURFACE WATER DIN VARIANCE, (ug/L) SQUARED
4860 IF I=2 THEN VARY3(I)=4.83^2*CF3 : VARY4(I)=VARY2(I) : VARX4(I)=VARX2(I) : Y3=-32.12*(CF3^.5): Y4=Y2 : GOTO 4910
4861 'STORMWATER DISCHARGE TO REACH 8
4862 IF I=8 THEN VARY3(I)=VARQVALLEY*CF3:VARY4(I)=VARTPVALLEY:VARX4(I)=VARDINVALLEY:Y3=QSW(8,1)*(CF3^.5):Y4=TPSW(8,1):GOTO 4910
4863 'STORMWATER DISCHARGE TO REACH 14
4864 IF I=14 THEN VARY3(I)=VARQSTORM14*CF3:VARY4(I)=VARTPSTORM14:VARX4(I)=VARDINSTORM14:Y3=QSW(14,2)*(CF3^.5):Y4=TPSW(14,2):GOTO 4910
4870 IF I=12 THEN VARY3(I)=18.24^2*CF3:VARY4(I)=VARTPHC:VARX4(I)=2905:Y3=QSW(12,1)*(CF3^.5):Y4=TPSW(12,1):GOTO 4910
4880 VARY3(I)=0
4890 VARY4(I)=0
4900 VARX4(I)=0
4910 VARX3(I)=VARY3(I)
4920 'VARY5 = GROUND WATER DISCHARGE VARIANCE, (CU.METERS/DAY) SQUARED
4930 'VARY6 = GROUND WATER TOTAL P VARIANCE, (ug/L) SQUARED
4940 'VARX6 = GROUND WATER DIN VARIANCE, (ug/L) SQUARED
4950 IF I=3 THEN VARY5(I)=54.18^2*CF3 : VARY6(I)=VARY2(I) : VARX6(I)=VARX2(I) :  GOTO 5080
4960 IF I=4 THEN VARY5(I)=22.82^2*CF3 : VARY6(I)=VARY2(I) : VARX6(I)=VARX2(I) :  GOTO 5080
4970 IF I=7 THEN VARY5(I)=121.81^2*CF3:VARY6(I)=2.402:VARX6(I)=93025!:GOTO 5080
4980 IF I=9 THEN VARY5(I)=65^2*CF3:VARY6(I)=VARY2(I):VARX6(I)=VARX2(I):GOTO 5080
4990 IF I=10 THEN VARY5(I)=144.9^2*CF3:VARY6(I)=10.82:VARX6(I)=2582:GOTO 5080
5000 IF I=11 THEN VARY5(I)=84^2*CF3 : VARY6(I)=VARY2(I) : VARX6(I)=VARX2(I) :   GOTO 5080
5010 IF I=12 THEN VARY5(I)=44.82^2*CF3:VARY6(I)=19.45:VARX6(I)=490000!:GOTO 5080
5020 IF I=13 THEN VARY5(I)=22.98^2*CF3:VARY6(I)=1.44:VARX6(I)=62500!:GOTO 5080
5030 IF I=14 THEN VARY5(I)=31.33^2*CF3:VARY6(I)=1.513:VARX6(I)=60025!:GOTO 5080
5040 IF I=15 THEN VARY5(I)=27.16^2*CF3:VARY6(I)=15.21:VARX6(I)=72361!:GOTO 5080
5050 VARY5(I)=0
5060 VARY6(I)=0
5070 VARX6(I)=0
5080 VARX5(I)=VARY5(I)
5090 'UNCERTAINTY IN REACH WIDTH IS ESTIMATED AS 10% IN POOL AREAS AND 20% IN RIFFLE AREAS (EXPRESSED AS COEF. OF VARIATION)
5100 IF I<3 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 5160
5110 IF I=8 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 5160
5120 IF I=9 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 5160
5130 IF I=11 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 5160
5140 IF I>14 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 5160
5150 VARY8(I)=(.2*Y8)*(.2*Y8)
5160 VARX7(I)=0
```

```
5170 VARX8(I)=VARY8(I)
5180 'VARIANCE IN DIN:TP RATIO = 1.69
5190 VARX9(I)=1.69
5200 X1=Y1
5210 X2=DINFINAL(I-1)
5220 X3=Y3
5230 X4=DINSWTOT(I)
5232 IF I=2 THEN X4=X2
5234 IF I=8 THEN X4=DINSW(8,1)
5236 IF I=12 THEN X4=DINSW(12,1)
5238 IF I=14 THEN X4=DINSW(14,2)
5240 X5=Y5
5250 X6=DINGW(I)
5260 X7=Y7
5270 X8=Y8
5280 X9=3.9
5290 M1=Y1*Y2
5300 M2=Y3*Y4
5310 M3=Y5*Y6
5320 M4=Y1+Y3+Y5
5330 M5=Y7*Y8
5340 M6=Y1+Y3
5350 L1=X1*X2
5360 L2=X3*X4
5370 L3=X5+X6
5380 L4=X1+X3+X5
5390 L5=X7*X8*X9
5400 L6=X1+X3
5410 F1=(M1+M2+M3)/M4
5420 F2=M5/M6
5430 F3=(M1+M2)/(M4+M6)
5440 F4=1+(M5/(M4+M6))
5450 E1=F1
5460 E2=L5/L6
5470 E3=F3
5480 E4=1+(L5/(L4+L6))
5490 DTPDF1=1/F4
5500 DTPDF2=-(F3/F4)
5510 DTPDF3=-(F2/F4)
5520 DTPDF4=((F2*F3)-F1)/(F4*F4)
5530 DTPDE1=1/E4
5540 DTPDE2=-(E3/E4)
5550 DTPDE3=-(E2/E4)
5560 DTPDE4=((E2*E3)-E1)/(E4*E4)
5570 IF Y5<0 THEN Y5=0
5580 DF1DY1=(((Y1+Y3+Y5)*Y2)-(Y1*Y2+Y3*Y4+Y5*Y6))/((Y1+Y3+Y5)*(Y1+Y3+Y5))
5590 DF1DY2=Y1/(Y1+Y3+Y5)
5600 DF1DY3=(((Y1+Y3+Y5)*Y4)-(Y1*Y2+Y3*Y4+Y5*Y6))/((Y1+Y3+Y5)*(Y1+Y3+Y5))
5610 DF1DY4=Y3/(Y1+Y3+Y5)
5620 DF1DY5=(((Y1+Y3+Y5)*Y6)-(Y1*Y2+Y3*Y4+Y5*Y6))/((Y1+Y3+Y5)*(Y1+Y3+Y5))
5630 IF Y5=0 THEN DF1DY5=0
5640 DF1DY6=Y5/(Y1+Y3+Y5)
5650 DF1DY7=0
5660 DF1DY8=0
5670 Y5=X5
5680 DF2DY1=-(Y7*Y8)/((Y1+Y3)*(Y1+Y3))
5690 DF2DY2=0
5700 DF2DY3=DF2DY1
5710 DF2DY4=0
5720 DF2DY5=0
```

```
5730 DF2DY6=0
5740 DF2DY7=Y8/(Y1+Y3)
5750 DF2DY8=Y7/(Y1+Y3)
5760 DF3DY1=(((2*Y1+2*Y3+Y5)*Y2)-(2*(Y1*Y2+Y3*Y4)))/((2*Y1+2*Y3+Y5)*(2*Y1+2*Y3+Y5))
5770 DF3DY2=Y1/(2*Y1+2*Y3+Y5)
5780 DF3DY3=(((2*Y1+2*Y3+Y5)*Y4)-(2*(Y1*Y2+Y3*Y4)))/((2*Y1+2*Y3+Y5)*(2*Y1+2*Y3+Y5))
5790 DF3DY4=((2*Y1+2*Y3+Y5)*Y3)/((2*Y1+2*Y3+Y5)*(2*Y1+2*Y3+Y5))
5800 DF3DY5=-(Y1*Y2+Y3*Y4)/((2*Y1+2*Y3+Y5)*(2*Y1+2*Y3+Y5))
5810 DF3DY6=0
5820 DF3DY7=0
5830 DF3DY8=0
5840 D=2*Y1+2*Y3+Y5
5850 DF4DY1=(2*D-(2*(2*Y1+2*Y3+Y5+Y7*Y8)))/(D*D)
5860 DF4DY2=0
5870 DF4DY3=DF4DY1
5880 DF4DY4=0
5890 DF4DY5=(D-(2*Y1+2*Y3+Y5+Y7*Y8))/(D*D)
5900 DF4DY6=0
5910 DF4DY7=Y8/D
5920 DF4DY8=Y7/D
5930 IF X5<0 THEN X5=0
5940 DE1DX1=DF1DY1
5950 DE1DX2=DF1DY2
5960 DE1DX3=DF1DY3
5970 DE1DX4=DF1DY4
5980 DE1DX5=DF1DY5
5990 DE1DX6=DF1DY6
6000 DE1DX7=DF1DY7
6010 DE1DX8=DF1DY8
