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PHOSPHORUS ATTENUATION IN THE SPOKANE RIVER

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PHOSPHORUS ATTENUATION IN THE SPOKANE RIVER

by

C.R. Patmont, G.J. Pelletier, and Dr. M.E. Harper

Harper-Owes

Seattle, Washington

in cooperation with

Dr. L.A. Esvelt, Esvelt Environmental Engineering

D.A. Nichols and Dr. R.A. Soltero, Eastern Washington University
Turnbull Laboratory for Ecological Studies

Dr. D.P. Lettenmaier, Dr. E.B. Welch, and Dr. J.E. Richey,
University of Washington

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ABSTRACT

The Spokane River Wasteload Allocation process was initiated by court order in 1979. Pursuant to this order, the Washington Department of Ecology determined the maximum permissible phosphorus loading from all sources in the river which would protect beneficial uses of Long Lake. The critical loading value was expressed as the seasonal influent load to Long Lake and did not specifically consider phosphorus loss or attenuation during riverine transport.

A study was conducted during the low flow (discharge range) season of 1984 to determine if significant losses of total phosphorus occurred within the river system from its source at Lake Coeur d'Alene, Idaho to Nine Mile Dam, Washington just above Long Lake. A detailed assessment of phosphorus transport within 15 reaches of the river and during 9 sampling dates revealed that more than 40 percent of the total influent load to the river was lost during transport. Most of this loss occurred via in-river removal processes, though river seepage into the adjacent aquifer system was also found to be a significant loss mechanism. Characteristics of the in-river attenuation process indicate that this removal may be due to biological uptake by attached plant populations and/or chemical adsorption on the river bottom.

The magnitude of the attenuation process was found to be controlled by both phosphorus and nitrogen concentrations within the river. Upper reaches of the study area appeared to be strongly nitrogen-limited, and were associated with a relatively low attenuation rate. The reach below the City of Spokane Advanced Wastewater Treatment Plant (AWT) also exhibited a low phosphorus attenuation rate, possibly the result of changes in river chemistry due to the AWT inputs.

A predictive model of phosphorus transport through the river system was developed as a tool for wasteload allocation. This model addresses uncertainties in hydrologic, phosphorus loading, and attenuation processes in the river system and may generally be appropriate for a variety of phosphorus loading scenarios. Wasteload allocation may possibly result in phosphorus loading limitations from municipal and industrial sources to maintain or enhance the improved water quality of Long Lake.

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INTRODUCTION

The Spokane River system, from its source at the outlet of Lake Coeur d'Alene, Idaho (RM 111.7) to its point of discharge into Long Lake near Nine Mile Dam, Washington (RM 58.1), presently serves as the receiving water for a variety of municipal and industrial wastewaters, storm drains, and combined sewer overflows (Figure 1). Many of these discharges contain relatively high concentrations of phosphorus (Singleton and Joy, 1982), which appears to be the principal growth-limiting nutrient to algae in Long Lake (Soltero et al, 1983). Preliminary loading calculations have suggested that more than 80 percent of the current total phosphorus load to the Spokane River during critical flow events originates from municipal and industrial sources (Singleton, 1981; URS, 1981).

The magnitude of the total phosphorus load which enters Long Lake has been observed to control the extent of algal biomass development and beneficial use impairment within this popular reservoir (Soltero et al, 1983). Previous studies have identified a critical phosphorus loading quantity to Long Lake which would lead to beneficial use impairment. Advanced wastewater treatment (AWT) of effluent from the City of Spokane, which historically has been the largest point source on the river, was initiated in late 1977 in an effort to control identified nuisance algal conditions in Long Lake. Ongoing monitoring of the lake has revealed that the employment of AWT at this plant has substantially reduced phosphorus and algal biomass levels in Long Lake. Phosphorus loads which now enter Long Lake are presently acceptably low and not associated with significant resource impairment (Singleton, 1981).

Population growth and a trend towards minimizing the use of individual septic systems in the Spokane River basin has resulted in a steady increase in the quantity of municipal and industrial wastewaters discharged to the river. Based on projected future increases in municipal discharges, it appears that phosphorus loading to Long Lake may exceed the established design "threshold" by 1990 if the City of Spokane remains the only discharger employing AWT (Singleton, 1981). This projection, however, assumes that phosphorus is transported conservatively through the river system over its entire length of more than 53 miles (86 km).

Studies conducted during 1979-81 in roughly the middle one-third of the river system (RM 94 to RM 73) revealed that during summer low flow periods a significant ($P<.05$) loss of phosphorus does occur (Yearsley, 1982 and data of Gibbons et al, 1982 and Singleton and Joy, 1982 analyzed by Harper-Owes; see Appendix D). Total phosphorus losses, or attenuation, within this reach amounted to roughly 30-50 pecent of the estimated input of this nutrient. At high river flows during both summer and non-summer months, no significant ($P>.05$) gain or loss of phosphorus was detected. Since the critical period of phosphorus loading to Long Lake is during the summer low flow season (Soltero et al, 1983), phosphorus attenuation was recognized by the regulatory agencies and dischargers as a process which could possibly mitigate the impacts of

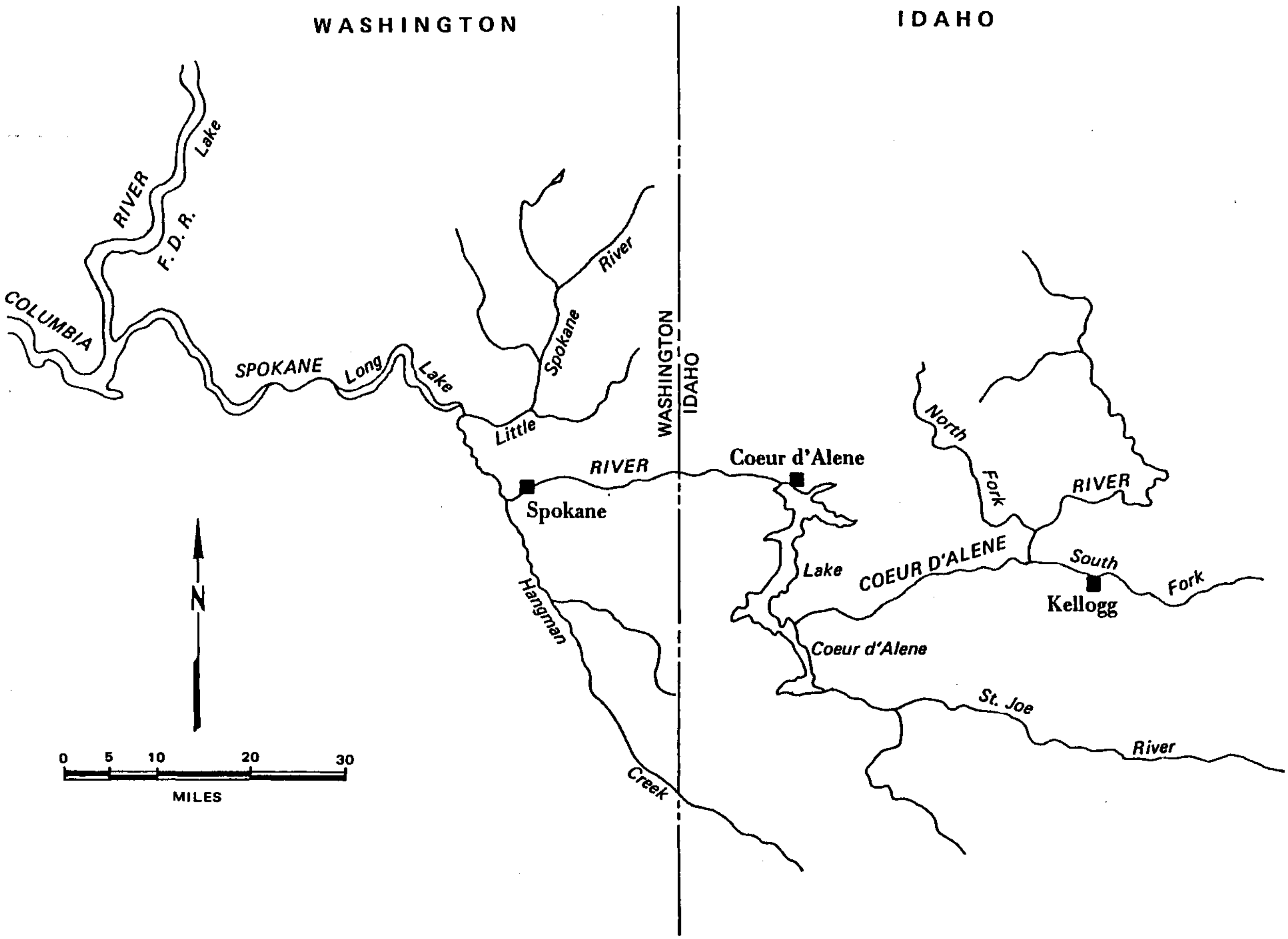


Figure 1. SPOKANE RIVER DRAINAGE SYSTEM

increased phosphorus loads on Long Lake. The available data, however, were not sufficient to permit reliable predictions of the magnitude of attenuation given variable loading and river flow conditions.

Harper-Owes was retained by the Washington Department of Ecology (WDOE) in cooperation with the U.S. Environmental Protection Agency (EPA) and the Idaho Department of Health and Welfare (IDHW) to perform a detailed assessment of phosphorus attenuation within the Spokane River from Lake Coeur d'Alene to Nine Mile Dam. The study included an extensive field collection effort during the summer low flow period of 1984. The investigation was oriented towards the determination of mass balance "residuals" in 15 river reaches. Measurement of attenuation was performed by examining the differences between total inputs and outputs within each reach. Although a mass balance approach may not be capable of reliably differentiating between the effects of a variety of possible attenuation mechanisms (e.g. biological uptake vs. chemical adsorption within the river channel), characterization of individual processes is in practice a very difficult task and was considered to be of marginal benefit to the objective of predicting total phosphorus loading. Mass balance techniques have the advantages of being statistically tractable (thus reducing predictive uncertainty) and are particularly appropriate in systems with large variations in river flow. Previous investigations of low flow hydrology in the Spokane River have revealed that alternating ground water inputs and outputs result in a very complex flow regime which could have a considerable effect on phosphorus attenuation characteristics within the river (Broom, 1951; Bolke and Vaccaro, 1981; URS, 1981). The impact of these flow variations on phosphorus attenuation is best addressed within a mass balance framework.

The study presented herein describes the methodology and results of the phosphorus attenuation investigation. The data were analyzed relative to the statistical significance and the predominant controlling characteristics of the attenuation process in the Spokane River. These data were then used to develop a computer model of phosphorus attenuation applicable to design flow conditions and a variety of differing loading allocation scenarios. Model limitations and predictive uncertainties are addressed. The model presented in this report -- or a modification thereof -- is intended to be used by state and federal regulatory agencies as a tool to allocate phosphorus wasteloads discharged into the Spokane River.

METHODOLOGY

The methodology used in this study to examine phosphorus loss (i.e. attenuation) during transport through the Spokane River system was based in large part upon the measurement of phosphorus loading at selected stations throughout the river between Coeur d'Alene, Idaho and Nine Mile, Washington. Adjacent river stations delineated the reaches of the river examined in this study. Attenuation was evaluated by measuring the total inputs and outputs of phosphorus to and from each reach, respectively, and determining whether or not statistically significant losses (or gains) had occurred within the reach. The sensitivity of this mass balance approach in assessing attenuation, of course, is largely determined by the ability to obtain precise measurements of all inputs and outputs within each reach. Characteristics of the sampling locations, sampling frequency and timing, and data quality control all influence the resolution of the mass balance measurements. These characteristics were evaluated during the study design phase of this project to assure that the outcome of this attenuation study would be successful. The rationale of the study design and details of sampling and analysis methodologies employed during the study are presented below.

The previously established design flow for determining the critical phosphorus load to Long Lake is 1,333 cfs (37.75 m^3/sec) at RM 100.7 (below Post Falls Dam; Singleton, 1981). This discharge represents the estimated 1-in-20-year low flow at a site near the upstream boundary of the present study area, expressed as the June-November average. All other conditions applicable to phosphorus allocation are basically tied to this flow. Because a principal objective of this study was to develop a predictive model capable of simulating phosphorus attenuation during the design flow condition, the field effort focused on the summer low flow season, and particularly on flows (at RM 100.7) of less than roughly 2,000 cfs (57 m^3/sec). In 1984, discharges of this magnitude were achieved by mid-July and persisted through September (see Results section). Accordingly, sampling commenced on July 17 and continued generally at weekly intervals through September 24, resulting in the completion of nine sampling events. Sampling dates were as follows:

o July 17	o August 13	o September 4
o July 30	o August 20	o September 10
o August 7	o August 27	o September 24

Discharge

During each of the sampling days, discharge was monitored at nine selected gaging sites along the Spokane River, as well as at eight point source discharges, one surface water input, and one surface water withdrawal (Table 1, Figures 2 and 3). The locations of the river gaging stations were largely selected on the basis of anticipated ground water input and output "nodes" as defined by the U.S. Geological Survey (USGS) computer model of the Spokane Aquifer (Bolke and Vaccaro, 1981). By locating sampling stations at these discharge nodes, the magnitude of ground water exchange and its influence on

TABLE 1

Discharge Monitoring Sites

	River Mile	Location	Data Source	Estimated Coefficient of a Variatio of a Discharg Measurement
RIVER SITES	100.7	Below Post Falls	USGS	2.5%
	93.6	Above Harvard Road	SCC	3.8%
	85.2	Below Trent Rd.	this study	3.4%
	79.8	Upriver Dam at Powerhouse	this study/ City of Spokane	1.8%
	78.0	Green St.	SCC	3.5%
	74.1	Post St. Dam Powerhouse	this study/WWP	1.4%
	72.9	Below Spokane Falls	USGS	2.5%
	62.0[a]	Seven Mile Bridge	this study	3.9%
	58.1	Nine Mile Dam Powerhouse	WWP/this study	2.7%
POINT SOURCES	111.0	Coeur d'Alene STP	City of Coeur d'Alene	10.0%
	92.7	Liberty Lake STP	Liberty Lake Sewer District	5.0%
	87.1	Spokane Industrial Park	this study/SIP	3.5%
	86.0	Kaiser Combined Effluent	Kaiser	5.0%
	82.6	Inland Empire Paper Co.	Inland Empire Paper Co.	5.0%
	82.3	Millwood STP	this study/ Millwood	10.0%
	67.4	Spokane AWT	this study/ City of Spokane	3.0%
	64.3	NW Terrace STP	this study/ NW Terrace	5.0%
SURFACE WATER:				
INPUTS	72.4	Hangman Creek	USGS	7.5%
OUTPUTS	106.6	Rathdrum Canal	USGS	5.0%

[a]Stilling well was located 2.3 miles upstream at RM 64.3

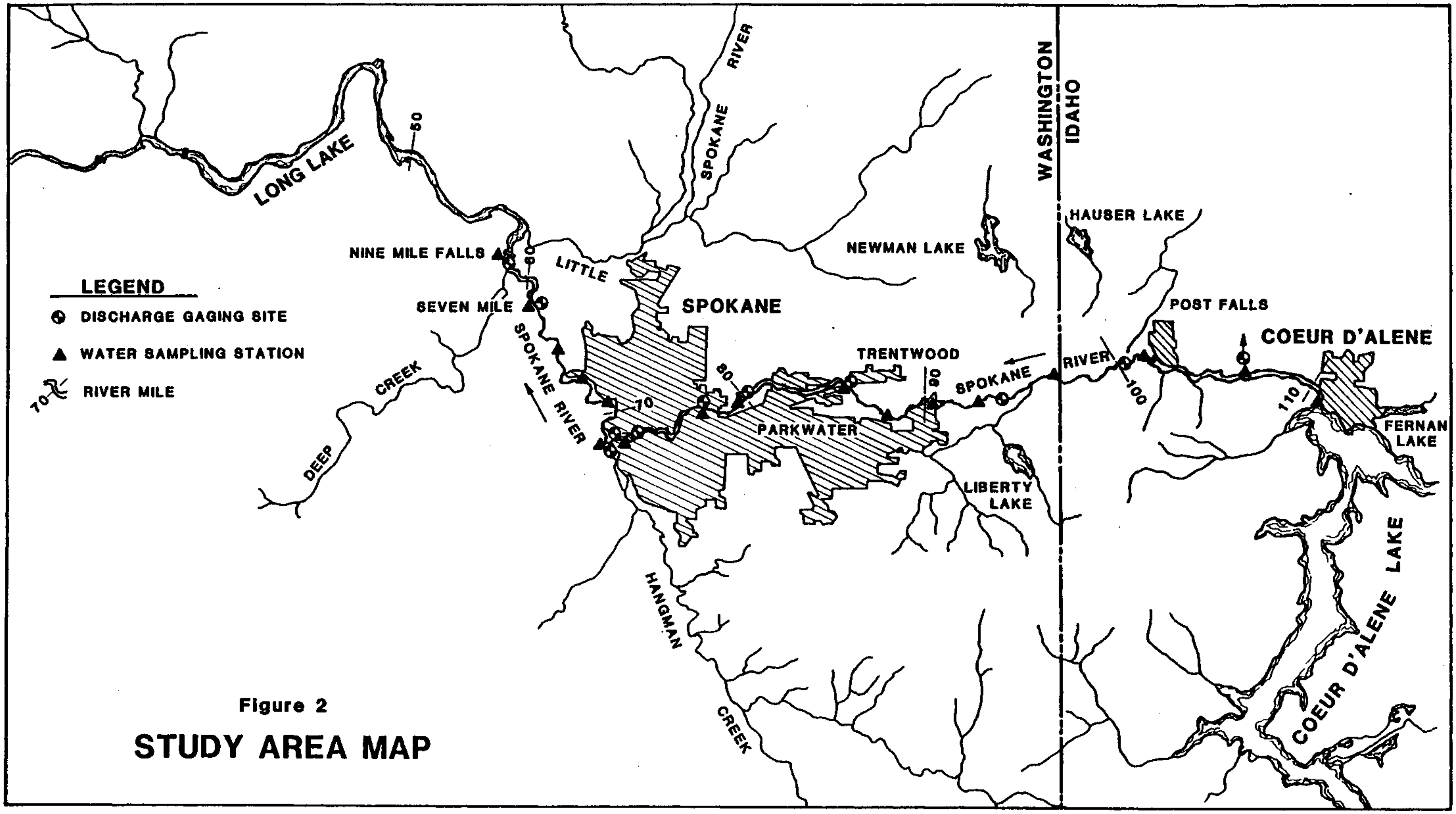
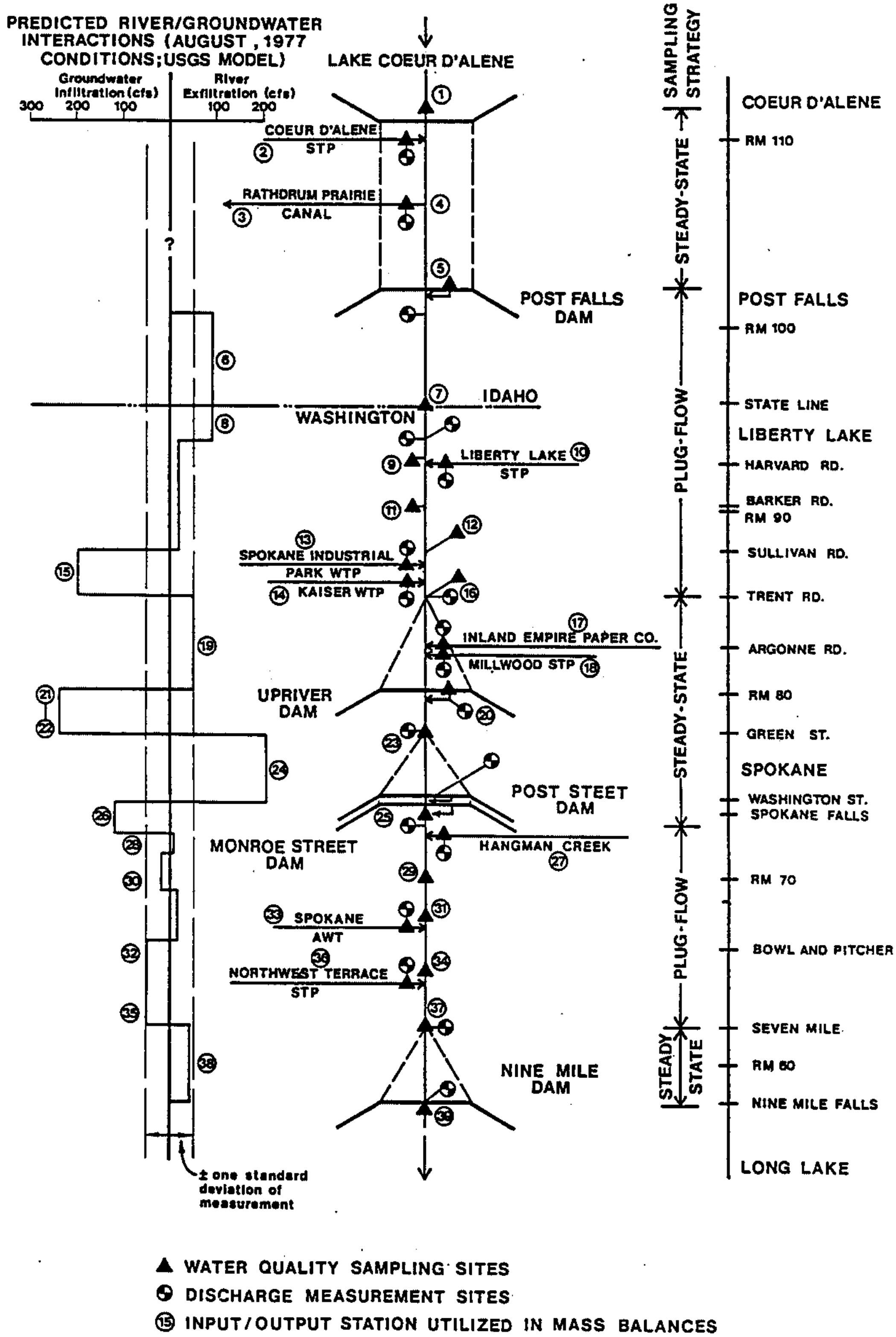


Figure 2

STUDY AREA MAP

FIGURE 3

Schematic of the Sampling Design Used During the 1984 Study



phosphorus transport in the river could be measured directly. A significant ground water node was defined here to be the upstream and downstream boundaries of a river reach which was predicted to gain or lose more than 50 cfs (1.4 m^3/sec) of water as a result of ground water discharge during summer low flow (August, 1977 conditions; URS, 1981). Fifty cfs represents an approximate magnitude of field measurement uncertainty under near-optimum conditions and typical summertime river flows of roughly 1,000 - 2,000 cfs. A change of less than 50 cfs would likely not be detectable by conventional measurement techniques.

The USGS model of river/aquifer interactions does not apply to that reach of the river between Lake Coeur d'Alene and Post Falls. In this area, the river level is known to be well above the static water level of the aquifer, and some seepage of river water to the aquifer might be expected, as is the case downstream of Post Falls (Broom, 1951). Previous attempts by USGS to quantify seepage losses within this eleven mile reach have been largely unsuccessful, primarily as a result of the low velocities common to this backwater area and the resultant difficulty in obtaining an accurate discharge measurement (Seitz and Jones, 1981). Limited reconnaisance by the study team of the Lake Coeur d'Alene outlet area also failed to identify a suitable gaging site. Changes in discharge through this reach as a result of ground water exchange are thus assumed to be negligible (as suggested by the limited USGS data), though the uncertainties associated with this assumption are substantial. Nevertheless, since nearly three-fourths of the total phosphorus load to this reach appears to be due to the Coeur d'Alene STP discharge (Yearsley, 1980), which was gaged, uncertainties in the lake outlet flow estimate were not expected to result in substantial errors in the phosphorus mass balance.

Of the nine river gaging stations monitored during this study, four represent actively maintained gages operated by either USGS (Post Falls and Spokane) or Spokane Community College (SCC; Harvard Rd. and Green St.). The accuracy of the two SCC gages was verified by performing an independent discharge measurement (see below) at each site and comparing the measured values against the recent rating tables. In each case the observed and predicted values agreed within two percent, and the rating table data were thus assumed to be accurate. No such independent verification of the accuracy of the USGS gages was undertaken.

A total of five river gages were activated during this study. Two of these gages (Trent Rd. and Seven Mile) were located in free flowing river areas, while the other three (Upriver Dam, Post St. Dam, and Nine Mile Dam) corresponded to sites either immediately above or below a hydroelectric facility. At the free flowing sites, a rating table was developed based upon the observed relationship between river stage (using abandoned USGS stilling wells) and measured discharge. Each rating table was constructed with 4-5 observations over the range of flows encountered during the study period. All discharge estimates were based on instantaneous gage height observations (typically 2 per day) and the rating table data.

Discharge measurements at each gaging station were performed using a pre-calibrated Price meter either suspended from a low bridge location (Post St. and Seven Mile bridge) or -- more commonly -- using a boat attached to a steel cable (i.e. tag line) spanning the width of the channel. Specific discharge measurement sites were selected based upon uniform flow characteristics and a relative lack of large boulders. Measurements were performed according to USGS protocol (Buchanan and Somers, 1969) and generally included more than 20 vertical profiles across the channel's width. Velocity was digitally integrated over a 60 second period at depths corresponding to 0.2, 0.6, and 0.8 of the total depth for each profile. Depth was measured using a steel cable attached to a lead sounding weight.

Discharge through the three hydroelectric facilities was determined using methods equivalent to those employed in the free flowing areas, except that in this case the rating table was based upon recorded power output (corrected for active head and water density) instead of stage height. This method essentially rates the efficiency of the hydroelectric turbines, and is based on the relationship:

$$Q = P/nyH$$

where:
- Q = discharge
- P = power output
- n = turbine efficiency
- y = water density
- H = active head

Power conversion efficiencies varied from roughly 70 percent for the older Washington Water Power (WWP) turbines at Post St. and Nine Mile Dam to 85 percent for newer units at the Upriver Dam facility. The efficiency of each turbine, or set of turbines, was remarkably constant over the range of flows encountered during the study period, and resulted in a rather low uncertainty in the discharge estimates at these sites (Table 1). At these hydroelectric facilities, nearly all of the river flow during the study period passed through the turbines; any bypassed flow was measured.

All of the known point sources which discharge to the Spokane River contain some flow monitoring device, though the accuracy and precision of these instruments was found to vary widely. Possible flow errors at most of the treatment plants were evaluated by performing independent measurements and comparing the values against plant records. Plant flow data were then adjusted, if appropriate, to correspond to the measured values. In some cases, plant records were found to be in error by as much as 25 percent. However, the majority of the point source discharge data was found to be unbiased. The accuracy of discharge data from Liberty Lake STP and Kaiser Aluminum Co. effluent were not specifically addressed during this study because of access difficulty, though recent Class II inspections of these facilities by WDOE indicate that the flow monitoring equipment was operating satisfactorily (WDOE, unpublished data).

In addition to the two river gages discussed above, USGS also maintains active gaging stations which monitor surface water withdrawals from the river into the Rathdrum Canal irrigation project (RM 106.6) and surface water inputs to the river from Hangman Creek (RM 72.4). During the summer low flow period, these two sites appeared to represent the only significant surface water input/output locations in the study area (exclusive of the point sources discussed above). Because all other hydraulic inputs and outputs to the river were believed to be measured, ground water exchange both to and from the river was evaluated by performing flow balances for each reach. This ground water calculation implicitly assumes that other sources of flow variations such as precipitation, evaporation, or channel storage are insignificant by comparison; such an assumption is supported by "first-cut" calculations of the magnitudes of these processes. Because the ground water discharge estimates represent calculated (vs. measured) quantities, the uncertainty of those estimates was evaluated by propagating variance of the gaging data within each reach (see error analysis discussions below).

Sampling and Analysis

Surface Water Sampling

During each of the nine sampling days, a total of 16 river stations were sampled for subsequent determinations of total phosphorus, total soluble phosphorus, soluble reactive phosphorus, nitrate plus nitrite, ammonia, and chlorophyll *a*. Temperature was also measured in the field. Roughly half of these sampling sites corresponded with nearby gaging stations (i.e., predicted ground water discharge "nodes"). The remainder of the sampling stations were selected based upon their proximity to major phosphorus sources, allowing reaches to be separated on the basis of differing phosphorus loading characteristics. The locations of these sites are presented in Figures 2 and 3 and Table 2. All identified point sources and surface water inputs and outputs of Table 1 were also sampled during each survey.

The specific location of each of the sampling sites was based on local mixing characteristics and access. Where possible, sites were preferrentially located just below major mixing zones (e.g. powerhouse tailwater areas) to minimize sampling related variability. Sites were avoided at locations close to major phosphorus inputs also because of concentration variability. All sites were examined both initially and at several points during the study for cross-sectional variability in total and soluble phosphorus concentrations. Based on the results of these quality control checks, sampling activities were modified at several sites to assure that sample variability was kept to a minimum (e.g. vertical and horizontal compositing or movement of the station to more turbulent areas.) Sampling was generally performed at mid-depth and mid-channel locations, utilizing horizontal Kemmerer samplers, pole-extended grabs, and vertically compositing tube samplers.

The timing of sampling activities was based on a consideration of both advective and dispersive characteristics of the river system. After examining

TABLE 2

River Sampling Sites

River Mile	Location	Sampling Method
111.7	Lake Coeur d'Alene outlet	6 vertical composites collected at 5 minute intervals from "Cedar's" dock (random sampling)
106.6	Harbor Island	vertical composites collected at 6 randomized locations from boat (random sampling)
101.7	Post Falls powerhouse	6 grabs collected at 5 minute intervals in turbulent tailwater area (random sampling)
96.0	Stateline bridge	6 grabs collected over 3 one-hour intervals from bridge (time-of-travel)
93.0	Harvard Rd. bridge	6 grabs collected over 3 one-hour intervals from bridge (time-of-travel)
90.4	Barker Rd. bridge	6 grabs collected over 3 one-hour intervals from bridge (time-of-travel)
87.8	Sullivan Rd. bridge	6 grabs collected over 3 one-hour intervals from bridge (time-of-travel)
85.3	Trent Rd. bridge	6 grabs collected over 3 one-hour intervals from bridge (time-of-travel)
79.8	Upriver Dam powerhouse	6 grabs collected at 5 minute intervals in turbulent tail-water area (random sampling)
78.0	Green St. bridge	6 grabs collected at 5 minute intervals from bridge (random sampling)

River Mile	Location	Sampling Method
73.4	Monroe St. powerhouse	6 grabs collected over 3 one-hour intervals in rapids below powerhouse (time-of-travel)
69.8	Fort Wright bridge	6 grabs collected over 3 one-hour intervals from bridge (time-of-travel)
67.6	Above Spokane AWT	6 grabs collected over 3 one-hour intervals in rapids above outfall (time-of-travel)
64.6	Gun Club	6 grabs collected over 3 one-hour intervals in rapids (time-of-travel)
62.0	Seven Mile bridge	6 grabs collected over 3 one-hour intervals from bridge (time-of-travel)
58.1	Nine Mile Dam powerhouse	6 grabs collected over 3 one-hour intervals in turbulent tail-water area (random sampling)

the available time-of-travel and dispersion data for the Spokane River (Singleton and Joy, 1982; WDOE, unpublished data; USGS, unpublished data), it became apparent that various river reaches could be separated into two groups: free- flowing areas characterized by relatively rapid velocities and minimal dispersion; and impoundment areas which exhibited much lower velocities and rather substantial lateral dispersion. The free-flowing reaches included the river between Post Falls and Trent Rd. (RM 101.7 to 85.3) and Monroe St. to Gun Club (RM 73.4 to 64.6). All other reaches in the study area were in impoundment backwaters.

In the free-flowing areas it was determined that a "plug flow," or time-of-travel, sampling method which followed a parcel of water through the system was both practical and appropriate. Time-of-travel estimates had been developed previously by Singleton and Joy (1982) for these reaches and were used during this study to time the sampling activities according to the river flow on each day. Based on the apparent variations in these statistical regressions of time-of-travel vs. discharge, the initial travel time estimates within each sampled reach were felt to be accurate to within roughly one hour at a Post Falls discharge of 1,300 cfs. The validity of the Singleton and Joy (1982) travel time estimates for the low river flows sampled during this study was examined mid-way through the study period by performing a dye injection study (see Dye Study discussions which follow).

Examination of the available dispersion data for the free-flowing reaches revealed that over a distance of 20 miles and during low river flow (1,300 cfs at Post Falls), a given "plug" of water travelling through the river would be expected to disperse most of its initial mass over a 1-2 hour time period on either side of the center of mass or centroid. Given this information and the uncertainties in the time-of-travel estimates, it was determined that each station within a free-flowing reach should be sampled repetitively at one hour intervals before, during, and after the predicted travel time (3 repetitions per site). Sampling in this manner was felt to provide a more representative characterization of river concentrations than a single sampling, and also provided important data on sampling related variability. Point source discharges in the free-flowing reaches were also monitored and sampled by the same methods (i.e. based on predicted travel time +/- one hour).

In general, changes in water quality characteristics in rivers with variable inputs (e.g. diurnal fluctuations in STP loading) are evaluated with greatest precision using time-of-travel sampling methods. However, if dispersive processes are large with respect to transport (e.g., in most lakes), the plug-flow approach has limited utility, and other more randomized sampling strategies become appropriate. Given the relatively long travel time and dispersive character of the impoundment areas of the Spokane River, all sampling in these areas was conducted without regard to travel time and at roughly the same times at all stations (i.e. simultaneous sampling). Repetitive sampling at these sites generally occurred at intervals of 5 minutes to obtain data on short-term sampling variability. The possibility of systematic biases introduced by both the simultaneous and time-of-travel sampling techniques is discussed in the "Results" section below.

Preliminary assessments of the statistical variability in phosphorus loading expected during this study revealed that sampling and analytical errors associated with phosphorus determinations were likely to be the major sources of uncertainty in the attenuation estimates. These uncertainties were minimized by careful attention to quality control procedures, but they can not be wholly eliminated. As such, this variability dictates the sample size necessary to obtain a statistically significant measurement of phosphorus attenuation. The specified criterion established for this study was the detection of a 10 percent change in the previously estimated total phosphorus load to the river (Singleton, 1981; 10% x 230 kg/day = 23 kg/day), with a significance level of 5 percent and a power of detection of 90 percent for each survey date (Sokol and Rohlf, 1969). Based on the anticipated variability in concentration (and discharge) measurements, 6 sampling replications per river station appeared to be required to meet the statistical criterion for total phosphorus (TP). Fewer replicates are required to meet the same criterion for total soluble (TSP) and soluble reactive phosphorus (SRP) (4 and 3 replicates, respectively). This replication schedule was adapted to the sampling schedule and was performed on all river stations and the two major point source inputs (Coeur d'Alene STP and Spokane AWT). A reduced number of replicates was utilized in sampling the minor point sources (4, 3, and 2 respectively, for TP, TSP, and SRP). Because nitrate, ammonia, chlorophyll, and temperature were not major parameters of interest to this study, only one sample from each station was submitted for determination. The actual variability in concentration and discharge measurements during the study was quite similar to the anticipated values discussed above, and the statistical resolution of the study design was thus considered adequate.

Ground Water Sampling

Because of the rather extensive amount of study which has previously been undertaken on the Spokane aquifer and its interaction with the river system, the location of most of the aquifer discharge zones to the river can be fairly accurately predicted (Esvelt, 1978; Bolke and Vaccaro, 1981; Yearsley, 1982). Selected existing ground water wells within each of these discharge zones were sampled during this study to determine the nutrient contribution of aquifer discharges to the Spokane River. Two wells within each zone were selected based upon a review of well construction methods, existing monitoring data (to establish if the well appeared to be representative of local conditions), and possible sampling and access difficulties. These wells were sampled at monthly intervals from July to September, 1984 (3 sampling events) and formed the basis of our determinations of aquifer concentrations (Table 3). Ground water samples were analyzed for total soluble phosphorus, soluble reactive phosphorus, nitrate plus nitrite, and ammonia.

In addition to the well series listed in Table 3, numerous additional wells in the study area were sampled and analyzed for total soluble and soluble reactive phosphorus concentration in cooperation with ongoing monitoring programs of the Spokane County Health District (208 program) and the City of Spokane Solid Waste Utility. These programs resulted in the sampling and analysis of water drawn from 24 wells in the aquifer discharge zones, and

TABLE 3

Summary of Ground Water Wells Routinely Sampled During the Study Period

Aquifer Discharge Zone	River Mile	Name
Dishman	87.8 - 85.3	Trentwood Progress Central Premix (depth selective)
Parkwater	79.8 - 78.0	Orchard #1 Spokane Community College (depth selective)
Upriver Dam Seepage	79.8 - 78.0	Knorr Bros. Mielke
Lower River	74.1 - 62.0	Walsh City Landfill (depth selective)

greatly improved our understanding of the distribution of phosphorus in the Spokane aquifer.

Sample Handling and Analysis

Throughout the study period, approximately 1,300 samples were collected for TP determinations, 930 for TSP, 760 for SRP, 290 for NO_2, NO_3, and NH_4, and approximately 135 samples for chl a. All analyses were performed according to EPA-approved methods appropriate to concentrations in the Spokane River system (APHA, 1980); these methods are summarized below:

Parameter	Method
TP	persulfate digestion/ascorbic acid determined manually with 10 cm cuvettes
TSP	as TP, but following filtration through 0.45 micron glass-fiber filter
SRP	as TSP, but using 0.45 micron Millipore[R] filters and without digestion; analyzed within 36 hours
NO_2^-+NO_3^--N	filtration through 0.45 micron Millipore[R] filters; cadmium reduction method
NH_4^+-N	filtration through 0.45 micron Millipore[R] filters; phenate method, analyzed within 36 hours
chl a	filtration onto 0.45 micron glass-fiber filters followed by extraction into 90% acetone; trichromatic method corrected for phaeophytin

All chemical determinations were performed by Eastern Washington University (EWU) at their Turnbull Laboratory for Ecological Studies. Quality control programs designed to monitor both the accuracy and precision of the phosphorus analyses were maintained throughout the study, and consisted of routine submittal of blind EPA quality assurance standards, independent verification of roughly five percent of all TP samples by submittal of duplicates to independent laboratories (including "round-robin" samples to more than one laboratory), spike recovery samples, field blanks (approximately 5 percent of all samples), and field duplicates (5-10 percent of all samples). All quality assurance, independent laboratory and spike recovery analyses were well within predetermined control limits (+/- 10%); no systematic errors in accuracy are thus believed to have occurred. Field blanks (i.e. bottle blanks) contained a significant ($P<.01$) concentration increase of 1.1 ug/l for TP, TSP, and SRP; this value was subtracted from the results of all phosphorus analyses determined by EWU.

Within several hours of field collection, all samples were delivered to a central processing station at Upriver Dam. Samples were then filtered (if appropriate) and distributed into acid-washed and triple-rinsed containers which specified the required analysis (e.g. high or low level TP). Each container was marked only with an identification number; all containers were received as blind samples by the laboratory. All samples were stored on ice prior to analysis and analyzed within 36 hours of collection for SRP and NH_4^+ and within 96 hours of collection for TP, TSP, NO_2^- + NO_3^- and chl a.