6020 DE1DX9=0
6030 X5=Y5
6040 DE2DX1=-(X7*X8*X9)/((X1+X3)*(X1+X3))
6050 DE2DX2=0
6060 DE2DX3=DE2DX1
6070 DE2DX4=0
6080 DE2DX5=0
6090 DE2DX6=0
6100 DE2DX7=(X8*X9)/(X1+X3)
6110 DE2DX8=(X7*X9)/(X1+X3)
6120 DE2DX9=(X7*X8)/(X1+X3)
6130 DE3DX1=DF3DY1
6140 DE3DX2=DF3DY2
6150 DE3DX3=DF3DY3
6160 DE3DX4=DF3DY4
6170 DE3DX5=DF3DY5
6180 DE3DX6=DF3DY6
6190 DE3DX7=DF3DY7
6200 DE3DX8=DF3DY8
6210 DE3DX9=0
6220 DE4DX1=((2*(2*X1+2*X3+X5))-(2*(2*X1+2*X3+X5+X7*X8*X9)))/((2*X1+2*X3+X5)*(2*X1+2*X3+X5))
6230 DE4DX2=0
6240 DE4DX3=DE4DX1
6250 DE4DX4=0
6260 DE4DX5=(2*X1+2*X3+X5-(2*X1+2*X3+X5+X7*X8*X9))/((2*X1+2*X3+X5)*(2*X1+2*X3+X5))
6270 DE4DX6=0
6280 DE4DX7=(X8*X9)/(2*X1+2*X3+X5)
6290 DE4DX8=(X7*X9)/(2*X1+2*X3+X5)
6300 DE4DX9=(X7*X8)/(2*X1+2*X3+X5)
6310 DTPDY1=DTPDF1*DF1DY1+DTPDF2*DF2DY1+DTPDF3*DF3DY1+DTPDF4*DF4DY1
6320 DTPDY2=DTPDF1*DF1DY2+DTPDF2*DF2DY2+DTPDF3*DF3DY2+DTPDF4*DF4DY2
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6330 DTPDY3=DTPDF1*DF1DY3+DTPDF2*DF2DY3+DTPDF3*DF3DY3+DTPDF4*DF4DY3
6340 DTPDY4=DTPDF1*DF1DY4+DTPDF2*DF2DY4+DTPDF3*DF3DY4+DTPDF4*DF4DY4
6350 DTPDY5=DTPDF1*DF1DY5+DTPDF2*DF2DY5+DTPDF3*DF3DY5+DTPDF4*DF4DY5
6360 DTPDY6=DTPDF1*DF1DY6+DTPDF2*DF2DY6+DTPDF3*DF3DY6+DTPDF4*DF4DY6
6370 DTPDY7=DTPDF1*DF1DY7+DTPDF2*DF2DY7+DTPDF3*DF3DY7+DTPDF4*DF4DY7
6380 DTPDY8=DTPDF1*DF1DY8+DTPDF2*DF2DY8+DTPDF3*DF3DY8+DTPDF4*DF4DY8
6390 DTPDX1=DTPDE1*DE1DX1+DTPDE2*DE2DX1+DTPDE3*DE3DX1+DTPDE4*DE4DX1
6400 DTPDX2=DTPDE1*DE1DX2+DTPDE2*DE2DX2+DTPDE3*DE3DX2+DTPDE4*DE4DX2
6410 DTPDX3=DTPDE1*DE1DX3+DTPDE2*DE2DX3+DTPDE3*DE3DX3+DTPDE4*DE4DX3
6420 DTPDX4=DTPDE1*DE1DX4+DTPDE2*DE2DX4+DTPDE3*DE3DX4+DTPDE4*DE4DX4
6430 DTPDX5=DTPDE1*DE1DX5+DTPDE2*DE2DX5+DTPDE3*DE3DX5+DTPDE4*DE4DX5
6440 DTPDX6=DTPDE1*DE1DX6+DTPDE2*DE2DX6+DTPDE3*DE3DX6+DTPDE4*DE4DX6
6450 DTPDX7=DTPDE1*DE1DX7+DTPDE2*DE2DX7+DTPDE3*DE3DX7+DTPDE4*DE4DX7
6460 DTPDX8=DTPDE1*DE1DX8+DTPDE2*DE2DX8+DTPDE3*DE3DX8+DTPDE4*DE4DX8
6470 DTPDX9=DTPDE1*DE1DX9+DTPDE2*DE2DX9+DTPDE3*DE3DX9+DTPDE4*DE4DX9
6472 'DTP(I,1)=DTPDY1:DTP(I,2)=DTPDY2:DTP(I,3)=DTPDY3:DTP(I,4)=DTPDY4:DTP(I,5)=DTPDY5:DTP(I,6)=DTPDY6:DTP(I,7)=DTPDY7
6473 '         DTP(I,8)=DTPDY8
6474 'FOR I=1 TO 16 : PRINT DTP(I,1),DTP(I,2),DTP(I,3),DTP(I,3),DTP(I,4):NEXT I
6480 'CALCULATED VARIANCE OF DIN CONCENTRATION AT DOWNSTREAM NODE OF EACH REACH (I)
6490 VARDIN(I)=(DTPDX1*DTPDX1*VARX1(I))+(DTPDX2*DTPDX2*VARX2(I))+(DTPDX3*DTPDX3*VARX3(I))+(DTPDX4*DTPDX4*VARX4(I))
6494 VARDIN(I)=VARDIN(I)+(DTPDX5*DTPDX5*VARX5(I))+(DTPDX6*DTPDX6*VARX6(I))+(DTPDX7*DTPDX7*VARX7(I))
6498 VARDIN(I)=VARDIN(I)+(DTPDX8*DTPDX8*VARX8(I))+(DTPDX9*DTPDX9*VARX9(I))
6500 'ESTIMATE VARIANCE OF K2(I)
6510 'CALCULATED VARIANCE OF ATTENUATION MODEL K2 FOR EACH REACH (I)
6520 VARY7(I)=((.425^2)*(K2(I)^2))+((((K2MAX(I)*29)/((DINAVG(I)+29)^2))^2)*VARDIN(I))
6530 'VARIANCE OF K2 FOR REACH 10 EQUALS ZERO
6540 VARY7(10)=0
6550 'VARIANCE OF K2 FOR REACHES DOWNSTREAM OF AWT EQUALS 0.0137 (M/DAY) SQUARED
6560 IF I>13 THEN IF Q$="Y" THEN VARY7(I)=.0137
6570 'CALCULATED VARIANCE OF TP CONCENTRATION AT DOWNSTREAM NODE OF EACH REACH I
6580 VARTPFINAL(I)=(DTPDY1*DTPDY1*VARY1(I))+(DTPDY2*DTPDY2*VARY2(I))+(DTPDY3*DTPDY3*VARY3(I))+(DTPDY4*DTPDY4*VARY4(I))
6581 VARTPFINAL(I)=VARTPFINAL(I)+(DTPDY5*DTPDY5*VARY5(I))+(DTPDY6*DTPDY6*VARY6(I))+(DTPDY7*DTPDY7*VARY7(I))+(DTPDY8*DTPDY8*VARY8(I))
6582 'VTP(I,1)=DTPDY1^2*VARY1(I)
6583 'VTP(I,2)=DTPDY2^2*VARY2(I)
6584 'VTP(I,3)=DTPDY3^2*VARY3(I)
6585 'VTP(I,4)=DTPDY4^2*VARY4(I)
6586 'VTP(I,5)=DTPDY5^2*VARY5(I)
6587 'VTP(I,6)=DTPDY6^2*VARY6(I)
6588 'VTP(I,7)=DTPDY7^2*VARY7(I)
6589 'VTP(I,8)=DTPDY8^2*VARY8(I)
6590 '
6600 NEXT I
6620 '
6640 '*********************************************************************
6650 '
6660 '                    OUTPUT SECTION (lines 6710-7930)
6670 '
6680 '*********************************************************************
6700 '
6705 IF ATTEN$="Y" OR ALLOC$="Y" THEN GOTO 6788
6710 FOR I=1 TO 25
6720 PRINT
6730 NEXT I
6740 '
6750 '---------------------------------------------------------------------
6760 'CALCULATE MEAN AND VARIANCE OF TP INFLUENT TO LONG LAKE ADDING THE TP LOAD FROM
6765 'THE LITTLE SPOKANE RIVER, ATMOSPHERIC FALLOUT, AND GROUNDWATER RESIDUAL
6770 '---------------------------------------------------------------------
6780 '
6782 'CALCULATION OF LITTLE SPOKANE RIVER TP LOAD
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6784 '
6788 QLSR=361.04+(.018511*QFINAL(0))                          ' CFS
6790 VARQLSR=35.91^2                                          ' CFS^2
6792 IF EDIT$="Y" THEN GOTO 6794
6793 KGLSRTPLOAD=-32.4162+(.163838*QLSR)                      ' Kg/day
6794 VARKGLSRTPLOAD=(13.2607^2)+((KGLSRTPLOAD^2/QLSR^2)*VARQLSR) ' Kg/day ^2
6796 'CONVERT LSR TP LOAD TO (ug/L)(CFS)
6797 LSRTPLOAD=KGLSRTPLOAD*CF2                                ' (ug/L)(CFS)
6798 VARLSRTPLOAD=VARKGLSRTPLOAD*(CF2^2)                      ' (ug/L)(CFS) ^2
6800 '
6802 'ATMOSPHERIC TP LOAD AND PRECIPITATION DISCHARGE TO LONG LAKE
6804 '
6806 QATM=6.85                                                ' CFS (PRECIP TO LL)
6808 VARQATM=2.08^2                                           ' CFS^2
6810 KGATMTPLOAD=.4                                           ' Kg/day
6812 VARKGATMTPLOAD=.19^2                                     ' Kg/day ^2
6814 ATMTPLOAD=KGATMTPLOAD*CF2                                ' (ug/L)(CFS)
6816 VARATMTPLOAD=VARKGATMTPLOAD*(CF2^2)                      ' (ug/L)(CFS) ^2
6818 '
6820 'GROUNDWATER RESIDUAL TOTAL P LOAD
6822 '
6824 QGWR=23.3                                                ' CFS
6826 VARQGWR=67.06^2                                          ' CFS^2
6828 TPGWR=23.1                                               ' ug/L
6830 VARTPGWR=3.9^2                                           ' ug/L ^2
6832 GWRTPLOAD=QGWR*TPGWR                                     ' (ug/L)(CFS)
6834 VARGWRTPLOAD=(TPGWR^2)*VARQGWR+(QGWR^2)*VARTPGWR         ' (ug/L)(CFS) ^2
6836 '
6838 'POOLED SOURCES TO REACH 17: LITTLE SPOKANE RIVER, ATMOSPHERIC FALLOUT, AND GROUNDWATER RESIDUAL TP LOAD
6840 '
6842 POOLTPLOAD=LSRTPLOAD+ATMTPLOAD+GWRTPLOAD  ' (ug/L)(CFS)
6844 VARPOOLTPLOAD=VARLSRTPLOAD+VARATMTPLOAD+VARGWRTPLOAD  ' (ug/L)(CFS) ^2
6846 QPOOL=QLSR+QATM+QGWR                                     ' CFS
6848 VARQPOOL=VARQLSR+VARQATM+VARQGWR                         ' CFS^2
6850 TPPOOL=POOLTPLOAD/QPOOL                                  ' ug/L
6852 VARTPPOOL=(VARPOOLTPLOAD-(TPPOOL^2)*VARQPOOL)/(QPOOL^2)   ' ug/L ^2
6854 '
6856 'ADD THE POOLED SOURCES TO REACH 17 TO NINE MILE DAM OUTFLOW
6858 '
6865 QFINAL(17)=QFINAL(16)+QPOOL
6866 VARQLLINFLOW=(VARY1(16)/CF3)+VARQLSR+VARQATM+VARQGWR
6867 QLLINFLOW=QFINAL(17)                    'UNCORRRECTED FOR EVAP & STORAGE
6868 TPFINAL(17)=(QFINAL(16)*TPFINAL(16)+POOLTPLOAD)/QFINAL(17)
6869 IF ATTEN$="Y" THEN GOTO 7050
6870 IF ATTEN$="N" THEN FINALTP1=TPFINAL(17)
6871 IF ALLOC$="Y" THEN GOTO 8430
6872 '
6873 'FIRST-ORDER VARIANCE CALCULATION FOR INFLUENT TP CONCENTRATION TO LONG LK
6874 '
6880 TPVAR(1)=(TPFINAL(16)*QFINAL(17)-TPFINAL(16)*QFINAL(16)-POOLTPLOAD)/(QFINAL(17)*QFINAL(17))
6890 TPVAR(2)=QFINAL(16)/QFINAL(17)
6900 TPVAR(3)=(TPPOOL*QFINAL(17)-TPFINAL(16)*QFINAL(16)-POOLTPLOAD)/(QFINAL(17)*QFINAL(17))
6910 TPVAR(4)=QPOOL/QFINAL(17)
6930 VARTPFINAL(17)=TPVAR(1)*TPVAR(1)*VARY1(16)/CF3+TPVAR(2)*TPVAR(2)*VARTPFINAL(16)+TPVAR(3)*TPVAR(3)*VARQPOOL
6935 VARTPFINAL(17)=VARTPFINAL(17)+TPVAR(4)*TPVAR(4)*VARTPPOOL
6940 '
6942 '------------------------------------------------------------------------
6943 '     CALCULATE WATER BALANCE FOR LONG LAKE (PRECIP IS ADDED ABOVE )
6944 '------------------------------------------------------------------------
6945 '
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6946 QSTORE=10.23        : VARQSTORE=20.24^2              ' CFS, CFS^2
6947 QEVAP=38.62         : VARQEVAP=10.62^2               ' CFS, CFS^2
6948 QFINAL(18)=QFINAL(17)-(QEVAP+QSTORE) : QLLDAM=QFINAL(18)
6949 VARQLLDAM=VARQLLINFLOW+VARQEVAP+VARQSTORE           ' CFS^2
6950 '
6951 '-------------------------------------------------------------------------
6952 '        PRINT SUMMARY AND EDITING OF SURFACE WATER INPUT VALUES
6953 '-------------------------------------------------------------------------
6954 '
6955 PRINT "SUMMARY OF INPUT VALUES FOR SURFACE SOURCES:" : PRINT
6956 PRINT USING "&";"SOURCE       NET Q (MGD)  TP REMOVAL (%)  TP (KgP/Day)   REACH(I,J)"
6958 PRINT USING "&";"==================================================================="
6959 PRINT "LAKE CDA",QFINAL(0)/CF1," NA          ",QFINAL(0)*TPFINAL(0)/CF2," 0 ";",";" 1"
6960 FOR I=1 TO 17 : FOR J=1 TO SOURCECNT(I)
6963 PRINT AA$(I,J),QSW(I,J)/CF1,100*TPREMOVE(I,J),(QSW(I,J)*TPSW(I,J))/CF2,I;",";J
6964 NEXT J : NEXT I
6965 PRINT "L SPOK R",QLSR/CF1," NA         ",KGLSRTPLOAD," 17 ";",";" 1"
6966 PRINT USING "&";"==================================================================="
6967 PRINT "WOULD YOU LIKE TO EDIT A SOURCE VALUE? (Y/N)"
6968 INPUT EDIT$