No problems were encountered in the chemical determinations other than an apparent instability of the molybdate complex in low-level SRP analyses. This instability was found to be more pronounced if the sample was filtered through a glass-fiber filter rather than a Millipore[R] filter; the instability was particularly evident in ground water samples and in the river below major aquifer inputs. This instability - which resulted in a continuous increase in color formation (and thus apparent SRP concentration) over time - was in part mitigated by maintaining a constant reaction time during the laboratory procedures; increased variability in these samples, however, was never wholly eliminated. No such instability was detected in the TSP or TP determinations. The cause of these variations in the SRP analysis has not been determined, but is believed to represent the slow reaction of a weakly labile phosphorus compound, perhaps as a result of an unstable acid-base buffering system within the sample. In any event, the observed instabilities appeared to weaken analytical precision of the SRP analysis. However, since the SRP data was of comparatively minor importance as compared to the TP and TSP information, reduced precision had only a minor consequence to the results of this study.

The precision of the phosphorus determination was evaluated primarily by comparing the results of field duplicates. For both TP and TSP, the standard deviation of an analytical determination for low level samples was approximately 2.0 ug/l (Table 4), which is considered good to excellent relative to comparable data from other studies (APHA, 1980). For SRP, the corresponding deviation was roughly 3.1 ug/l which is considered only fair. These values include errors introduced during sample handling (e.g. filtering) and laboratory analysis. Compared to the sampling variability, however, these analytical variations for TP and TSP are relatively small and represent only 20-30 percent of the total observed variability in the repetitive river sampling replicates. Most of the observed variability in river phosphorus concentrations, therefore, appears to have been due to short-term changes in the concentation at each site, either as a result of sampling deficiencies or "true" instabilities in the river itself. Relative to the low-level river samples, sampling and analytical variances in the high-level point source effluent samples (expressed as the coefficient of variation) were comparatively small.

Dye Studies

Three dye (Rhodamine WT) injections were tracked between Upriver Dam and the Spokane Gun Club (August 27; RM 79.8 to 64.5), Post Falls Dam to Upriver Dam (August 30; RM 101.7 to 79.8), and from the Spokane AWT to Nine Mile Dam (September 7; RM 67.4 to 58.1). Injections at Upriver Dam and Post Falls Dam were accomplished by pouring 5.5 and 4.0 liters of dye, respectively, into the

TABLE 4

Summary of Analytical and Sampling Variance Data for

Total Phosphorus and Total Soluble Phosphorus Determinations

	Average Variance; $(ug/l)^2$	Coefficient of Variation	Number of Samples	Percent of Total Sampling Variance due to Analytical
Analytical Replicates (TP):				
- low level (0-100 ug/l)	3.93	8.5%	134	--
- high level (5,000-10,000 ug/l)	100,200.	4.1%	20	--
Sampling Replicates (within each sampling day):				
- low level (river stations, excl. RM 106.6):				
Total Soluble Phosphorus	13.5	22.4%	512	29%
Total Phosphorus	18.3	18.3%	788	21%
- high level:				
Total Soluble Phosphorus	228,200.	6.1%	84	44%
Total Phosphorus	168,500.	5.3%	130	59%

forebay immediately upstream of the turbines for rapid initial mixing with river water. The injection at the Spokane AWT was accomplished by pouring 2.0 liters of dye directly into the effluent stream. Dye doses were set in order to achieve a maximum downstream concentration in the river of 1 ug/l rhodamine WT.

The concentration of dye versus time was measured at seven locations along the river using a Turner^R fluorometer equipped with a submersible pump, a flow-through cell, and a strip-chart recorder. These locations included Corbin Park (RM 99.9), Trent Rd. (RM 85.3), Upriver Dam (RM 79.9), Green St. (RM 78.0), Monroe St. Dam (RM 73.4), Spokane Gun Club (RM 64.5), and Nine Mile Dam (RM 58.1). Locations for measuring time-concentration profiles were determined based on functional divisions of the river into free-flowing and impoundment segments; these locations also corresponded to discharge and water quality sampling stations. Dye concentration versus time at each location was measured continuously from the time of occurrence at the leading edge until the trailing edge concentration decreased to approximately 25 percent of the peak. Trailing edge concentration versus time was later extrapolated to zero concentration for the unmeasured portion of the plot in order to estimate the dye cloud centroid and variance (i.e. dispersion). The centroid and variance of the dye cloud at specific locations were determined by the area-moment method (Fischer, 1968; Hubbard et al, 1982).

Past dye studies of the Spokane River were also combined with the present study in order to derive relationships between velocity and discharge for specific river segments. The USGS conducted two surveys in 1968 at intermediate and high flows (Post Falls discharge averaged 4020 and 6890 cfs, respectively, during the two surveys). In addition, WDOE conducted a survey at moderately low flow during 1980 (Post Falls discharge averaged roughly 1770 cfs during four dye injections). Both the USGS and WDOE dye studies examined the time-concentration profiles at four or more sites along the river, though the precise locations of the sampling sites varied between the studies. The raw data for time-concentration relationships from the USGS and WDOE surveys (L. Singleton, WDOE, unpublished data) were evaluated by the area-moment method. The USGS and WDOE data were adjusted to the river reaches described above where possible in order to evaluate velocity-discharge relationships.

Both the historical and current (i.e. 1984) dye studies in the Spokane River examined travel time characteristics in the river below Post Falls. However, no such studies have been conducted in the large impoundment between Lake Coeur d'Alene (RM 111.7) and Post Falls Dam (RM 101.7). The relationship between velocity and discharge for this pool segment was estimated based upon an analysis of 19 measurements of cross-sectional area in this region previously performed by EPA (Yearsley, 1980) and USGS (Seitz and Jones, 1981). This data was found to be sufficient to estimate the volume of the impoundment (as a function of lake stage). Travel time and velocity of a given discharge were estimated by assuming uniform flow conditions throughout the reach.

Diurnal Studies

Preliminary assessments of phosphorus attenuation in the Spokane River (based on previous data; Appendix D) suggested that the process could be largely biological, resulting from photosynthetic plant uptake of this critical nutrient by periphyton (attached algae) or macrophytes (flowering aquatic plants) within the river. Since plant photosynthesis is strongly diurnal, and since the sampling design for assessing phosphorus attentuation was largely biased toward the daylight hours (particularly for time-of-travel reaches), a study was initiated on September 4-5, 1984 to assess whether or not phosphorus attenuation exhibited a significant diurnal fluctuation.

Three reaches were selected for diurnal study on the basis of sampling and time-of-travel considerations. These reaches included: Barker Rd. to Sullivan Rd. (RM 90.4 - 87.8); Green St. to Post St. (RM 78.0 - 74.1); and Post St. to Fort Wright (RM 74.1 - 69.8). Estimated travel times through these reaches were based upon the results of our dye studies completed during the previous week and were 2.9 hours, 7.2 hours, and 5.0 hours, respectively, during the diurnal study. River discharge had been stable over the previous several weeks, with flow at Post Falls (RM 100.7) averaging 1,200 cfs. Each site was sampled roughly every four hours over a 24-hour period; sampling within each reach was staggered by the travel times reported above to allow comparisons of water masses over time. Duplicate samples were collected from each site for subsequent determinations of TP, TSP, and dissolved oxygen (DO). Changes in DO were examined in order to monitor photosynthetic activity within the river (Hall and Moll, 1975). DO analyses were performed using the Winkler titration method (APHA, 1980), and only in the non-turbulent Green St. to Post St. reach.

Biological Sampling

In order to assess the nutritional content of periphyton and macrophyte tissues in the Spokane River relative to supplies of nitrogen and phosphorus, biological samples were collected between September 4-10, 1984. The nutritional content of plant tissue has been shown to be a good indicator of the degree of nitrogen and phsophorus limitation of phytoplankton, periphyton, and macrophyte growth (Gerloff, 1975; Healey and Hendzel, 1980; Bothwell, in press). Tissue content was examined here to assess whether changes in nutrient supply to the Spokane River might control growth of the plant community and thus influence biological phophorus attenuation characteristics. Periphyton samples were collected at Harvard Rd. (RM 93.0), Barker Rd. (RM 90.4), Green St. (RM 78.0) and Gun Club (RM 64.6). Three to five samples were collected from each station by randomly selecting sites at points across the width of the channel. Periphyton was sampled by scraping all material within a 4.9 cm^2 area (enclosed by a plexiglass tube apparatus) and then transfering the material into vials. Water depth and velocity at a point 4.4 cm above the sampled area were recorded at the time of sampling. Periphyton sampling was intended to be semi-quantitative, though the large spatial variability characteristic of most periphyton communities was not specifically addressed during this effort (i.e. sample sizes were small relative to those normally required to reliably assess population levels). As discussed above, however, the emphasis of this sampling was on the determination of nutritional content of the plant tissue and not on the assessment of population levels. Periphyton samples were analyzed for dry weight, total organic carbon, total Kjeldahl nitrogen, total phosphorus and chlorophyll a content of the filterable (i.e. particulate) fraction according to APHA (1980). Total carbon and nitrogen analyses were performed using a Perkin-Elmer Model 240 C-H-N Analyzer.

Macrophyte tissue was collected from the Lake Coeur d'Alene outlet (RM 111.7), Post Falls (RM 102.0), Upriver Dam (RM 80.1), Washington St. (RM 74.1), and Nine Mile Dam (RM 59.8). At all sites except Upriver Dam, the only species of plant collected was the apparently dominant *Elodea canadensis*. No *Elodea* was found in the Upriver Dam area, but a species of *Potamogeton* was collected instead. Following collection, the second one-inch index segments of the lateral branches were removed from each plant according to the standard method originally developed by Gerloff (1975). These segments were rinsed of epiphytes and subsequently analyzed for dry weight, ash-free dry weight, phosphorus, and nitrogen. Phosphorus was determined according to Gerloff (1975), and consisted of a weak acid hydrolysis of the plant tissue in order to solubilize "available" phosphorus. Nitrogen was determined following persulfate digestion (Valderrama, 1981); the measurement included organic and weakly labile forms of nitrogen within the tissue analagous to a total Kjeldahl determination. Again, the purpose of these samples was to assess the nutritional content of the plants and not to quantify population levels.

Uncertainty Analysis

The confidence bounds for any estimate of discharge or concentration is a function of both random and systematic variability inherent in each measurement. Conclusions based upon such measurements are in part limited by the magnitude of these variations. Because the mass balance techniques utilized in this study rely heavily upon such measurement data, it was desirable to evaluate the effects contributing variances have on the total mass balance uncertainty. The completed uncertainty analysis would then permit confidence bounds to be approximated for the estimates of phosphorus attenuation and allow statistical assessments of the significance of the measured attenuation.

Uncertainties associated with concentration measurements were based on replicate sampling data; these data are summarized in Table 4. Variance in the discharge measurements utilized for this study were estimated from the regression error of the appropriate stage -- or power -- discharge relationship. These regressions were either performed directly, or in the case of the USGS gages, taken from published uncertainty approximations. For gages without a continuous stage or power record, the variance between readings collected during each survey date was included in the total measurement uncertainty. Discharge measurement uncertainties for each gage are summarized in Table 1. All ground water discharge variances presented in this report include propagated uncertainties from adjacent gages (ground water discharge was calculated by difference; see below).

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 which differs from conventional error propagation techniques only in its treatment of covariance, or correlated uncertainties between two or more variables (Bevingdon, 1969; Cornell, 1973; Lettenmaier and Richey, 1979). Covariance was found to be a significant component of the total variance terms of the mass balances in this study, particularly relative to the ground water calculations.

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 quanitity 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:

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

The quantity $\left(\frac{\delta Y}{\delta X_i}\right)^2$ is analagous to the correlation coefficient describing the covariance between the calculated value and the various measured parameters which describe the function. The equation above is strictly only valid when the variances of each measured 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.

Solutions of the first-order uncertainty analysis formulations were performed using matrix algebra techniques. The distributions of all parameters monitored during this study were found to approximate the Poisson (or normal) distribution, and each parameter variance term was thus evaluated as the second moment about the average. Any deviations from non-normality and its possible effect on the uncertainty estimates are noted in the sections which follow.

RESULTS

As previously discussed, the present regulatory framework which establishes the maximum permissible phosphorus load which can enter Long Lake is based upon the June-November flow period, and does not consider the impact of flows which occur during other non-critical months (Singleton, 1981). Water exchange rates in Long Lake during the spring months typically exceed 10% per day, resulting in the washout of previous phosphorus inputs to the reservoir and restricting the development of algal populations within Long Lake until flows subside (URS, 1981; Soltero et al, 1983). Because the critical phosphorus loading to Long Lake is defined on a seasonal (vs. annual) basis, temporary phosphorus attenuation processes which result in a seasonal storage of this nutrient within the river channel (e.g. plant uptake) could limit the magnitude of algal growth downstream in Long Lake. Phosphorus loading conditions which occur during the winter and spring months are thus not considered relevant to Long Lake under the present management scheme. Similarly, this study did not investigate conditions during the winter-spring season. The results of this study therefore apply only to summer low flow conditions (< 2,000 cfs at Post Falls) applicable to the current management of Long Lake.

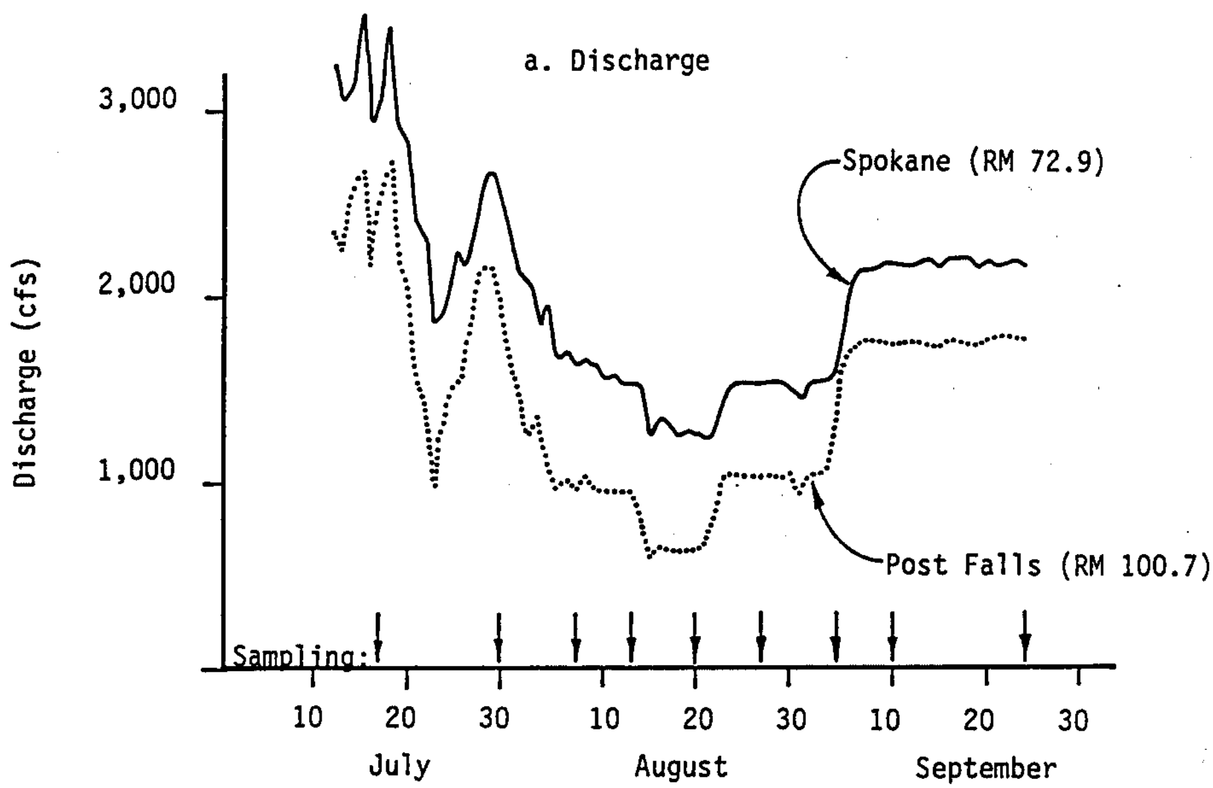
Hydrology

Temporal changes in river discharge during the study period at Post Falls (RM 100.7) and Spokane (RM 72.9) are presented in Figure 4a. Generally, flow conditions in the river during much of the July to September 1984 sampling period were rather stable and exhibited discharges slightly greater than a typical-year condition, based on the 1913-1984 period of record for these gages (USGS, written communication). The average discharge at Post Falls during the nine selected sampling days, however, was 1,440 cfs (range: 637-2,530 cfs), which is only slightly higher than the previously established design flow (1-in-20-year low flow) at this site of 1,333 cfs (Singleton, 1981).

The estimated discharge for Lake Coeur d'Alene -- calculated by correcting for surface water withdrawals and the minor STP input between the lake and Post Falls -- averaged 1,470 cfs during the study period. This value is slightly lower than the estimated 1-in-20-year June-November low flow of 1,500 cfs at the lake outlet obtained by correcting for surface water withdrawals (Table 5; based on graphical analysis of the 71 year period of record). Previous estimates of low flow conditions within the Spokane River (URS 1981; Singleton 1981) did not consider the effect of historical withdrawals on the river's flow regime. Because of marked reductions during the 1960's in the quantity of water withdrawn from the river (see Appendix E), these previous estimates appear to have underestimated the present-day low flow condition by roughly 130 cfs. The corrected values are represented in the Lake Coeur d'Alene outlet flows presented in Table 5, and reveal that surface water inputs from the lake during the study period were nearly equivalent to the June-November 1-in-20-year low flow condition. As stated above, this correspondence resulted from the selection of minimum flows during the sampling

FIGURE 4

Temporal Variation in Discharge and Phosphorus Concentration in the Study Area (phosphorus values presented as the average of all river stations on each sampling day ± one standard error)



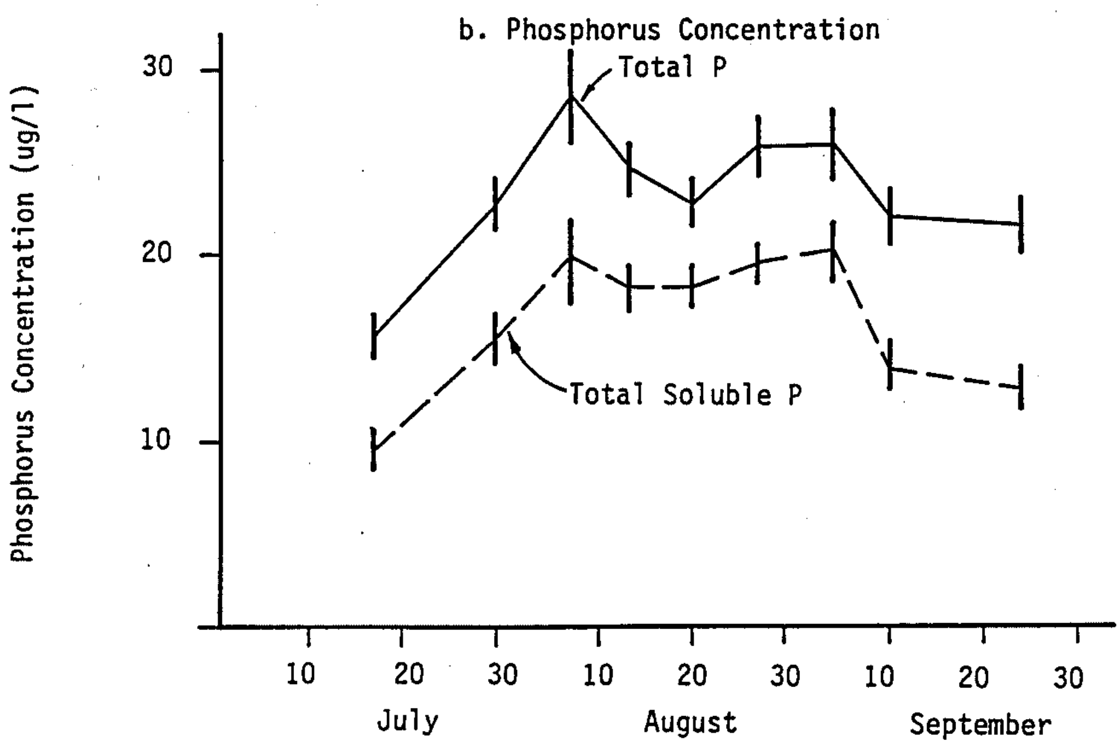


TABLE 5

Comparison of Discharge Measured During the 1984 Study Period with USGS Model Predictions and Previous Measurements

(all units in cfs; see text for explanations)

Location	Spokane River Mile	Average During July-September 1984 Study	USGS Model Predictions August, 1977	June-November Average of Previous USGS Measurements		
				Median	(Estimated 90% range)	Period of Record
Lake Coeur d'Alene Outlet[a]	111.7	1,470	n.d.	2,900	(1,500 , 6,420)	1913-1983(71)
Rathdrum Canal Withdrawal	106.6	- 33	n.d.	- 27	(-34 , -20)	1946-1983(38)
Old Farm Canal Withdrawal	101.7	0	n.d.	- 140	(-155 ,- 67)	1913-1966(54)
Post Falls	100.7	1,440	n.d.	2,730	(1,340 , 6,280)	1913-1983(71)
ΔPost Falls → Harvard Rd.[b]	100.7→93.6	- 144	- 90	- 74	(-167 , 38)	1929-1983(55)
ΔHarvard Rd. →Trent Rd.	93.6→85.2	+ 404	+ 214	+ 579	(377 , 780)	1948-1954(7)
ΔTrent Rd.→Green St.	85.2→78.0	+ 321	+ 191	+ 410	(208 , 613)	1949-1952(4)
ΔGreen St. → Spokane	78.0→72.9	- 75	- 96	- 29	(-71 , 13)	1949-1952(4)
Hangman Creek	72.4	31	n.d.	27	(5 , 72)	1948-1983(36)
Spokane AWT	67.4	+ 49	n.d.	n.d.		n.d.
ΔSpokane→Nine Mile	72.9→58.1	+ 115	+ 14	+ 375	(215 , 535)	1948-1950(3)
Little Spokane River (mouth)	56.3	450	357	444	(368 , 540)	1913-1983(18)
IMPOUNDMENT SEEPAGE:						
Upriver Dam	79.8	- 256	- 50	n.d.		n.d.
Post St. Dam	74.1	- 180	- 208	n.d.		n.d.
Nine Mile Dam	58.1	- 52	- 41	n.d.		n.d.

[a]Calculated by correcting the Post Falls discharge for irrigation withdrawals and the minor STP effluent contribution.

[b]"Δ" denotes the calculated difference between adjacent gages, corrected for identified surface water inputs (e.g. point sources, creeks) which entered the reach.

effort (primarily by excluding the high-flow month of June), and not because 1984 represented a low flow year.

The low-flow hydrology of the Spokane River between Post Falls and Nine Mile Dam has been shown to be dominated by two processes: outlet flows from Lake Coeur d'Alene and ground water inputs from the rather large Spokane aquifer system (Broom, 1951; Pluhowski and Thomas, 1968; Bolke and Vaccaro, 1981). Other inputs are minor in comparison to these sources, and are represented by Hangman Creek and the various point source discharges which contributed 1.4% and 2.7%, respectively, to the total measured flow at Nine Mile Dam during the study period.

A computer model of the aquifer system constructed by the USGS has predicted that seepage losses and subsequent tailwater return flows in the vicinity of many of the existing dams on the river are likely to be an important component of the low-flow hydrologic regime, though the model predictions were largely unverified (J.J. Vaccaro, USGS, personal communication). These model predictions, however, were utilized in a previous study of phosphorus allocation in the Spokane River (Singleton, 1981; URS, 1981). The discussions presented below address the gaging data collected during this investigation in the context of ground water inputs. Comparisons with data from previous studies are included.

Ground Water Inflow and Outflow

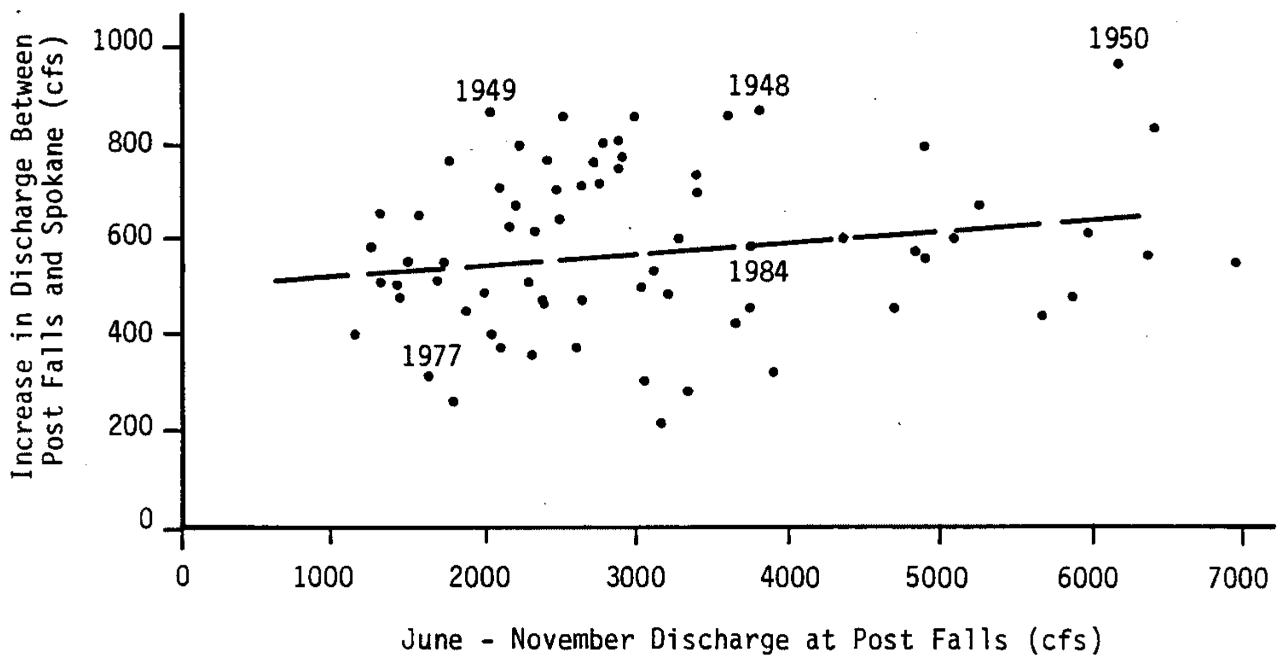
The difference between the average discharge during the study period at Nine Mile Dam (RM 58.1; 2,144 cfs) and at Post Falls (RM 100.7; 1432 cfs) was 707 cfs. Point sources and surface water inputs to the river contributed approximately 85 cfs, or roughly 12 percent of this apparent residual. The remainder of this input represents an estimate of the net ground water input to the river -- 622 cfs. This net input is considerably lower than similar values calculated from previous USGS data (Wells, 1955; Hendricks, 1964) which ranged between 1,100 and 1,430 cfs for the summer-fall periods of 1948-1950, (assuming point source inputs of 40 cfs during these years). However, the 1984 value is over 2.5 times larger than predictions of the USGS aquifer model, which estimated a net input of only 233 cfs during August 1977 (Bolke and Vacarro, 1981; URS, 1981). Monthly variations in aquifer discharge during the summer-fall low flow period were remarkably small during the years of 1948-1950 and 1984, and the August 1977 predictions may therefore generally apply to the average June-November conditions.

Although the USGS model output is not strictly comparable to the measured data (since the output was not independently verified), differences between these various measurements and estimates of net ground water input in the study area may be due largely to year-to-year fluctuations in aquifer discharges to the river. Using the net increase in river discharge between Post Falls and Spokane as an index of ground water inputs to the entire study area, the years of 1948-1950 can be characterized as having an abnormally high ground water input, representing the highest flow years over the 72 year period of record (Figure 5). The year 1977, however, appears to have been a relatively low discharge year, with a flow increase between Post Falls and

FIGURE 5

Relationship Between Apparent Ground Water Input Above Spokane and Average Discharge at Post Falls

(All data presented as the June-November average from 1913-1984; the correlation between these two variables is not significant; P>.05)



Spokane corresponding to the lower seven percent of the observed values. In comparison, 1984 was a rather typical year for aquifer inputs, and the 622 cfs value measured during this study may thus approximate the average net discharge to the river. Data presented in Figure 5 also reveal that observed variations in the net ground water input fluctuate independently of surface water inputs; this observation will be discussed further in a subsequent section which describes the phosphorus loading/attenuation model.

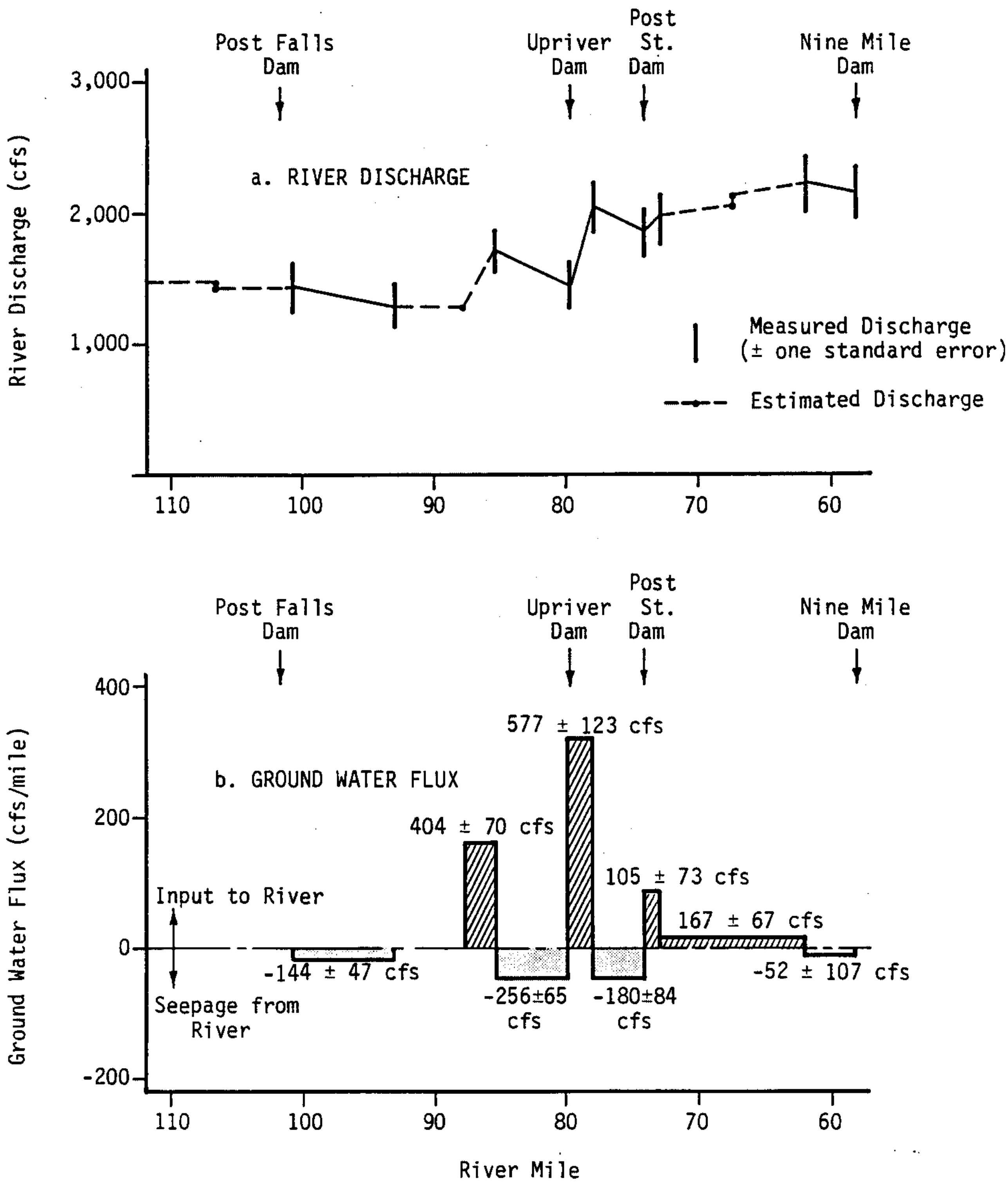
The net ground water discharge values discussed above are of limited utility in defining hydrologic (and phosphorus) fluxes, since they actually represent the difference between total ground water inputs and seepage losses occurring throughout the river system. Ground water inputs to the river occur when the static water level of the aquifer is higher than that of the river, while seepage losses occur when the river height exceeds that of the aquifer. Previous investigations of exchange characteristics between the river and aquifer systems in the Spokane basin have revealed that the entire river upstream of approximately RM 88 (Sullivan Rd.) is situated above the aquifer (Esvelt, 1978; Bolke and Vaccaro, 1981). Seepage losses from the river channel upstream of RM 93 during low flow conditions have been well documented (Broom, 1951; USGS Water Resources Data, 1929-1983), and are summarized in Table 5. Calculated losses in river discharge between Post Falls and Harvard Rd. (RM 100.7 - 93.6) during the study period averaged 144 +/- 47 cfs; this value is consistent with historical data collected over a 55 year period of record and also with the results of the USGS aquifer model. Seepage losses from the river appear to be considerably greater during periods of high river flow, owing to changes in the gradient between river and aquifer at high river stages (Broom, 1951).

Downstream of approximately RM 88, the gradient between aquifer and river shifts, allowing ground water to begin discharging into the river channel (Table 5; Drost and Seitz, 1978; Esvelt, 1978; Bolke and Vacarro, 1981). However, this condition appears to be altered in the vicinity of the hydropower dams along the river, which effect a localized raising of the river level relative to the aquifer. The result of these localized shifts in the river/aquifer gradient is that the river loses water to the aquifer upstream of the dams and then gains water from the aquifer at points downstream of the impoundments. The quantity of alternating seepage losses and aquifer inputs which occur in the vicinity of dams along the Spokane River has been estimated using the USGS aquifer model, though these predictions were not verified with in-river flow measurements.

To our knowledge, discharge data collected during this study represent the first direct measurements of ground water flux in the vicinity of the Spokane River impoundments. Discharge data collected during the nine sampling days of the study period are summarized in Figure 6, and generally reveal a rather complex hydrologic system in the river characterized by alternating inputs and outputs of ground water to and from the river channel. The direction of the observed ground water flux within each reach is consistent with the local water table gradient between the river and aquifer (Drost and Seitz, 1978; Esvelt, 1978).

FIGURE 6

Variation in Average River Discharge and Apparent Ground Water Flux by River Mile, July-September 1984 (data presented as mean ± one standard error)



Seepage losses occurred in four of the eight reaches of the river where discharge data were collected. These reaches included Post Falls to Harvard Rd. (RM 100.7 - 93.6), Trent Rd. to Upriver Dam (RM 85.2 - 79.8), Green St. to Post St. (RM 78.0 - 74.1) and Seven Mile to Nine Mile Dam (RM 62.0 - 58.1) (Table 5). The total seepage loss throughout the river during the study period averaged 631 +/- 158 cfs, and represents approximately 44 percent of the surface water discharge measured at Post Falls over the same period. The magnitude of this process is thus large enough to be a significant factor controlling the low flow hydrologic regime of the Spokane River. Seepage losses may also be an important factor controlling phosphorus transport through the river, particularly if such losses remain within the aquifer system for an extended period of time before returning to the river (see below).

Statistically significant (P<.02) seepage losses were observed from Post Falls to Harvard Rd. and in the Upriver Dam and Post St. dam impoundments. It is interesting to note that the major portion of the variance in the seepage estimates from each of these reaches was due to the inherent uncertainty (i.e. possible systematic errors) in the accuracy of the gages at each end of the reach (both random and systematic variations are included in the uncertainty estimates). Seepage losses calculated for each of the nine days when flow was determined were remarkably consistent within a given reach from one measurement day to the next and did not exhibit any detectable increase or decrease over time. The temporal variability would be lower still if days when the river exhibited unsteady flow were excluded from consideration (e.g. as a result of flow-altering activities at the various dams which lowered the resolution of some of the downstream gaging data).

As stated above, the USGS aquifer model has estimated the quantity of seepage losses which occur in the vicinity of impoundments along the Spokane River. Model predictions for August 1977 conditions (URS, 1981) are presented along with the measured 1984 values in Table 5. Although model predictions agree quite closely with the measured values for most of the reaches evaluated, a large discrepancy does exist relative to the Upriver Dam seepage estimates (50 cfs vs 256 cfs measured). Part of this apparent discrepancy may be related to the different hydrologic regimes present during the August 1977 model conditions and the 1984 study period, though both the river and aquifer levels in the impoundment area during these two periods appeared to be equivalent to within 0.1 m (0.4 ft) (based on river stage records and water level measurements at Central Premix and the SCC "208" wells; Bolke and Vaccaro, 1979 and this study). The difference is also possibly related to uncertainties in the reservoir leakage coefficients assumed in the USGS model, since the coefficients represent approximate values derived by examining data collected in 1950 (the highest aquifer discharge year on record; Figure 5) and over a larger reach division (Trent Rd. to Green St.; RM 85.2 - 78.0) than just the impoundment area (Bolke and Vaccaro, 1981). Given these uncertainties, the measured 1984 seepage loss values from the Upriver Dam impoundment are felt to be the present best estimate of typical flow losses from this reservoir during the summer/fall period.

Slight, but non-significant (P<.05) seepage losses were also associated with the Nine Mile Dam reservoir during the study period. This area is apparently characterized by a rather large positive hydraulic head between the pool surface and the aquifer, though the reduced hydraulic transmissivity of local soils in the Nine Mile Dam vicinity may be one reason why a substantial seepage loss did not occur during the study period (Bolke and Vaccaro, 1981). No data were collected on ground water flux above Post Falls. Previous attempts to characterize the low flow hydrology of this reach, however, have suggested that seepage losses are likely to be small (< 100 cfs; Seitz and Jones, 1981).

During the study period, limited field investigations were initiated to determine if the observed seepage losses in the vicinity of Upriver Dam and Post St. Dam were simply due to leakage of water around the dam abutments. At both of these sites, the principal dam which forms each impoundment is located several hundred meters upstream from the powerhouse facilities, such that a section of the natural river channel exists which does not normally carry surface water discharge during low flows (i.e. all flow is routed through the turbines). Leakage around the immediate vicinity of the dams can thus be monitored simply by measuring the discharge in the river channel immediately above the tailwater (powerhouse discharge) area. At both sites, the localized "leakage" flows in these channels were less than 19 cfs, and represented less than 10 percent of the observed loss through the reservoirs. Since evaporative losses are also quite small (estimated at less than 5 cfs for each area, based on methods of Linsley et al, 1975), the bulk of the observed seepage losses in the reservoir areas probably represent broad scale contributions to the local aquifer system. This water may subsequently return to the river through aquifer discharge zones, though an extended residence time in the aquifer prior to discharge appears likely. The range of probable residence times of the seepage flows within the aquifer was not estimated.

During the study period, significant (P<.05) aquifer inputs to the river were observed in three of the eight reaches where discharge data were collected. These reaches included Harvard Rd. to Trent Rd. (RM 93.6 - 85.2), Upriver Dam to Green St. (RM 79.8 - 78.0), and Spokane to Seven Mile (RM 72.9 - 62.0) (Figure 6). Moderate (105 cfs) but non-significant (P>.01) gains were also observed between Post St. Dam and Spokane (RM 74.1 - 72.9). The total aquifer input to the study area averaged 1,253 +/- 173 cfs, a quantity which is nearly equivalent to the surface water discharge measured at Post Falls (Table 5). As with the seepage losses discussed above, temporal variations in aquifer inputs within each reach were minor, and were generally quite small in comparison to the estimated accuracy of the gaging data.