6969 IF EDIT$<>"Y" AND EDIT$<>"N" THEN GOTO 6968
6970 IF EDIT$="N" THEN GOTO 6998
6971 IF EDIT$="Y" THEN PRINT "ENTER THE REACH 'I' OF THE SOURCE FROM THE TABLE ABOVE"
6972 INPUT I
6973 PRINT "ENTER THE SOURCE NUMBER 'J' FROM THE TABLE ABOVE"
6974 INPUT J
6975 IF I=0 AND J=1 THEN PRINT "THE EXISTING LAKE COEUR D'ALENE OUTLET TP CONCENTRATION =";TPFINAL(0);"ug P/L" ELSE GOTO 6978
6976 PRINT "ENTER THE DESIRED TP CONCENTRATION IN ug P/L"
6977 INPUT TPFINAL(0) : GOTO 3830
6978 IF I=12 AND J=1 THEN PRINT "THE EXISTING HANGMAN CREEK TP LOADING =";KGHCTPLOAD;"kg P/day" ELSE GOTO 6981
6979 PRINT "ENTER THE DESIRED TP LOADING IN kg P/day"
6980 INPUT KGHCTPLOAD : TPSW(I,J)=KGHCTPLOAD*CF2/QSW(I,J) : GOTO 2520
6981 IF I=17 AND J=1 THEN PRINT "THE EXISTING LITTLE SPOKANE RIVER TP LOADING =";KGLSRTPLOAD;"kg P/day" ELSE GOTO 6984
6982 PRINT "ENTER THE DESIRED TP LOADING IN kg P/day"
6983 INPUT KGLSRTPLOAD :GOTO 6794
6984 PRINT:PRINT "YOU HAVE SELECTED THE SOURCE '";A$(I,J);"' FOR EDITING"
6985 PRINT "Is This Correct? (Y/N)"
6986 INPUT P$
6987 IF P$<>"Y" AND P$<>"N" THEN GOTO 6986
6988 IF P$="N" THEN GOTO 6950
6989 IF (I=8 AND J=1) OR (I=14 AND J=2) THEN PRINT "THE EXISTING TP LOADING =";QSW(I,J)*TPSW(I,J)/CF2;"kg P/day" ELSE GOTO 6992
6990 PRINT "ENTER THE DESIRED TP LOADING IN kg P/day"
6991 INPUT X# : TPSW(I,J)=X#*CF2/QSW(I,J) : GOTO 1515
6992 IF J>SOURCECNT(I) THEN PRINT:PRINT "YOU MUST START OVER TO ADD ANOTHER SOURCE. CONFIFM (Y/N)" ELSE GOTO 6995
6993 INPUT P$
6994 IF P$<>"Y" AND P$<>"N" THEN GOTO 6993
IF P$="Y" THEN GOTO 1360
IF P$="N" THEN GOTO 6950
6995 GOTO 2560
6996 '-------------------------------------------------------------------------
6997 '  PRINT UPSTREAM AND DOWNSTREAM RIVER MILES, NET SURFACE AND GROUNDWATER FLOWS AND RIVER FLOW
6998 '-------------------------------------------------------------------------
6999 PRINT: FOR K=1 TO 25 : PRINT : NEXT K
7000 PRINT "WATER BALANCE BY REACH":PRINT
7001 PRINT " UPSTREAM    DOWNSTREAM  SURFACE WATER   GROUNDWATER       RIVER"
7002 PRINT "RIVER MILE   RIVER MILE   IN/OUT (cfs)  IN/OUT (cfs)   FLOW(cfs)"
7003 PRINT USING "&";"================================================================="
7005 FOR I=1 TO 16
7006 IF I=2 THEN PRINT USING "     #,###.#";RM(I-1),RM(I),QSWTOT(I)-32.12,QGW(I),QFINAL(I) : GOTO 7008
7007 PRINT USING "     #,###.#";RM(I-1),RM(I),QSWTOT(I),QGW(I),QFINAL(I)
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7008 NEXT I
7009 PRINT USING "    #,###.#";RM(16),RM(17),QLSR+QATM-(QEVAP+QSTORE),QGWR,QFINAL(18)
7010 VARY1(17)=VARY1(16)+VARY3(16)+VARY5(16)
7011 DEVTPFINAL(I)=(VARTPFINAL(I)^.5)
7012 PRINT USING "&";"-----------------------------------------------------------------"
7013 PRINT "LONG LAKE DAM OUTFLOW  =";QFINAL(18);"+/-";VARQLLDAM^.5;"cfs"
7014 '
7015 INPUT "PRESS RETURN TO CONTINUE",NOTHING
7016 '
7020 '--------------------------------------------------------------------------
7021 '  PRINT PHOSPHORUS MASS BALANCES BY REACH
7022 '--------------------------------------------------------------------------
7023 PRINT:PRINT "PHOSPHORUS MASS BALANCES BY REACH":PRINT
7024 PRINT " UPSTREAM    DOWNSTREAM     UPSTREAM  SURFACE INPUT         DOWNSTREAM"
7025 PRINT "RIVER MILE   RIVER MILE     kg P/day     kg P/day       kg P/day     ug/L"
7026 PRINT USING "&";"========================================================================"
7028 FOR I=1 TO 16
7029 UPSTREAM(I)=QFINAL(I-1)*TPFINAL(I-1)/CF2 : DOWNSTREAM(I)=QFINAL(I)*TPFINAL(I)/CF2
7030 PRINT USING "     #,###.#";RM(I-1),RM(I),UPSTREAM(I),QSWTOT(I)*TPSWTOT(I)/CF2,DOWNSTREAM(I);TPFINAL(I)
7031 NEXT I
7032 PRINT USING "     #,###.#";RM(16),RM(17),QFINAL(16)*TPFINAL(16)/CF2,POOLTPLOAD/CF2
7034 PRINT USING "&";"------------------------------------------------------------------------"
7035 LLOADERR=((VARTPFINAL(17)*QFINAL(17)^2+VARQLLINFLOW*FINALTP1^2)^.5)/CF2
7036 PRINT "LONG LAKE INPUT =";QFINAL(17)*FINALTP1/CF2;"+/-";LLOADERR;"kg P/day;    TMDL = 259 kg P/day"
7037 '
7038 INPUT "PRESS RETURN TO CONTINUE",NOTHING
7039 '
7040 '-------------------------------------------------------------------------
7041 '      CALCULATE AND PRINT SUMMARY OF ATTENUATION OF SURFACE WATER INPUTS
7042 '-------------------------------------------------------------------------
7043 '
7044 'TP ATTENUATION USING SYSTEM RESPONSE TO A 1 kg P/day ADDITION
7045 ATTEN$="Y"
7046
7047 FOR K=1 TO 16
7048 PRINT "COMPUTING REACH";K
7049 GOTO 3990
7050 IF ALLOC$="Y" THEN GOTO 8470
7051 TPTRANS(K)=(TPFINAL(17)-FINALTP1)*QFINAL(17)/CF2
7054 NEXT K
7055 PRINT:PRINT:PRINT:PRINT
7056 PRINT "SUMMARY OF TOTAL PHOSPHORUS ATTENUATION :" : PRINT
7057 PRINT "         TP REMOVAL    TP LOADING     RIVER TP        EFFECTIVE TP"
7058 PRINT "SOURCE         (%)     (kg P/day)  ATTENUATION (%)  LOAD (kg P/day)"
7059 PRINT USING "&";"=================================================================="
7060 PRINT "LAKE CDA",0,QFINAL(0)*TPFINAL(0)/CF2,100*(1-TPTRANS(1)),QFINAL(0)*TPFINAL(0)*TPTRANS(1)/CF2
7061 ATTTPLOAD=QFINAL(0)*TPFINAL(0)*TPTRANS(1)/CF2 : FOR I=1 TO 16 : FOR J=1 TO SOURCECNT(I)
7062 PRINT AA$(I,J),100*TPREMOVE(I,J),QSW(I,J)*TPSW(I,J)/CF2,100*(1-TPTRANS(I)),QSW(I,J)*TPSW(I,J)*TPTRANS(I)/CF2
7063 ATTTPLOAD=ATTTPLOAD+QSW(I,J)*TPSW(I,J)*TPTRANS(I)/CF2 : NEXT J : NEXT I
7064 AQUIATM=(TOTGWTPLOAD+ATMTPLOAD+GWRTPLOAD)/CF2 : RESIDUAL=(QFINAL(17)*FINALTP1/CF2)-(ATTTPLOAD+(LSRTPLOAD/CF2))
7065 PRINT "L SPOK R",0,KGLSRTPLOAD,0,KGLSRTPLOAD
7066 PRINT "TOTAL AQUIFER/ATMOSPHERIC",AQUIATM,100*(1-RESIDUAL/AQUIATM),RESIDUAL
7067 PRINT USING "%";"=================================================================="
7068 TOTLOAD=(QFINAL(0)*TPFINAL(0)+TOTSWTPLOAD+TOTGWTPLOAD+POOLTPLOAD)/CF2
7069 PRINT "TOTAL                 ",TOTLOAD,100*(1-(QFINAL(17)*FINALTP1/(CF2*TOTLOAD))),QFINAL(17)*FINALTP1/CF2
7070 INPUT "PRESS RETURN TO CONTINUE",NOTHING
7071 '
7550 '
7560 '-------------------------------------------------------------------------
7570 '               CALCULATE AND PRINT PREDICTED LONG LAKE EUPHOTIC ZONE CONDITIONS (lines 7600-7890)
```

```
7580 '----------------------------------------------------------------------
7590 '
7610 FOR K=1 TO 25 : PRINT : NEXT K
7622 '
7624 'EUPHOTIC ZONE TOTAL P CONCENTRATION : MEAN JUNE-OCTOBER
7626 '------------------------------------------------------
7630 EZTP=1.0048*FINALTP1                                        'ug/L MEAN
7640 ERREZTP=(FINALTP1^2*.1576^2+1.0048^2*VARTPFINAL(17))^.5     'ug/L STD ERR
7642 '
7644 'EUPHOTIC ZONE CHLOROPHYLL A CONCENTRATION : MEAN JUNE-OCTOBER
7646 '------------------------------------------------------------
7650 EZCHLA=EXP(.6623+.5368*LOG(FINALTP1))                       'ug/L MEAN
7652 CVTPFINAL=(VARTPFINAL(17)^.5)/FINALTP1                      'FRACTION
7654 CVEZCHLA=(.203^2+(.5368*CVTPFINAL)^2)^.5                    'FRACTION
7656 ERREZCHLA=CVEZCHLA*EZCHLA                                   'ug/L STD ERR
7658 '
7660 'EUPHOTIC ZONE CHLOROPHYLL A CONCENTRATION : UPPER 95% PEAK JUNE-OCTOBER
7661 '----------------------------------------------------------------------
7662 EZPKCHLA=EXP(1.1595+.60649*LOG(FINALTP1))                   'ug/L MEAN
7663 CVEZPKCHLA=(.206^2+(.60649*CVTPFINAL)^2)^.5                 'FRACTION
7664 ERREZPKCHLA=CVEZPKCHLA*EZPKCHLA                             'ug/L STD ERR
7670 ERREZCHLA=CVEZCHLA*EZCHLA                                   'ug/L STD ERR
7672 '
7674 'EUPHOTIC ZONE PHYTOPLANKTON BIOVOLUME : MEDIAN JUNE-OCTOBER
7676 '----------------------------------------------------------
7680 EZPHYVOL=EXP(.80946*LOG(FINALTP1)-1.6392)                   'mm3/L MEDIAN
7690 CVEZPHYVOL=(.236^2+(.80946*CVTPFINAL)^2)^.5                 'FRACTION
7700 ERREZPHYVOL=CVEZPHYVOL*EZPHYVOL                             'mm3/L STD ERR
7710 '
7720 'EUPHOTIC ZONE SECCHI DISK DEPTH : MEDIAN JULY-OCTOBER
7730 '----------------------------------------------------
7740 SECCHI=EXP(-.29469*LOG(FINALTP1)+2.1521)                    'METERS MEDIAN
7750 CVSECCHI=(.128^2+(.29469*CVTPFINAL)^2)^.5                   'FRACTION
7760 ERRSECCHI=CVSECCHI*SECCHI                                   'METERS STD ERR
7770 '
7780 'EUPHOTIC ZONE EXTINCTION COEFFICIENT : JUNE-OCTOBER MEAN
7790 '-------------------------------------------------------
7800 EXTINCT=EXP(.16144*LOG(FINALTP1)-.97271)                    '1/M MEAN
7810 CVEXTINCT=(.142^2+(.16144*CVTPFINAL)^2)^.5                  'FRACTION
7820 ERREXTINCT=CVEXTINCT*EXTINCT                                '1/M STD ERR
7830 '
7890 'MINIMUM HYPOLIMNETIC DISSOLVED OXYGEN : JUNE-OCTOBER
7900 '---------------------------------------------------
7910 MINDO=EXP(-1.45596*LOG(FINALTP1)+2.1946E-04*(QFINAL(18))+4.95921)  'mg/L HYP MIN
7920 CVQFINAL=(VARQLLDAM^.5)/QLLDAM                                     'FRACTION
7930 CVMINDO=(.295^2+(1.45596*CVTPFINAL)^2+(1.08232*CVQFINAL)^2)^.5     'FRACTION
7940 ERRMINDO=CVMINDO*MINDO                                             'mg/L STD ERR
7960 '