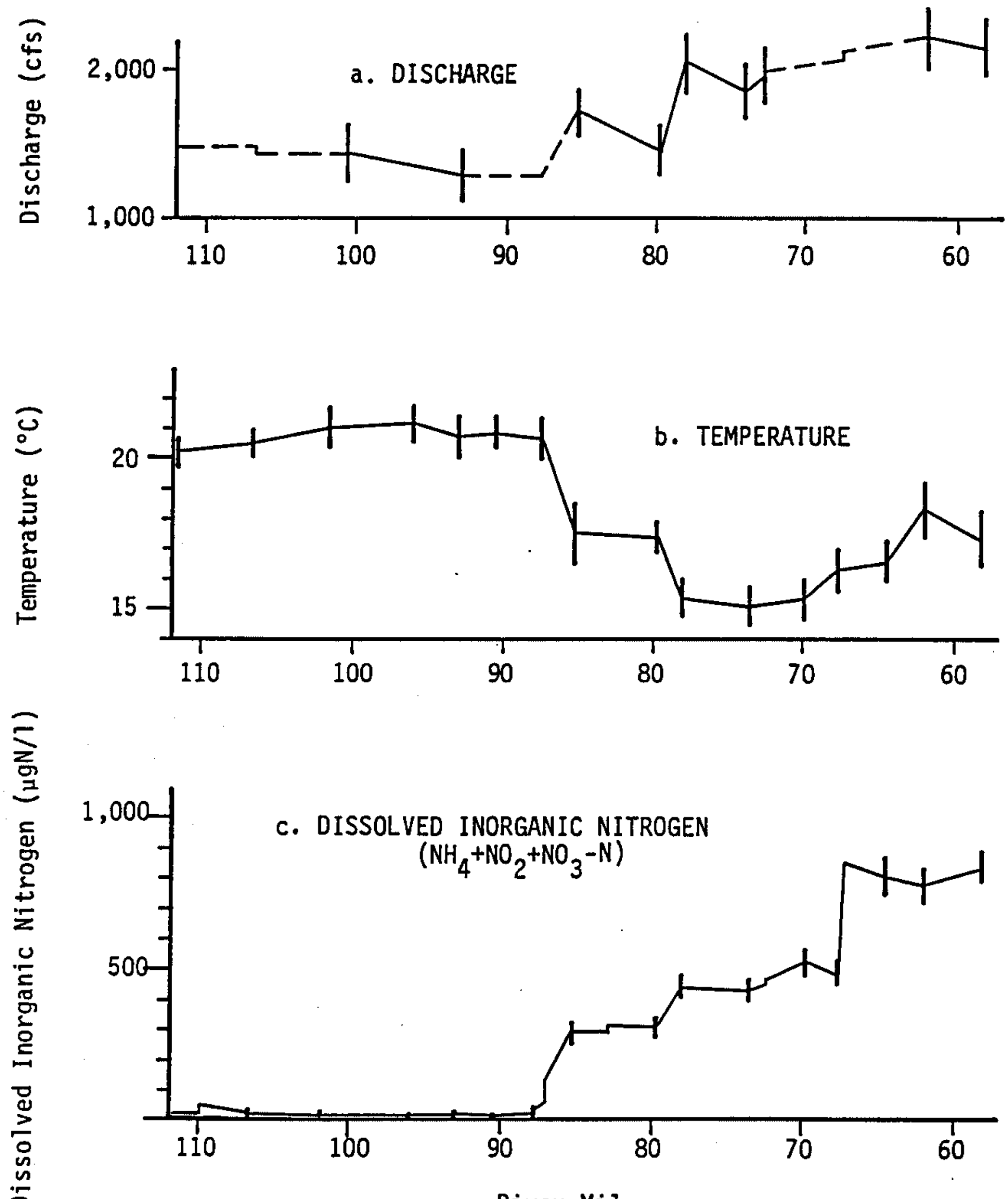
If one assumes that seepage losses around the Upriver Dam, Post St. Dam, and Nine Mile Dam impoundments were equivalent between 1948-1954 and 1984 (changes in pool elevations at these dams have been minimal since 1940), then the aquifer inputs measured during this study can be compared with previous discharge measurements performed in the river (Wells, 1955; Hendricks, 1964). These comparisons are presented in Table 5, and generally reveal that the 1984 inputs were lower than those observed in the summer/fall periods of the late 1940's and early 1950's, but were larger than those predicted by the USGS model for August 1977. These differences are consistent with historical variations in the net ground water input between Post Falls and Spokane (Figure 5), and appear to be the result of year to year fluctuations in aquifer inputs. On the basis of the data presented in Figure 5, 1984 could be characterized as a typical ground water flow year.

The discharge of the Spokane aquifer into the river has been observed to result in large changes in river temperature and nitrate concentration during summer low flow periods, since the aquifer is typically 10-12^{o} C cooler than Lake Coeur d'Alene and contains an average nitrate level more than 150 times the summer lake value (Esvelt, 1978; Yearsley, 1980, 1982). These parameters can be used as "tracers" of ground water input if consideration is given to the influence of other processes on the observed values (e.g. solar warming, point source inputs, etc.). The spatial variations in discharge, water temperature, and inorganic nitrogen (NH_4^+ + NO_2^- + NO_3^- - N) concentration over the study period are presented in Figure 7. The data reveal a pronounced cooling and inorganic nitrogen enrichment in the areas where ground water inputs are largest (Figure 6), and appear to support the locations of the sampling station network as approximate "nodes" of ground water flux as predicted by the USGS model. The expected correspondence between aquifer inputs and temperature and nitrogen variations appears to hold quite closely for the middle reaches of the river, which receives the large majority of ground water discharges. In the river below Spokane, however, the relationships may be obscured by both the relatively minor ground water contribution to the total river flow and the influence of significant point sources in the region. The Spokane AWT discharge is a major source of nitrogen to the river. During the study period, inorganic nitrogen concentrations increased by an average of nearly 80 percent in the river as a result of AWT discharges (RM 67.4).

The largest and most significant ($P<.01$) area of ground water input to the study area is between Upriver Dam and Green St., where the input averaged 577 cfs over a 1.8 mile distance (Figure 6b). This input effected a 40 percent increase in river flow through the reach, apparently contributed by numerous springs evident on both sides (north and south) of the river channel. The chemical composition of the aquifers on the two sides of the river, however, appear to differ markedly with respect to a variety of parameters, including nitrogen ($P<.001$) and phosphorus ($P<.05$). The aquifer on the north side of the river exhibits levels of most constituents which are statistically ($P<.01$) below the Spokane Aquifer average (e.g. mean NO_3-N of 340 ug/l vs 1,800 ug/l) (Vaccaro and Bolke, 1983). Based on chemical similarities, it has been hypothesized that this northern aquifer, or reach of the aquifer, is fed primarily by river seepage (Esvelt, 1978). Chemical characteristics of the aquifer on the south side of the river, however, are statistically equivalent to the larger Spokane Aquifer (e.g. mean NO_3-N of 1,450 ug/l; $P>.05$). Even wells which are nearly adjacent to the river in this area do not exhibit the reduced nitrogen concentration (or other "tracer" level) one would expect if river seepasge was occurring to the south. The striking chemical differences between these two ground water zones thus appears to be due to different source characteristics, though the hydrogeologic mechanism for such a situation has not been well established.

FIGURE 7

Variation in Average Discharge, Temperature and Total Inorganic Nitrogen Concentration by River Mile, July-September 1984
(data presented as mean ± one standard error)



It was considered desirable to attempt to quantify the relative contributions of the two aquifer systems to the observed ground water input between Upriver Dam and Green St. The different phosphorus concentrations of the ground waters (5.6 vs 10.3 ug/l for TSP in the seepage and aquifer zones, respectively) was found to have a marked influence on estimates of phosphorus attenuation within the reach. Because of the observed constancy and rather large differences in the nitrate ($NO_2^- + NO_3^-$ - N) concentrations of the ground waters, a nitrate mass-balance was performed for the reach to estimate the two aquifer inputs:

$$Q_U*C_U + Q_A*C_A + Q_S*C_S = Q_G*C_G$$

where: Q = discharge
C = $NO_2^- + NO_3^-$ - N concentration

and subscripts denote: U = Upriver Dam
A = Aquifer Inputs
G = Green St.
S = Seepage Inputs

Since the nitrate concentration observed in the seepage zone (mean = 340 ug/l) was not significantly ($P>.05$) different from the observed Upriver Dam concentration (mean = 295 ug/l), these values were set equal to one another (at 295 ug/l) and the solution reduced to:

$$Q_A = Q_G * [(C_U - C_G)/(C_A - C_G)]$$

This nitrate balance model was run for each of the sampling days, and the results, averaged over the nine days, are presented below:

Aquifer	Discharge (cfs) mean +/- standard error*	Percent of Total
Aquifer	221 +/- 125	38%
Seepage	355 +/- 128	62%

*) the standard error values include estimates of propagated uncertainty from all contributing sources (e.g. gages, aquifer concentrations, etc.)

Based on the above data, it appears that nearly two-thirds of the total ground water input between Upriver Dam and Green St. was due to seepage inputs. It is interesting to note that the calculated discharge from this source (355 +/- 128 cfs) is only slightly larger than the seepage loss measured in the pool above Upriver Dam (256 +/- 65 cfs)and that the difference between these values is not statistically significant ($P>.05$). The relationship between seepage losses upstream of Upriver Dam and subsequent return back into the river above Green St., however, cannot be established without supporting hydrogeologic data.

Velocity and Dispersion

The time-concentration curves measured at specific downstream locations following three separate dye injections into the river during the study period are presented in Appendix C. Velocity and dispersion data were derived from these curves based on centroid and variance characteristics of the dye plumes. The results from three other dye studies conducted previously in the river, encompassing a broad range of flow conditions, were also analyzed using similar techniques and combined with the 1984 data in order to construct relationships between velocity and discharge. Since no dye studies have been completed between Coeur d'Alene and Post Falls, velocity in this reach was calculated based upon an analysis of available morphometric data. The methodology and results of these and other related analyses are described in detail in Appendix C. The discussion below highlights several of the more pertinent results of these evaluations.

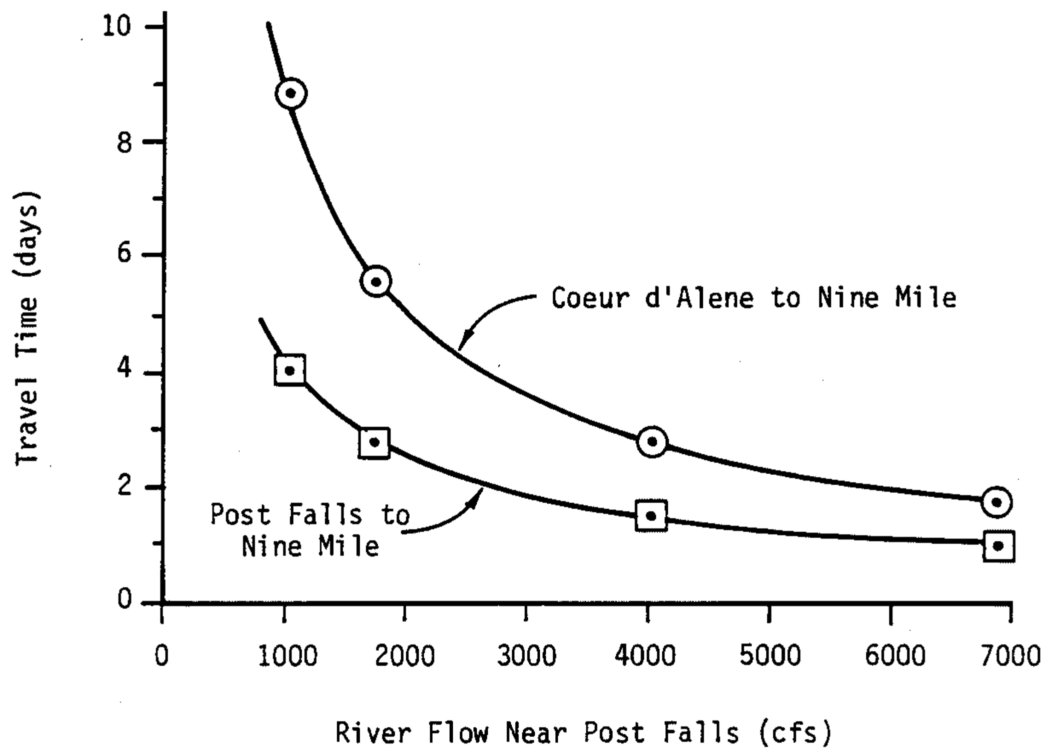
The travel time of a parcel of water traveling through the study area is strongly dependent upon discharge, as would be expected. The relationship between river discharge and travel time from Coeur d'Alene to Nine Mile Dam was found to be best described by a log-log regression of the data (r^2 = .9996), which is presented in Figure 8. During the study period, more than half of the travel time through the river occurred within the first ten river miles from Lake Coeur d'Alene to Post Falls. Travel time through this relatively large impoundment varied from 2 to 7 days and averaged 4.1 days. Velocity in this reach is estimated to have averaged only 4.3 cm/sec (0.14 ft/sec) during the study period.

Below Post Falls, the river travels approximately 17 miles as a free-flowing stream prior to reaching the Upriver Dam pool region. During the study period, river velocities in this area averaged approximately 43 cm/sec (1.4 ft/sec), corresponding to a travel time through the reach of 17 hours. River velocities in other free-flowing reaches of the river (e.g. Spokane to Gun Club) were only slightly higher, averaging 44 cm/sec (1.5 ft/sec). Velocities in the Upriver Dam, Post St. Dam, and Nine Mile Dam impoundments were considerably slower than those of the free flowing reaches, and averaged 11 cm/sec, 28 cm/sec, and 16 cm/sec, respectively. Travel time through the Upriver Dam and Nine Mile Dam pool areas averaged slightly under one day, versus 6 hours through the Post St. Dam impoundment. The average travel time through the entire river system (Coeur d'Alene to Nine Mile Dam) during the study period was 7.4 days; nearly 85 percent of the residence time of water in the Spokane River occurred in pool areas formed by the hydropower dams. These areas are also the principal sites of longitudinal dispersion (i.e. mixing) in the river.

In general, the velocity and dispersion data evaluated during this study confirm that the sampling scheme employed to attempt to follow a parcel of water moving through free-flowing reaches of the river channel was representative of actual transport conditions (Appendix C). However, sampling of the river at the Gun Club (RM 64.6) and Seven Mile (RM 62.0) stations was found to be typically several hours ahead of the desired water parcel. Data collected

FIGURE 8

Relationship Between Travel Time Through the Study Area and River Discharge Near Post Falls



from the upstream AWT discharge site (RM 67.4) and that obtained from these downstream stations, therefore, may not be strictly comparable. This condition appears to have been made even more problematic as a result of large diurnal fluctuations in effluent discharged from the Spokane AWT facility (Figure 9), which effect rather large short-term variations in the volumetric fraction of effluent present in the river.

Because of the importance of the Spokane AWT discharge to the phosphorus loading regime of the river (the AWT discharge represents the largest point source contribution of phosphorus to the Spokane River), all available discharge, velocity, dispersion, and sampling timing data collected in this area were evaluated in order to correct for possible sampling biases and thus allow a comparison of data collected from adjacent river stations. This evaluation was conducted with the use of a finite difference model of convection and dispersion processes in the river, which simulated effluent transport and mixing from the AWT discharge to Nine Mile Dam (see Appendix C).

The principal outputs of the finite difference model were normalized AWT effluent discharge values (including confidence limits) which were representative of loading conditions affecting samples collected at Nine Mile Dam (Table 6). Those normalized discharges were significantly ($P<.001$) lower than the instantaneous discharges measured during effluent sampling but were also significantly ($P<.05$) higher than the daily average effluent flow. The average normalized effluent discharge during the study period was 51.2 cfs, versus 62.6 cfs as the instantaneous average and 47.0 cfs as the daily average. Insufficient data on velocity and dispersion characteristics were available to permit similar adjustments of the Gun Club and Seven Mile sampling data, and information from these two stations is thus not strictly comparable to that of other adjacent sampling sites. This sampling deficiency, however, has only a minor effect upon the river mass balance calculations, since the Gun Club and Seven Mile stations are spanned by the aggregated -- and normalized -- AWT to Nine Mile Dam reach discussed above.

Nutrients and Phytoplankton

In addition to the three phosphorus parameters (TP, TSP, and SRP) which formed the basis of this study effort, a limited amount of monitoring was conducted for dissolved inorganic nitrogen (DIN: $NH_4^+ + NO_2^- + NO_3^- - N$) and chlorophyll a in the river and in the various inputs. Inorganic nitrogen (primarily NO_3) is a useful "tracer" of ground water inputs to the river because of the greatly elevated levels in the aquifer relative to the Lake Coeur d'Alene surface water input (Figure 7c).

Nitrogen can also be a critical nutrient for plant (i.e. algal and macrophyte) growth in aquatic systems (Wetzel, 1975), and has been identified as a principal limiting nutrient to algal growth in the Lake Coeur d'Alene outlet (Yearsley, 1980). Nitrogen is generally known to replace phosphorus as the principal growth-limiting nutrient to algae when the available nitrogen to phosphorus ratio drops below approximately 10:1 by weight (Forsberg, 1980).

FIGURE 9

Diurnal Variations in Effluent Discharge from Spokane AWT
During the Study Period

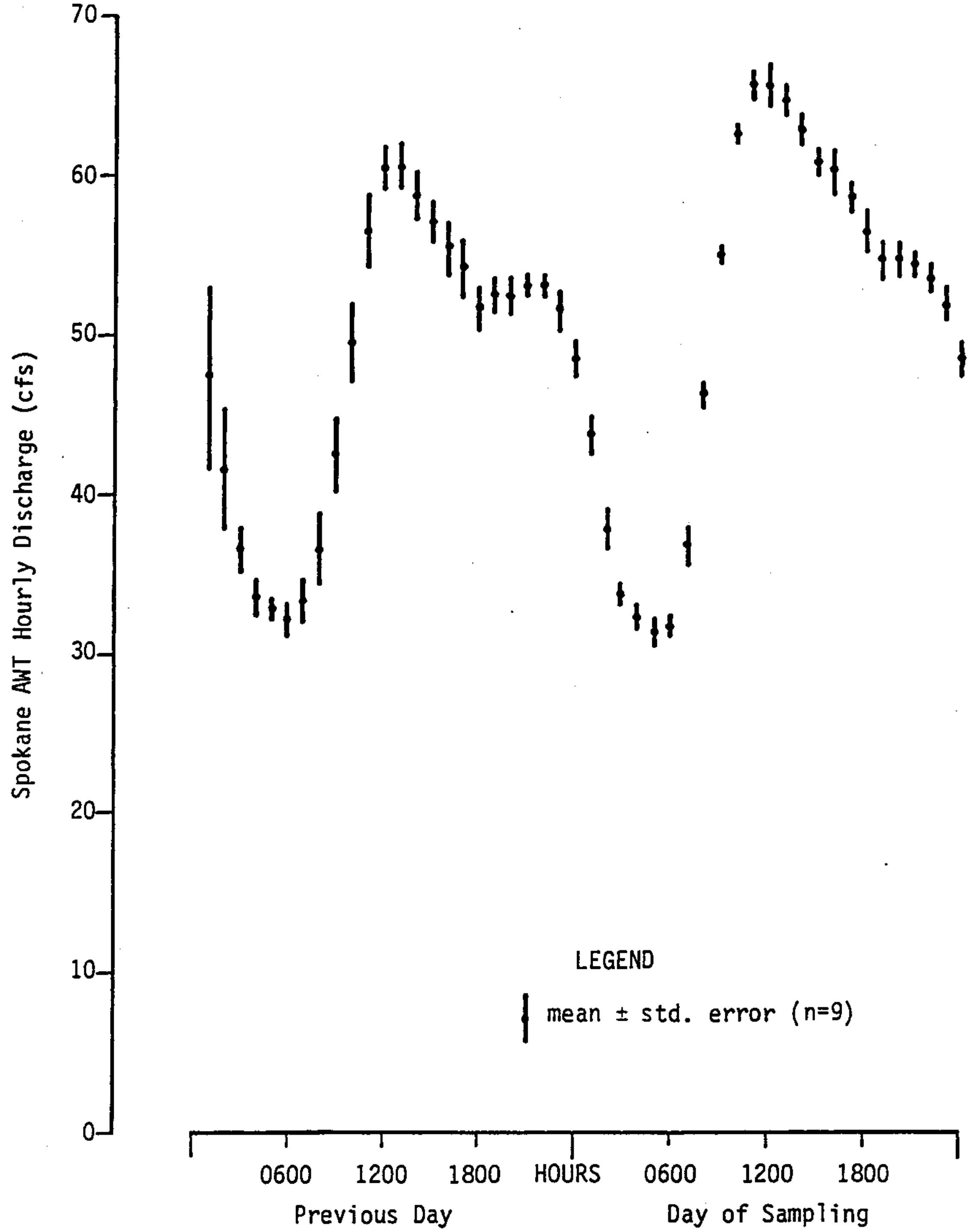


TABLE 6

Spokane AWT Discharge at the time of AWT Sampling and Estimated

AWT Discharge Representative of Nine Mile Dam Sampling Conditions

	Initial Spokane AWT Discharge at Sampling (cfs)	Representative "AWT Discharge" at Nine Mile Sampling (cfs)	Difference (cfs)
7-17-84	64.11	46.82+/-0.35	17.29
7-30-84	67.83	51.11+/-0.87	16.72
8-7-84	62.04	63.56+/-1.67	-1.52
8-13-84	65.19	53.17+/-0.26	12.02
8-20-84	60.84	43.28+/-2.15	17.56
8-27.84	61.65	48.71+/-0.32	12.94
9-4-84	63.01	49.77+/-1.37	13.24
9-10-84	60.70	49.28+/-0.63	11.42
9-24-84	58.24	54.88+/-0.95	3.36
MEAN	62.62	51.18+/-0.95	11.45
S.E.			2.35 (P<.001)

Phosphorus limitation is suggested by N:P ratios greater than 15:1, while intermediate values could be associated with either N or P control or possibly colimitation.

The DIN:SRP ratio in the Spokane River is presented in Figure 10b. These data suggest that the river above the first aquifer input (approximately RM 87) appears to have been strongly nitrogen limited, exhibiting N:P ratios of less than 3:1 and generally non-detectable inorganic nitrogen concentrations (<10 ug/l). Below the first aquifer discharge (i.e. RM 85), however, nitrogen levels increased dramatically within the river, resulting in a concurrent switch to phosphorus limitation. The N:P ratios throughout the lower half of the study area were maintained at levels greater than 20:1.

Total Phosphorus

The observed distributions of TP concentration over time and within the study area are shown in Figures 4b and 10a. The TP concentration of the Lake Coeur d'Alene outflow consistently exhibited the lowest value of any surface water sampled in the study area, and averaged 8.7 +/- 2.4 ug/l. According to the lake classification scheme discussed by Welch (1980), a TP value this low in a lentic system (i.e. standing water) is generally associated with oligotrophic (or unproductive) conditions.

Shortly after entering the Spokane River system, river TP concentrations were observed to increase over 3-fold as a result of inputs from the Coeur d'Alene STP (RM 111.0; Figure 10a). From this point to the next effluent discharge site (Liberty Lake STP; RM 92.7), TP concentrations exhibited a pronounced decline indicative of phosphorus attenuation, particularly within the slow-moving backwater area upstream of Post Falls. Below RM 93, TP concentrations appeared to fluctuate considerably and in a rather complex fashion as a result of the combined effects of other point source inputs, ground water dilution, and (possibly) phosphorus attenuation. Further downstream, the influence of discharges from the Spokane AWT plant (RM 67.4) are very apparent; phosphorus inputs to the river from the facility effected a doubling of the TP concentration during the study period.

The magnitude of point source and surface water loadings of TP measured during the study period are summarized in Table 7. These values represent the estimated loadings appropriate to the river sampling design, and include a combination of time-of-travel, convection/dispersion-adjusted, and daily average loading values as appropriate to the sampled reach characteristics. As such, these values do not necessarily correspond to average summer loading conditions during 1984. The data reveal however, that the Coeur d'Alene STP and Spokane AWT discharges were the principal phosphorus sources to the river (excluding ground water influences). Most of the other sources were minor in relation to these two inputs: many of these "minor" sources were of comparable magnitude.

FIGURE 10

Variation in Total Phosphorus, Soluble Phosphorus and N:P Ratio by River Mile, July- September, 1984 (data presented as mean ± one standard error)

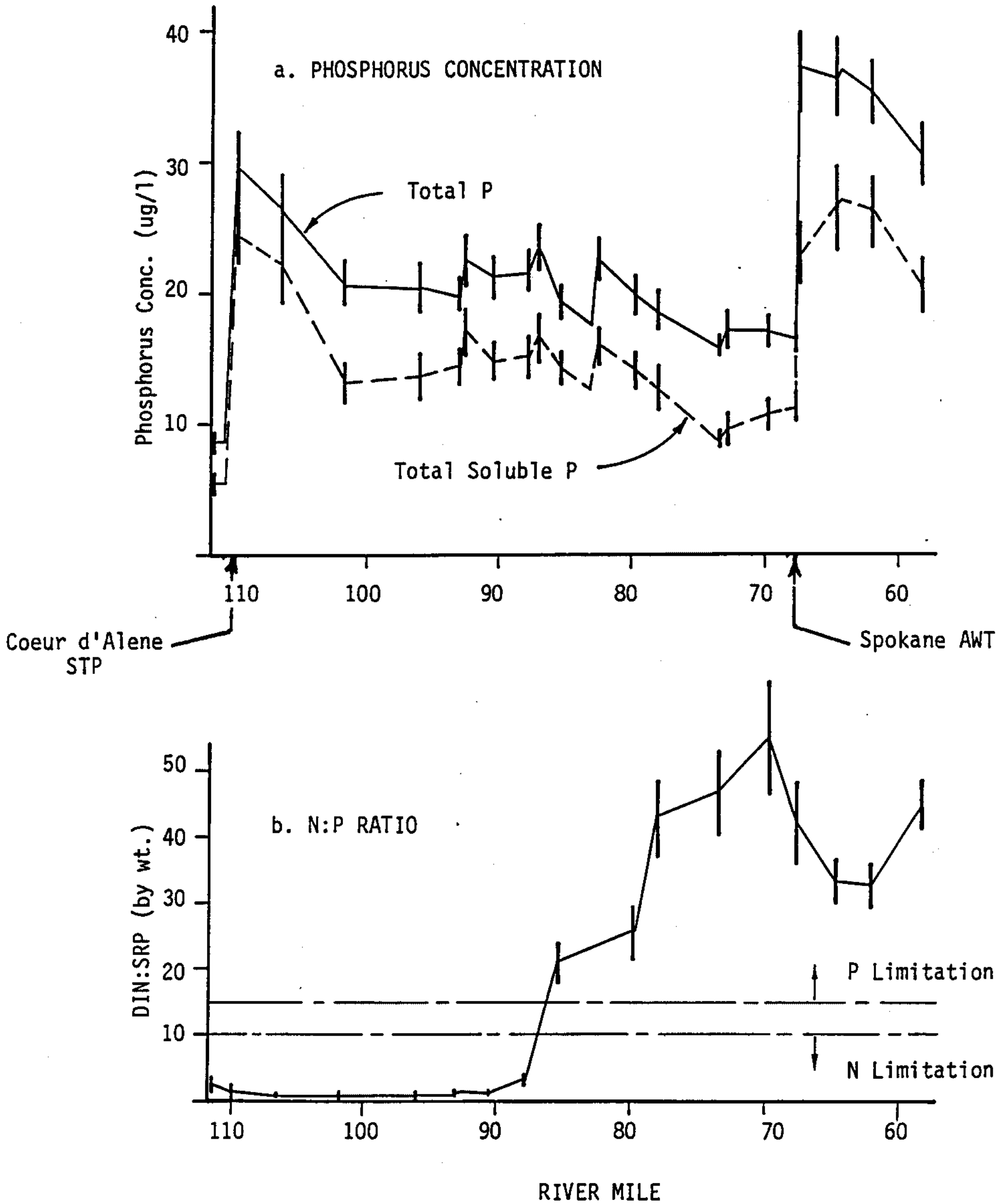


TABLE 7

Summary of Surface Water and Point Source Loadings

of Total Phosphorus Observed During the Study Period.

(data presented as mean +/- one standard error)

Input Location	**Type of Sampling**	**Source**	**Discharge (cfs)**	**TP Concentration (ug/l)**	**TP Load (kg/day)**
111.7	random	Lake Coeur d'Alene	1,470+/-208	8.7+/-2.4	31.7+/-11.2
111.0	daily average	Coeur d'Alene STP	3.58+/-0.37	7,790+/-253	68.3+/-7.4
92.7	time-of-travel	Liberty Lake STP	0.40+/-0.04	7,430+/-256	7.3+/-0.7
87.1	time-of-travel	Spokane Ind. Park	1.46+/-0.05	2,150+/-277	7.7+/-1.0
86.0	time-of-travel	Kaiser	37.5+/-2.0	55.6+/-11.2[a]	5.1+/-1.1[a]
82.6	daily average	Inland Empire	3.38+/-0.49	1,670+/-248	13.6+/-2.9
82.3	time-of-travel	Millwood STP	0.03+/-0.01	4,870+/-429	0.4+/-0.1
72.4	time-of-travel	Hangman Creek	30.6+/-3.5	97.4+/-12.1	7.3+/-1.2
67.4	time-of-travel[b]	Spokane AWT	63.9+/-2.3[b]	677+/-72	105.8+/-11.9[b]
	conv-disp adj.[c]	Spokane AWT	51.2+/-4.0[c]	677+/-72	84.8+/-11.2[c]
64.3	time-of-travel	NW Terrace STP	0.13+/-0.01	9,050+/-637	2.9+/-0.3

a) refers to the TP contributed by the plant, corrected for predicted river inputs to the coolant water system.

b) relative to river samples collected at RM 64.6 and 62.0.

c) relative to river samples collected at RM 58.1 (Nine Mile Dam); standard errors include propagated uncertainty of the convection/dispersion model (see text).

Alternating ground water inputs and outputs have a major influence on the low flow hydrology of the Spokane River and may also be an important aspect of the river's phosphorus loading regime. The phosphorus concentration of ground waters in the various input zones was monitored by sampling existing wells close to the river in each identified zone for TSP, SRP, and inorganic nitrogen fractions. No particulate phosphorus was assumed to be present in the ground waters. The results of this monitoring data have been grouped according to the aquifer discharge zones identified in the USGS model and are presented in Table 8. These data include information collected in cooperation with the Spokane County Health District and the City of Spokane Solid Waste Utility. Phosphorus concentrations in most of the wells sampled generally ranged from 5 to 25 ug/l. The estimated flow-weighted input concentration of TP and TSP in ground water discharges to the river is roughly 8.6 +/- 1.6 ug/l, which is nearly identical to the measured input concentration from Lake Coeur d'Alene.

Although the majority of wells in the Spokane Aquifer appear to contain rather low phosphorus concentrations, localized regions of the aquifer were observed to consistently exhibit TP levels as high as 50 ug/l. The presence of elevated TP in wells within the aquifer discharge zones had a pronounced effect upon estimates of the mean and variance of the "true" aquifer concentration in these areas. Most of these "enriched" ground water areas appeared to be associated with potential phosphorus sources (e.g. community septic systems or large solid waste landfills) and were often located in areas of minimal ground water flow (i.e. dilution) as predicted by the USGS aquifer model. The available information (based on an analysis of data collected from 64 wells throughout the Spokane Aquifer) suggests that average TP concentrations within the aquifer increase moderately proceeding from upgradient to downgradient locations (approximately southeast to northwest). These data also indicate that the statistical distribution of phosphorus concentrations within a given area is nearly log-normal; arithmetic averages are strongly influenced by the occurrence of these elevated concentrations. Considering this information and the fact that the aquifer input concentrations within each discharge zone were estimated based on a relatively small number of wells (Table 8), the possibility exists that the "true" average ground water TP concentrations and loads may have been somewhat greater than the observed data indicate. This possible bias, however, is likely to be less than a factor of 1.5 to 2. The possible significance of such a bias on the phosphorus attenuation estimates is discussed in more detail later.

Soluble and Particulate Phosphorus

The distribution of TSP within the river is presented in Figure 10a. Generally, TSP varied in proportion to changes in TP, as TSP accounted for 65-75 percent of the total phosphorus concentration within the river during the study period (Figure 4b). A similar percentage of the TP in surface water and point source inputs was also present as TSP. Approximately 90-100 percent of the TSP in both the river and inputs registered as SRP. Therefore most of the TSP and more than half of the TP was present in a highly reactive or labile

TABLE 8

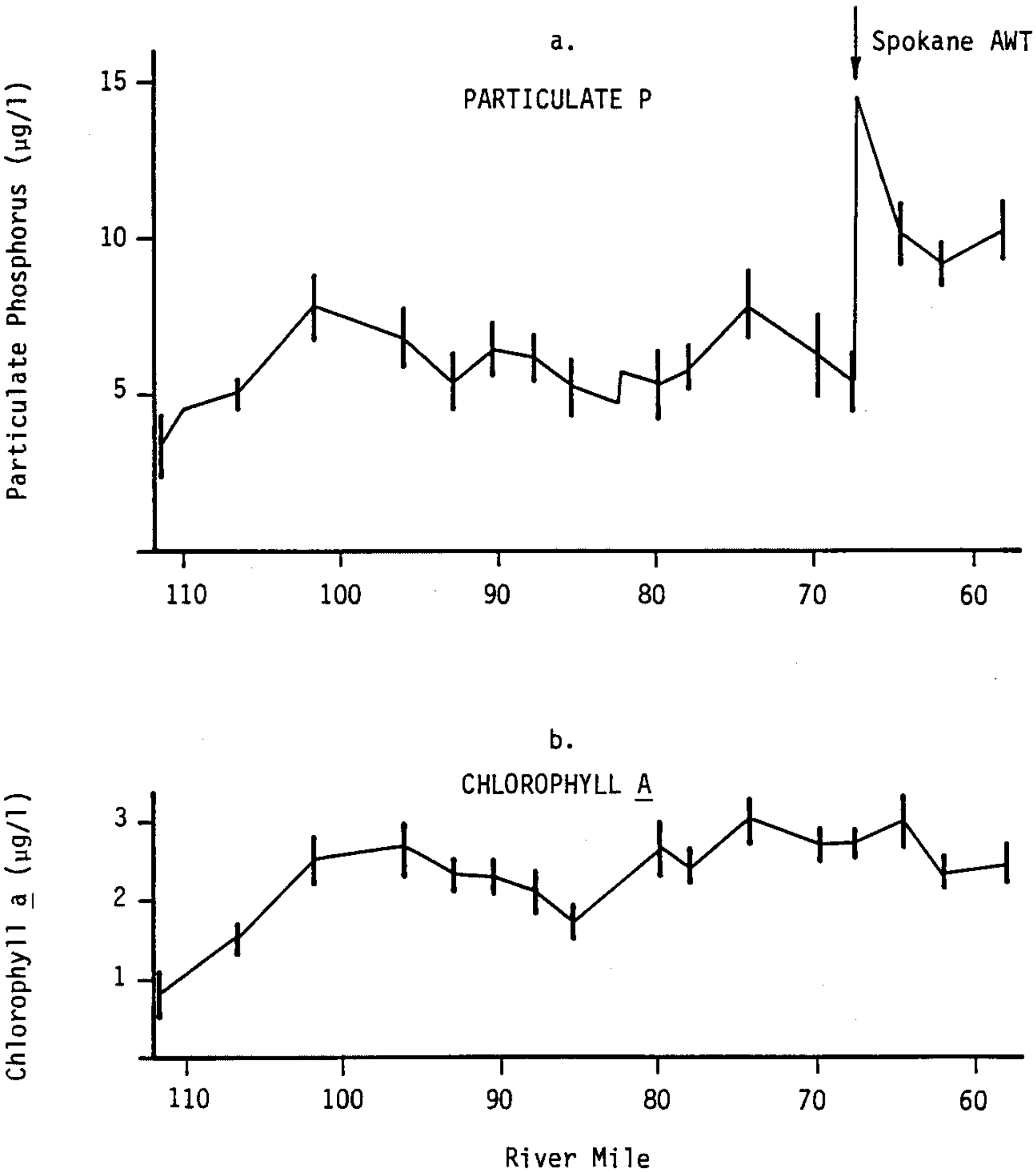
Summary of Phosphorus Data Collected from Ground Waters Adjacent to the Spokane River (data presented as mean +/- one standard error)

Aquifer Discharge Zone (RM)	Discharge (cfs)	# Wells	# Observations	Phosphorus Conc. (μg/l)	Estimated Load (kg/day)
87.8 - 85.3	404+/-70	6	19	6.9+/-1.6	6.8+/-1.9
79.8 - 78.0:South	221+/-125	4	24	10.3+/-1.7	5.6+/-3.3
North	355+/-128	2	4	5.6+/-1.8	4.8+/-2.3
Total	577+/-123				10.4+/-4.0
74.1 - 72.9	105+/-73	2	10	15.7+/-3.2	4.0+/-2.9
72.9 - 69.8	47+/-36[a]	1	5	6.9+/-1.6	0.8+/-6.6
69.8 - 67.6	34+/-30[a]	2	3	10.5+/-1.2	0.9+/-0.8
67.6 - 64.6	46+/-35[a]	2	6	10.6+/-1.1	1.2+/-0.9
64.6 - 62.0	40+/-33[a]	16	20	23.1+/-3.5	2.3+/-1.9
TOTAL	1250+/-173				26.4+/-5.7

[a]Ground water discharge in these areas was estimated by prorating the total observed input between Seven Mile (RM 62.0) and Spokane (RM 72.9) by river mile (i.e. a constant discharge rate per length (see text).

FIGURE 11

Variation in Particulate Phosphorus and Chlorophyll a Concentrations by River Mile, July-September, 1984 (values presented as mean ± one standard error)



form readily available for plant uptake and chemical adsorption (Wetzel, 1975; Stumm and Morgan, 1981).

Throughout much of the river above the Spokane AWT outfall, PP (particulate phosphorus, determined by difference between TP and TSP) appeared to be highly correlated ($P<.01$) with the suspended chlorophyll *a* concentration (Figure 11). Based on this association, it is likely that the majority of the PP in these reaches simply represents algal material. Both of these parameters (PP and chl *a*) generally exhibited increases within pool areas and decreases within free-flowing (i.e. riffle) zones, apparently as a result of phytoplankton growth in the pools and possibly a combination of ground water dilution and in-river loss mechanisms within riffles (see below).

Below the Spokane AWT discharge, however, the PP concentration in the river was observed to nearly double, without a concurrent increase in suspended chlorophyll *a* (Figure 11). Approximately half of the TP input from the AWT outfall was apparently present in a particulate form, and may represent the residual alum-phosphorus floc which was not removed by sedimentation within the plant. Removal of approximately 88 percent of phosphorus from the wastewater influent was typical of AWT treatment efficiency during the study period and equivalent to performance observed since AWT began in 1978 (Singleton, 1981; Arnold, 1985). However, operational changes at the plant in 1984 resulted in the use of 13 percent less alum and a concurrent increase in the PP fraction present in the effluent (D. Nichols, EWU, personal communication).