GOTO 7999
7970 'PRINT PREDICTED LONG LAKE WATER QUALITY CONDITIONS
7980 '-------------------------------------------------
7990 PRINT "The following table presents a summary of Long Lake predicted"
7992 PRINT "water quality for a variety of trophic state indicators."
7994 PRINT "The predictions are presented with estimated standard errors,"
7996 PRINT "as well as commonly accepted trophic state criteria."
7998 PRINT : INPUT "ENTER RETURN TO CONTINUE",NOTHING
7999 FOR I=1 TO 25 : PRINT : NEXT I
8000 PRINT "SUMMARY OF LONG LAKE WATER QUALITY PREDICTIONS (Jun-Oct):" : PRINT
8002 PRINT USING "&";"PARAMETER                    PREDICTION    STD ERR       CRITERIA"
8004 PRINT USING "&";"================================================================"
```

```
8010 PRINT "EZ MEAN TOTAL P             ";EZTP;"+/-";ERREZTP,"25 ug P/L"
8012 PRINT
8022 PRINT "EZ CHL a - UPPER 95%tile    ";EZPKCHLA;"+/-";ERREZPKCHLA,"16 ug/L"
8024 PRINT
8030 PRINT "EZ CHL a - MEAN             ";EZCHLA;"+/-";ERREZCHLA,"10 ug/L"
8032 PRINT
8050 PRINT "EZ PHYTO. BIOVOLUME         ";EZPHYVOL;"+/-";ERREZPHYVOL,"5 mm3/L"
8052 PRINT
8070 PRINT "SECCHI DISK DEPTH           ";SECCHI;"+/-";ERRSECCHI,"3 meters"
8072 PRINT
8090 PRINT "EXTINCTION COEFFICIENT      ";EXTINCT;"+/-";ERREXTINCT,"0.5 /m"
8092 PRINT
8130 PRINT "MINIMUM HYPOLIMNETIC DO     ";MINDO;"+/-";ERRMINDO,"4 mg/L"
8132 PRINT USING "&";"=============================================================="
8134 PRINT : INPUT "ENTER RETURN TO CONTINUE",NOTHING
8136 FOR I=1 TO 25 : PRINT : NEXT I
8138 '
8140 PRINT "OPTIONS MENU:":PRINT
8150 PRINT:PRINT "     1.  EDIT EXISTING SURFACE WATER DISCHARGES"
8160 PRINT:PRINT "     2.  ENTER NEW SOURCES OR MAKE MAJOR CHANGES TO INPUT CONDITIONS"
8170 PRINT:PRINT "     3.  ESTIMATE WASTELOAD ALLOCATION BASED ON ATTENUATION-BASED TP REMOVAL"
8180 PRINT:PRINT "     4.  END PROGRAM"
8190 PRINT:PRINT:PRINT "ENTER YOUR SELECTION NUMBER"
8200 INPUT X
8210 IF X<>1 AND X<>2 AND X<>3 AND X<>4 THEN GOTO 8200
8220 IF X=1 THEN ATTEN$="N":ALLOC$="N":PRINT:PRINT:PRINT:PRINT: GOTO 6955
8230 IF X=2 THEN PRINT:PRINT:PRINT:PRINT: GOTO 10
8240 IF X=3 THEN GOTO 8300
8250 IF X=4 THEN END
8260 '
8270 '-------------------------------------------------------------------------
8280 ' CALCULATE ATTENUATION-BASED WASTELOAD ALLOCATION
8290 '-------------------------------------------------------------------------
8300 '
8310 ALLOCOUNT=0 : TESTK#=.12
8320 ALLOC$="Y" : ATTEN$="N"
8330 FOR I=1 TO 16 : SUMTP=0 : FOR J=1 TO SOURCECNT(I)
8340 IF (I=8 AND J=1) OR (I=12 AND J=1) OR (I=14 AND J=2) THEN GOTO 8380
8350 TPREMOVE(I,J)=1-(TESTK#/TPTRANS(I))
8360 TPSW(I,J)=TPINSW(I,J)*(1-TPREMOVE(I,J))
8380 SUMTP=SUMTP+(TPSW(I,J)*QSW(I,J))
8390 SWTPLOAD(I)=SUMTP
8395 IF QSWTOT(I)=0 THEN GOTO 8410
8400 TPSWTOT(I)=SUMTP/QSWTOT(I)
8410 NEXT J : NEXT I
8420 GOTO 3990
8430 IF .001>(ABS(FINALTP1-(25/1.0048))) THEN GOTO 8530
8435 ATTEN$="Y" : ALLOCOUNT=ALLOCOUNT+1
8440 PRINT "COMPUTATIONAL PASS NUMBER";ALLOCOUNT
8450 FOR K=1 TO 16
8460 GOTO 3990
8470 TPTRANS(K)=(TPFINAL(17)-FINALTP1)*QFINAL(17)/CF2
8480 NEXT K : TOTSWTPLOAD=0 : TOTGWTPLOAD=0
8481 FOR I=1 TO 16
8482 TOTSWTPLOAD=TOTSWTPLOAD+SWTPLOAD(I)                        '(ug/L)(CFS)
8483 IF QGW(I)<0 THEN GOTO 8485 ELSE GOTO 8484
8484 TOTGWTPLOAD=TOTGWTPLOAD+(QGW(I)*TPGW(I))                   '(ug/L)(CFS)
8485 NEXT I
8486 POINTSOURCE=(TOTSWTPLOAD-(QSW(8,1)*TPSW(8,1)+QSW(12,1)*TPSW(12,1)+QSW(14,2)*TPSW(14,2)))/CF2  'Kg/day
8487 TOTLOAD=(TOTSWTPLOAD+TOTGWTPLOAD+(QFINAL(0)*TPFINAL(0))+POOLTPLOAD)/CF2                    'Kg/day
```

```
8490 ALLOWABLE=((25/(1.0048*FINALTP1))*TOTLOAD)-(TOTLOAD-POINTSOURCE)
8500 TESTK#=TESTK#*ALLOWABLE/POINTSOURCE
8510 GOTO 8320
8520 '
8530 PRINT:PRINT:PRINT:PRINT:PRINT
8540 PRINT "SUMMARY OF ATTENUATION-BASED TP ALLOCATION FOR INPUT CONDITIONS" : PRINT
8545 PRINT USING "%";"                            REQUIRED       ALLOWABLE         RIVER"
8550 PRINT USING "%";"               NET Q        REMOVAL      TP LOADING    ATTENUATION"
8560 PRINT USING "%";"SOURCE        (MGD)            (%)      (kg P/day)            (%)"
8570 PRINT USING "%";"================================================================="
8580 FOR I=1 TO 17 : FOR J=1 TO SOURCECNT(I)
8590 IF (I=8 AND J=1) OR (I=12 AND J=1) OR (I=14 AND J=2) THEN GOTO 8610
8600 PRINT AA$(I,J),QSW(I,J)/CF1,100*TPREMOVE(I,J),(QSW(I,J)*TPSW(I,J))/CF2,100*(1-TPTRANS(I))
8610 NEXT J : NEXT I
8620 PRINT USING "%";"================================================================="
8625 PRINT "PREDICTED LONG LAKE EUPHOTIC ZONE TP =";1.0048*FINALTP1;"ug P/L"
8630 PRINT:PRINT : INPUT "ENTER RETURN TO CONTINUE",NOTHING
8640 GOTO 8136
```

APPENDIX F

REVIEW AND COMMENTS

APPENDIX F

REVEIW AND COMMENT

PUBLIC PARTICIPATION AND REVIEW

Public participation has been an integral part of the TMDL revision process. People and agencies involved in the earlier "Phosphorus Attenuation In The Spokane River" work, and all dischargers were informed of this upcoming report in January 1987. As a result, 55 draft copies of the "Spokane River Basin: allowable phosphorus Loading" were distributed on March 13, 1987 for a 45 day review period.

The following submitted comments:

John Yearsley	USEPA Region X
Susan Kaun	Liberty Lake Sewer District
William Funk	Washington State University
Kenneth Hartz	Washington State University
Barry Moore	Washington State University
Fred Shiosake	Washington Water Power
Kent Helmer	City of Post Falls
Joseph Hargrave	Hayden Area Regional Sewer Board
Ray Stone	City of Couer d' Alene
John Schaefer	Kaiser Aluminum
Phil Williams	City of Spokane
Larry Esvelt	Esvelt Environmental Engineering
Thereon Rust	Spokane Industrial Park
Thomas Yeager	City of Rathdrum
Gordon Boyd	National Park Service
Roger Tinkey	Idaho Division of Environment
Mike Beckwith	Idaho Division of Environment

Response to the comments and resolution of any related issues was accomplished through consensus by Harper-Owes and members of the involved regulatory agencies:

Ecology	John Arnquist
	Dick Cunningham
	Carol Jolly
	Claude Sappington
	Lynn Singleton
USEPA	Bob Byrd
	Cecil Carroll
	Clark Gaulding
	Sally Marquis
	Warren McFall
	Lynn McKee
	Tom Wilson
	John Yearsley

Idaho Division of Environment	Mike Beckwith Al Murray Roger Tinkey Ed Tulloch

Because several reviewers had similar comments, they and our general responses have been summarized below. Lengthy technical responses have been incorporated into the report when appropriate.

QUALITY ASSURANCE AND DATA

The report discusses results of external QA analyses which revealed that original EWU determinations of TP and chl a underestimated the true values for these parameters. Adjustments to this prior data were found to be necessary. The additional random errors introduced by correction of systematic bias of TP and chl a data were estimated at 3 percent and 0-14 percent, respectively.

In reference to the accuracy and precision of EWU TP and chl a analyses, one reviewer commented, "A major problem exists in the lack of technical reliability, as documented in the report, of the limnological analyses of Long Lake." Although we concur that EWU chl a determinations performed prior to 1981 are somewhat uncertain (+/- 14 percent), we disagree that the identified deficiencies in the TP and chl a analyses constitute a "major problem," particularly relative to the conclusions of this study. Our reasons are summarized below.

- A random error of +/- 3 percent resulting from bias correction of EWU TP analyses is, in our opinion, not excessive compared to performance characteristics of state-of-the-art methods.

- Although other random variations (i.e. precision errors) in the EWU TP determinations also contribute to the variability observed in the data base, we believe that these random variations are compensated by the large number of determinations performed over the 13-year study period.

- The principal EWU data used in the development of the TMDL for Long Lake concerned 1981-85 EZ-TP determinations and their relationship (evaluated by regression) with influent-TP. The previously completed P-attenuation model (Patmont et al., 1985) with modifications as discussed in this report, was used as the basis for determining phosphorus transport to Long Lake. We believe that all of these data are valid and supported by concurrent internal and external QA/QC information. In the case of the EZ-TP versus influent-TP regressions, any error in the EWU TP determinations would likely affect both parameters equally, and would, therefore, not alter the observed relationship.

- EWU chl a data did not form the basis for the TMDL determination. The chl a data and a variety of other trophic parameters were used only to determine if Long Lake responded to TP inputs similarly to other northern temperate lakes. Because several other tropic measures were included in this evaluation, additional random errors introduced by bias correction of the chl a data (0-14 percent) would not significantly alter the outcome. In addition, more recent EWU chl a determinations (e.g. 1985 data), which did not exhibit an analytical bias, were consistent with the adjusted prior data. The importance of phosphorus as the primary determinant of algal growth in Long Lake is also well supported by bioassay data.

Silica Interferences With Phosphorus Analyses

One reviewer expressed concern over silica concentrations in the Spokane River because high concentrations may interfere with phosphorus analyses. Documentation for the problem is presented in Standard Methods for the Examination of Water and Wastewater, 16th Edition (APHA, 1985). It reports that concentrations of 10 mg/L will not interfere with phosphorus determinations. By omission, it is therefore implied that some higher silica concentration will interfere. The reviewer requested a study to determine the possible significance of the Spokane River silica concentrations on the phosphorus results. A study does not appear necessary because the silica concentrations in the Spokane River and Long Lake are generally lower than the 10 mg/L criterion. For example, Long Lake euphotic zone concentrations over the 13 year period of record have averaged 7.4 +/- 2.7 mg/L. This concentration is also similar to the world-wide average silica concentration of 6.5 mg/L (Wetzel, 1975) and within the range reported for lakes used to develop the trophic indicators found in this report.

Lake Coeur d' Alene Data

One reviewer believed more flow and quality data were needed for the outlet of Lake Coeur d'Alene in order to determine the magnitude of this input. Three data sources were used in the present study spanning three growing seasons. Evaluation of these records indicated that phosphorus concentrations in the outflow did not vary significantly with seasonal Coeur d'Alene discharges ranging from approximately 2,000 to 4,000 cfs. Because the river is being managed for 2,970 cs, which represents the median flow event at Lake Coeur d' Alene, available data are believed to be adequate.

Low Flow Bias

Concern was expressed by one reviewer that three very low flow years have occurred over a 15 year study period and skewed the results. The data base has high, medium and low flow years and therefore represents a complete range of flow conditions. The influence of flow variations on water quality conditions of the Spokane River and Long Lake was addressed in the water quality models developed during this study. The median flow condition (obtained from the 1913 to 1985 discharge records) has been chosen for the management goal on Long Lake.

Data Adequacy

Several of the points discussed above concern the general adequacy of the data. The Spokane River Basin, unlike the great majority of other systems, has an extremely large and complete data base, spanning more than 15 years. The data uncertainties and the questions resulting from the earlier 1981 Wasteload Allocation efforts have been addressed. Additional data are not likely to significantly alter the results of this study because of this large data base. The allocation has been an issue since 1979. We are now in a position to move anead.