Between the outfall site and the next sampling station 2.8 miles downstream (Gun Club; RM 64.6), PP concentrations generally exhibited a sharp reduction from the predicted initial mixed concentration (Figure 11a). This apparent decrease in PP was balanced by a concurrent increase in TSP, resulting in an approximate conservation of TP over this reach (Figure 10a). This result implies that a change in the physical (or chemical) character of the AWT-derived phosphorus took place within the reach, and may indicate that the alum-phosphorus floc is destabilized upon discharge to the river, resulting in desorption of TSP from the floc. Such a process is generally supported by chemical considerations (Stumm and Morgan, 1981). The magnitude of this apparent desorption is equivalent to roughly half of the particulate phosphorus estimated to have been discharged from the plant. However, the apparent desorption may also be an artifact -- at least in part -- of chemical changes which occurred within the sample containers during the several hours which elapsed between sampling and subsequent filtering. That is, during this time period a conversion of TSP to PP could have occurred within the sample bottles simply as a result of extended contact of the TSP with the alum floc, resulting in an overestimation of the "true" effluent PP fraction. The relative importance of these two processes (i.e. river desorption vs. sample reaction) to the observed TSP-PP changes could not be evaluated with the available data. Regardless of which process may dominate, however, this information does reveal a potential limitation in the analysis of TSP and PP residuals, though TP balances would not be affected.

Macrophytes and Periphyton

Elemental ratios of the three predominant plant nutrients, nitrogen (N), phosphorus (P), and carbon (C), have been utilized to assess the nutrient status of plant tissue and estimate the severity of limitation in phytoplankton, periphyton, and macrophytes (Gerloff, 1975; Healey and Hendzel, 1980; Bothwell, in press). Analysis of tissue nutrition was undertaken for this study primarily to assess whether N and/or P supplies are likely to limit plant growth and thus influence biological phosphorus attenuation. The elemental composition of periphyton and macrophyte tissue collected from various locations throughout the Spokane River is summarized in Table 9, along with the approximate range of "critical" values reported in the literature. All samples were collected from reaches of similar depth (0.4 - 0.6 m) and velocity (21 - 28 cm/sec). Although uncertainties in the measurements and in the critical values are too large to permit strong conclusions regarding nutrient limitation of the plant populations, the information does reveal some important trends in the supply of N and P.

Periphyton in an upper region of the river exhibited elemental ratios of N:P and N:C which have been associated with moderate to severe nitrogen deficiency in phytoplankton (Table 9; Healey and Hendzel, 1980). As discussed above, this area of the river (near Harvard Rd; RM 91.5) is characterized by extremely low DIN concentrations and DIN:SRP ratios in the water column. Therefore nitrogen limitation of plant growth in this area is a possibility. Periphyton samples collected from points below the aquifer input zones exhibited substantial increases in nitrogen content.

Phosphorus supplies in periphyton samples appeared to show an inverse relationship with nitrogen. Samples collected from the upper river exhibited the highest P:C levels, while those collected at points further downstream showed a tendency to become more strongly P-limited (Table 9). Changes which occurred between the first two stations (Harvard Rd, RM 91.5, and Green St, RM 77.5) are consistent with the anticipated shift from N to P limitation over this area (Figure 10b).

A slight but non-significant (P>.05) decline in the P:C ratio also occurred between Green St. and the Gun Club (RM 64.6) (Table 9). Water column concentrations of TP, however, increased approximately two-fold between these stations during the month which preceeded periphyton sampling (21.9 vs. 42.3 ug/l). Apparently, increases in TP supply in the water column did not result in a discernable "saturation" of this nutrient within the periphyton.

As an ancillary component of the nutrient content sampling and analysis effort discussed above, data were also collected on areal biomass levels of the periphyton population in the Spokane River. Based on the average of 3 to 5 sampling replicates per station, the mean chlorphyll a levels at RM 91.5, 77.5, and 64.6 increased from 20 to 162 to 461 mg/m^2, respectively. Total organic carbon biomass within the periphyton exhibited a similar increase over these stations of 4.7 to 13.2 to 25.2 gms/m^2, repsectively. These values are indicative of a substantial increase in periphyton biomass from upstream to

TABLE 9

Summary of Periphyton and Macrophyte Nutritional Data (all samples collected 9/5 - 9/10/84; results presented as mean +/- one standard error)

	N:P	N:DW[a]	N:C[b]	P:DW[a]	P:C[b]
"Critical" Ratios:[c]					
Nitrogen Deficiency:					
moderate	<10	-	80-140	-	-
severe	-	8-16	<80	-	-
Phosphorus Deficiency:					
moderate	>10	-	-	-	10-20
severe	-	-	-	0.7-1.4	<10
PERIPHYTON:					
RM 91.5	4.8+/-1.1		82+/-4		20+/-3
RM 77.5	8.1+/-0.7		118+/-2		15+/-1
RM 64.6	8.5+/-1.3		137+/-7		12+/-2
MACROPHYTES:					
RM 111.7	13.3+/-6.3	28+/-3		2.1+/-1.0	
RM 103.0	8.6+/-1.5	62+/-6		7.1+/-1.2	
RM 81.5	15.3+/-2.0	70+/-7		4.6+/-0.6	
RM 74.0	10.3+/-1.1	48+/-5		4.7+/-0.5	
RM 59.5	9.1+/-0.6	69+/-7		7.6+/-0.5	

[a]Critical nitrogen and phosphorus to dry weight (DW) ratios are based on Gerloff (1975) and were developed by assaying the second 1" segments of macrophyte tissue. Units are percentages.

[b]Critical nitrogen and phosphorus to organic carbon ratios are based on Healey and Hendzel (1980) for phytoplankton. Units are percentages x 10.

[c]Critical nutrient ratios are determined using laboratory bioassay methods and are defined as the minimum nutrient concentration within the plant which can support subsequent tissue growth or productivity.

downstream sites in the river channel, consistent with observed increases in N and P concentrations in the water column. Given the rather small sample sizes on which those averages were based, the mean values listed above are probably only accurate to within 25 to 50 percent, though such an uncertainty is small relative to the large differences observed between stations. It is also interesting to note that the chlorophyll *a* levels observed at RM 77.5 and 64.6 exceed a "nuisance" criterion of 150 mg/m^2 suggested by Horner et al (1983), and are within the upper range of values observed throughout the Pacific Northwest (J. Jacoby, UW, personal communication).

In addition to quantitative differences noted in periphyton populations along the river, changes in qualitative characteristics of the attached plant community were also observed. Microscopic examination of the periphyton samples -- conducted by J. Jacoby of the University of Washington -- revealed that the periphyton at the Harvard Rd. site (RM 91.5) was composed primarily of diatoms, which represented approximately 80% of the cell volume within the periphyton. At the Green St. site (RM 77.5), filamentous green algae dominated the flora (approximately 60% of volume), though diatoms were still abundant. At the Gun Club station (RM 64.6), the plant community was heavily dominated by filamentous blue-green algae, primarily of the genus *Phormidium*. These changes in population dominants are consistent with observed differences in N and P supply between stations and also with generalized differences in nutritional requirements between algal groupings (Wetzel, 1975).

Macrophyte tissue within the Spokane River appeared to contain a higher content of both N and P than periphyton, indicating that nutrient limitation of this population does not appear likely using Gerloff's (1975) "critical" values (Table 9). This result is not surprising, since many macrophytes, including the *Elodea* sampled during this study, are capable of obtaining much of their mineral nutrition from the substrate (Denny, 1972). A previous study of macrophyte distribution within the Coeur d'Alene to Post Falls reach suggested that macrophyte populations in this area may be largely limited by seasonal high flow conditions within the river (Falter and Mitchell, 1982).

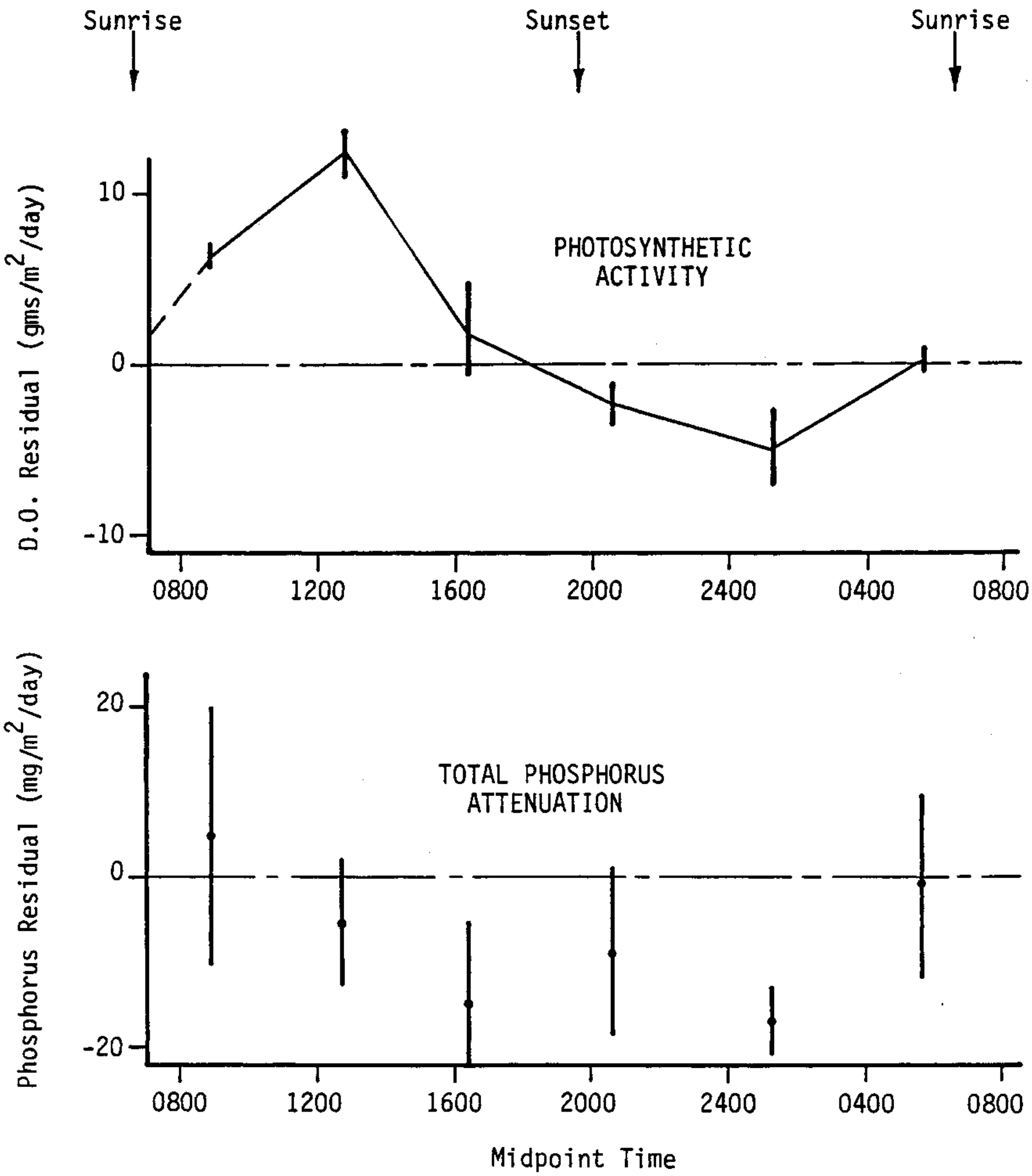
Diurnal Fluctuation

The diurnal fluctuation in phosphorus attenuation was evaluated in three reaches of the Spokane River over a 24 hour period in early September 1984. This diurnal study was initiated primarily to determine if the daytime sampling of the river employed in the monitoring program (particularly in time-of-travel reaches) would lead to a significant bias in the estimation of total daily attenuation. The photoperiod during the study period was approximately 12 hours, and permitted the monitoring of several river "plugs" which passed through the study reaches entirely during daytime or nighttime conditions (see Methods chapter above).

Results from the most "active" (on the basis of the P attenuation rate) reach investigated, Green St. to Post St., are presented in Figure 12. These results are presented as the dissolved oxygen (D.O.) and TP residual normalized for reach discharge and surface area. Although this reach exhibited a

FIGURE 12

Diurnal Fluctuation of Dissolved Oxygen Production and Total Phosphorus Attenuation Between Green St. (RM 78.0) and Post St. (RM 74.1), September 4-5, 1984 (Q = 2310 cfs; Travel Time - 7.2 hours)



substantial fluctuation in D.O. characteristic of daytime photosythetic production and continuous respiration, no such variation (P>0.05) was evident in the TP or TSP attenuation rate. Similar results of nonsignificant (P>0.05) differences between day and night phosphorus uptake were observed at the two other reaches monitored.

It is interesting to note that the D.O. fluctuations from Green St. to Post St. correspond to an estimated gross production value within the reach of roughly 2,000 mgC/m^2 day (Figure 12; based on the methodology of Hall and Moll, 1975). This value is generally considered indicative of moderately to highly productive conditions in aquatic systems (Wetzel, 1975) and indicates that photosythetic plant activity in this reach may have been quite substantial. Given the low suspended chlorophyll a values measured in the water column on this day (mean of 2.3 ug/l), it is likely that most of the production was due to attached plant forms such as periphyton or macrophytes.

As a further test of whether or not phosphorus attenuation exhibited a diurnal pattern, the extensive sampling data collected by EPA in 1979 were reviewed for diurnal differences (J. Yearsley, EPA, unpublished data). Velocity-discharge relationships developed during this study were used to determine the comparability of upstream and downstream sampling data (see Appendix C). Again, no significant (P>.05) differences in the TP attenuation between daytime and nighttime conditions were observed, and it was therefore concluded that the daylight sampling program utilized during this study would yield results appropriate to daily average conditions.

MASS BALANCES

For the purposes of this study, phosphorus attenuation was defined as any process which results in a loss of mass of this element from the river. Accordingly, phosphorus attenuation within the Spokane River system was evaluated by constructing mass-balances for each reach of the river to account for all inputs and outputs of phosphorus to and from the river, respectively.

Phosphorus attenuation mechanisms were separated into two categories in the mass balances: losses due to hydraulic outputs from the river (e.g. surface water withdrawals and ground water seepage) and losses which result from in-river processes (e.g. biological uptake, sedimentation, etc.). Hydraulic losses were evaluated by first constructing a flow balance of the river which described all significant hydraulic inputs and outputs by sampling reach. Since all other terms were measured, the ground water flows both to and from the river were determined by difference in the flow balance, as described in the "Results" section above. However, several of these "hydrologic" reaches with gages at each node spanned more than one water quality sampling reach; in these areas the calculated ground water flows were prorated by river mile (see below). The calculated ground water outputs and measured surface water outputs from each reach were then multiplied by the measured river concentrations to obtain estimates of the quantity of phosphorus (in mass flux units) which left the river by displacement of flow.

The second mechanism of phosphorus attenuation, in-river removal (M_L), was evaluated by difference in the reach mass balances. M_L was calculated as the residual term obtained by subtracting total identified outputs (including the hydraulic attenuation terms discussed above) from inputs:

$$M_L = M_{RIV(IN)} + M_{SURF(IN)} + M_{GRD(IN)} - M_{RIV(OUT)} - M_{SURF(OUT)} - M_{GRD(OUT)}$$

where M refers to mass flux (mass/time) and subscripts denote:

RIV = River (upstream and downstream)
SURF = Surface water (inputs and outputs including point sources)
GRD = Ground water (inputs and outputs)

Because the in-river attenuation value is entirely a calculated (vs. measured) quantity, it is quite sensitive to any variability (random and systematic) introduced in the measurement and calculation of the other contributing flux terms. Uncertainties in each of these terms were evaluated and propagated by first-order analysis techniques to obtain estimates of the total uncertainty associated with the in-river attenuation values. A statistically significant positive value of M_L would reveal that in-river removal processes were detected, and might represent biological uptake, sedimentation, chemical adsorption, or any combination of these and other attenuation mechanisms. Conversely, a negative M_L would imply that a <u>source</u> is present within the reach which was not previously identified, the magnitude of which exceeds the in-river loss quantity.

The following sections present the mass balance model as it was applied to data collected during this study. The results of the mass balance and uncertainty calculations for TP attenuation by reach and by sampling day are then presented. The significance of TP attenuation to the river's existing loading regime is also discussed.

Formulations

Velocity and dispersion data discussed in the previous chapter identified two reaches of the river which appear to have been associated with a sampling bias and thus required some form of adjustment to permit mass balance comparisons: Coeur d'Alene to Post Falls (RM 111.7 to 101.7) and Seven Mile to Nine Mile Dam (RM 62.0 to 58.1). These reaches correspond to the most upstream and downstream regions of the study area, respectively. Both of these areas contain extensive pool regions which greatly reduced stream velocity. Stations within these reaches were sampled at approximately the same time of day and without regard to travel time.

Water samples collected from Post Falls were estimated to have had a residence time within the Coeur d'Alene to Post Falls impoundment of between 2.1 and 7.3 days (Appendix C.) Since substantial daily variations in river discharge and phosphorus loading conditions often occurred during this rather long travel period (e.g. weekend flow increases at Coeur d'Alene STP), reach flow and loading conditions which existed on each day of sampling may have been quite different from those which affected a parcel of water sampled at the downstream boundary of the reach. In order to assess the appropriate loading conditions applicable to phosphorus data collected in the river at Post Falls, all input and output data utilized in the mass balance calculations for this reach were thus normalized to average daily conditions which were present as the sampled "plug" of water travelled through the reach, rounded to the nearest day. Concentrations in the Coeur d'Alene lake and STP effluent and in the Rathdrum Canal irrigation diversion were assumed to have been equal to values measured on the sampling days. These assumptions are supported by the observed constancy of the lake and STP concentrations over the study period and by the relative insensitivity of the reach mass balance calculation to the range of observed concentrations in and around the diversion site. These adjustments appropriate to the Post Falls data eliminated only a small systematic bias which would have occured if average discharge values from the day of sampling were used in the mass balances, but also resulted in a substantial reduction in the variability of the computed mass balance residuals (M_L) in this reach.

Rather than attempt to perform a similar adjustment of loading/travel time conditions applicable to the Harbor Island (RM 106.6) data collected at a point roughly midway from Coeur d'Alene to Post Falls, information from this site was instead removed from the mass balance calculations. The equations for this reach therefore rely on the aggregated Coeur d'Alene to Post Falls reach data. This was done primarily because observations made during this study revealed that the STP effluent was only poorly dispersed into the river at this point. The TP and TSP variances between replicate vertical composite samples were over 2.5 times that of the rest of the river; such a high variability would limit an assessment of the "true" TP concentration in this area. A large spatial and temporal variability in TP at this site was also observed by Yearsley (1980). Similarly, because the Harbor Island site was generally only 1.5 days travel time below the Coeur d'Alene STP (vs. approximately 4 days to Post Falls), the site could be influenced by diurnal variations in flow from the STP. Without any available dye study data regarding travel time and dispersion characteristics of the reach, such diurnal influences could not be reliably assessed.

The other sampled reach of the Spokane River which appeared to exhibit a sampling bias was Seven Mile bridge to Nine Mile Dam. The TP concentrations at both these sites are predicted to have exhibited a rather pronounced diurnal variation in response to changes in Spokane AWT discharges (Figure 9). The Nine Mile Dam sampling data were found to be significantly out of phase with the Seven Mile, Gun Club, and Spokane AWT time-of-travel information, and were therefore not directly comparable.

Results of a finite-difference model of advection and dispersion were used to determine the Spokane AWT discharge which is comparable to the Nine Mile Dam sampling data (Table 6). This model is described in Appendix C. As with the Coeur d'Alene to Post Falls reach, concentrations in all inputs (e.g. upstream and in AWT effluent) were assumed to be constant over the day. All other discharges in the reach except the Spokane AWT were set equal to the daily averages.

The adjustment described above establishes a reach from Spokane AWT to Nine Mile Dam which encompasses the two time-of-travel sampling reaches below the discharge. Data collected within these time-of-travel areas is thought to be generally valid for the conditions which existed at the time of sampling, though the sampling schedule utilized during the study appeared to have been slightly ahead of the actual travel time. A sampling bias may thus have occurred within these two reaches. In any event, however, the time-of-travel data are not directly comparable to information generated within the overlapping Spokane AWT to Nine Mile Dam reach. The bias-corrected mass balance computations for the aggregated AWT to Nine Mile reach are considered most useful for this study and are emphasized in the discussions which follow.

The formulations utilized in the mass balance calculations are presented in Table 10 for the generalized condition of comparable reaches (i.e. without specifically addressing the reach adjustments discussed above). Some of the more important assumptions in the mass balance and their supporting rationales are related to ground water exchange and are briefly summarized below. Most of these points have been described in previous sections of this report:

TABLE 10

Summary of Stations Used

to Construct Phosphorus Mass Balances

Station #	Location	River Mile	Discharge*	Concentration*
1	Lake Coeur d'Alene	111.7	5-3-2	Measured
2	Coeur d'Alene STP	111.0	Measured	Measured
3	Rathdrum Canal	106.6	Measured (-)	Measured
4	Harbor Island	106.6	= 5	Measured
5	Post Falls Dam	101.7	Measured (RM 100.7)	Measured
6	Seepage to Aquifer	101.7-96.0	7-5	(5+7)/2
7	Stateline	96.0	9-5; prorated by RM	Measured
8	Seepage to Aquifer	96.0-93.0	9-7	(7+9)/2
9	Harvard Road Bridge	93.0	Measured	Measured
10	Liberty Lake STP	92.7	Measured	Measured
11	Barker Road Bridge	90.4	9+10	Measured
12	Sullivan Road Bridge	87.8	9+10	Measured
13	Spokane Ind. Pk. WTP	87.1	Measured	Measured
14	Kaiser WTP	86.0	Measured (recirculated)	Measured
15	Aquifer Input	87.8-85.3	16-13-12	Measured (wells)
16	Trent Road Bridge	85.3	Measured	Measured
17	Inland Empire STP	82.6	Measured	Measured
18	Millwood STP	82.3	Measured	Measured
19	Seepage to Aquifer	85.3-79.8	20-18-17-16	=20

20	Upriver Dam	79.8	Measured	Measured
21	Aquifer Input	79.8-78.0	Calculated by NO_3 balance	Measured (wells)
22	Seepage Input	79.8-78.0	23-21-20	Measured (wells)
23	Green Street Bridge	78.0	Measured	Measured
24	Seepage to Aquifer	78.0-74.1	25-23	(23+25)/2
25	Post Street	74.1	Measured	Measured
26	Aquifer Exchange	74.1-72.9	Measured RM 72.9-25	Measured (wells) (+) or (25+29)/2(-)
27	Hangman Creek	72.4	Measured	Measured
28	Aquifer Input	72.9-69.8	A.R.; prorated by RM	Measured (wells)
29	Fort Wright Bridge	69.8	25+26+27+28	Measured
30	Aquifer Input	69.8-67.6	A.R.; prorated by RM	Measured (wells)
31	"Rapids"	67.6	29+30	
32	Aquifer Input	67.6-64.6	A.R.; prorated by RM	Measured (wells)
33	Spokane ATP	67.4	Measured	Measured
34	Gun Club	64.6	31+32+33	Measured
35	Aquifer Input	64.6-62.0	A.R.; prorated by RM	Measured (wells)
36	NW Terrace STP	64.3	Measured	Measured
37	Seven Mile Bridge	62.0	Measured	Measured
38	Aquifer Exchange	62.0-58.0	39-37	Measured (wells) or (37+39)/2(-)
39	Nine Mile	58.0	Measured	Measured

"A.R." denotes total Aquifer Residual input from RM 72.9 - 62.0 and is calculated as 37-36-33-27- RM 72.9.

* Discharge and concentration estimates at some locations were calculated based upon data collected from adjacent sampling stations; the form of the calculations are indicated where appropriate.

1. No ground water exchange between Lake Coeur d'Alene and Post Falls. Some seepage loss in this region is thought to be likely, on the basis of aquifer characteristics, but has proven difficult to measure. Seitz and Jones (1981) reported no measurable gain or loss of discharge during two low flow surveys. Post Falls Dam is in a region of relatively impervious basalt. Most of the TP input to this reach (ca. 75%) is from the Coeur d'Alene STP discharge, so the effect of lake discharge uncertainty on loading calculations is minor. Violations of this assumption are likely to result in a conservatively low estimate of attenuation.

2. No ground water exchange between Harvard Rd. and Sullivan Rd. Such a condition is predicted by the USGS aquifer model (i.e. river level = aquifer level). Ground water "tracers" (especially NO_3) reveal that aquifer inputs are minor above Sullivan Rd.

3. Aquifer inputs between the Spokane and Seven Mile gages (RM 72.9 to 62.0) occur over the entire reach and can be prorated by river mile (i.e. a constant linear discharge). This assumption is supported by the USGS aquifer model and the limited ground water contour information in the area.

Reach Mass Balances

Initial results of the mass balance calculations, aggregated across the study area and over all sampling dates, are summarized in Table 11. Of the 256 kg/day (564 lbs/day) which was estimated to have entered the Spokane River during the study period, only 157 kg/day (346 lbs/day) left the study area through Nine Mile Dam. The estimated loss, 98.5 kg/day (217 lbs/day), is equivalent to 38 percent of the input and is highly significant ($P<.01$).

Approximately 34 percent of the total phosphorus attenuation during the study period was attributable to hydraulic losses associated with irigation withdrawals and seepage to the aquifer system (Table 11). The significance of hydraulic attenuation and particularly seepage attenuation to the total river phosphorus loading regime, however, is to some extent dependent upon the differences between river concentrations and aquifer concentrations. That is, the quantity of seepage discharge which leaves the river within a reach is approximately balanced by subsequent ground water inputs to a lower reach. Although specific water masses associated with outputs and inputs may be generally out of phase as a result of an extended residence time within the aquifer, the net effect to the river is nevertheless a function of the concentration difference between the outflowing river and the inflowing aquifer. During this study period, the flow-weighted TP concentration of seepage losses from the river was 20.5 ug/l. In comparison, the flow-weighted aquifer input concentration to the river is estimated to have been only 8.6 ug/l, representing a net "loss" within the aquifer system of 60 percent of the seepage concentration if flow was conserved. Net losses of TP within the aquifer system might occur as a result of physical and chemical removal processes or

TABLE 11

Summary of Mass Balance Calculations

Aggregated Across the Study Area Over All Sampling Dates

(all data presented as mean +/- one standard error)

	Discharge (cfs)	TP Load (kg/day) Unadjusted	TP Load (kg/day) Adjusted[a]
INPUTS:			
Surface Water	1,500 +/- 208.	39.0 +/- 11.3	39.0 +/- 11.3
Ground Water	1,250 +/- 173.	26.4 +/- 5.7	37.8 +/- 6.0
Point Sources	60 +/- 4.0	190. +/- 13.8	190. +/- 13.8
TOTAL	2,810 +/- 271.	256. +/- 18.8	267. +/- 18.8
OUTPUTS:			
Nine Mile Dam	2,150 +/- 203.	157. +/- 17.9	157. +/- 17.9
ATTENUATION:			
Hydraulic[b]	675 +/- 158.	33.9 +/- 10.4*	33.9 +/- 10.4*
In-River (M_L)	0	64.6 +/ 20.8*	76.0 +/- 20.3*
TOTAL	675 +/- 158.	98.5 +/- 20.8*	110. +/- 22.8*

Note: "*" denotes that value is significantly different from zero at P<.02.

[a]Adjusted values refer to loading data obtained by calculating the ground water input between Upriver Dam and Green St. (RM 79.8 - 78.0) by difference (i.e. assuming no attenuation occurs within this reach; see text).

[b]Hydraulic attenuation refers to discharge which leaves the river via irrigation withdrawal or seepage to the adjacent aquifer (see text).

could simply be due to transport conditions within the aquifer which allow river seepage to remain in the aquifer long enough to be effectively "lost" from the river during the summer low flow time period. The aquifer inputs to the river could have a source other than the seepage losses or may be the result of seepage during high flow months when river concentrations of TP and TSP are generaly lowest. Regardless of the mechanism, however, seepage losses during the study period did represent a net loss of TP from the river, though the magnitude of the removal, of course, is dependent upon the accuracy of estimates of the aquifer concentration.

The mass balance calculations reveal that the majority (two-thirds) of phosphorus attenuation during the study period occurred via in-river removal processes (Table 11). This attenuation component was significant at $P<.02$. In-river attenuation appeared to occur throughout the length of the study area; cumulative total phosphorus attenuation increased in a nearly linear fashion proceding down the river (Figure 13).

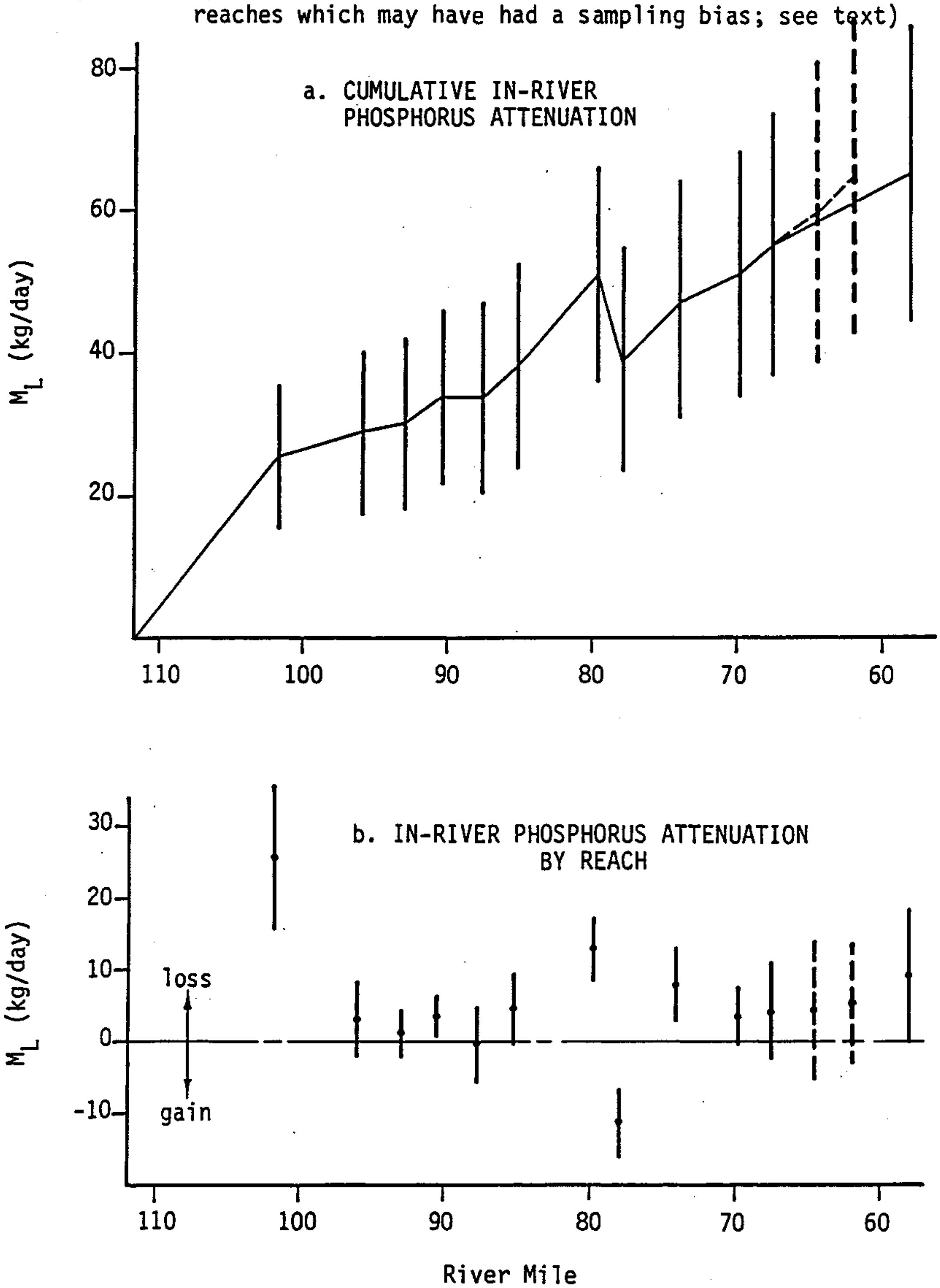
The reach mass balances presented in Figure 13 reveal that one reach exhibited a significant ($P<0.05$) gain in TP; all other reaches either revealed a significant TP loss indicative of in-river attenuation or exhibited no significant residual. The one "gaining" reach is located between Upriver Dam (RM 79.8) and Green St. (RM 78.0) and was the shortest (1.8 miles) reach evaluated during this study. This reach also receives the greatest quantity of ground water discharge of any reach evaluated. Aquifer inputs to this area totalled 577 cfs, and effected an average 40 percent increase in river discharge over the reach during the study period (Figure 6). No point source inputs or other significant surface discharges are known to enter this reach.

The error analysis techniques utilized in computing the uncertainty in each reach mass balance estimate included all identified uncertainties associated with measurement errors and in-river fluctuations. Discharge and river sampling uncertainties at the two nodes of the "gaining" reach (i.e. Upriver Dam and Green St.) are believed to have been well described in the variance propagation procedure. The magnitude of the residual "gain" term is large with respect to these uncertainties. However, the remaining term in the mass balance equation for this reach, ground water TP concentration, may not be well described.

The aquifer concentration used in the mass balance for Upriver Dam to Green St. was a flow-weighted average of well data collected in the Parkwater area. Flow-weighting was based on a nitrate mass balance between these two river sampling stations, and indicated that nearly two-thirds of the aquifer input to this reach originated from nitrate-poor seepage from the Upriver Dam impoundment. Compared to the aquifer flow which was represented by 24 samples collected from 4 wells, however, the average concentration in the more important seepage zone was described by only 4 samples from 2 wells in the area (Table 8). Since the distribution of phosphorus concentrations within various regions of the Spokane Aquifer (including the Parkwater ground water discussed above) was found to be characterized by a small number of relatively high values (i.e. log-normal), a small sample size would generally lead to an

FIGURE 13

In-River Total Phosphorus Attenuation (M_L) Aggregated Across All Survey Dates (all data presented as mean ± one standard error; dashed lines denote reaches which may have had a sampling bias; see text)



underestimate of the true average concentration within the aquifer. This possible bias was not specifically addressed in the variance calculations.

Based on the foregoing discussion, it appears that the total phosphorus "gain" observed between Upriver Dam and Green St. was most likely due to deficiencies in the measurement of the large ground water input which enters this area. Adding this apparent "gain" (11.4 kg/day) to the previously estimated aquifer load to this reach (10.4 kg/day) represents an increase in the flow-weighted ground water concentration from 7.4 ug/l to 15.4 ug/l. This final calculated value is well within the range of TP concentrations observed in wells of the Parkwater area (1.4 to 23.6 ug/l) and illustrates the sensitivity of mass balances within this reach to the assumed inflow concentration. As previously pointed out, this reach received nearly half of the total (i.e. gross) ground water input to the entire river and would thus be expected to be particularly sensitive to changes in ground water inputs. Other reaches of the river are less influenced by ground water discharges. The other major ground water discharge zones (e.g. RM 87.8-85.3) were monitored more intensively than the Upriver Dam seepage zone, and the sampled values in these other regions are therefore more likely to represent the actual distribution of phosphorus concentrations in the ground water inputs.

The aquifer concentration adjustment described above for the Parkwater area was applied to the mass balance computations, since this procedure generated the best estimate of the true aquifer load to the river within the Upriver Dam to Green St. reach. This adjustment, of course, assumes that in-river attenuation processes are negligible in this reach, an assumption which likely results in a conservative underestimation of the true total phosphorus attenuation rate. However, given the small size of this reach (approximately 2 percent of the total estimated area of the river), TP attenuation between Upriver Dam and Green St, is probably minimal in relation to the river as a whole, and this assumption is likely to be inconsequential.

The resultant attenuation calculations are presented in Table 14, and are roughly 12 percent greater than the unadjusted values. This best estimate of total attenuation averaged 110 +/- 23 kg/day (243 +/- 50 lbs/day) or 41 percent of the total input. TP attenuation throughout the river was statistically very significant ($P<.01$) and appeared to have been an important process controlling TP loading at Nine Mile Dam. About 69 percent of the total attenuation appeared to be due to in-river processes, with the remainder ascribed to hydraulic losses (i.e. irrigation and seepage).

Mass Balances by Functional Form

In-river (M_L) mass balances similar to those discussed above for total phosphorus were also performed for TSP, SRP, PP, DIN, and chl *a*. For clarity, the results of these analyses were aggregated into five groupings on the basis of differing velocity, N:P ratio, and TP concentrations. To permit comparisons between reaches, all in-river attenuation data have been normalized based on the estimated reach area. Reach areas were estimated from USGS topographic maps and measured widths at the stream gaging sites.

The results of these in-river mass balance calculations are summarized in Table 12. Although variability within the data is quite large, particularly in the free-flowing "riffle" areas, several trends are nevertheless apparent within the slower-moving "pool" areas above the Spokane AWT discharge. In these impoundment areas nearly all of the apparent in-river attenuation of phosphorus is accounted for by significant ($P<.05$) losses from the TSP and SRP fractions. These areas also generally exhibited a significant increase ($P<.05$) in PP and chl<u>a</u>, though the magnitude of this increase was small in comparison to the TP, TSP, and SRP losses.

The river reach from Spokane AWT to Nine Mile Dam is also primarily a pool area and generally contained the highest P concentration observed over the study area. Total phosphorus loss rates, however, were among the lowest observed (Table 12). Interpretation of TSP, SRP, and PP data in this area is complicated by sampling deficiencies and/or particulate desorption reactions associated with the Spokane AWT effluent, resulting in a large apparent increase in TSP and a concurrent decrease in PP immediately below this facility. Based on data collected at the next station below the AWT discharge (i.e. Gun Club; RM 64.6), it appears that most of the TP attenuation from the AWT outfall to Nine Mile Dam was attributable to losses from the TSP and SRP fractions, though these losses were not statistically significant ($P>.05$).

The information discussed above generally reveals that most of the observed in-river attenuation of TP within the pool areas of the Spokane River was due to losses of soluble reactive forms. This information is consistent with a biological uptake mechanism, though in-river chemical adsorption processes would also yield similar results. Both of these processes have been shown to be important P attenuation mechanisms in other river and stream systems (Ball and Hooper, 1961; Elwood and Nelson, 1972; Johnson et al, 1976; Meyer 1979). Variability in the M_L calculations performed within the riffle regions of the Spokane River were too large to permit any statements regarding mass balance residuals of the various functional forms of phosphorus within these areas (Table 12).

The value in being able to differentiate -- for the purposes of this study -- between in-river phosphorus attenuation processes by functional form (e.g. TSP vs. PP) is primarily related to predictive considerations. That is, if separate consideration of these component processes (e.g. PP gain in pools vs. loss in riffles) has the result of reducing predictive uncertainty relative to an aggregated total phosphorus model, then such processes should be described. However, examination of the variability in data collected on the attenuation of the various phosphorus forms reveals that separate consideration of these forms would actually increase predictive uncertainty. In the case of the Spokane AWT, this deficiency is particularly evident. The predictive model which describes phosphorus attenuation within the Spokane River, therefore, was developed by only considering the aggregate of all forms of phosphorus (i.e. TP).