HYDRODYNAMIC ANALYSIS

The text has been clarified to discuss how the hydrodynamic analysis was used. Basically, it was conducted to evaluate whether the Spokane River is isolated from the Long Lake epilimnion during the growing season. It was determined that this critical region of Long Lake is continually flushed with incoming river water. Therefore, changes in the seasonal phosphorus loading will readily influence surface water characteristics. This result influenced the selection of appropriate water quality models developed during this study.

PERIPHYTON

Several reviewers were concerned over the intended regulatory use of the periphyton data. Because phosphorus does not appear to be a major factor presently controlling periphyton growth, Ecology will not be using periphyton indicators to manage water quality in the Spokane River.

UNCERTAINTY ANALYSIS

Several reviewers requested that additional information be provided on the methods used to estimate and propagate systematic and random uncertainties in the data and predictive models. An example calculation and additional discussion on these methods is presented in Appendix B.

MODEL DOCUMENTATION AND AVAILABILITY OF DATA

Several reviewers requested additional documentation of the Spokane River/Long Lake model and data base. The structure and development of phosphorus transport elements of the model are described in detail in Patmont et al. (1985). A complete model listing is presented in Appendix E. In addition, a user's manual and diskette (BASIC) ae available through Ecology. Pertinent Long Lake and river data are available through Ecology, also in diskette (DBASE III Plus) form.

KAISER TP LOADING

The Kaiser wastewater discharge represents the combined flow of coolant water withdrawn from the Spokane River and a small quantity (typically 1 percent) of wastewater. The TP load contributed by the facility was calculated based on the increase in phosphorus between the river intake and the wastewater outfall. These methods and raw data are presented in Patmont et al. (1985).

CAUSES(s) OF DISSOLVED OXYGEN DEPLETIONS

One reviewer hypothesized that much, if not all, of the improvement in hypolimnetic D.O. levels in Long Lake was due to reductions in BOD discharged from wastewater sources. In particular, BOD removals at the Spokane wastewater treatment plant, which began secondary treatment in 1977, appeared to correlate with D.O. improvements within the reservoir. However, an assessment of inputs of oxygen demanding materials to Long Lake from all sources suggested that wastewater BOD inputs were minor in comparison to reservoir totals (see Table 8). Algal-derived inputs appeared to be the principal cause of oxygen depletion in Long Lake. Algal growth, in turn, was shown to be strongly controlled by phosphorus. The proposed phosphorus standard discussed in this report was designed to provide reasonable protection of Long Lake's oxygen resources.

RESERVOIR VS. LAKE

Several reviewers stated that water quality characteristics of Long Lake should not be compared with criteria developed from natural, northern temperate lakes because of possible metabolism differences. Although we agree that many reservoirs which receive a large silt load often support less algal growth than lakes with a similar supply of phosphorus (primarily due to light limitation and a higher proportion of unavailable particulate P), Long Lake does not conform to this generalized typology. Observed concentrations of chl a in Long Lake over the 13-year record correspond very closely with those predicted using Smith's (1982) model of algal growth in northern temperate lakes. Algal growth in Long Lake apparently follows the "average" defined by the same set of lakes used to develop the trophic criteria.

BASIS FOR WATER QUALITY STANDARD

A number of reviewers questioned the selection of the 25 ug/L EZ-TP standard as the appropriate concentration (and variable) which would adequately protect Long Lake from eutrophy. As discussed in the report, trophic criteria can not be defined in absolute terms. Some measure of uncertainty (and therefore risk) is always present when "acceptable" limits are defined. Given these potential limitations, we believe that a water quality standard should be established on the basis of the preponderance of the information available. This information is summarized below:

- TP is the variable most correlated with trophic status in northern temperate lakes.
- A considerable amount of data collected on Long Lake identifies phosphorus as the primary determinant of algal growth and oxygen depletion.
- Phosphorus concentrations in Long Lake can be modelled with the least amount of uncertainty (also considering QA data) compared to the other common trophic variables.
- OECD (1982) recommended a general lake management goal of mid-mesotrophy. Based on OECD's statistical analyses, mid-misotrophic conditions corresponded to an in-lake TP concentration of 26.9 ug/L.
- EPA (1986) recommended an approximate criterion for TP to protect trophic conditions of 25 ug/L, based largely on the results of OECD (1982).

- Existing phosphorus loads to the Spokane River result in median seasonal in-lake levels of 24.8 ug/L. This level may be interpreted as a standard under an antidegradation policy.

- A 25 ug/L EZ-TP concentration in Long Lake is generally consistent with approximate trophic criteria for other parameters (e.g. chl a, phytoplankton biovolume, D.O.).

LONG LAKE DAM AND ITS ROLE IN THE WASTELOAD ALLOCATION

One reviewer believes Washington Water Power, which owns Long Lake Dam, is partially responsible for the maintenance and protection of reservoir water quality. The argument is based on the premise that, without the dam we would not have a water quality problem in Long Lake. The dam, like most, was built before environmental laws were in force or of significant concern. Present today, Ecology must do what is necessary and feasible in order to protect water quality. Without man's input of phosphorus and other pollutants, the dam's presence would be a relatively unimportant water quality factor.

NON-POINT POLLUTION SOURCES

The reports' treatment of non-point pollution sources has been raised. The reviewers argue that all sources should be identified, quantified, and considered in any allocation plan. Control measures could then be instituted. Ecology's present position of including only point source control measures in an allocation is based on an assessment of the magnitude and potential control of all sources. This does not preclude the future inclusion of additional non-point controls. A major combined sewer overflow reduction project is currently underway by the City of Spokane. This program is expected to reduce the total seasonal non-point phosphorus loading by approximately 20-30 percent. It should also be recognized that phosphorus occurs naturally and some background concentration is expected in any drainage. In the case of Lake Coeur d' Alene, the major surface water source, an average TP concentration of 8-10 ug/L over the growing season is low and has been interpreted as the natural condition. Admittedly there are cultural sources above the mouth, but their impact after the long residence time is probably small and very difficult to quantify.

POINT SOURCE LOADING AND/OR OPERATIONAL ASSUMPTIONS

Several reviewers had specific comments about their individual wastewater quality and quantity for both present and future discharge conditions. These have been more clearly discussed in the text. However, it should be noted that future conditions are presented for illustration only and simply reflect present permit conditions. Detailed refinements for future conditions were outside the scope of the present effort.

WASTELOAD ALLOCATION COSTS

The costs of implementing phosphorus control measures in the drainage basin was raised by several reviewers. Ecology recognizes additional controls will be expensive in both dollars and potential impacts on growth. As per the Federal Clean Water Act, the allocation must proceed on the water quality limited section of the Spokane River.

WASTELOAD ALLOCATION: THE NEXT STEP

Several reviewers have wondered how the results of the completed report would be used to implement a phosphorus control strategy. The report provides the technical foundation needed to manage Long Lake water quality, a task Ecology is committed to accomplishing. A new water quality total phosphorus standard is being promulgated for Long Lake based on information presented in this report. Ecology will then work with the other involved regulatory agencies and dischargers to begin developing implementation strategies and assessing funding options. Currently Ecology is initiating a process where the interstate dischargers will be given one year to collectively decide how to approach phosphorus limitations in the drainage. If agreement cannot be reached, effluent limitations will be placed into NPDES discharge permits along with implementation schedules where appropriate.