TABLE 12

Summary of In-Stream Phosphorus Attenuation Data (M_L) by Functional Form
in the Five Principal Environments of the Spokane River
(results presented as mean +/- one standard error)

	Lake Coeur d'Alene to Post Falls	Post Falls to Sullivan Rd.	Sullivan Rd. to Spokane AWT: Riffles[a]	Sullivan Rd. to Spokane AWT: Pools	Spokane AWT to Nine Mile Dam
Number of Observations	9	36	22	18	9
Total Reach Area (km^2)	2.80	1.21	0.81	1.17	1.75
Average Velocity (cm/sec)	5.0	42.1	44.5	19.4	17.6
Total P (ug/l)	25.3 +/- 1.9	21.0 +/- 0.8	17.8 +/- 0.7	19.3 +/- 1.0	31.8 +/- 2.3
DIN:SRP (by wt)	1.8 +/- 0.4	1.1 +/- 0.1	38.5 +/- 5.2	31.5 +/- 3.7	42.3 +/- 4.6
Total P Residual ($mg/m^2 \cdot day$)	-9.2 +/- 2.4	-6.5 +/- 4.3	-12.4 +/- 9.8	-17.9 +/- 5.0	-5.4 +/- 3.6
Total Soluble P Residual ($mg/m^2 \cdot day$)	-12.4 +/- 2.6	-3.7 +/- 4.6	2.9 +/-10.9	-23.5 +/- 8.2	0.1 +/- 2.8
Soluble Reactive P Residual ($mg/m^2 \cdot day$)	-12.3 +/- 1.0	0.3 +/- 8.9	17.8 +/- 16.9	-13.0 +/- 9.6	-4.3 +/- 5.0
Inorganic N Residual ($mg/m^2 \cdot day$	-38.7 +/- 4.7	-22.3 +/- 10.9	---	-44.1 +/- 125.1	-29.6 +/- 156.3
Particulate P Residual ($mg/m^2 \cdot day$)	3.2 +/- 1.3	2.8 +/- 4.7	-15.5 +/- 15.3	7.2 +/- 7.5	-5.5 +/- 3.1
Chlorophyll a ($mg/m^2 \cdot day$)	2.0 +/- 0.3	-1.5 +/- 1.7	-1.4 +/- 1.5	6.4 +/- 2.2	-0.4 +/- 0.8

[a] Excluding the Upriver Dam to Green St. reach (RM 79.8 to 78.0)

PHOSPHORUS ATTENUATION MODEL

The principal contractual objective of this study was the development of a predictive model of the Spokane River system which could reliably simulate the average total phosphorus load entering Long Lake at Nine Mile Dam during low river discharge conditions. Such a model is intended to be applicable to the current management and wasteload allocation framework previously developed for the study area (Singleton, 1981). The model must be adaptable to changes in point source loadings from those existing during the 1984 study period and must also address the effect of differing point source locations along the river on attenuation characteristics. These stated objectives require that the low flow (1-in-20-year condition) hydrologic regime within the river be described, particularly with respect to the significant seepage losses and associated "hydraulic" attenuation observed within the river system. The relationship between "in-river" attenuation and phosphorus loading to the river under these low flow conditions must also be established for each segment of the river system which possesses unique attenuation characteristics.

The following sections present the development of a simulation model which describes phosphorus loading and attenuation characteristics within the study area applicable to the current WDOE management of Long Lake. The low flow hydrology of the Spokane River is described, based on an analysis of data collected during this study and previous measurements conducted by USGS (Wells, 1955; Hendricks, 1964; USGS, 1961-1981; USGS, preliminary data). In-river phosphorus attenuation is evaluated relative to some of the more important parameters which are believed to influence this process, including river flow, phosphorus concentration, and nitrogen concentration. Although results from the 1984 field effort formed the basis of the in-river component of the phosphorus attenuation model, results of previous investigations within the Spokane River (Yearsley, 1982; R.A. Soltero, EWU, unpublished data) were examined as a check on the validity of the model. Uncertainties in both the hydraulic and in-river attenuation estimates are addressed, and are propagated through the model with the use of first-order techniques. Output from the model includes a probabilistic assessment of phosphorus discharged into Long Lake, incorporating loading contributions from the Little Spokane River, which enters the lake below Nine Mile Dam (USGS, 1971-1980; R.A. Soltero, EWU, unpublished data). Phosphorus inputs are evaluated relative to algal biomass development and nuisance conditions within Long Lake, based on an analysis of data collected by EWU during the period 1973 to 1982 (Soltero et al, 1982).

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 Rd., 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 (including the 20-year-low-flow) in discharge within the river system and are summarized for the June to November period in Appendix E. Year to year variations in measured and calculated (by difference) inputs and outputs in the river system were found to approximate a Gaussian (normal) distribution. Statistical properties of the discharges (obtained by graphical techniques) are summarized below:

Input/Output Location (RM)	June-November Discharge (cfs) median +/- std. dev.	Approximate Range of Normality	Period of Record (years)
Lk. Coeur d'Alene (111.7)	2,900 +/- 983	lower 70%	71
Rathdrum Canal (106.6)	- 27 +/- 4	all	38
Seepage Loss (100.7-93.6)	- 74 +/- 68	all	55
Net Aquifer Input (93.6-72.9)	674 +/- 195	all	55
Hangman Creek (72.4)	27 +/- 9	lower 60%	36
Net Aquifer Input (72.9-58.1)*	243 +/- 90	all	17
Little Spokane River (56.3)	440 +/- 41	all	18

*Calculated by difference between Spokane (RM 72.9) and Long Lake Dam (RM 33.9), corrected for change in storage within Long Lake and inputs from Hangman Creek, Spokane STP/AWT, and the Little Spokane River.

Discharges at Lake Coeur d'Alene (calculated) and Hangman Creek deviated from the normal distribution, particularly at the high flows, and are better described by a log-normal distribution. However, over the lower flow range (i.e. discharges less than the median) the Gaussian distribution closely approxiamtes the observed annual variation. Since low flow conditions are of principal concern to the management of Long Lake, such an approximation appears suitable. The assumption of normality also greatly simplifies the first-order variance propagation procedure used in the model (see below).

The stated "design condition" for the management of Long Lake is the 1-in-20-year low flow, evaluated primarily at the upstream boundary of the study area (Singleton, 1981). As discussed in the "Results" section, the estimated 20-year low flow at the outlet of Lake Coeur d'Alene is 1,500 cfs, or slightly less than 50 percent of the median discharge. Evaluation of the 20 year low flow condition throughout the entire river system, however, is potentially more difficult, since other inputs and outputs to and from the river below Coeur d'Alene may or may not be correlated to the lake outlet discharge. The net ground water input between Post Falls and Spokane, for example, was previously shown to be uncorrelated with the Post Falls discharge, suggesting that aquifer inputs may fluctuate independently of surface water flows in the study area (Figure 5). The Hangman Creek discharge was the only input/output location which exhibited a significant ($P<.05$) correlation with the Coeur d'Alene discharge (evaluated during years with < 2,900 cfs). In this case a positive correlation was observed between the two discharges, though the correlation described less than one-third of the variability in the Hangman Creek flow and was not considered further.

The observation that surface and ground water flows appear uncorrelated within the study area simply implies that the 20-year low flow condition for ground water exchanges with the Spokane River does not necessarily coincide with the 20-year low flow at the outlet of Lake Coeur d'Alene. Within the phosphorus loading/attenuation model, therefore, all other discharges to and from the river except the Lake Coeur d'Alene outlet flows were treated as uncertain quantities characterized by a mean and a variance; the effect of these uncertainties on the model output were assessed using first-order methods. The Lake Coeur d'Alene outlet flow was set equal to the 1-in-20-year value, 1,500 cfs (with no variance), in keeping with the present management framework. Hydrologic parameters utilized in the model are summarized in Table 13, based on the same reach division utilized in the mass balance calculations described previously.

Seepage losses in the vicinity of impoundments within the study area were assumed in the model to be equivalent to those measured in 1984. Aquifer inputs to the river above Spokane (RM 72.9), however, were calculated based on an analysis of previous USGS measurements (1948-1954) and the data collected during this study. Examination of the available data revealed that a rather constant fraction of the net input observed between Harvard Rd. and Spokane during each year was apportioned into the various aquifer input zones. These fractions are as follows:

Reach (RM)	Percent of net Harvard Rd. - Spokane Input	Number of Years
Harvard Rd. - Trent Rd. (93.6-85.3)	61.8 +/- 8.3	8
Upriver Dam - Green St. (79.8 - 78.0)	72.4 +/- 10.2*	5
Post St. Dam - Spokane (74.1-72.9)	16.1 +/- 4.1*	5

*Assumes a constant seepage loss around the dams during previous years (i.e. 1948-1954) equivalent to that measured in 1984.

The aquifer input fractions were then multiplied by the average net discharge observed between Harvard Rd. and Spokane over the 35 year period of record to obtain estimates of the long-term average aquifer input to each reach. The variances in both the fraction estimates and in the year to year net input quantity were combined in this calculation procedure, though the annual variation in the net Harvard Rd. to Spokane input accounted for over 80 percent of the total uncertainty in the calculated aquifer input values. These values are presented in Table 13.

Ground water inputs to the Spokane River between Spokane and Nine Mile Dam were estimated by calculating the difference between the Long Lake Dam and Spokane discharges, corrected for storage changes and measured inputs from Hangman Creek, Spokane STP/AWT, and the Little Spokane River (at its mouth). This rather indirect procedure for estimating the ground water input was employed primarily because very little gaging data exists for the Spokane to Nine Mile area, and most of what has been collected was obtained during high ground water flow conditions within the Spokane Aquifer (1948-1950; Figure 5).

TABLE 13

Summary of Hydrologic Conditions and Total Phosphorus Concentrations Utilized in the Loading/Attenuation Model (excluding point sources)

Input/Output Location (RM)	Discharge (cfs) Mean ± std. dev.	TP Concentration (μg/l) Mean ± std. error
Lake Coeur d'Alene (111.7)	1,500 (20-year)	8.7 ± 2.4
Rathdrum Canal (106.6)	-27 ± 4	[River]
Seepage Loss (101.7-96.0)	-52 ± 47	[River]
Seepage Loss (96.0-93.6)	-23 ± 21	[River]
Aquifer Input (87.8-85.3)	417 ± 133	6.9 ± 1.5
Seepage Loss (82.6-79.8)	-256 ± 65	[River]
Aquifer Input (79.8-78.0)	488 ± 157	15.4 ± 3.3
Seepage Loss (78.0 - 74.1)	-180 ± 84	[River]
Aquifer Input (74.1-69.8)	178 ± 49	12.2 ± 4.4
Hangman Creek (72.4)	27 ± 9	72.3 ± 21.4
Aquifer Input (69.8-67.6)	49 ± 22	10.5 ± 1.2
Aquifer Input (67.6-64.6)	67 ± 25	10.6 ± 1.2
Aquifer Input (64.6-62.0)	58 ± 21	23.1 ± 3.9
Little Spokane River (56.3)	440 ± 41	32.4 ± 5.9

However, the previous gaging data, as well as that collected in 1984, supports the use of this difference procedure, since during these years nearly all of the input between Spokane and Long Lake (less the Little Spokane River) was observed to enter above Nine Mile Dam.

In-River Attenuation

Controlling Parameters

PHOSPHORUS CONCENTRATION

Previous field and laboratory studies of phosphorus removal from river and stream environments have generally observed that losses occur as a result of accumulation onto the benthic substrate. Two predominant mechanisms of phosphorus attenuation have been described: biological uptake by attached plant populations (primarily periphyton) and chemical adsoprtion onto fine-grained sediments (Ball and Hooper, 1961; Whitford and Schumacher, 1961; Brink and Widell, 1967; McColl, 1974; Johnson et al, 1976; Perkins, 1976; Stockner and Shortreed, 1978; Meyer, 1979; Elwood et al, 1981; Horner and Welch, 1981; Hill, 1982; Horner et al, 1983; Bothwell, 1985; Klotz, 1985). Attempts to quantify the relative importance of these two (and other) processes in determining phosphorus losses have generally proven to be quite difficult, though both mechanisms have been shown to be quanititatively important in more than one lotic system studied. Generalizations regarding "typical" attenuation processes also appear to be complicated by a variety of site-specific factors such as substrate quality and light availability, which may have a large effect upon removal rates.

Both chemical sorption and biological uptake rates -- expressed on an areal basis (e.g. mg/m^2 day) -- have been shown to increase roughly in proportion to the water column P concentration (see references cited in previous paragraph). Although in theory this rate increase would eventually level off as phosphorus concentrations approach "saturation" values, the available literature on this subject suggests that the saturation TP value may often be more than 50 ug/l, though considerable variations between river systems have been noted (Bothwell, 1985). For biological (especially periphytic) uptake, this saturation value may increase as stream velocities decrease, owing to possible diffusive limitations in the rate of nutrient supply to plant tissue (Whitford and Schumacher, 1961; Horner et al, 1983). In general, chemical removal (i.e. adsorption) rates appear to "saturate" at a higher river concentration than biological uptake processes.

Assuming that phosphorus attenuation is benthic and is proportional to the river TP concentration, the rate of attenuation within any area can be expressed as:

$$\text{Benthic Attenuation } (mg/m^2.day) = \frac{M_L}{A} = K_2 * C$$

Where: M_L = In-River Attenuation (kg/day)
A = Reach Area (km^2)
K_2 = First Order Rate Constant (m/day)
C = TP Concentration (ug/l)

K_2 in this case is the reach-specific rate constant, and is conceptually equivalent to first-order (i.e. concentration dependent) decay rates used in a variety of water quality modeling applications. If concentration changes within each reach are small, the value of K_2 averaged over the area can be approximated as:

$$K_2 = \frac{M_L}{A * \overline{C}}$$

where $\overline{C}$ is the average phosphorus concentration within the reach.

The appropriateness of this formulation for describing TP attenuation within the Spokane River was first evaluated by examining data collected from the middle reaches of the study area. Reaches were selected which exhibited similar TP concentrations and N:P ratios and thus varied primarily in relation to physical characteristics. For this evaluation, all reaches between Sullivan Rd. (RM 87.8) and Spokane AWT (RM 67.6) were selected, excluding the Upriver Dam to Green St. reach. Length and width data for most of these reaches were derived from USGS topographic maps of the area. Width of the free-flowing riffle areas was based on a power-curve regression ($P<.05$) of riffle areas during the study:

$$\text{Width (m)} = 22.1 * Q\ (\text{cfs})^{.125}$$

Based on regression statistics, the error in each width estimate is roughly +/- 20 percent. Nominal depth was calculated based on the width estimates and measured discharge and velocity within each reach:

Depth = discharge/(velocity * width)

Physical characteristics of each study reach are presented in Appendix C.

Total phosphorus residuals (i.e. in-river attenuation) for the middle reaches of the Spokane River are summarized in Table 14. Of the various alternative formulations which could describe the attenuation process, normalizing for reach length, width, or volume with or without a concentration adjustment, the first-order relationship presented above appears to fit the data most closely, and appeared to explain a considerable amount of the observed variability in attenuation both within and between reaches of this section of the river. This same formulation also appears to be conceptually the most appropriate considering what is currently known about the process of attenuation in river and stream environments.

As discussed above, the range in concentrations observed within the study

TABLE 14

Summary of In-River Phosphorus Attenuation Data in the Middle Spokane River Grouped by Reach Velocity

(only data collected from Sullivan Rd. (RM 87.8) to Spokane AWT (RM 67.4) are presented; attenuation data from Upriver Dam (RM 79.8) to Green St. (RM 78.0) are excluded: data presented as mean +/- one standard error)

	Velocity Range		
	Low	Mid	High
Number of Observations	9	9	27
Velocity (cm/sec)	10.9 +/- 1.2	27.9 +/- 2.3	44.5 +/- 1.9
Total P (ug/l)	21.1 +/- 1.4	17.6 +/- 1.4	17.8 +/- 0.7
Total P Residuals:			
By Reach Length (mg/km.day)	-14.5 +/- 0.41	-1.26 +/- 0.65	-0.70 +/- 0.55
By Reach Area (mg/m^2.day)	-17.9 +/- 5.1	-17.8 +/- 9.1	-12.4 +/-9.8
By Reach Volume (mg/m^3·day)	-3.51 +/- 0.99	-6.35 +/- 3.25	-6.00 +/- 4.74
First-Order Rate Constants:			
By Reach Length (m^2/day)	-68 +/- 19	-68 +/- 34	-42 +/- 32
By Reach Area (m/day)	-0.83 +/- 0.23	-0.95 +/- 0.49	-0.74 +/- 0.57
By Reach Volume (/day)	-0.16 +/- 0.05	-0.34 +/- 0.17	-0.36 +/- 0.27

As discussed above, the range in concentrations observed within the study area (particularly within the middle region of the river; Table 14) was rather narrow. The average TP concentration observed in most of the river -- approximately 19 ug/l -- is also below the typical "saturation" values reported in the literature and is thus within the anticipated first-order (i.e. concentration dependent) range.

In order to evaluate whether the first-order assumption is appropriate to higher river concentrations, attenuation information collected in the river below the Spokane AWT outfall were expressed as the first-order constant (K_2) and compared with the middle river data discussed above. This lower reach contained the highest phosphorus concentrations within the study area (mean of 32 ug/l; Figure 10a), and also exhibited an N:P ratio similar to the middle river area (i.e. eliminating the possible complicating influence of nitrogen limitation).

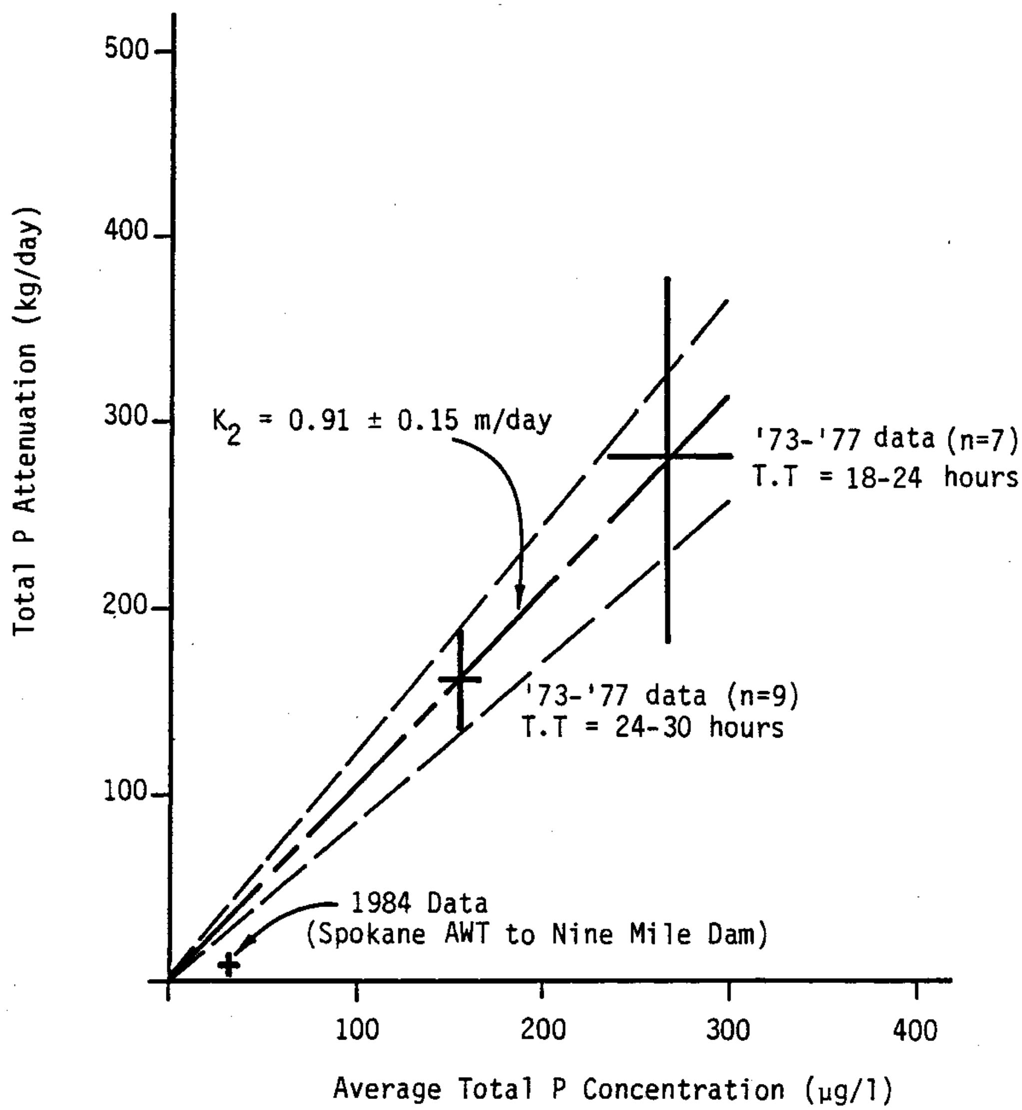
Attenuation rate constants (i.e. K_2) for the river below the AWT outfall are summarized in Figure 14 for both the 1984 data collected during this study and for data from earlier years (1973-1977) prior to AWT at the City of Spokane Treatment Facility. Information from the earlier years was based on monitoring data collected by Eastern Washington University (R. Soltero, EWU, unpublished data). Attenuation during these earlier dates was calculated by comparing phosphorus samples collected at Seven Mile (RM 62.0) and Nine Mile Dam (RM 58.1) during summer periods when the travel time between these sites was approximately 24 hours (thus minimizing the sampling bias; samples were collected at these sites at roughly the same time). Discharge data for these earlier years was obtained from Washington Water Power records at Nine Mile Dam.

The apparent total phosphorus attenuation rate during the earlier years appeared to remain roughly constant at 0.91 m/day, even when river concentrations exceeded 300 ug/l (Figure 14). This value is not significantly different ($P<.05$) from the 1984 average K_2 rate observed in the middle river of 0.84 m/day (Table 14). The correspondence between these two values adds additional support to the first-order formulation and also suggests that "saturation" of the phosphorus attenuation rate may not occur in this area within a TP range of 0-300 ug/l. Because of the slow velocities and possible resultant diffusive limitation in this lower reach, however, such a high saturation condition implied from this data may not be appropriate for the more turbulent riffle reaches (Whitford and Schumacher, 1961; Horner et al, 1983). A saturation value of this magnitude is also suggestive of a chemical adsorption process.

The 1984 data collected from the reach between Spokane AWT and Nine Mile Dam, however, yield phosphorus attenuation rates of a substantially smaller magnitude than the historical Seven Mile to Nine Mile data (Figure 14). In addition, during 1984 this area of the river exhibited some of the lowest in-river loss rates observed throughout the river system, particularly relative to those calculated for the middle reaches of the river (Table 12). The difference between both the areal loss rates (i.e. $mg/m^2.day$) and the K_2 decay

FIGURE 14

Historical Relationship Between Average Total Phosphorus Concentration and Apparent Attenuation in the Lower Spokane River; Seven Mile Bridge to Nine Mile Dam[1]



[1] June-October data only; T.T refers to estimated travel time between stations on each sampling day; results presented as mean ± one standard error neglecting measurement uncertainty

rates between the middle and lower (i.e. AWT to Nine Mile) reaches were both significant ($P<.05$) during the 1984 study period. The K_2 rate calculated for this lower reach (0.18 +/- 0.12 m/day) is less than 25 percent of that from the middle reaches of the river.

Because the reduction in phosphorus attenuation in the river below the AWT outfall appears to be a recent phenomenon (i.e. post-1977), it is doubtful that the low observed loss rates in this area are simply a result of a unique substrate environment. Rather, the most likely explanation of the data appears to be that the residual aluminum discharged from the AWT plant may have complexed the available phosphorus in the river into a form which was relatively unavailable for biological uptake or unreactive to chemical adsorption, yet was still present within the water column. Such a condition is possible based on known chemical properties of the aluminum-phosphorus complex (Stumm and Morgan, 1981), and appears to be somewhat supported by the observation of a phosphorus deficiency in periphyton tissue from the lower river (Table 7), but can not be established with the available data. It is also interesting to note that the retention coefficient of phosphorus within Long Lake has been reduced by more than 50 percent since AWT was initiated (Soltero et al., 1983), perhaps as a result of the hypothesized chemical change. In any event, the statistical significance of the lower K_2 value in the Spokane AWT to Nine Mile Dam reach is sufficient justification to use these lower values in the predictive model. However, the implications of a reduced P attenuation rate in response to AWT discharges in other areas of the Spokane River (e.g. at Coeur d'Alene WTP) are quite important and are a likely limitation of the adaptability of the model. Clearly, more research into this area would be necessary to determine the relationship between AWT effluent and phosphorus attenuation.

NITROGEN CONCENTRATION

Thus far this discussion has considered only those river reaches which contain a high N:P ratio indicative of biological phosphorus limitation. Above Sullivan Rd. (RM 87.8), however, both the water column and periphyton tissue levels of nitrogen are low enough to lead to nitrogen control of plant growth and its attendant phosphorus attenuation (Figure 10b, Table 7).

Phosphorus attenuation data summarized in Table 12 reveal that in-river losses of TP (expressed as $mg/m^2.day$) in reaches above Sullivan Rd. (RM 88) were approximately half those below this station (excluding Up-River Dam to Green St. and Spokane AWT to Nine Mile Dam reaches). The difference between the calculated K_2 decay rates for these aggregated areas was even greater, 0.32 +/- 0.12 m/day for the river above Sullivan Rd. vs. 0.84 +/- 0.20 m/day for the river below this point; this difference is marginally significant ($P<.06$). A similar result of increasing TP attenuation below RM 88 is also apparent in data collected by EPA during an extended low flow event in August 1977 (Yearsley, 1980 and 1982). The apparent K_2 rate in the upper river (Coeur d'Alene to Sullivan Rd.) during this earlier study averaged 0.34 m/day, and is nearly identical to the 1984 value. All information considered, it appears likely that nitrogen supplies may exert some control on the total phosphorus attenuation rate in the upper river, though uncertainties associated with this interpretation are presently substantial. Such an interpretation, of course, includes an implicit assumption that P attenuation in this area is predominantly biological.

Generally, the influence of nitrogen supplies on plant growth is best modeled using a Michaelis-Menten formulation analogous to enzyme kinetics (Lehman et al, 1975). Assuming that K_2 is the rate constant controlled by nitrogen, the formulation can be represented as:

$$K_2 = \frac{K_{2(MAX)} * \bar{C}_n}{K_m + \bar{C}_n}$$

where:

K_2 = first-order total phosphorus attenuation rate normalized to reach area

$K_{2(MAX)}$ = K_2 rate without any nitrogen limitation

$\bar{C}_N$ = average nitrogen concentration over the reach

K_M = Michaelis-Menten half-saturation constant, equivalent to the C_N concentration which would limit K_2 to half of $K_{2(MAX)}$.

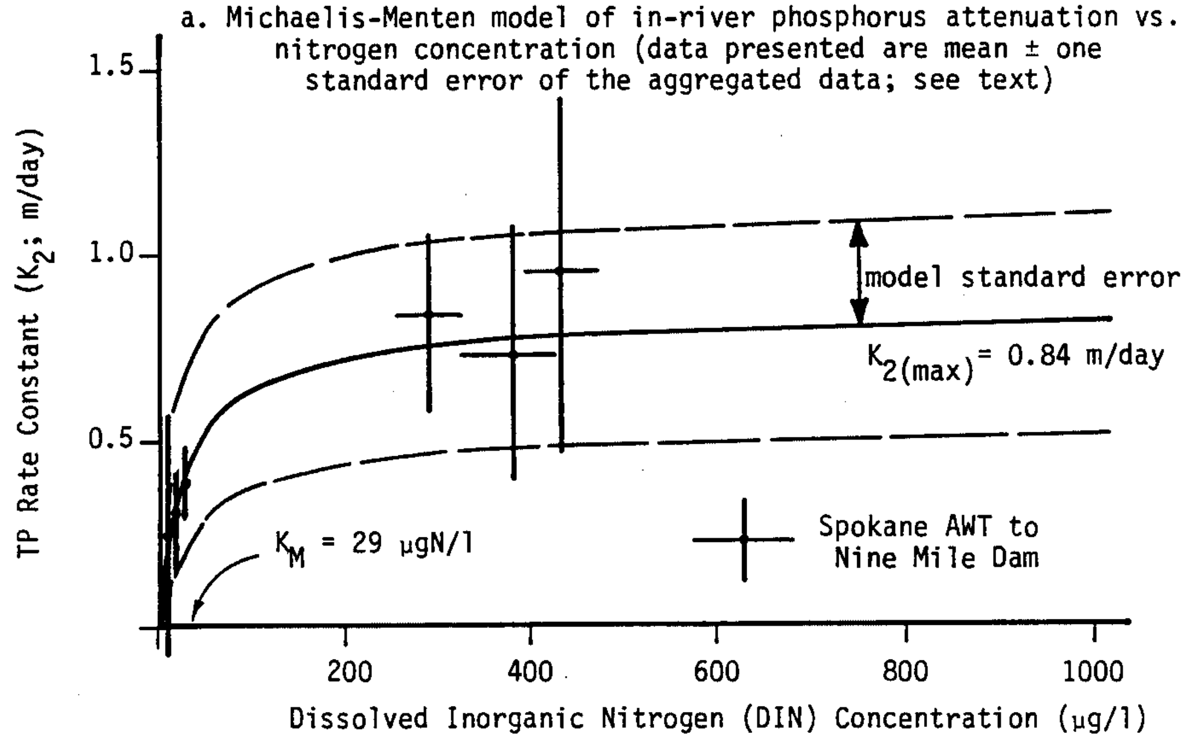
The value of $K_{2(MAX)}$ and K_M appropriate to a particular data set are evaluated by regressing $1/K_2$ vs $1/C_N$; such a regression is known as a Linnweaver-Burke plot and is presented in Figure 15. The means from each reach (aggregating adjacent riffle reaches so that reach areas are nearly comparable) appear to fit the Michaelis-Menten formulation quite well, and yield values of $K_{2(MAX)}$ and K_M of 0.84 m/day and 29 ug/l, respectively. It is interesting to note that this K_M value is in the middle of the range of values obtained from phytoplankton culture experiments (10-50 ugN/l; Lehman et al, 1975). The correspondence of these values lends support to the validity of the formulation.

The completed rate relationship of in-river phosphorus attenuation is presented in Figure 15, and appears to fit the observed data quite well. Because the data are essentially clustered at two ends of the range and are not generally continuous, the standard error of the model was not taken from the regression statistics. Rather, the model error was estimated by calculating the root mean squared deviation from the regression line. This

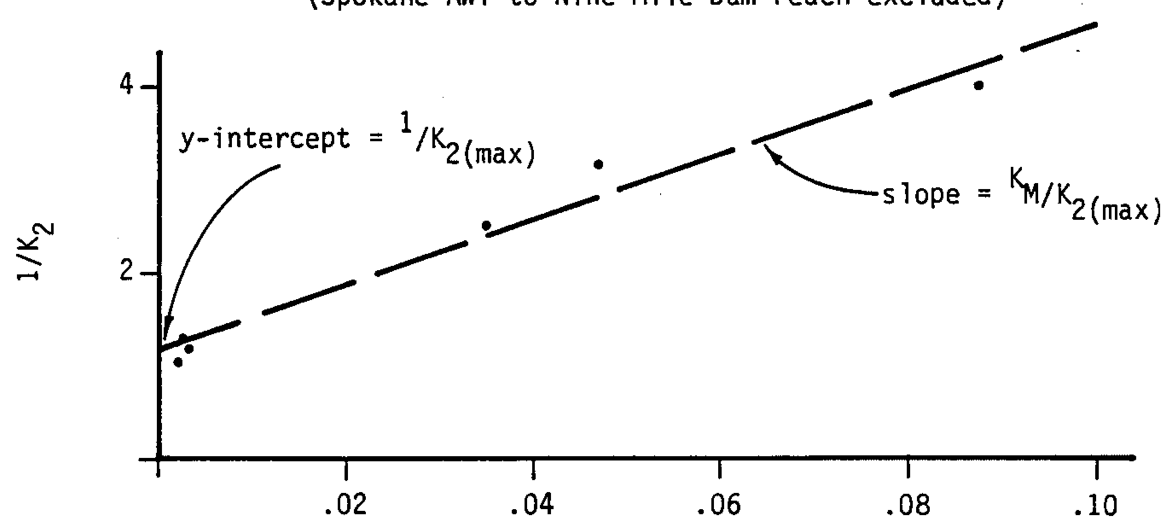
FIGURE 15

Relationship Between Nitrogen Concentration and the First-Order In-River Phosphorus Attenuation Constant

a. Michaelis-Menten model of in-river phosphorus attenuation vs. nitrogen concentration (data presented are mean ± one standard error of the aggregated data; see text)



b. Linnweaver-Burke plot to determine Michaelis-Menten model parameters based on the means of the aggregated data (Spokane AWT to Nine Mile Dam reach excluded)



estimated error is shown graphically in Figure 15, and represents an uncertainty of +/- 42 percent in the estimated K_2 value throughout the observed range of nitrogen concentrations.

DISCHARGE

Correlation analyses between the in-river attenuation rate vs. discharge and/or velocity within each reach were performed to determine if these physical parameters controlled in-river losses. However, no significant (P>.2) correlations between these variables were detected, indicating that these variables are not likely to be important determinants of attenuation beyond their influence upon concentration and possibly area. Since the range of river flows studied encompassed most of the discharge conditions anticipated during a 1-in-20 year low-flow event, this condition should also hold true during design conditions.

Over the study period, however, the magnitude of the in-river attenuation rate aggregated across the entire study area exhibited a pronounced decline (Figure 16). This observation did not appear to be consistent with any other variable examined except photoperiod, which is consistent with a biological attenuation mechanism implicated by some of the other data collected during this study. The temporal variability in K_{2MAX} represented approximately 20 percent of the total variance in this parameter, and is included in the Michaelis-Menten model error discussed above (Figure 15).

Model Construction

The discussions above have identified the general form of a predictive model appropriate to the simulation of phosphorus attenuation in the Spokane River. The model essentially normalizes the mass balance data collected during the field survey to account for different reach characteristics, and incorporates the combined effects of area, phosphorus concentration, and nitrogen concentration. 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. Ground water inputs and outputs are assumed to be linear across the length of the reach:

$$Q_{I(n)} = Q_{F(n-1)} + Q_{SW(n)}$$

$$Q_{F(n)} = Q_{I(n)} + Q_{GW(n)}$$

where I = initial
F = final
SW = surface water
GW = ground water
n = reach number

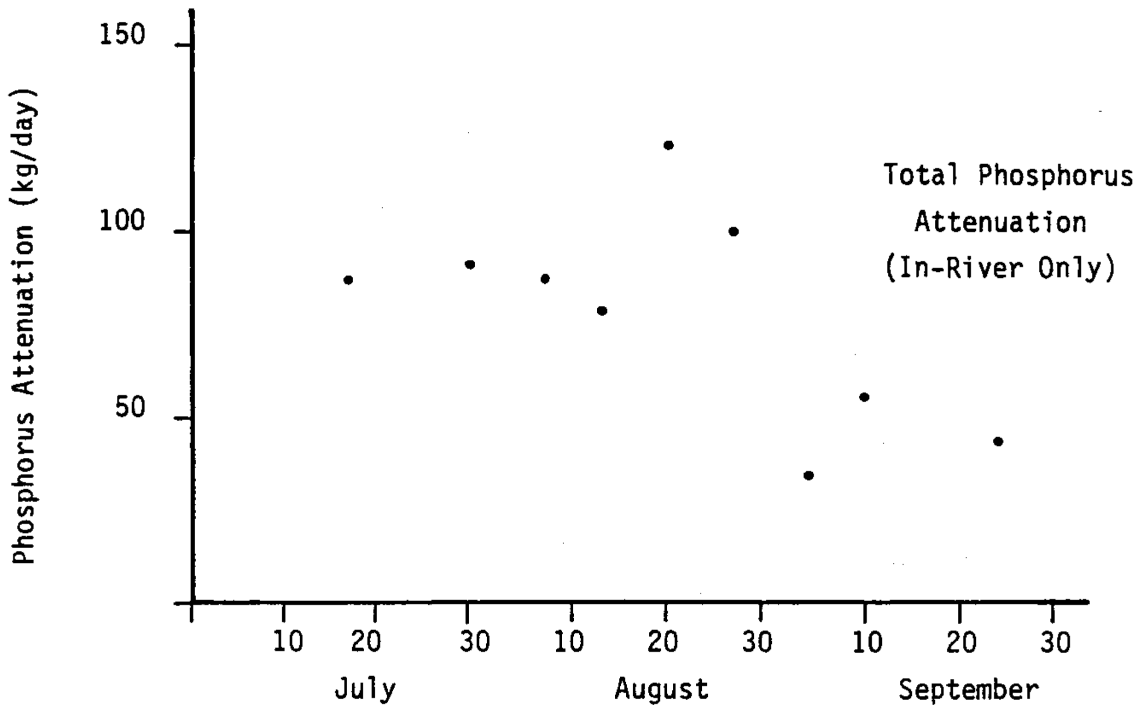
Average flow within each reach is calculated as:

$$\overline{Q} = 1/2\ [Q_{I(n)} + Q_{F(n)}]$$

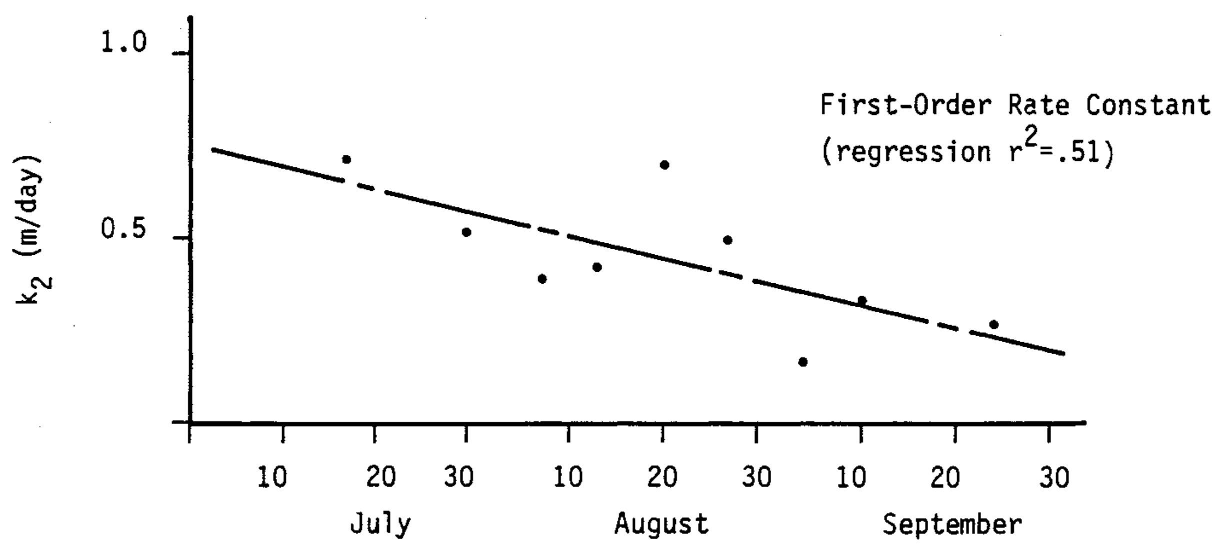
FIGURE 16

Temporal Variation in In-River Phosphorus Attenuation and the First-Order Rate Constant (k_2) over the Study Area.

a.



b.



Area of each reach is either constant (pool reaches) or a function of discharge:

$$A = f(Q)$$

The initial concentration of both nitrogen and phosphorus is calculated as:

$$C_{I(n)} = \frac{Q_{F(n-1)}C_{F(n-1)} + Q_{SW(n)}C_{SW(n)}}{Q_{F(n-1)} + Q_{SW(n)}}$$

If ground water inputs are positive (i.e. discharge to the river), the final concentration is calculated as:

$$C_{F(n)} = \frac{Q_{I(n)}C_{I(n)} + Q_{GW(n)}C_{GW(n)}}{Q_{I(n)} + Q_{GW(n)}} - \Delta C$$

where ΔC = in-river loss (see below).

The concentration of phosphorus (and nitrogen) in ground water inputs was assumed to be independent of river concentration and was set equal to values observed during 1984, with the RM 79.8 to 78.0 correction (Table 14). If ground water discharge was negative (i.e. seepage), the final concentration was simply:

$$C_{F(n)} + C_{I(n)} - \Delta C$$

Average concentrations of both N and P were thus:

$$\bar{C} = 1/2\ (C_{I(n)} + C_{F(n)})$$

The change in phosphorus concentration within each reach (ΔC_p) was evaluated as:

$$\Delta C_p = \frac{K_2\ \bar{C}\ A}{\bar{Q}}$$

where: $$K_2 = \frac{K_{2(MAX)}C_N}{C_N + K_M}$$

$K_{2(MAX)}$ and K_M are the Michaelis-Menten constants for nitrogen control of in-river phosphorus attenuation. $K_{2(MAX)}$ for the river above Spokane AWT was set equal to the mean of the observed values (0.84 m/day); for the river below Spokane AWT, $K_{2(MAX)}$ was changed to 0.18 m/day only if AWT was operational. The phosphorus attenuation rate within the short Upriver Dam to Green St. reach was set equal to zero, in keeping with the method of computing mass balances for this large ground water input zone (see Mass Balances section above).

The change in nitrogen within each reach was based on the average DIN:TP attenuation ratio observed within the river, 3.9 +/- 1.3:

$$\Delta C_N = 3.9 \times \Delta C_p$$

Within each reach, ΔC_p and ΔC_N were evaluated iteratively until ΔC was within one percent of $C_{I(n)} - C_{F(n)}$.

Uncertainties in each term of the phosphorus attenuation model were propagated through the model using first-order techniques. Variances in the ground and surface water flows and TP concentrations are presented in Table 14. Uncertainties in the point source loads (specified during input) were assumed to be negligible, since these values are intended to be analogous to permit conditions and thus describe the maximum allowable discharge from a particular point source (L. Singleton, WDOE, personal communication).

As described previously, the in-river TP attenuation rate (K_2) estimate for the river above the Spokane AWT outfall was assumed to have a coefficient of variation equal to 42 percent of the average. Below the AWT outfall, the coefficient of variation was equivalent to nearly 70 percent of the mean. These rather high variances reflect the variability of in-river TP attenuation observed within and between individual reaches. However, the coefficient of variation in the in-river attenuation value aggregated across all reaches of the study area is considerably lower than the individual reach estimates, reflecting the greater confidence inherent in attenuation estimates for the entire study area. The contribution of the K_2 uncertainty to the total model uncertainty is discussed below.

The predictive model was programmed in BASIC and is listed in Appendix B. The model is interactive, and allows the operator to vary point source loading quantities by location and magnitude. Both the phosphorus and nitrogen concentrations of each effluent discharge are specified during input.

Limitations of the model are primarily associated with extrapolations beyond the range of conditions observed during the study period. Output from the model is felt to have a particularly large uncertainty when river TP concentrations exceed 50-100 ug/l or if AWT is employed at any other wastewater treatment plant along the river system other than the Spokane treatment facility. In general, however, the model appears to be an adequate representation of river atenuation within the study area, and particularly when the phosphorus load at Nine Mile Dam, does not exceed the existing design threshhold (equivalent to a TP concentration of approxiamtely 45 ug/l at Nine Mile; Singleton, 1981). The significance of the existing TP loads in the Spokane River relative to Long Lake criteria are discussed in more detail below.

<u>Model Output</u>

The phosphorus loading/attenuation model discussed above was run for design year discharge conditions (i.e. 1-in-20-year low flow) using the average point source loading values observed during the study period. The results of this model run are summarized below:

	TP load (kg/day) mean +/- std error
Point Source Inputs	184 +/- 0
Total Inputs Above Nine Mile	258 +/- 12
Nine Mile Dam Output	160 +/- 21
Little Spokane River Input	35 +/- 7
Long Lake Input	195 +/- 22

The estimated design-year input to Long Lake, 195 +/- 22 kg/day, is approximately 21 percent lower than the maximum permissible loading value of 248 kg/day previously established by WDOE (Singleton, 1981). By this criterion, therefore, the present TP load to Long Lake appears to be well within the established regulatory maximum. Total phosphorus attenuation (i.e. hydraulic and in-river mechanisms) within the river system resulted in the loss of 38 percent of the input load.

The contribution of the variance associated with the in-river phosphorus attenuation rate (i.e. K_2) to the total uncertainty in the Long Lake loading estimate was assessed using the first-order methodology. For the design-year condition discussed above (i.e. no uncertainty in point source loads or in the estimated 20-year low flows from Lake Coeur d'Alene), the variance in K_2 contributed approximately 28 percent to the total uncertainty in the Long Lake load. The majority of the variance in this reservoir loading estimate appeared to have been due to uncertainties in ground water discharges, and primarily relative to year-to-year fluctuations in flows which are uncorrelated with the Lake Coeur d'Alene outlet discharge (see Hydrology section above). In general, however, the uncertainty associated with the estimated Long Lake input during design year conditions was rather small, representing a coefficient of variation of only 11 percent.

It is interesting to note that rather wide variations in discharge at Lake Coeur d'Alene do not result in equivalent changes in the magnitude of the TP loading or influent concentration to Long Lake:

Lake Coeur d'Alene Outflow in cfs (Recurrence Interval in Parentheses)	Long Lake Input (mean +/- std. error)	
	TP Load (kg/day)	TP Concentration (ug/l)
2,900 (1:2)	245 +/- 19	24.2 +/- 1.1
2,070 (1:5)	217 +/- 20	26.8 +/- 1.3
1,650 (1:10)	201 +/- 21	28.5 +/- 1.8
1,500 (1:20)	195 +/- 22	29.1 +/- 1.8

This apparent "stability" in the Long Lake input is due to a number of factors, including ground water inputs, seepage losses, and the first-order form of the in-river attenuation model. All of these factors tend to stabilize the river concentration either by dilution or by increasing attenuation losses (both hydraulic and in-river) when river TP concentrations are elevated.

Long Lake Criteria

The critical phosphorus load previously adopted by WDOE for the protection of Long Lake, 248 kg/day, was based upon a relationship between influent TP loading and the euphotic zone chlorophyll *a* concentration in the lake, expressed as the June to November average and using data collected by EWU (Singleton, 1981). The critical loading value was defined as the TP input which would maintain average chlorophyll *a* concentrations in Long Lake of less than 10 ug/l during the 20 year low flow condition. Chlorophyll *a* levels greater than 10 ug/l are generally regarded throughout North America as indicative of undesirable eutrophic conditions and this criterion has often been applied as a management "goal" in many lake systems (Welch, 1980).

Since publication of the initial Spokane River phosphorus allocation study (Singleton, 1981; URS, 1981), additional information has become available which may affect the determination of a critical TP loading quantity to Long Lake. This additional information includes the collection of five more years of data (1980 - 1984) on the phosphorus loading/algal growth relationship in Long Lake and the results of quality assurance (QA) samples analyzed by EWU. These data are briefly discussed below relative to the existing TP load entering Long Lake.

During the period 1980-1982, QA samples were submitted to the EWU laboratory by WDOE and analyzed for TP (10 samples), chlorophyll *a* (3 samples), and a variety of other parameters (L. Singleton, WDOE, unpublished data). The results of these analyses suggested that previous TP analyses underestimated the true value by 13 +/- 4%; chlorophyll *a* was apparently underestimated by 37 +/- 7%. Differences between the EWU values and the true concentrations for these parameters were both significant ($P<.02$). The low chlorophyll *a* values reported by EWU appear to be due to the rather wide band width (20 nm) utilized in the spectrophotometric determinations. Chlorophyll *a* underestimation similar to the EWU values is reported to be rather common when such a method is employed (APHA, 1980).

Beginning in 1981, TP was analyzed in samples collected from Long Lake's euphotic zone. Based on the 1981 through 1984 data, it appears that the average euphotic zone TP concentration during the summer-fall period is reduced by only 7 +/- 4 percent from the flow-weighted influent value. This apparent in-lake retention is not statistically significant ($P>.05$). Differences in retention (or in-lake sedimentation) between years were not associated with changes in the influent TP load or flushing rate. However, the bulk water exchange rate of Long Lake is generally regarded as quite rapid (mean of 4%/day during June to November periods of 1972-1984). The rapid flushing rate likely minimizes the opportunity for sedimentation within the lake (Welch, 1980).

Because of the close correspondence apparent between inflow and lake TP concentrations, the retention or sedimentation term utilized in most steady-state lake models has limited utility in the case of Long Lake. Without the sedimentation term (or even with a constant retention rate), these models (e.g. Dillon-Rigler, Vollenweider) reduce to a simple comparison of influent TP concentration vs. in-lake chlorophyll *a*. Data collected over the period

1972 - 1984 for these parameters (Soltero et al, 1982; R.A. Soltero, EWU, personal communication) and adjusted based on the Q/A data, are presented in Figure 17. The relationship describing TP and chlorophyll a appears to be best approximated (i.e. lowest variance) by using the Michaelis-Menten formulation:

$$\text{chlorophyll } \underline{a} \text{ (ug/l)} = \frac{40.9 * TP}{58.0 + TP}$$

The variance in this formulation is dominated (>80%) by uncertainties in the historical chlorophyll a data; the total model uncertainty is presented in Figure 17.

A similar expression relating TP to phytoplankton biovolume was also developed. Excluding the 1978 values, the data are represented by:

$$\text{Phytoplankton Biovolume } (mm^3/l) = \frac{58.0 * TP}{469 + TP}$$

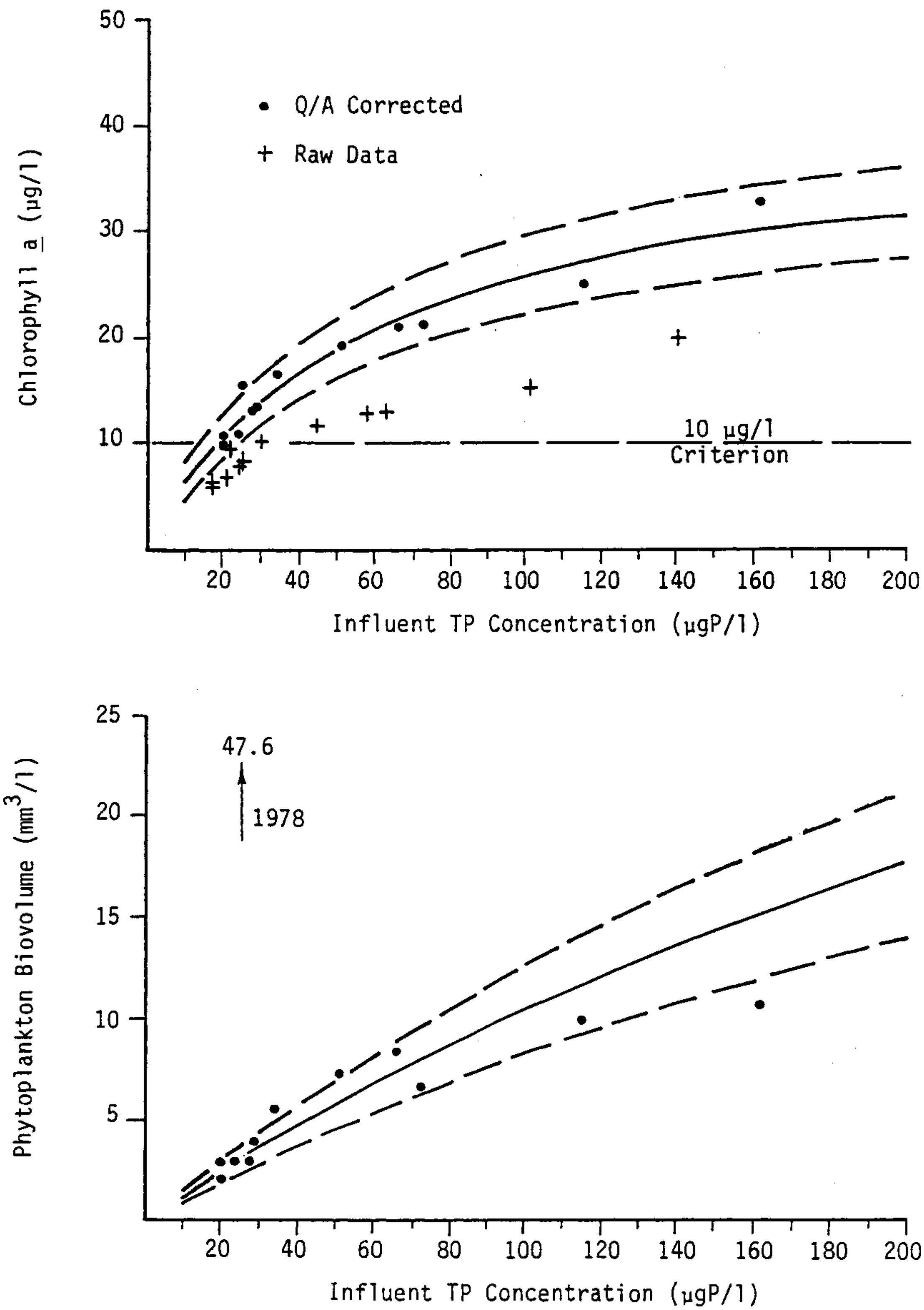
Both chlorophyll a and phytoplankton biovolume exhibit a strong correspondence with TP concentration, although at higher TP concentrations this relationship appears to diminish, particularly for chlorophyll a (Figure 17). This pattern is consistent with an apparent oversupply in phosphorus (relative to nitrogen) available to algae during previous years (particularly 1973; Soltero et al, 1983) and changes in the chlorophyll a/phytoplankton biovolume ratio which typically accompany shifts from P to N limitation in lakes (Nicolls and Dillon, 1978).

The chlorophyll a and phytoplankton biovolume expressions discussed above refer to the June-October time period. The present regulatory framework for Long Lake, however, is based upon the June-November period (Singleton, 1981); Long Lake summary data for this longer period are not presently available. The rationale for use of these differing time periods has been discussed by Singleton (1981), URS (1981), and Soltero et al (1982), and is not reiterated here. For the purposes of this report, however, it was determined appropriate to compare the June-November output from the river attenuation model with the above June-October algal growth relationships in order to estimate trophic conditions in Long Lake during the design-year event. Use of the June-October formulations may slightly overestimate the true average June-November values for chlorophyll a and phytoplankton, since the month of November is typiclly characterized by both lower than average algal biomass and low-river discharge (and thus higher input TP concentration). Nevertheless, the discrepancies between the different time periods appear to have only a minor (and conservative) influence on the algal predictions and were considered acceptable. Further data analysis efforts (beyond the scope of this study) would be required to develop TP/algal growth relationships directly applicable to the June-November regulatory period.

The predicted trophic indicator levels within Long Lake during design-year conditions and under the existing TP loading regime were evaluated with respect to eutrophic criteria (Wetzel, 1975; Welch 1980). In-lake TP levels were estimated based upon the retention data discussed above. Uncertainties

FIGURE 17

The Relationships Between Influent TP and In-Lake Chlorophyll a and Phytoplankton Biovolume in Long Lake, June-October, 1972-1984
(model presented as mean ± one standard error)



associated with each relationship (as well as with the TP input estimate) were propagated using first-order methods; the output is summarized below:

	Predicted Long Lake Concentrations (mean +/- std. error)	Eutrophic Criteria*
TP/(ug/l)	27.0 +/- 2.0	>20
Chlorophyll _a_ (ug/l)	13.7 +/- 2.4	>10
Phytoplankton Biovolume (mm^3/l)	3.4 +/- 0.7	>3-5

*Criteria based on Wetzel (1975) and Welch (1980).

By these formulations, therefore, the present condition of Long Lake during the 20-year design condition could be described as somewhat eutrophic. Existing conditions, however, are much improved relative to the quality of the lake prior to AWT (Soltero et al, 1983).

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APPENDIX A

Discharge and Chemical Data

(refer to Figure 3 and Table 10 for station locations; values for some stations represent calculated values)

Legend:

STA = Mass Balance Station

Q = Discharge (cfs)

SRP = Soluble Reactive Phosphorus (μgP/l)

TSP = Total Soluble Phosphorus (μgP/l)

TSPDEV = Standard Deviation of Replicate TSP Samples (μgP/l)

TSPNUM = Number of TSP Replicates

TP = Total Phosphorus (μgP/l)

TPDEV = Standard Deviation of Replicate TP Samples (μgP/l)

TPNUM = Number of TP Replicates

NO3 = NO_2^-+NO_3- Nitrogen (μgN/l)

NH4 = NH_4^+-Nitrogen (μgN/l)

CHL-a = Chlorophyll a (μg/l)

Monitoring Dates (listed sequentially)

7-17-84
7-30-84
8-07-84
8-13-84
8-20-84
8-27-84
9-04-84
9-10-84
9-24-84

Var	1	2	3	4	5	6	7	8	9	10	11	12
OBS	STA	Q	SRP	TSP	TSPDEV	TSPNUM	TP	TPDEV	TPNUM	NO3	NH4	CHL-a
1	1.00	2575.35	-.00	1.40	1.42	4.00	7.40	3.37	6.00	5.00	5.00	.20
2	2.00	3.65	-.00	8398.80	190.00	4.00	8528.80	240.00	6.00	3380.00	9870.00	0.00
3	3.00	-49.00	-.00	23.40	3.85	3.00	28.60	6.15	4.00	5.00	5.00	.80
4	4.00	2530.00	-.00	23.40	3.85	3.00	28.60	6.15	4.00	5.00	5.00	.80
5	5.00	2530.00	-.00	6.20	.60	4.00	11.90	2.17	6.00	5.00	5.00	2.00
6	6.00	-286.15	-.00	5.90	-.00	-.00	11.85	-.00	-.00	5.00	5.00	1.10
7	7.00	2243.85	-.00	5.60	1.56	4.00	11.80	1.69	6.00	5.00	5.00	.20
8	8.00	-127.85	-.00	6.55	-.00	-.00	11.60	-.00	-.00	5.00	5.00	.90
9	9.00	2116.00	-.00	7.50	2.30	4.00	11.40	2.69	6.00	5.00	5.00	1.60
10	10.00	.53	-.00	6638.80	54.00	4.00	6778.80	55.00	6.00	22020.00	5.00	0.00
11	11.00	2116.53	-.00	8.40	1.53	4.00	12.40	1.63	6.00	5.00	5.00	2.00
12	12.00	2116.53	-.00	7.50	.81	4.00	13.20	2.40	6.00	30.00	5.00	1.20
13	13.00	1.53	-.00	2268.80	130.00	3.00	2858.80	330.00	3.00	1950.00	1350.00	0.00
14	14.00	34.80	-.00	58.80	7.67	3.00	80.20	11.00	3.00	160.00	5.00	0.00
15	15.00	404.20	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00
16	16.00	2522.26	-.00	8.20	.88	4.00	12.60	1.43	6.00	150.00	5.00	1.20
17	17.00	5.03	-.00	502.80	14.00	3.00	936.80	54.00	3.00	10.00	5.00	0.00
18	18.00	.03	-.00	3308.80	104.00	3.00	3718.80	56.00	3.00	780.00	12730.00	0.00
19	19.00	-319.32	-.00	5.90	.70	4.00	13.30	1.74	6.00	260.00	5.00	1.20
20	20.00	2208.00	-.00	5.90	.70	4.00	13.30	1.74	6.00	260.00	5.00	1.20
21	21.00	159.90	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
22	22.00	792.10	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
23	23.00	3160.00	-.00	4.90	.48	4.00	10.70	.70	6.00	320.00	5.00	1.20
24	24.00	-420.00	-.00	5.10	-.00	-.00	10.60	-.00	-.00	330.00	5.00	1.80
25	25.00	2740.00	-.00	5.20	1.23	4.00	10.60	1.86	6.00	340.00	5.00	2.40
26	26.00	310.00	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
27	27.00	49.00	-.00	55.60	1.80	3.00	89.10	16.90	3.00	800.00	5.00	12.80
28	28.00	46.59	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
29	29.00	3145.59	-.00	5.20	1.05	4.00	11.80	1.85	6.00	480.00	5.00	2.40
30	30.00	33.08	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
31	31.00	3178.67	-.00	5.80	2.17	4.00	10.10	2.40	6.00	430.00	5.00	2.00
32	32.00	45.08	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
33	33.00	66.39	-.00	196.80	148.00	4.00	753.80	20.00	6.00	430.00	14550.00	0.00
34	34.00	3290.14	-.00	16.40	2.85	4.00	23.00	2.24	6.00	530.00	248.00	2.00
35	35.00	39.07	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
36	36.00	.12	-.00	9198.80	18.00	3.00	9138.80	320.00	3.00	130.00	18010.00	0.00
37	37.00	3329.33	-.00	16.50	2.17	4.00	25.40	2.64	6.00	620.00	275.00	2.40
38	38.00	-146.33	-.00	14.00	-.00	-.00	23.20	-.00	-.00	630.00	166.50	2.20
39	39.00	3183.00	-.00	11.50	1.76	4.00	21.00	4.25	6.00	640.00	58.00	2.00
40	1.00	2021.20	-.00	4.30	1.97	4.00	9.20	1.33	5.00	5.00	5.00	.40
41	2.00	3.80	8298.70	8328.80	300.00	4.00	8838.80	170.00	6.00	130.00	14090.00	0.00
42	3.00	-45.00	16.00	17.20	3.39	4.00	23.90	2.80	6.00	10.00	5.00	.40
43	4.00	1980.00	16.00	17.20	3.39	4.00	23.90	2.80	6.00	10.00	5.00	.40
44	5.00	1980.00	-.00	20.40	7.11	4.00	27.30	7.98	6.00	5.00	5.00	1.50
45	6.00	-41.12	10.90	17.45	-.00	-.00	23.50	-.00	-.00	12.50	5.00	1.45
46	7.00	1938.88	10.90	14.50	.76	4.00	19.70	1.68	6.00	20.00	5.00	1.40
47	8.00	-18.38	14.80	15.25	-.00	-.00	19.15	-.00	-.00	12.50	5.00	1.80
48	9.00	1920.50	18.70	16.00	.99	4.00	18.60	1.74	6.00	5.00	5.00	2.20
49	10.00	.50	6338.70	6788.80	150.00	3.00	6998.80	130.00	4.00	15800.00	15800.00	0.00
50	11.00	1921.00	12.60	14.40	4.02	4.00	18.80	1.05	5.00	5.00	5.00	1.80
51	12.00	1921.00	16.50	16.20	2.19	3.00	20.00	1.27	6.00	30.00	5.00	1.50
52	13.00	1.55	1758.70	1898.80	400.00	3.00	2398.80	670.00	4.00	1481.20	2274.00	0.00
53	14.00	37.50	82.00	101.80	21.30	3.00	146.80	15.80	4.00	200.00	5.00	0.00
54	15.00	409.45	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00

Var	1	2	3	4	5	6	7	8	9	10	11	12
OBS	STA	Q	SRP	TSP	TSPDEV	TSPNUM	TP	TPDEV	TPNUM	NO3	NH4	CHL-a
55	16.00	2332.00	15.90	17.30	.81	3.00	20.30	1.66	5.00	210.00	5.00	1.80
56	17.00	4.08	299.70	990.80	57.00	3.00	1478.80	137.00	4.00	10.00	5.00	0.00
57	18.00	.04	2378.70	2638.80	-.00	1.00	4838.80	1200.00	2.00	110.00	2230.00	0.00
58	19.00	-300.12	-.00	13.00	.83	3.00	17.10	1.22	5.00	190.00	5.00	1.80
59	20.00	2036.00	-.00	13.00	.83	3.00	17.10	1.22	5.00	190.00	5.00	1.80
60	21.00	322.50	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
61	22.00	341.50	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
62	23.00	2700.00	-.00	10.60	.17	3.00	18.50	2.67	6.00	340.00	5.00	2.20
63	24.00	-297.00	-.00	9.20	-.00	-.00	17.60	-.00	-.00	325.00	5.00	2.55
64	25.00	2403.00	-.00	7.70	1.03	4.00	16.80	3.26	5.00	310.00	5.00	2.90
65	26.00	177.00	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
66	27.00	34.00	74.20	65.60	1.60	2.00	146.80	44.00	3.00	830.00	5.00	14.90
67	28.00	62.92	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
68	29.00	2676.92	-.00	9.20	2.33	2.00	18.20	2.81	6.00	400.00	5.00	2.90
69	30.00	44.67	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
70	31.00	2721.59	12.60	13.20	2.37	3.00	15.50	1.96	5.00	360.00	5.00	2.90
71	32.00	60.89	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
72	33.00	71.68	316.70	209.80	44.00	4.00	796.80	184.00	6.00	60.00	5470.00	0.00
73	34.00	2854.16	22.10	20.00	1.26	4.00	34.50	3.90	6.00	410.00	66.00	2.90
74	35.00	52.77	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
75	36.00	.07	8528.70	8698.80	-.00	1.00	9328.80	279.00	4.00	10.00	22910.00	0.00
76	37.00	2907.00	-.00	19.80	1.08	4.00	31.80	2.22	6.00	470.00	44.00	2.90
77	38.00	-82.00	17.20	19.00	-.00	-.00	31.50	-.00	-.00	480.00	33.00	3.30
78	39.00	2825.00	17.20	18.20	1.02	4.00	31.20	5.38	6.00	490.00	22.00	3.70
79	1.00	1007.26	4.60	4.20	1.28	4.00	8.40	2.21	5.00	5.00	5.00	.20
80	2.00	3.74	7108.70	7498.80	200.00	4.00	7818.80	120.00	6.00	4120.00	7940.00	0.00
81	3.00	-37.00	17.60	27.20	12.50	4.00	30.60	14.50	6.00	10.00	5.00	1.40
82	4.00	974.00	17.60	27.20	12.50	4.00	30.60	14.50	6.00	10.00	5.00	1.40
83	5.00	974.00	11.90	15.20	.74	4.00	28.70	11.20	6.00	5.00	10.00	2.80
84	6.00	-87.09	12.75	17.20	-.00	-.00	28.60	-.00	-.00	5.00	10.00	3.05
85	7.00	886.91	13.60	19.20	8.17	4.00	28.50	9.67	6.00	5.00	5.00	3.30
86	8.00	-38.91	13.40	18.40	-.00	-.00	26.60	-.00	-.00	5.00	5.00	2.70
87	9.00	848.00	13.20	17.60	7.17	4.00	24.70	7.72	6.00	5.00	5.00	2.10
88	10.00	.46	6908.70	7408.80	22.00	3.00	7418.80	144.00	4.00	17220.00	560.00	0.00
89	11.00	848.46	13.80	17.20	.88	4.00	28.20	6.61	6.00	10.00	5.00	3.30
90	12.00	848.46	10.70	14.10	1.28	4.00	22.30	5.02	6.00	60.00	5.00	2.90
91	13.00	1.46	2808.70	2868.80	120.00	3.00	3568.80	110.00	4.00	1490.00	2140.00	0.00
92	14.00	40.00	44.40	36.60	3.10	3.00	64.10	4.13	4.00	370.00	5.00	0.00
93	15.00	517.10	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00
94	16.00	1367.00	16.00	16.70	.96	4.00	27.50	9.13	6.00	350.00	5.00	2.20
95	17.00	4.06	320.70	1138.80	21.00	3.00	1868.80	48.00	4.00	10.00	410.00	0.00
96	18.00	.03	3161.00	3568.80	68.00	3.00	6058.80	154.00	4.00	125.00	9700.00	0.00
97	19.00	-257.00	19.70	23.30	5.07	4.00	25.90	6.75	6.00	390.00	5.00	2.90
98	20.00	1114.00	19.70	23.30	5.07	4.00	25.90	6.75	6.00	390.00	5.00	2.90
99	21.00	204.40	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
100	22.00	341.60	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
101	23.00	1660.00	23.10	23.20	4.49	4.00	26.50	7.97	5.00	520.00	5.00	3.30
102	24.00	-118.00	18.20	15.70	-.00	-.00	24.90	-.00	-.00	520.00	5.00	3.30
103	25.00	1542.00	13.30	8.10	1.73	4.00	23.30	5.13	6.00	520.00	5.00	3.30
104	26.00	88.00	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
105	27.00	32.00	83.90	113.20	54.80	2.00	113.50	18.60	3.00	1120.00	5.00	10.50
106	28.00	26.38	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
107	29.00	1688.38	12.40	10.90	5.05	4.00	23.60	12.49	6.00	660.00	5.00	3.20
108	30.00	18.73	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
109	31.00	1707.11	26.10	16.50	7.83	4.00	21.40	3.71	6.00	630.00	5.00	3.60

Var	1	2	3	4	5	6	7	8	9	10	11	12
OBS	STA	Q	SRP	TSP	TSPDEV	TSPNUM	TP	TPDEV	TPNUM	NO3	NH4	CHL-a
110	32.00	25.52	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
111	33.00	62.14	177.70	311.80	83.50	4.00	428.80	59.60	6.00	370.00	11640.00	0.00
112	34.00	1794.77	22.10	27.00	3.39	4.00	36.40	2.85	4.00	680.00	385.00	3.70
113	35.00	22.12	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
114	36.00	.11	4308.70	3938.80	290.00	3.00	4798.80	365.00	4.00	2210.00	10000.00	0.00
115	37.00	1817.00	26.10	27.20	10.04	4.00	38.50	6.28	6.00	740.00	280.00	2.60
116	38.00	89.00	10.20	8.60	3.11	2.00	8.60	3.11	2.00	2085.00	5.00	0.00
117	39.00	1906.00	23.10	27.40	5.90	3.00	31.60	3.64	6.00	780.00	310.00	2.20
118	1.00	978.26	2.80	2.50	.87	4.00	5.40	1.75	6.00	5.00	5.00	.10
119	2.00	3.74	6775.50	6339.60	126.84	4.00	7104.90	293.57	6.00	4960.00	13062.60	0.00
120	3.00	-42.00	20.30	27.90	12.00	4.00	32.10	8.91	6.00	5.00	5.00	1.40
121	4.00	940.00	20.30	27.90	12.00	4.00	32.10	8.91	6.00	5.00	5.00	1.40
122	5.00	940.00	14.80	14.30	1.35	4.00	23.20	3.10	6.00	5.00	5.00	2.50
123	6.00	-85.71	14.00	14.45	-.00	-.00	22.50	-.00	-.00	5.00	5.00	2.90
124	7.00	854.29	13.20	14.60	1.61	4.00	21.80	1.99	6.00	5.00	5.00	3.30
125	8.00	-38.29	14.35	14.75	-.00	-.00	20.60	-.00	-.00	5.00	5.00	3.10
126	9.00	816.00	15.50	14.90	.95	4.00	19.40	2.16	6.00	5.00	5.00	2.90
127	10.00	.38	6736.50	6956.00	40.38	3.00	7103.20	83.11	4.00	18440.00	211.90	0.00
128	11.00	816.38	15.90	16.00	.72	4.00	20.90	1.40	6.00	5.00	5.00	2.20
129	12.00	816.38	12.90	16.00	1.57	4.00	22.20	4.06	5.00	50.00	5.00	2.10
130	13.00	1.47	863.70	989.50	40.44	3.00	2936.50	2688.54	4.00	1380.00	3523.60	0.00
131	14.00	39.40	48.10	50.20	2.47	3.00	67.10	8.82	4.00	350.00	5.00	0.00
132	15.00	489.20	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00
133	16.00	1307.00	14.50	13.90	1.76	4.00	18.80	1.80	6.00	360.00	5.00	1.80
134	17.00	3.83	639.10	1729.20	43.75	3.00	2158.40	253.32	4.00	10.00	5.00	0.00
135	18.00	.04	3161.00	2746.50	96.10	2.00	3901.30	100.20	2.00	6870.00	155.30	0.00
136	19.00	-240.80	16.10	12.10	3.06	4.00	18.80	1.29	6.00	420.00	5.00	2.90
137	20.00	1070.00	16.10	12.10	3.06	4.00	18.80	1.29	6.00	420.00	5.00	2.90
138	21.00	214.30	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
139	22.00	285.70	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
140	23.00	1570.00	11.90	12.00	2.01	4.00	16.80	2.05	6.00	560.00	5.00	2.20
141	24.00	-167.00	9.10	10.50	-.00	-.00	16.20	-.00	-.00	545.00	5.00	2.85
142	25.00	1403.00	6.30	8.90	.80	4.00	15.70	2.30	6.00	530.00	5.00	3.50
143	26.00	117.00	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
144	27.00	28.00	65.80	70.50	4.45	2.00	101.90	5.28	3.00	1160.00	5.00	9.40
145	28.00	57.26	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
146	29.00	1605.26	11.00	9.50	2.51	4.00	15.90	1.64	6.00	620.00	5.00	2.60
147	30.00	40.65	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
148	31.00	1645.91	11.30	9.20	1.87	4.00	16.80	1.66	6.00	550.00	5.00	2.50
149	32.00	55.41	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
150	33.00	67.53	466.50	559.00	76.52	4.00	680.80	95.68	6.00	15950.00	7727.00	0.00
151	34.00	1768.85	28.80	32.20	2.10	4.00	41.50	2.07	6.00	740.00	197.00	2.90
152	35.00	48.02	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
153	36.00	.13	8633.40	8839.10	192.19	2.00	8994.40	120.93	3.00	40.00	9750.00	0.00
154	37.00	1817.00	32.30	32.60	2.22	4.00	40.80	3.56	6.00	770.00	197.00	1.50
155	38.00	33.00	10.20	8.60	3.11	2.00	8.60	3.11	2.00	2085.00	5.00	0.00
156	39.00	1850.00	18.20	20.40	1.03	4.00	32.60	1.97	6.00	940.00	5.00	1.80
157	1.00	664.47	5.70	9.20	4.60	4.00	7.80	2.80	6.00	5.00	5.00	.10
158	2.00	3.53	7096.60	6069.30	1949.10	4.00	7260.90	235.50	6.00	3380.00	12986.20	0.00
159	3.00	-31.00	17.10	20.50	3.21	4.00	26.90	2.73	6.00	5.00	5.00	2.00
160	4.00	637.00	17.10	20.50	3.21	4.00	26.90	2.73	6.00	5.00	5.00	2.00
161	5.00	637.00	16.10	16.10	1.44	4.00	18.70	1.84	6.00	5.00	5.00	2.10
162	6.00	-68.43	15.90	16.10	-.00	-.00	19.30	-.00	-.00	5.00	5.00	2.25
163	7.00	568.57	11.70	15.76	1.39	4.00	19.90	2.75	6.00	5.00	5.00	2.40
164	8.00	-30.57	[illegible]	[illegible]	-.00	-.00	20.80	-.00	-.00	5.00	5.00	2.05

Var	1	2	3	4	5	6	7	8	9	10	11	12
OBS	STA	Q	SRP	TSP	TSPDEV	TSPNUM	TP	TPDEV	TPNUM	NO3	NH4	CHL-a
165	9.00	538.00	12.20	16.10	1.70	4.00	21.70	3.46	6.00	5.00	5.00	1.70
166	10.00	.44	6950.10	7683.00	159.00	3.00	7735.30	107.00	5.00	19490.00	29.20	0.00
167	11.00	538.44	15.00	19.40	1.04	4.00	21.70	2.62	6.00	10.00	5.00	1.70
168	12.00	538.44	16.90	22.40	4.01	3.00	24.40	3.59	6.00	60.00	5.00	1.00
169	13.00	1.39	1010.60	1204.90	84.00	3.00	1654.60	127.10	4.00	1550.00	2191.90	0.00
170	14.00	40.50	35.40	42.20	1.30	3.00	48.40	6.47	4.00	450.00	52.30	0.00
171	15.00	497.20	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00
172	16.00	1037.00	12.20	16.70	2.96	4.00	18.40	2.61	6.00	500.00	5.00	1.40
173	17.00	3.37	268.50	282.40	163.50	2.00	1148.20	1328.70	4.00	190.00	199.40	0.00
174	18.00	.03	3161.00	3010.00	18.20	2.00	3157.70	118.10	2.00	4110.00	3975.20	0.00
175	19.00	-275.40	12.80	14.30	2.59	4.00	18.40	1.94	6.00	390.00	5.00	2.80
176	20.00	765.00	12.80	14.30	2.59	4.00	18.40	1.94	6.00	390.00	5.00	2.80
177	21.00	298.30	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
178	22.00	196.70	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
179	23.00	1260.00	10.90	16.00	4.50	4.00	19.10	3.27	6.00	640.00	5.00	2.50
180	24.00	-188.00	10.50	12.80	-.00	-.00	16.40	-.00	-.00	615.00	5.00	2.45
181	25.00	1072.00	10.20	9.50	1.76	4.00	13.70	4.52	6.00	590.00	5.00	2.40
182	26.00	198.00	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
183	27.00	26.00	57.40	78.10	0.00	2.00	79.70	15.10	3.00	1200.00	5.00	5.40
184	28.00	38.37	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
185	29.00	1334.37	8.20	11.80	1.37	4.00	14.20	2.01	6.00	780.00	5.00	1.70
186	30.00	27.24	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
187	31.00	1361.61	9.80	9.00	1.66	4.00	10.60	1.64	6.00	700.00	5.00	1.70
188	32.00	37.13	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
189	33.00	60.98	264.30	235.70	109.00	4.00	795.80	873.60	6.00	3150.00	5934.00	0.00
190	34.00	1459.72	26.70	28.60	2.54	4.00	33.70	1.19	6.00	830.00	198.00	1.80
191	35.00	32.18	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
192	36.00	.10	9014.40	8074.00	1115.90	3.00	8704.60	1251.40	4.00	470.00	15607.00	0.00
193	37.00	1492.00	25.20	22.70	4.61	4.00	29.50	3.33	6.00	850.00	53.00	1.00
194	38.00	-14.00	22.50	19.20	-.00	-.00	26.40	-.00	-.00	850.00	59.00	1.55
195	39.00	1478.00	19.80	15.60	.98	4.00	23.30	1.98	6.00	850.00	65.00	2.10
196	1.00	1077.26	6.50	7.40	1.39	3.00	11.10	1.60	6.00	5.00	5.00	.10
197	2.00	3.74	6639.70	7011.60	168.60	4.00	8016.50	176.90	6.00	5440.00	8055.00	0.00
198	3.00	-41.00	14.50	20.90	1.28	4.00	24.00	1.32	6.00	5.00	5.00	1.70
199	4.00	1040.00	14.50	20.90	1.28	4.00	24.00	1.32	6.00	5.00	5.00	1.70
200	5.00	1040.00	13.90	16.50	2.59	4.00	24.60	4.41	6.00	5.00	5.00	2.60
201	6.00	-91.24	13.90	16.90	-.00	-.00	25.70	-.00	-.00	5.00	5.00	2.45
202	7.00	948.76	13.90	17.30	2.77	4.00	26.80	7.28	6.00	5.00	5.00	2.30
203	8.00	-40.76	16.40	19.20	-.00	-.00	25.00	-.00	-.00	5.00	5.00	2.00
204	9.00	908.00	18.90	21.10	4.70	3.00	23.20	3.84	6.00	5.00	5.00	1.70
205	10.00	.37	6543.70	7297.90	45.60	3.00	7138.10	599.90	4.00	20730.00	85.60	0.00
206	11.00	908.37	18.00	21.60	5.40	4.00	29.50	6.20	6.00	5.00	5.00	2.30
207	12.00	908.37	27.90	23.50	4.51	4.00	27.70	5.17	6.00	40.00	5.00	2.40
208	13.00	1.49	676.60	738.60	48.30	3.00	1516.40	70.30	4.00	1520.00	2146.20	0.00
209	14.00	36.30	59.40	77.40	12.30	3.00	87.20	6.36	4.00	310.00	42.70	0.00
210	15.00	402.20	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00
211	16.00	1312.00	15.80	19.00	3.38	4.00	22.30	3.43	6.00	360.00	5.00	1.70
212	17.00	3.15	724.40	653.00	2.65	3.00	805.90	285.30	4.00	40.00	140.30	0.00
213	18.00	.03	3161.00	4349.40	-.00	1.00	5741.40	-.00	1.00	9170.00	734.00	0.00
214	19.00	-240.10	18.00	15.10	.75	4.00	21.60	1.54	6.00	330.00	5.00	4.40
215	20.00	1075.00	18.00	15.10	.75	4.00	21.60	1.54	6.00	330.00	5.00	4.40
216	21.00	222.30	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
217	22.00	252.70	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
218	23.00	1550.00	11.90	15.70	6.21	4.00	23.00	2.16	6.00	490.00	5.00	3.00
219	24.00	-168.00	13.60	13.40	-.00	-.00	20.50	-.00	-.00	470.00	5.00	2.40

Var	1	2	3	4	5	6	7	8	9	10	11	12
OBS	STA	Q	SRP	TSP	TSPDEV	TSPNUM	TP	TPDEV	TPNUM	NO3	NH4	CHL-a
220	25.00	1382.00	15.40	11.00	2.51	4.00	18.00	1.01	6.00	450.00	5.00	1.80
221	26.00	138.00	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
222	27.00	24.00	92.50	74.60	14.30	3.00	109.00	17.10	4.00	1040.00	5.00	7.60
223	28.00	45.71	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
224	29.00	1589.71	9.40	17.80	6.46	4.00	16.90	1.77	5.00	550.00	5.00	2.40
225	30.00	32.45	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
226	31.00	1622.16	15.30	10.20	2.10	4.00	18.70	1.29	5.00	450.00	5.00	2.00
227	32.00	44.23	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
228	33.00	62.14	257.90	379.80	67.57	4.00	571.00	60.05	6.00	710.00	9037.00	0.00
229	34.00	1728.53	26.40	27.20	3.38	4.00	35.90	4.17	6.00	720.00	195.00	2.60
230	35.00	38.34	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
231	36.00	.13	7759.30	8514.80	177.20	3.00	8905.00	70.60	4.00	140.00	23100.00	0.00
232	37.00	1767.00	21.20	24.10	3.55	4.00	33.00	2.50	6.00	700.00	95.00	1.70
233	38.00	-123.00	19.00	20.40	-.00	-.00	30.40	-.00	-.00	755.00	107.00	2.10
234	39.00	1644.00	16.90	16.60	5.88	4.00	27.80	6.40	4.00	810.00	119.00	2.50
235	1.00	1354.30	7.10	3.70	1.38	4.00	6.40	.77	6.00	5.00	5.00	.90
236	2.00	3.70	6934.20	7348.90	86.80	4.00	7663.70	141.50	6.00	3840.00	508.40	0.00
237	3.00	-28.00	9.70	20.30	1.05	4.00	23.80	4.40	6.00	10.00	5.00	1.40
238	4.00	1330.00	9.70	20.30	1.05	4.00	23.80	4.40	6.00	10.00	5.00	1.40
239	5.00	1330.00	15.80	12.00	5.61	4.00	18.60	3.95	6.00	10.00	5.00	3.10
240	6.00	-98.15	14.35	15.50	-.00	-.00	19.80	-.00	-.00	10.00	5.00	3.10
241	7.00	1231.85	12.90	19.00	9.40	2.00	21.00	6.14	5.00	10.00	5.00	3.10
242	8.00	-43.85	13.60	18.35	-.00	-.00	22.05	-.00	-.00	10.00	5.00	3.10
243	9.00	1188.00	14.30	17.70	4.66	4.00	23.10	4.30	4.00	5.00	5.00	3.10
244	10.00	.38	8110.70	8571.00	298.40	3.00	8506.00	201.70	3.00	21100.00	112.00	0.00
245	11.00	1188.38	17.60	14.80	2.30	7.00	22.00	3.78	9.00	10.00	5.00	1.80
246	12.00	1188.38	14.60	13.80	.93	7.00	21.90	2.97	8.00	30.00	5.00	2.10
247	13.00	1.48	915.90	985.80	60.00	3.00	1455.70	171.70	4.00	1360.00	1098.00	0.00
248	14.00	36.20	25.50	51.70	30.20	3.00	48.80	19.00	4.00	260.00	5.00	0.00
249	15.00	167.20	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00
250	16.00	1357.00	16.40	12.30	1.69	4.00	16.90	2.51	6.00	240.00	5.00	1.50
251	17.00	0.00	0.00	0.00	-.00	-.00	0.00	-.00	0.00	0.00	0.00	0.00
252	18.00	.03	3161.00	3946.60	186.70	2.00	6071.30	44.50	2.00	1630.00	8507.70	0.00
253	19.00	-266.00	7.30	17.10	1.41	2.00	16.30	3.57	5.00	330.00	5.00	1.65
254	20.00	1091.00	7.30	17.10	1.41	2.00	16.30	3.57	5.00	330.00	5.00	1.80
255	21.00	149.60	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
256	22.00	429.40	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
257	23.00	1670.00	6.80	7.70	1.34	6.00	13.70	1.47	7.00	430.00	5.00	2.50
258	24.00	-128.00	9.40	8.30	-.00	-.00	14.00	-.00	-.00	365.00	5.00	2.30
259	25.00	1542.00	12.00	8.90	2.05	5.00	14.40	1.78	6.00	300.00	5.00	2.10
260	26.00	58.00	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
261	27.00	24.00	57.20	76.90	49.80	3.00	85.00	33.50	4.00	870.00	5.00	10.80
262	28.00	25.43	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
263	29.00	1649.43	13.50	8.60	3.34	6.00	17.00	4.59	7.00	400.00	5.00	2.70
264	30.00	18.06	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
265	31.00	1667.49	11.80	13.10	1.21	4.00	15.40	1.98	4.00	350.00	5.00	2.80
266	32.00	24.61	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
267	33.00	63.41	579.30	769.50	101.10	4.00	1024.70	25.60	5.00	3320.00	4238.00	0.00
268	34.00	1755.51	42.80	47.90	14.30	4.00	58.10	6.93	6.00	700.00	114.00	3.20
269	35.00	21.33	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
270	36.00	.16	9326.00	9972.80	36.30	3.00	10512.30	581.50	4.00	100.00	21085.00	0.00
271	37.00	1777.00	39.30	44.40	5.57	3.00	51.20	6.05	6.00	500.00	221.00	2.60
272	38.00	-107.00	31.30	39.20	-.00	-.00	48.90	-.00	-.00	650.00	143.50	2.70
273	39.00	1670.00	23.30	33.90	2.66	4.00	46.70	11.50	6.00	800.00	66.00	2.80
274	1.00	1748.34	2.30	5.80	.57	4.00	9.00	2.29	6.00	5.00	5.00	2.40

Var	1	2	3	4	5	6	7	8	9	10	11	12
OBS	STA	Q	SRP	TSP	TSPDEV	TSPNUM	TP	TPDEV	TPNUM	NO3	NH4	CHL-a
275	2.00	3.66	6717.90	6712.90	83.50	4.00	7242.60	193.20	6.00	5180.00	8257.50	0.00
276	3.00	-22.00	7.50	11.00	3.54	4.00	18.00	1.21	6.00	5.00	5.00	2.70
277	4.00	1730.00	7.50	11.00	3.54	4.00	18.00	1.21	6.00	5.00	5.00	2.70
278	5.00	1730.00	7.00	8.70	.93	4.00	15.40	1.31	7.00	5.00	5.00	3.00
279	6.00	-79.49	6.50	9.05	-.00	-.00	16.30	-.00	-.00	5.00	5.00	3.05
280	7.00	1650.51	6.00	9.40	2.81	4.00	17.20	1.34	6.00	5.00	5.00	3.10
281	8.00	-35.51	6.85	9.45	-.00	-.00	16.90	-.00	-.00	5.00	5.00	3.10
282	9.00	1615.00	7.70	9.50	3.91	4.00	16.60	2.64	6.00	5.00	5.00	3.10
283	10.00	.30	7346.80	7620.00	41.50	3.00	7833.50	47.10	4.00	17590.00	20.50	0.00
284	11.00	1615.30	10.50	9.80	.68	4.00	17.90	2.78	6.00	5.00	5.00	2.80
285	12.00	1615.30	10.10	10.20	2.15	4.00	17.10	2.93	6.00	20.00	5.00	2.80
286	13.00	1.42	870.40	978.70	112.90	3.00	1400.90	46.50	4.00	1030.00	1761.10	0.00
287	14.00	36.80	45.10	67.70	12.50	3.00	107.20	19.50	4.00	160.00	5.00	0.00
288	15.00	370.30	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00
289	16.00	1987.00	10.30	10.60	.85	4.00	19.10	3.98	6.00	190.00	5.00	2.00
290	17.00	3.44	316.20	1580.10	33.20	3.00	2360.10	55.60	4.00	10.00	2280.80	0.00
291	18.00	.02	3161.00	4545.30	99.40	2.00	6212.60	352.40	2.00	20.00	14520.00	0.00
292	19.00	-214.40	12.70	11.10	1.89	4.00	21.10	2.60	5.00	200.00	5.00	3.50
293	20.00	1776.00	12.70	11.10	1.89	4.00	21.10	2.60	5.00	200.00	5.00	3.50
294	21.00	201.30	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
295	22.00	302.70	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
296	23.00	2280.00	10.30	13.20	2.78	4.00	18.70	2.84	6.00	310.00	5.00	2.00
297	24.00	-49.00	9.80	12.40	-.00	-.00	19.90	-.00	-.00	340.00	5.00	3.15
298	25.00	2231.00	9.30	11.60	1.42	4.00	21.20	1.53	6.00	370.00	5.00	4.30
299	26.00	-61.00	9.40	12.75	-.00	-.00	20.80	-.00	-.00	360.00	5.00	4.10
300	27.00	26.00	42.80	54.70	10.20	3.00	83.50	3.81	4.00	1080.00	5.00	11.60
301	28.00	42.46	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
302	29.00	2238.46	9.50	13.90	5.71	4.00	20.40	3.54	6.00	350.00	5.00	3.90
303	30.00	30.14	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
304	31.00	2268.60	9.00	10.70	2.92	4.00	19.60	2.15	6.00	340.00	5.00	3.80
305	32.00	41.09	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
306	33.00	61.57	341.10	452.20	45.20	4.00	657.70	49.10	6.00	680.00	8491.00	0.00
307	34.00	2371.26	18.50	21.60	4.66	4.00	35.20	3.90	6.00	420.00	177.00	3.70
308	35.00	35.61	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
309	36.00	.13	9082.10	9915.40	258.20	3.00	9952.70	292.20	4.00	160.00	20210.00	0.00
310	37.00	2407.00	22.90	27.60	5.00	4.00	35.20	1.13	6.00	430.00	59.00	2.90
311	38.00	-133.00	20.50	24.30	-.00	-.00	32.60	-.00	-.00	560.00	83.50	2.65
312	39.00	2274.00	18.10	20.90	2.38	4.00	30.00	2.34	6.00	690.00	108.00	2.40
313	1.00	1766.32	5.60	9.60	5.57	4.00	13.40	1.34	6.00	5.00	5.00	2.90
314	2.00	3.68	7086.80	7350.80	42.40	4.00	7656.40	155.50	6.00	5530.00	11066.40	0.00
315	3.00	0.00	12.20	12.70	1.81	4.00	18.70	4.96	6.00	10.00	5.00	2.40
316	4.00	1770.00	12.20	12.70	1.81	4.00	18.70	4.96	6.00	10.00	5.00	2.40
317	5.00	1770.00	12.60	8.10	1.65	4.00	19.30	1.67	6.00	5.00	5.00	3.50
318	6.00	-59.44	12.50	7.95	-.00	-.00	18.20	-.00	-.00	5.00	5.00	4.10
319	7.00	1710.58	12.40	7.80	3.91	4.00	17.10	3.76	6.00	5.00	5.00	4.70
320	8.00	-26.56	12.25	8.30	-.00	-.00	18.45	-.00	-.00	5.00	5.00	3.80
321	9.00	1684.00	12.10	8.80	1.66	4.00	19.80	5.57	6.00	5.00	5.00	2.90
322	10.00	.26	6634.40	7315.10	68.60	3.00	7400.00	93.70	4.00	15920.00	70.70	0.00
323	11.00	1684.26	11.40	11.20	2.22	4.00	19.50	6.22	6.00	10.00	5.00	3.20
324	12.00	1684.26	10.60	11.50	3.07	4.00	21.40	8.64	5.00	20.00	5.00	2.80
325	13.00	1.39	797.70	988.00	9.68	3.00	1564.10	113.70	4.00	1570.00	3985.00	0.00
326	14.00	36.30	50.70	54.50	3.11	3.00	71.10	13.80	4.00	240.00	5.00	0.00
327	15.00	381.40	8.10	6.91	3.79	19.00	6.91	3.79	19.00	1070.00	5.00	0.00
328	16.00	2067.00	17.00	11.90	7.08	4.00	17.70	3.54	6.00	140.00	5.00	2.10
329	17.00	3.45	785.50	1848.00	77.30	3.00	2590.30	160.70	4.00	1570.00	104.20	0.00

Var	1	2	3	4	5	6	7	8	9	10	11	12
OBS	STA	Q	SRP	TSP	TSPDEV	TSPNUM	TP	TPDEV	TPNUM	NO3	NH4	CHL-a
330	18.00	.02	3161.10	3247.70	170.30	2.00	4172.70	152.30	2.00	8070.00	3877.90	0.00
331	19.00	-192.40	13.70	14.50	3.87	4.00	22.10	1.80	6.00	140.00	5.00	2.80
332	20.00	1878.00	13.70	14.50	3.87	4.00	22.10	1.80	6.00	140.00	5.00	2.80
333	21.00	216.00	11.20	10.29	8.00	24.00	10.29	8.00	24.00	1446.00	5.00	0.00
334	22.00	256.00	5.10	5.55	3.08	4.00	5.55	3.08	4.00	342.00	5.00	0.00
335	23.00	2350.00	14.80	11.30	6.65	4.00	20.50	7.20	6.00	260.00	5.00	2.80
336	24.00	-82.00	12.50	9.60	-.00	-.00	18.10	-.00	-.00	300.00	5.00	3.55
337	25.00	2268.00	10.30	7.90	1.91	4.00	15.80	3.38	6.00	340.00	5.00	4.30
338	26.00	-78.00	12.30	9.10	-.00	-.00	15.35	-.00	-.00	340.00	5.00	3.50
339	27.00	32.00	57.60	39.30	3.04	3.00	68.00	4.07	4.00	810.00	5.00	16.40
340	28.00	74.20	7.60	6.86	3.09	5.00	6.86	3.09	5.00	2860.00	5.00	0.00
341	29.00	2296.20	14.30	10.30	2.46	4.00	14.90	2.08	6.00	340.00	5.00	2.70
342	30.00	52.67	10.80	10.50	.46	3.00	10.50	.46	3.00	1300.00	5.00	0.00
343	31.00	2348.87	15.20	12.10	5.86	4.00	20.30	5.80	6.00	450.00	5.00	3.10
344	32.00	71.80	9.80	10.60	1.74	6.00	10.60	1.74	6.00	1555.00	5.00	0.00
345	33.00	58.93	59.50	201.80	55.30	4.00	382.60	75.70	6.00	170.00	11909.00	0.00
346	34.00	2479.60	22.60	16.40	4.08	4.00	29.20	9.82	6.00	380.00	173.00	4.20
347	35.00	62.22	26.30	23.13	15.59	20.00	23.13	15.59	20.00	2398.00	5.00	0.00
348	36.00	.18	9087.20	10242.10	611.00	3.00	11097.40	1326.50	4.00	110.00	28103.00	0.00
349	37.00	2542.00	21.50	20.40	3.18	4.00	31.50	10.10	6.00	440.00	144.00	3.30
350	38.00	-76.00	22.70	19.90	-.00	-.00	31.30	-.00	-.00	525.00	139.50	2.85
351	39.00	2466.00	23.90	19.30	8.88	4.00	31.10	6.77	6.00	610.00	135.00	2.40

APPENDIX B

Model Listing (Microsoft BASIC)

```
10 'SPOKANE RIVER TP ATTENUATION MODEL
20 DIM QINIT(17)
30 DIM QFINAL(17)
40 DIM QAVG(17)
50 DIM TPINIT(17)
60 DIM DININIT(17)
70 DIM TPFINAL(17)
80 DIM DINFINAL(17)
90 DIM TPAVG(17)
100 DIM DINAVG(17)
110 DIM QSW(17,5)
120 DIM TPSW(17,5)
130 DIM DINSW(17,5)
140 DIM QSWTOT(17)
150 DIM TPSWTOT(17)
160 DIM DINSWTOT(17)
170 DIM SWTPLOAD(17)
180 DIM SWDINLOAD(17)
190 DIM QGW(17)
200 DIM TPGW(17)
210 DIM DINGW(17)
220 DIM SOURCECNT(17)
230 DIM K2(17)
240 DIM K2MAX(17)
250 DIM DELTP(17)
260 DIM DELDIN(17)
270 DIM AREA(17)
280 DIM RM(18)
290 DIM VARY1(18)
300 DIM VARY2(18)
310 DIM VARY3(18)
320 DIM VARY4(18)
330 DIM VARY5(18)
340 DIM VARY6(18)
350 DIM VARY7(18)
360 DIM VARY8(18)
370 DIM VARX1(18)
380 DIM VARX2(18)
390 DIM VARX3(18)
400 DIM VARX4(18)
410 DIM VARX5(18)
420 DIM VARX6(18)
430 DIM VARX7(18)
440 DIM VARX8(18)
450 DIM VARX9(18)
460 DIM VARTPFINAL(18)
470 DIM VARDIN(18)
480 DIM DEVTPFINAL(18)
490 'INITIAL DISCHARGE VALUES IN MGD
500 QSW(1,1)=2.314
510 QSW(3,1)=0
520 QSW(5,1)=.259
530 QSW(7,1)=.944
540 QSW(9,1)=2.185
550 QSW(9,2)=.0194
560 QSW(12,1)=17.32
570 QSW(14,1)=30.69
580 QSW(15,1)=.084
590 'INITIAL SURFACE WATER TP IN ug P /l
```

```
600 TPSW(1,1)=7790
610 TPSW(3,1)=0
620 TPSW(5,1)=7430
630 TPSW(7,1)=2150
640 TPSW(9,1)=1670
650 TPSW(9,2)=4870
660 TPSW(12,1)=72.3
670 TPSW(14,1)=677
680 TPSW(15,1)=9050
690 'INITIAL SURFACE WATER DIN IN ug N /l
700 DINSW(1,1)=13500
710 DINSW(3,1)=0
720 DINSW(5,1)=18800
730 DINSW(7,1)=3760
740 DINSW(9,1)=624
750 DINSW(9,2)=9700
760 DINSW(12,1)=995
770 DINSW(14,1)=11500
780 DINSW(15,1)=19100
790 'NET TP AND DIN LOAD FROM KAISER WTP IN Kg /day
800 KAISERTP=5.1
810 KAISERDIN=22.3
820 'GROUNDWATER DISCHARGE (cfs), TP (ug P /l), AND DIN (ug N /l)
830 QGW(3)=-51.5
840 QGW(4)=-23!
850 QGW(7)=417
860 TPGW(7)=6.91
870 DINGW(7)=1075
880 QGW(9)=-256.2
890 QGW(10)=488
900 TPGW(10)=15.4
910 DINGW(10)=757
920 QGW(11)=-179.7
930 QGW(12)=178
940 TPGW(12)=12.2
950 DINGW(12)=2865
960 QGW(13)=49
970 TPGW(13)=10.5
980 DINGW(13)=1305
990 QGW(14)=66.9
1000 TPGW(14)=10.6
1010 DINGW(14)=1560
1020 QGW(15)=58!
1030 TPGW(15)=23.1
1040 DINGW(15)=2400
1050 QGW(16)=0!
1060 'REACH(0)=LAKE COUER D'ALENE
1070 'Q (cfs), TP (ug P /l), AND DIN (ug N /l)
1080 FOR I=1 TO 25
1090 PRINT
1100 NEXT I
1110 PRINT "SPOKANE RIVER PHOSPHORUS LOADING/ATTENUATION MODEL FROM COUER D'ALEN
E, IDAHO TO LONG LAKE, WASHINGTON  (HARPER-OWES, 5/85)"
1120 PRINT
1130 PRINT
1140 PRINT "DO YOU WANT TO EVALUATE THE ESTIMATED 20-YEAR LOW FLOW EVENT AT THE
OUTLET OF   LAKE COUER D'ALENE OR THE ESTIMATED PROBABILISTIC CONDITION FOR THE
ENTIRE RIVERSYSTEM ? (enter 20 for the 20-year low-flow selection, otherwise ret
urn)"
```

```
1150 INPUT FLOW
1160 IF FLOW=20 THEN QFINAL(0)=1500 ELSE QFINAL(0)=2900
1170 TPFINAL(0)=8.68
1180 DINFINAL(0)=10
1190 RM(0)=111.7
1200 RM(1)=106.6
1210 RM(2)=101.7
1220 RM(3)=96!
1230 RM(4)=93!
1240 RM(5)=90.4
1250 RM(6)=87.8
1260 RM(7)=85.3
1270 RM(8)=82.6
1280 RM(9)=79.8
1290 RM(10)=78!
1300 RM(11)=74.1
1310 RM(12)=69.8
1320 RM(13)=67.6
1330 RM(14)=64.6
1340 RM(15)=62!
1350 RM(16)=58.1
1360 '
1370 '
1380 '
1390 FOR I=1 TO 16
1400 '
1410 SOURCECNT(I)=0
1420 IF I=1 THEN R1$="RM 111.7 TO 106.6"
1430 IF I=1 THEN R2$="LAKE COUER D'ALENE TO HARBOR ISLAND"
1440 IF I=2 THEN R1$="RM 106.6 TO 101.7"
1450 IF I=2 THEN R2$="HARBOR ISLAND TO POST FALLS DAM"
1460 IF I=3 THEN R1$="RM 101.7 TO 96.0"
1470 IF I=3 THEN R2$="POST FALLS DAM TO STATELINE"
1480 IF I=4 THEN R1$="RM 96.0 TO 93.0"
1490 IF I=4 THEN R2$="STATELINE TO HARVARD ROAD"
1500 IF I=5 THEN R1$="RM 93.0 TO 90.4"
1510 IF I=5 THEN R2$="HARVARD ROAD TO BARKER ROAD"
1520 IF I=6 THEN R1$="RM 90.4 TO 87.8"
1530 IF I=6 THEN R2$="BARKER ROAD TO SULLIVAN ROAD"
1540 IF I=7 THEN R1$="RM 87.8 TO 85.3"
1550 IF I=7 THEN R2$="SULLIVAN ROAD TO TRENT ROAD"
1560 IF I=8 THEN R1$="RM 85.3 TO 82.6"
1570 IF I=8 THEN R2$="TRENT ROAD TO ARGONNE ROAD"
1580 IF I=9 THEN R1$="RM 82.6 TO 79.8"
1590 IF I=9 THEN R2$="ARGONNE ROAD TO UPRIVER DAM"
1600 IF I=10 THEN R1$="RM 79.8 TO 78.0"
1610 IF I=10 THEN R2$="UPRIVER DAM TO GREEN STREET"
1620 IF I=11 THEN R1$="RM 78.0 TO 74.1"
1630 IF I=11 THEN R2$="GREEN STREET TO POST STREET"
1640 IF I=12 THEN R1$="RM 74.1 TO 69.8"
1650 IF I=12 THEN R2$="POST STREET TO FORT WRIGHT BRIDGE"
1660 IF I=13 THEN R1$="RM 69.8 TO 67.6"
1670 IF I=13 THEN R2$="FORT WRIGHT BRIDGE TO SPOKANE AWT"
1680 IF I=14 THEN R1$="RM 67.6 TO 64.6"
1690 IF I=14 THEN R2$="SPOKANE AWT TO GUN CLUB"
1700 IF I=15 THEN R1$="RM 64.6 TO 62.0"
1710 IF I=15 THEN R2$="GUN CLUB TO SEVEN MILE BRIDGE"
1720 IF I=16 THEN R1$="RM 62.0 TO 58.1"
1730 IF I=16 THEN R2$="SEVEN MILE BRIDGE TO NINE MILE DAM"
1740 FOR J=1 TO 25
1750 PRINT
```

```
1760 NEXT J
1770 PRINT "REACH ",I
1780 PRINT R1$
1790 PRINT R2$
1800 '
1810 FOR J=1 TO 5
1820 '
1830 A$="0"
1840 IF I=1 THEN IF J=1 THEN A$="COUER D'ALENE STP"
1850 IF I=3 THEN IF J=1 THEN A$="POST FALLS STP"
1860 IF I=5 THEN IF J=1 THEN A$="LIBERTY LAKE STP"
1870 IF I=7 THEN IF J=1 THEN A$="SPOKANE INDUSTRIAL PARK WTP"
1880 IF I=7 THEN IF J=2 THEN A$="KAISER WTP"
1890 IF I=9 THEN IF J=1 THEN A$="INLAND EMPIRE WTP"
1900 IF I=9 THEN IF J=2 THEN A$="MILLWOOD STP"
1910 IF I=12 THEN IF J=1 THEN A$="HANGMAN CREEK"
1920 IF I=14 THEN IF J=1 THEN A$="SPOKANE AWT"
1930 IF I=15 THEN IF J=1 THEN A$="NORTHWEST TERRACE STP"
1940 IF I=1 THEN IF J=2 THEN A$="MISCELLANEOUS SOURCES"
1950 IF I=2 THEN IF J=1 THEN A$="MISCELLANEOUS SOURCES"
1960 IF I=3 THEN IF J=2 THEN A$="MISCELLANEOUS SOURCES"
1970 IF I=4 THEN IF J=1 THEN A$="MISCELLANEOUS SOURCES"
1980 IF I=5 THEN IF J=2 THEN A$="MISCELLANEOUS SOURCES"
1990 IF I=6 THEN IF J=1 THEN A$="MISCELLANEOUS SOURCES"
2000 IF I=7 THEN IF J=3 THEN A$="MISCELLANEOUS SOURCES"
2010 IF I=8 THEN IF J=1 THEN A$="MISCELLANEOUS SOURCES"
2020 IF I=9 THEN IF J=3 THEN A$="MISCELLANEOUS SOURCES"
2030 IF I=10 THEN IF J=1 THEN A$="MISCELLANEOUS SOURCES"
2040 IF I=11 THEN IF J=1 THEN A$="MISCELLANEOUS SOURCES"
2050 IF I=12 THEN IF J=2 THEN A$="MISCELLANEOUS SOURCES"
2060 IF I=13 THEN IF J=1 THEN A$="MISCELLANEOUS SOURCES"
2070 IF I=14 THEN IF J=2 THEN A$="MISCELLANEOUS SOURCES"
2080 IF I=15 THEN IF J=2 THEN A$="MISCELLANEOUS SOURCES"
2090 IF I=16 THEN IF J=1 THEN A$="MISCELLANEOUS SOURCES"
2100 '
2110 'HANGMAN CREEK INPUT
2120 IF I=12 THEN GOTO 2130 ELSE GOTO 2180
2130 IF J=1 THEN GOTO 2140 ELSE GOTO 2180
2140 QSW(I,J)=QSW(I,J)*1.54723
2150 SOURCECNT(I)=SOURCECNT(I)+1
2160 GOTO 3130
2170 '
2180 IF A$="MISCELLANEOUS SOURCES" THEN GOTO 2910
2190 '
2200 '
2210 '
2220 '
2230 '
2240 IF I=7 THEN GOTO 2250 ELSE GOTO 2520
2250 IF J=2 THEN GOTO 2290 ELSE GOTO 2520
2260 '
2270 'INPUTN OF KAISER WTP LOAD
2280 '
2290 PRINT
2300 PRINT
2310 PRINT "KAISER WTP"
2320 PRINT
2330 PRINT "1984 Net TP Load (Kg P /day):",KAISERTP
2340 PRINT
2350 PRINT "Enter TP LOAD (-1 for 1984 value)"
```

```
2360 INPUT X
2370 IF X=-1 THEN KAISERTP=KAISERTP*408.734 ELSE KAISERTP=X*408.734
2380 PRINT
2390 PRINT
2400 PRINT "KAISER WTP"
2410 PRINT
2420 PRINT "1984 Net DIN LOAD (Kg N /day):",KAISERDIN
2430 PRINT
2440 PRINT "Enter DIN LOAD (-1 for 1984 value)"
2450 INPUT X
2460 IF X=-1 THEN KAISERDIN=KAISERDIN*408.734 ELSE KAISERDIN=X*408.734
2470 SOURCECNT(I)=SOURCECNT(I)+1
2480 GOTO 3130
2490 '
2500 '
2510 'INPUT FOR SURFACE WATER SOURCES
2520 IF A$="SPOKANE AWT" THEN GOTO 2530 ELSE GOTO 2590
2530 PRINT
2540 PRINT
2550 PRINT A$
2560 PRINT
2570 PRINT "Is AWT Operational (Y or N)?"
2580 INPUT Q$
2590 PRINT
2600 PRINT
2610 PRINT A$
2620 PRINT
2630 PRINT "1984 Average Discharge (MGD):",QSW(I,J)
2640 PRINT
2650 PRINT "Enter DISCHARGE (-1 for 1984 value)"
2660 INPUT X
2670 IF X=-1 THEN QSW(I,J)=QSW(I,J)*1.54723 ELSE QSW(I,J)=X*1.54723
2680 PRINT
2690 PRINT
2700 PRINT A$
2710 PRINT
2720 PRINT "1984 Average TP (ug P /l):",TPSW(I,J)
2730 PRINT
2740 PRINT "Enter TP (-1 for 1984 value)"
2750 INPUT X
2760 IF X=-1 THEN GOTO 2770 ELSE TPSW(I,J)=X
2770 PRINT
2780 PRINT
2790 PRINT A$
2800 PRINT
2810 PRINT "1984 Average DIN (ug N /l):",DINSW(I,J)
2820 PRINT
2830 PRINT "Enter DIN (-1 for 1984 value)"
2840 INPUT X
2850 IF X=-1 THEN GOTO 2860 ELSE DINSW(I,J)=X
2860 SOURCECNT(I)=SOURCECNT(I)+1
2870 GOTO 3130
2880 '
2890 'INPUT OF MISCELLANEOUS SOURCES
2900 '
2910 PRINT
2920 PRINT
2930 PRINT "MISCELLANEOUS SOURCES"
2940 PRINT
2950 PRINT "Enter DISCHARGE (MGD)"
```

```
2960 INPUT X
2970 IF X=-1 THEN GOTO 3180
2980 IF X=0 THEN GOTO 3180 ELSE QSW(I,J)=X*1.54723
2990 PRINT
3000 PRINT
3010 PRINT "Enter TP"
3020 INPUT TPSW(I,J)
3030 PRINT
3040 PRINT
3050 PRINT "Enter DIN"
3060 INPUT DINSW(I,J)
3070 SOURCECNT(I)=SOURCECNT(I)+1
3080 GOTO 3180
3090 '
3100 '
3110 '
3120 '
3130 NEXT J
3140 '
3150 '
3160 '
3170 '
3180 SUMQ=0
3190 SUMTP=0
3200 SUMDIN=0
3210 '
3220 IF SOURCECNT(I)=0 THEN GOTO 3430
3230 '
3240 FOR J=1 TO SOURCECNT(I)
3250 '
3260 SUMQ=SUMQ+QSW(I,J)
3270 IF I=7 THEN IF J=2 THEN GOTO 3310
3280 SUMTP=SUMTP+(TPSW(I,J)*QSW(I,J))
3290 SUMDIN=SUMDIN+(DINSW(I,J)*QSW(I,J))
3300 GOTO 3330
3310 SUMTP=SUMTP+KAISERTP
3320 SUMDIN=SUMDIN+KAISERDIN
3330 QSWTOT(I)=SUMQ
3340 TPSWTOT(I)=SUMTP/SUMQ
3350 DINSWTOT(I)=SUMDIN/SUMQ
3360 SWTPLOAD(I)=SUMTP
3370 SWDINLOAD(I)=SUMDIN
3380 '
3390 '
3400 NEXT J
3410 '
3420 '
3430 NEXT I
3440 '
3450 '
3460 FOR K=1 TO 25
3470 PRINT
3480 NEXT K
3490 PRINT "COMPUTING (computations typically take approximately 1-2 minutes)"
3500 '
3510 '
3520 FOR I=1 TO 16
3530 '
3540 '
3550 DELTP(I)=0
```

```
3560 DELDIN(I)=0
3570 '
3580 TESTDELTP=DELTP(I)
3590 TESTDELDIN=DELDIN(I)
3600 QINIT(I)=QFINAL(I-1)+QSWTOT(I)
3610 IF I=2 THEN QINIT(I)=QINIT(I)-27!
3620 QFINAL(I)=QINIT(I)+QGW(I)
3630 QAVG(I)=(QINIT(I)+QFINAL(I))/2
3640 '
3650 AREA(1)=5.1*1609*182
3660 AREA(2)=4.9*1609*188
3670 AREA(3)=5.7*1609*22.093*(QAVG(3)^.1252)
3680 AREA(4)=3!*1609*22.093*(QAVG(4)^.1252)
3690 AREA(5)=2.6*1609*22.093*(QAVG(5)^.1252)
3700 AREA(6)=2.6*1609*22.093*(QAVG(6)^.1252)
3710 AREA(7)=2.5*1609*22.093*(QAVG(7)^.1252)
3720 AREA(8)=2.7*1609*65
3730 AREA(9)=2.8*1609*97
3740 AREA(10)=1.8*1609*22.093*(QAVG(10)^.1252)
3750 AREA(11)=3.9*1609*71
3760 AREA(12)=4.3*1609*22.093*(QAVG(12)^.1252)
3770 AREA(13)=2.2*1609*22.093*(QAVG(13)^.1252)
3780 AREA(14)=3!*1609*22.093*(QAVG(14)^.1252)
3790 AREA(15)=2.6*1609*79
3800 AREA(16)=3.9*1609*181
3810 '
3820 TPINIT(I)=((QFINAL(I-1)*TPFINAL(I-1))+SWTPLOAD(I))/QINIT(I)
3830 TPFINAL(I)=(((QFINAL(I-1)*TPFINAL(I-1))+SWTPLOAD(I)+(QGW(I)*TPGW(I)))/QFINA
L(I))-DELTP(I)
3840 '
3850 DININIT(I)=((QFINAL(I-1)*DINFINAL(I-1))+SWDINLOAD(I))/QINIT(I)
3860 DINFINAL(I)=(((QFINAL(I-1)*DINFINAL(I-1))+SWDINLOAD(I)+(QGW(I)*DINGW(I)))/Q
FINAL(I))-DELDIN(I)
3870 '
3880 IF QGW(I)<0 THEN TPFINAL(I)=TPINIT(I)-DELTP(I):DINFINAL(I)=DININIT(I)-DELDI
N(I)
3890 IF DININIT(I)<10 THEN DININIT(I)=10
3900 IF DINFINAL(I)<10 THEN DINFINAL(I)=10
3910 '
3920 TPAVG(I)=(TPINIT(I)+TPFINAL(I))/2
3930 DINAVG(I)=(DININIT(I)+DINFINAL(I))/2
3940 '
3950 K2MAX(I)=.835
3960 IF I>13 THEN IF Q$="Y" THEN K2MAX(I)=.178
3970 K2MAX(10)=0
3980 K2MAX(I)=K2MAX(I)*1!
3990 K2(I)=(K2MAX(I)*DINAVG(I))/(DINAVG(I)+29)
4000 '
4010 DELTP(I)=(K2(I)*TPAVG(I)*AREA(I))/(QAVG(I)*2446.58)
4020 DELDIN(I)=DELTP(I)*3.9
4030 IF .01<(ABS(TESTDELTP-DELTP(I))/DELTP(I)) THEN IF .05<(ABS(TESTDELDIN-DELDI
N(I))/DELDIN(I)) THEN GOTO 3580
4040 '
4050 Y1=QFINAL(I-1)*2446.58
4060 Y2=TPFINAL(I-1)
4070 Y3=QSWTOT(I)*2446.58
4080 Y4=TPSWTOT(I)
4090 Y5=QGW(I)*2446.58
4100 Y6=TPGW(I)
4110 Y7=K2(I)
```

```
4120 Y8=AREA(I)
4130 '
4140 METRIC=5.98571E+06
4150 IF FLOW=20 THEN VARY1(0)=0 ELSE VARY1(0)=966289!*METRIC
4160 VARY3(0)=0
4170 VARY5(0)=0
4180 VARTPFINAL(0)=.6529
4190 VARDIN(0)=25
4200 VARY1(I)=VARY1(I-1)+VARY3(I-1)+VARY5(I-1)
4210 VARX1(I)=VARY1(I)
4220 VARY2(I)=VARTPFINAL(I-1)
4230 VARX2(I)=VARDIN(I-1)
4240 IF I=2 THEN VARY3(I)=16.48*METRIC:VARY4(I)=VARY2(I):VARX4(I)=VARX2(I):GOTO
4290
4250 IF I=12 THEN VARY3(I)=87.61*METRIC:VARY4(I)=458:VARX4(I)=2905:GOTO 4290
4260 VARY3(I)=0
4270 VARY4(I)=0
4280 VARX4(I)=0
4290 VARX3(I)=VARY3(I)
4300 IF I=3 THEN VARY5(I)=2218*METRIC:VARY6(I)=VARY2(I):VARX6(I)=VARX2(I):GOTO 4
430
4310 IF I=4 THEN VARY5(I)=445.2*METRIC:VARY6(I)=VARY2(I):VARX6(I)=VARX2(I):GOTO
4430
4320 IF I=7 THEN VARY5(I)=17689*METRIC:VARY6(I)=2.402:VARX6(I)=93025!:GOTO 4430
4330 IF I=9 THEN VARY5(I)=4225*METRIC:VARY6(I)=VARY2(I):VARX6(I)=VARX2(I):GOTO 4
430
4340 IF I=10 THEN VARY5(I)=24649*METRIC:VARY6(I)=10.82:VARX6(I)=2582:GOTO 4430
4350 IF I=11 THEN VARY5(I)=7056*METRIC:VARY6(I)=VARY2(I):VARX6(I)=VARX2(I):GOTO
4430
4360 IF I=12 THEN VARY5(I)=2421*METRIC:VARY6(I)=19.45:VARX6(I)=490000!:GOTO 4430
4370 IF I=13 THEN VARY5(I)=492.8*METRIC:VARY6(I)=1.44:VARX6(I)=62500!:GOTO 4430
4380 IF I=14 THEN VARY5(I)=610.1*METRIC:VARY6(I)=1.513:VARX6(I)=60025!:GOTO 4430
4390 IF I=15 THEN VARY5(I)=458*METRIC:VARY6(I)=15.21:VARX6(I)=72361!:GOTO 4430
4400 VARY5(I)=0
4410 VARY6(I)=0
4420 VARX6(I)=0
4430 VARX5(I)=VARY5(I)
4440 IF I<3 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 4500
4450 IF I=8 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 4500
4460 IF I=9 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 4500
4470 IF I=11 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 4500
4480 IF I>14 THEN VARY8(I)=(.1*Y8)*(.1*Y8):GOTO 4500
4490 VARY8(I)=(.2*Y8)*(.2*Y8)
4500 VARX7(I)=0
4510 VARX8(I)=VARY8(I)
4520 VARX9(I)=1.69
4530 '
4540 X1=Y1
4550 X2=DINFINAL(I-1)
4560 X3=Y3
4570 X4=DINSWTOT(I)
4580 X5=Y5
4590 X6=DINGW(I)
4600 X7=Y7
4610 X8=Y8
4620 X9=3.9
4630 '
4640 M1=Y1*Y2
4650 M2=Y3*Y4
4660 M3=Y5*Y6
```

```
4670 M4=Y1+Y3+Y5
4680 M5=Y7*Y8
4690 M6=Y1+Y3
4700 '
4710 L1=M1
4720 L2=M2
4730 L3=M3
4740 L4=M4
4750 L5=X7*X8*X9
4760 L6=M6
4770 '
4780 F1=(M1+M2+M3)/M4
4790 F2=M5/M6
4800 F3=(M1+M2)/(M4+M6)
4810 F4=1+(M5/(M4+M6))
4820 '
4830 E1=F1
4840 E2=L5/L6
4850 E3=F3
4860 E4=1+(L5/(L4+L6))
4870 '
4880 DTPDF1=1/F4
4890 DTPDF2=-(F3/F4)
4900 DTPDF3=-(F2/F4)
4910 DTPDF4=((F2*F3)-F1)/(F4*F4)
4920 '
4930 DTPDE1=1/E4
4940 DTPDE2=-(E3/E4)
4950 DTPDE3=-(E2/E4)
4960 DTPDE4=((E2*E3)-E1)/(E4*E4)
4970 '
4980 IF Y5<0 THEN Y5=0
4990 DF1DY1=((Y2*(Y1+Y3+Y5))-(Y1*Y2+Y3*Y4+Y5*Y6))/((Y1+Y3+Y5)*(Y1+Y3+Y5))
5000 DF1DY2=Y1/(Y1+Y3+Y5)
5010 DF1DY3=(((Y1+Y3+Y5)*Y4)-(Y1*Y2+Y3*Y4+Y5*Y6))/((Y1+Y3+Y5)*(Y1+Y3+Y5))
5020 DF1DY4=Y3/(Y1+Y3+Y5)
5030 DF1DY5=(((Y1+Y3+Y5)*Y6)-(Y1*Y2+Y3*Y4+Y5*Y6))/((Y1+Y3+Y5)*(Y1+Y3+Y5))
5040 IF Y5=0 THEN DF1DY5=0
5050 DF1DY6=Y5/(Y1+Y3+Y5)
5060 DF1DY7=0
5070 DF1DY8=0
5080 Y5=X5
5090 DF2DY1=-(Y7*Y8)/((Y1+Y3)*(Y1+Y3))
5100 DF2DY2=0
5110 DF2DY3=DF2DY1
5120 DF2DY4=0
5130 DF2DY5=0
5140 DF2DY6=0
5150 DF2DY7=Y8/(Y1+Y3)
5160 DF2DY8=Y7/(Y1+Y3)
5170 DF3DY1=(((2*Y1+2*Y3+Y5)*Y2)-(2*(Y1*Y2+Y3*Y4)))/((2*Y1+2*Y3+Y5)*(2*Y1+2*Y3+Y
5))
5180 DF3DY2=Y1/(2*Y1+2*Y3+Y5)
5190 DF3DY3=(((2*Y1+2*Y3+Y5)*Y4)-(2*(Y1*Y2+Y3*Y4)))/((2*Y1+2*Y3+Y5)*(2*Y1+2*Y3+Y
5))
5200 DF3DY4=((2*Y1+2*Y3+Y5)*Y3)/((2*Y1+2*Y3+Y5)*(2*Y1+2*Y3+Y5))
5210 DF3DY5=-(Y1*Y2+Y3*Y4)/((2*Y1+2*Y3+Y5)*(2*Y1+2*Y3+Y5))
5220 DF3DY6=0
5230 DF3DY7=0
5240 DF3DY8=0
```

```
5250 D=2*Y1+2*Y3+Y5
5260 DF4DY1=(2*D-(2*(2*Y1+2*Y3+Y5+Y7*Y8)))/(D*D)
5270 DF4DY2=0
5280 DF4DY3=DF4DY1
5290 DF4DY4=0
5300 DF4DY5=(D-(2*Y1+2*Y3+Y5+Y7*Y8))/(D*D)
5310 DF4DY6=0
5320 DF4DY7=Y8/D
5330 DF4DY8=Y7/D
5340 '
5350 IF X5<0 THEN X5=0
5360 DE1DX1=DF1DY1
5370 DE1DX2=DF1DY2
5380 DE1DX3=DF1DY3
5390 DE1DX4=DF1DY4
5400 DE1DX5=DF1DY5
5410 DE1DX6=DF1DY6
5420 DE1DX7=DF1DY7
5430 DE1DX8=DF1DY8
5440 DE1DX9=0
5450 X5=Y5
5460 DE2DX1=-(X7*X8*X9)/((X1+X3)*(X1+X3))
5470 DE2DX2=0
5480 DE2DX3=DE2DX1
5490 DE2DX4=0
5500 DE2DX5=0
5510 DE2DX6=0
5520 DE2DX7=(X8*X9)/(X1+X3)
5530 DE2DX8=(X7*X9)/(X1+X3)
5540 DE2DX9=(X7*X8)/(X1+X3)
5550 DE3DX1=DF3DY1
5560 DE3DX2=DF3DY2
5570 DE3DX3=DF3DY3
5580 DE3DX4=DF3DY4
5590 DE3DX5=DF3DY5
5600 DE3DX6=DF3DY6
5610 DE3DX7=DF3DY7
5620 DE3DX8=DF3DY8
5630 DE3DX9=0
5640 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))
5650 DE4DX2=0
5660 DE4DX3=DE4DX1
5670 DE4DX4=0
5680 DE4DX5=(2*X1+2*X3+X5-(2*X1+2*X3+X5+X7*X8*X9))/((2*X1+2*X3+X5)*(2*X1+2*X3+X5
))
5690 DE4DX6=0
5700 DE4DX7=(X8*X9)/(2*X1+2*X3+X5)
5710 DE4DX8=(X7*X9)/(2*X1+2*X3+X5)
5720 DE4DX9=(X7*X8)/(2*X1+2*X3+X5)
5730 '
5740 DTPDY1=DTPDF1*DF1DY1+DTPDF2*DF2DY1+DTPDF3*DF3DY1+DTPDF4*DF4DY1
5750 DTPDY2=DTPDF1*DF1DY2+DTPDF2*DF2DY2+DTPDF3*DF3DY2+DTPDF4*DF4DY2
5760 DTPDY3=DTPDF1*DF1DY3+DTPDF2*DF2DY3+DTPDF3*DF3DY3+DTPDF4*DF4DY3
5770 DTPDY4=DTPDF1*DF1DY4+DTPDF2*DF2DY4+DTPDF3*DF3DY4+DTPDF4*DF4DY4
5780 DTPDY5=DTPDF1*DF1DY5+DTPDF2*DF2DY5+DTPDF3*DF3DY5+DTPDF4*DF4DY5
5790 DTPDY6=DTPDF1*DF1DY6+DTPDF2*DF2DY6+DTPDF3*DF3DY6+DTPDF4*DF4DY6
5800 DTPDY7=DTPDF1*DF1DY7+DTPDF2*DF2DY7+DTPDF3*DF3DY7+DTPDF4*DF4DY7
5810 DTPDY8=DTPDF1*DF1DY8+DTPDF2*DF2DY8+DTPDF3*DF3DY8+DTPDF4*DF4DY8
5820 '
```

```
5830 DTPDX1=DTPDE1*DE1DX1+DTPDE2*DE2DX1+DTPDE3*DE3DX1+DTPDE4*DE4DX1
5840 DTPDX2=DTPDE1*DE1DX2+DTPDE2*DE2DX2+DTPDE3*DE3DX2+DTPDE4*DE4DX2
5850 DTPDX3=DTPDE1*DE1DX3+DTPDE2*DE2DX3+DTPDE3*DE3DX3+DTPDE4*DE4DX3
5860 DTPDX4=DTPDE1*DE1DX4+DTPDE2*DE2DX4+DTPDE3*DE3DX4+DTPDE4*DE4DX4
5870 DTPDX5=DTPDE1*DE1DX5+DTPDE2*DE2DX5+DTPDE3*DE3DX5+DTPDE4*DE4DX5
5880 DTPDX6=DTPDE1*DE1DX6+DTPDE2*DE2DX6+DTPDE3*DE3DX6+DTPDE4*DE4DX6
5890 DTPDX7=DTPDE1*DE1DX7+DTPDE2*DE2DX7+DTPDE3*DE3DX7+DTPDE4*DE4DX7
5900 DTPDX8=DTPDE1*DE1DX8+DTPDE2*DE2DX8+DTPDE3*DE3DX8+DTPDE4*DE4DX8
5910 DTPDX9=DTPDE1*DE1DX9+DTPDE2*DE2DX9+DTPDE3*DE3DX9+DTPDE4*DE4DX9
5920 '
5930 VARDIN(I)=(DTPDX1*DTPDX1*VARX1(I))+(DTPDX2*DTPDX2*VARX2(I))+(DTPDX3*DTPDX3*
VARX3(I))+(DTPDX4*DTPDX4*VARX4(I))+(DTPDX5*DTPDX5*VARX5(I))+(DTPDX6*DTPDX6*VARX6
(I))+(DTPDX7*DTPDX7*VARX7(I))+(DTPDX8*DTPDX8*VARX8(I))+(DTPDX9*DTPDX9*VARX9(I))
5940 '
5950 '
5960 'ESTIMATE VARIANCE OF K2(I)
5970 '
5980 VARY7(I)=((.425^2)*(K2(I)^2))+((((K2MAX(I)*29)/((DINAVG(I)+29)^2))^2)*VARDI
N(I))
5990 VARY7(10)=0
6000 IF I>13 THEN IF Q$="Y" THEN VARY7(I)=.0137
6010 '
6020 'ESTIMATE VARIANCE OF TPFINAL(I)
6030 '
6040 VARTPFINAL(I)=(DTPDY1*DTPDY1*VARY1(I))+(DTPDY2*DTPDY2*VARY2(I))+(DTPDY3*DTP
DY3*VARY3(I))+(DTPDY4*DTPDY4*VARY4(I))+(DTPDY5*DTPDY5*VARY5(I))+(DTPDY6*DTPDY6*V
ARY6(I))+(DTPDY7*DTPDY7*VARY7(I))+(DTPDY8*DTPDY8*VARY8(I))
6050 '
6060 '
6070 '
6080 '
6090 NEXT I
6100 '
6110 '
6120 FOR I=1 TO 25
6130 PRINT
6140 NEXT I
6150 '
6160 'LONG LAKE INFLUENT CALCULATIONS
6170 '
6180 I=17
6190 RM(I)=56.3
6200 QFINAL(I)=QFINAL(I-1)+440
6210 TPFINAL(I)=(QFINAL(I-1)*TPFINAL(I-1)+440*32.4)/QFINAL(I)
6220 TPVAR(1)=(TPFINAL(I-1)*QFINAL(I)-TPFINAL(I-1)*QFINAL(I-1)-32.4*440)/(QFINAL
(I)*QFINAL(I))
6230 TPVAR(2)=QFINAL(I-1)/QFINAL(I)
6240 TPVAR(3)=(32.4*QFINAL(I)-TPFINAL(I-1)*QFINAL(I-1)-32.4*440)/(QFINAL(I)*QFIN
AL(I))
6250 TPVAR(4)=440/QFINAL(I)
6260 VARTPFINAL(I)=TPVAR(1)*TPVAR(1)*VARY1(I-1)/METRIC+TPVAR(2)*TPVAR(2)*VARTPFI
NAL(I-1)+TPVAR(3)*TPVAR(3)*1673+TPVAR(4)*TPVAR(4)*20.52
6270 PRINT "RM","Q (cfs)","TP (ug P /l)","TPDEV (ug/l)"
6280 PRINT "--------","--------","--------","--------"
6290 FOR I=0 TO 17
6300 DEVTPFINAL(I)=(VARTPFINAL(I)^.5)
6310 TPFLUX=QFINAL(I)*TPFINAL(I)*2.4466E-03
6320 LBTPFLUX=TPFLUX*2.205
6330 PRINT RM(I),QFINAL(I),TPFINAL(I),DEVTPFINAL(I)
6340 NEXT I
```

```
6350 PRINT
6360 PRINT
6370 PRINT "PRESS RETURN TO EVALUATE LONG LAKE CHARACTERISTICS"
6380 INPUT NOTHING
6390 TOTSWTPLOAD=0
6400 TOTGWTPLOAD=0
6410 FOR I=1 TO 16
6420 TOTSWTPLOAD=TOTSWTPLOAD+SWTPLOAD(I)
6430 IF QGW(I)<0 THEN GOTO 6450 ELSE GOTO 6440
6440 TOTGWTPLOAD=TOTGWTPLOAD+(QGW(I)*TPGW(I))
6450 NEXT I
6460 POINTSOURCE=(TOTSWTPLOAD-(QSW(12,1)*TPSW(12,1)))*2.4466E-03
6470 TOTLOAD=(TOTSWTPLOAD+TOTGWTPLOAD+(QFINAL(0)*TPFINAL(0))+440*32.4)*2.4466E-0
3
6480 NMLOAD=QFINAL(16)*TPFINAL(16)*2.4466E-03
6490 LLLOAD=NMLOAD+440*32.4*2.4466E-03
6500 LBLLLOAD=LLLOAD*2.205
6510 LBPOINTSOURCE=POINTSOURCE*2.205
6520 LBTOTLOAD=TOTLOAD*2.205
6530 LBNMLOAD=NMLOAD*2.205
6540 FOR K=1 TO 25
6550 PRINT
6560 NEXT K
6570 PRINT "PHOSPHORUS LOADING:"
6580 PRINT
6590 PRINT " ","KILOGRAMS/DAY","POUNDS/DAY"
6600 PRINT " ","-------------","----------"
6610 PRINT "Total TP Load =",TOTLOAD,LBTOTLOAD
6620 PRINT "Point Sources =",POINTSOURCE,LBPOINTSOURCE
6630 PRINT "Nine Mile Dam =",NMLOAD,LBNMLOAD
6640 PRINT "Long Lk.Input =",LLLOAD,LBLLLOAD
6650 PRINT
6660 PRINT
6670 PRINT "LONG LAKE INFLUENT CONCENTRATION:"
6680 PRINT
6690 PRINT "MEDIAN =";TPFINAL(17);"ugP/l"
6700 PRINT "UPPER 10% =";TPFINAL(17)+1.282*(VARTPFINAL(17))^.5;"ugP/l"
6710 PRINT "UPPER 5% =";TPFINAL(17)+1.645*(VARTPFINAL(17))^.5;"ugP/l"
6720 PRINT
6730 PRINT "Based on Soltero's 1981 & 1982 data, the average epilimnetic concent
ration in   Long Lake is equivalent (within roughly 7%) to the influent concentr
ations      presented above."
6740 PRINT
6750 PRINT "Eutrophic conditions are indicated when the total phosphorus concent
ration      exceeds 20 ug/l."
6760 PRINT
6770 PRINT "PRESS RETURN TO EVALUATE LONG LAKE BIOLOGICAL CONDITIONS"
6780 INPUT NOTHING
6790 FOR K=1 TO 25
6800 PRINT
6810 NEXT K
6820 PRINT "LONG LAKE CHLOROPHYLL A (including Q/A corrections) AND PHYTOPLANKTO
N BIOVOLUME:"
6830 PRINT
6840 CHLMEDIAN=36.62*TPFINAL(17)/(43.6+TPFINAL(17))
6850 VARTPSOLTERO=(VARTPFINAL(17)+.001714*TPFINAL(17))
6860 VARCHLTP=((36.62*43.6/((43.6+TPFINAL(17))^2))^2)*VARTPSOLTERO
6870 TOTVARCHL=VARCHLTP+((.0996*CHLMEDIAN)^2)+((.237*CHLMEDIAN)^2)
6880 PERCENTSOLTERO%=100*((.237*CHLMEDIAN)^2)/TOTVARCHL
6890 BIOMEDIAN=40.98*TPFINAL(17)/(344.7+TPFINAL(17))
```

```
6900 TOTVARBIO=((40.98*344.7/((344.7+TPFINAL(17))^2))^2)*VARTPSOLTERO+((.1587*BI
OMEDIAN)^2)
6910 PRINT
6920 PRINT " ","CHLORO. A","PHYTOPLANKTON"
6930 PRINT " ","(ug/l)","(mm3/l)"
6940 PRINT
6950 PRINT "MEDIAN ",CHLMEDIAN,BIOMEDIAN
6960 PRINT "UPPER 10% ",CHLMEDIAN+1.282*(TOTVARCHL^.5),BIOMEDIAN+1.282*(TOTVARBI
O^.5)
6970 PRINT "UPPER 5% ",CHLMEDIAN+1.645*(TOTVARCHL^.5),BIOMEDIAN+1.645*(TOTVARBIO
^.5)
6980 PRINT
6990 PRINT "Eutrophic"
7000 PRINT " criteria:","> 10 ug/l","> 3-5 mm3/l"
7010 PRINT
7020 PRINT "Uncertainties in the historical chlorophyll a data account for an es
timated";PERCENTSOLTERO%;"%of the total variance in the predicted chlorophyll a
concentration."
7030 PRINT
7040 PRINT
7050 PRINT "Thats all there is - it's certainly been a pleasure!"
7060 END
```

APPENDIX C

Velocity and Dispersion Characteristics of the Spokane River

Dye Study Results

The velocity and dispersion characteristics of the Spokane River between Post Falls Dam and Nine Mile Dam (RM 101.7 to RM 58.1) are depicted in the time-concentration curves measured during the present study at specific downstream locations (Figures C-1, C-2, and C-3). As expected, the process of dispersion in the river resulted in progressively more dissipated profiles of concentration versus time as distance from the point of injection increased. The centroid and variance of the measured time-concentration curves were used to estimate velocity and dispersion rates in the river.

A total of four dye studies within the study area, encompassing a broad range of flows, have been conducted by various investigators. The four surveys include two conducted by the USGS at intermediate and high flow during 1968, and one conducted by the WDOE during 1980 during low flow conditions. The present and most recent survey by Harper-Owes was conducted during low flow conditions in 1984. Raw data from the three previous studies were provided by the WDOE for the present analysis (L. Singleton, personal communication).

The average reach velocities and dispersion coefficients were determined for each of the four surveys by the area-moment method (Fischer, 1968; Hubbard et al., 1982). The resulting velocity and dispersion estimates for the originally sampled reaches are presented in Tables C-1, C-2, and C-3 for the four dye studies.

Although the four dye studies were each conducted within nearly the same study area boundaries, the sampling locations for evaluating time-concentration dye relationships were not consistent. Each of the three investigators (USGS, WDOE, and Harper-Owes) divided the study area into different segments or reaches. In order to develop relationships betweeen velocity and discharge for specific reaches within the study area, the USGS and WDOE results were evaluated (if possible) for the reach boundaries defined during the Harper-Owes study. In general, Harper-Owes reach boundaries were based on functional divisions of the river into riffle and pool segments as described in the Methods chapter. The original USGS and WDOE reach segments frequently contained both riffle and pool areas; therefore adjustments were accomplished by assuming that the riffle portion of a composite (riffle and pool) reach could be represented by the velocity of the adjacent riffle reach. Consequently, adjustments of composite USGS and WDOE results to Harper-Owes reaches were only possible if the original (USGS or WDOE) composite reaches contained riffle areas adjacent to non-composite riffle reaches. For example, the three original USGS reaches for the lower Spokane River extended from RM 72.9 to 66.2, 66.2 to 61.9, and 61.9 to 58.1, and the adjusted pool reach desired for comparison with the Harper-Owes study extended from RM 64.5 to 58.1. The USGS results were adjusted algebraically by assuming the velocity from RM 66.2 to 64.5 was equal to that from RM 72.9 to 66.2 (adjacent riffle areas). The resulting estimates of velocities (within Harper-Owes defined reaches) are presented in Table C-4.

The reference discharges for velocity estimates (Table C-4) represent the "best-estimate" of actual discharge within each reach based on existing

FIGURE C-1

Dye Concentration Versus Time Following Injection at
Post Falls Dam (RM 101.7) at 16:18, August 30, 1984
The dashed line indicates extrapolated trailing edge concentration.

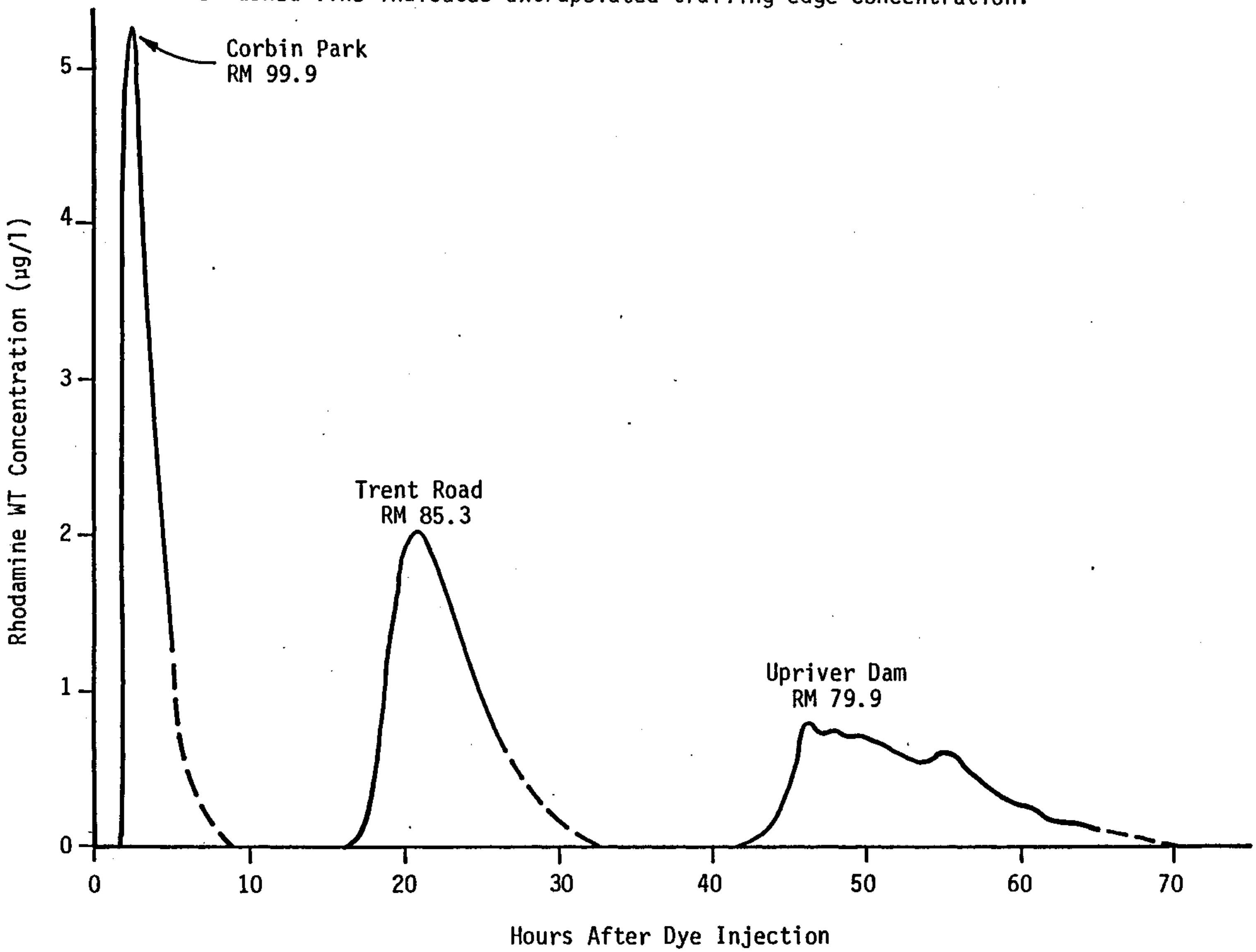


FIGURE C-2

Dye Concentration Versus Time Following Injection at Upriver Dam (RM 79.8) at 07:41, August 27, 1984
The dashed line indicates extrapolated trailing edge concentration.

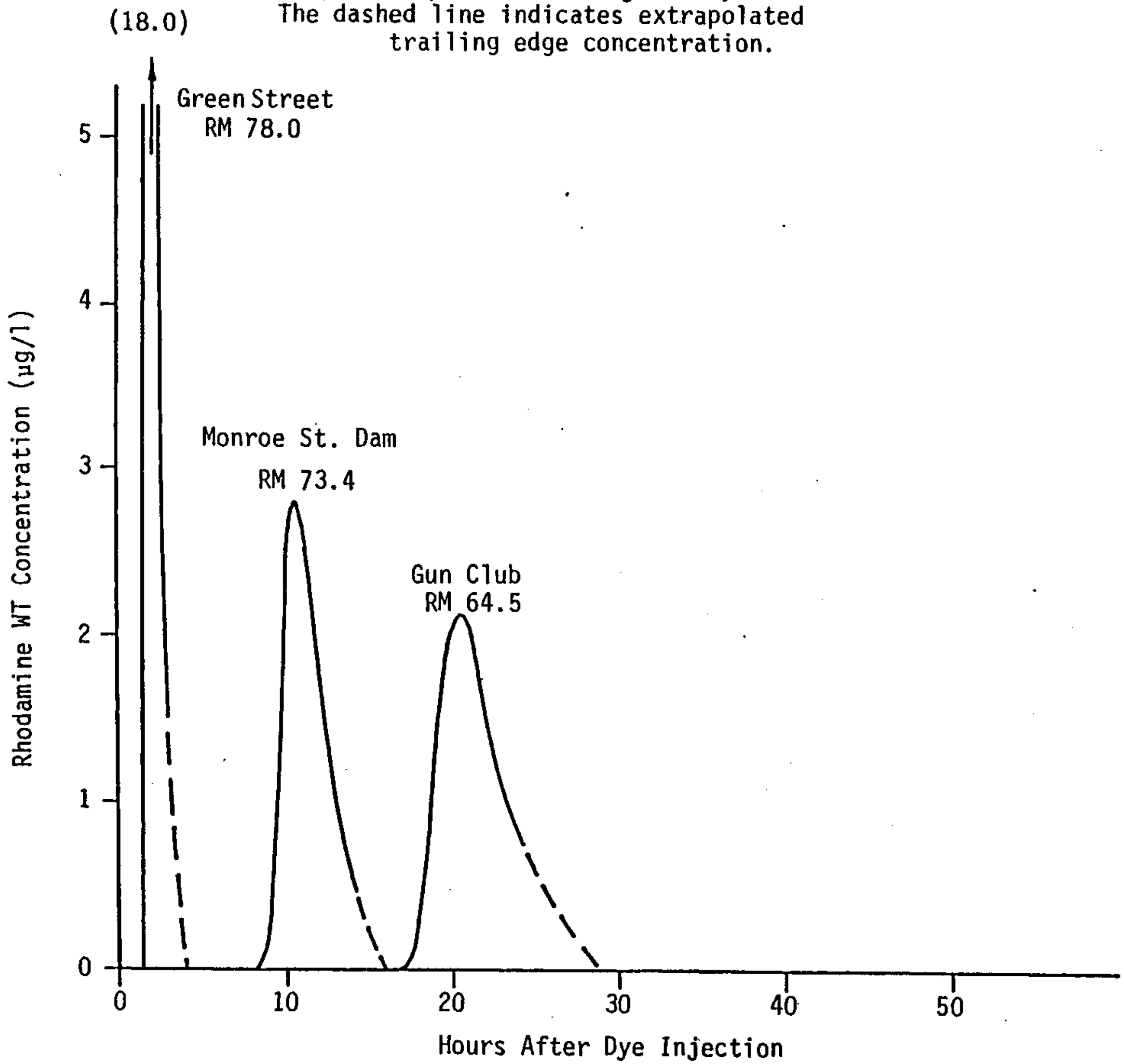


FIGURE C-3

Dye Concentration Versus Time Following Injection at the Spokane WTP at 16:00, September 7, 1984
The dashed line represents extrapolated trailing edge concentration.

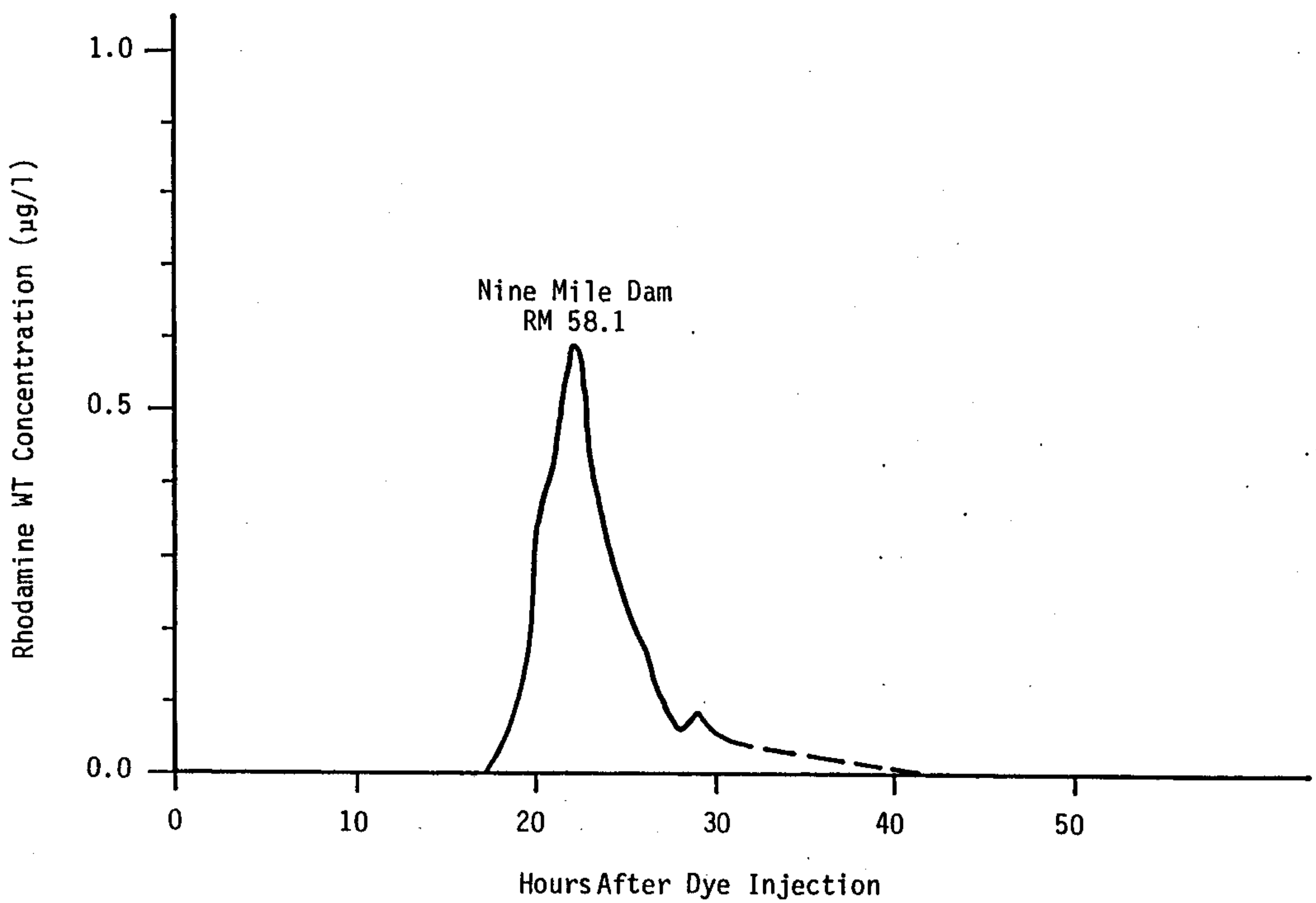


TABLE C-1

Average Reach Velocity and Dispersion Determined from Harper-Owes and WDOE Dye Studies Based on the Area-Moment Method

SOURCE	NODE 1 (RM)	NODE 2 (RM)	VELOCITY (ft/sec)	DISPERSION (ft2/sec)
Harper-Owes (this study)	Post Falls Dam (101.7) 8-30-84	Corbin Park (99.9) 8-30-84	0.793	322
	Corbin Park (99.9) 8-30-84	Trent Road (85.3) 8-31-84	1.11	879
	Trent Road (85.3) 8-31-84	Upriver Dam (79.8) 9-1,2-84	0.264	100
	Upriver Dam (79.8) 8-27-84	Green St. (18.0) 8-27-84	1.23	202
	Green St. (78.0) 8-27-84	Monroe St. (73.4) 8-27-84	0.741	183
	Monroe St. (73.4) 8-27-84	Gun Club (64.5) 8-28-84	1.26	854
	Spokane WTP (67.4) 9-7-84	Nine Mile Dam (58.1) 9-8-84	0.572	383
W.D.O.E., 1980	Stateline (96.0) 10-9-80	Sullivan Rd. (87.1) 10-9-80	1.74	698
	Sullivan Rd. (87.1) 10-8-80	Upriver Dam (79.8) 10-9-80	0.530	121
	Upriver Dam (79.8) 9-24-80	Fort Wright Br. (69.8) 9-25-80	1.39	131
	Fort Wright Br. (69.8) 9-23-80	Nine Mile Dam (58.1) 9-24-80	0.734	213

TABLE C-2

Average Reach Velocity and Dispersion Determined from USGS Dye Study Data Based on the Area-Moment Method

SOURCE	NODE 1 (RM)	NODE 2 (RM)	VELOCITY (ft/sec)	DISPERSION (ft2/sec)
U.S.G.S., 1968 (April 24-25, 1968)	Stateline Br. (96.0) 4-24-68	Barker Rd. (90.4) 4-24-68	3.73	977
	Barker Rd. (90.4) 4-24-68	Trent Rd. (85.3) 4-24-68	4.32	1767
	Trent Rd. (85.3) 4-24-68	Argonne Rd. (82.6) 4-24-68	2.83	952
	Argonne Rd. (82.6) 4-24-68	Green St. (78.0) 4-24-68	1.50	693
	Green St. (78.0) 4-24-68	Division St. (74.9) 4-24-68	2.53	96
	Division St. (74.9) 4-24-68	Spokane Gage (72.9) 4-24-68	3.45	4554
	Spokane Gage (72.9) 4-24-68	Bowl and Pitcher (66.2) 4-24-68	3.71	1510
	Bowl and Pitcher (66.2) 4-24-68	Seven Mile Br. (61.9) 4-24-68	3.80	543
	Seven Mile Br. (61.9) 4-24-68	Nine Mile Dam (58.1) 4-25-68	0.992	737
	Bowl and Pitcher (66.2) 4-25-68	Nine Mile Dam (58.1) 4-25-68	1.63	1563

TABLE C-3

Average Reach Velocity and Dispersion Determined from USGS Dye Study Data Based on the Area-Moment Method

SOURCE	NODE 1 (RM)	NODE 2 (RM)	VELOCITY (ft/sec)	DISPERSION (ft2/sec)
U.S.G.S., 1968 (Jan 23-24, 1968)	Stateline Br. (96.0) 1-23-68	Barker Rd. (90.4) 1-23-68	2.67	558
	Barker Rd. (90.4) 1-23-68	Trent Rd. (85.3) 1-23-68	2.81	1405
	Trent Rd. (85.3) 1-23-68	Argonne Rd. (82.6) 1-24-68	1.64	823
	Argonne Rd. (82.6) 1-24-68	Division St. (74.9) 1-24-68	1.08	231
	Division St. (74.9) 1-24-68	Spokane Gage (72.9) 1-24-68	2.11	4104
	Spokane Gage (72.9) 1-24-68	Bowl and Pitcher (66.2) 1-24-68	2.73	1291
	Bowl and Pitcher (66.2) 1-24-68	Seven Mile Br. (61.9) 1-24-68	2.29	1007
	Seven Mile Br. (61.9) 1-24-68	Nine Mile Dam (58.1) 1-24-68	0.589	373
	Bowl and Pitcher (66.2) 1-24-68	Nine Mile Dam (58.1) 1-24-68	0.972	828

TABLE C-4

Estimated Average Reach Velocities and Discharges for Adjusted Reaches

NODE 1 (RM)	NODE 2 (RM)	HARPER - OWES velocity (ft/sec)	HARPER - OWES discharge (cfs)	W. D. O. E. velocity (ft/sec)	W. D. O. E. discharge (cfs)	U. S. G. S. velocity (ft/sec)	U. S. G. S. discharge (cfs)	U. S. G. S. velocity (ft/sec)	U. S. G. S. discharge (cfs)
Post Falls Dam (101.7)	Trent Rd. (85.3)	1.06	878	1.74	1720	2.67, 2.81	3710, 3892	3.73, 4.32	6790, 6866
Trent Rd. (85.3)	Upriver Dam (79.8)	0.264	1195	0.430	1836	0.791	3936	1.53	6838
Upriver Dam (79.8)	Green St. Br. (78.0)	1.23	1313	N/C	N/C	2.7	3969	3.9	6980
Green St. Br. (78.0)	Post St. (74.1)	0.741	1466	N/C	N/C	2.26	4019	2.62	7189
Post St. (74.1)	Gun Club (64.5)	1.26	1670	N/C	N/C	2.73	4472	3.71	7249
Gun Club (64.5)	Nine Mile Dam (58.1)	0.442	2387	0.512	2327	0.830	4505	1.42	7282

information. Reach discharge estimates for each velocity estimate were obtained in order to develop a discharge/velocity relationship by regression analysis (Figures C-4, C-5, and C-6). Reach discharge was considered more appropriate than reference discharge at a remote location, especially at low flow, because of the importance of ground water infiltration. The relationship between velocity and discharge was found to be best represented by a power curve fit:

$$U = aQ^b \qquad \text{(eqn C-1)}$$

where:

- U = average reach velocity (ft/sec)
- Q = average reach discharge (cfs)
- a = power curve constant (by regression)
- b = power curve exponent (by regression).

The importance of evaluating reach discharge for equation C-1 can be explained by the fact that the power curve regression forces the relationship through the origin. Therefore use of a remote reference location upstream of significant ground water inflows would lead to inaccurate results, especially at low flow, since velocity within a reach would not (necessarily) approach zero as remote discharge approaches zero.

Discharge estimates for specific reaches were based on gaged surface water inflow (Table C-5) as well as observed (in the case of the Harper-Owes study) or estimated (for USGS and WDOE studies) groundwater infiltration and exfiltration. Ground water evaluations were based on the present study, as described in previous sections of this report. The importance of ground water becomes insignificant as discharge increases and surface water inflow becomes dominant. Therefore, the present analysis is not particularly sensitive to potential inaccuracies in estimating ground water discharges for the intermediate and high flow dye studies. The ground water discharge estimates are considered to be most accurate for the low flow condition, especially since the estimates for the present study are based on gaged measurements. Estimated reach discharge for the USGS and WDOE study conditions were interpolated between active gaging stations based on the seepage measurements from the present study.

Velocity Estimates Based on Morphometry

Both the upstream and downstream segments of the Spokane River study area are characterized as large pools. The river reach between Lake Coeur d'Alene and Post Falls Dam (RM 111.7 to 101.7) and from the Spokane AWT to Nine Mile Dam contain large impoundments of water behind their respective dams. The largest single pool of the study area lies between Lake Coeur d'Alene and Post Falls Dam. The relationship between velocity and discharge for the pool between Lake Coeur d'ALene and Post Falls Dam was estimated based upon measurements of river cross-sectional area along this reach (Table C-6). A relationship between impoundment volume and lake stage was developed by assuming that changes in channel area which accompany stage changes would result in negligible changes in volume.

FIGURE C-4

Velocity Versus Discharge for the Spokane River Between Post Falls Dam (RM 101.7) and Upriver Dam (RM 79.8)

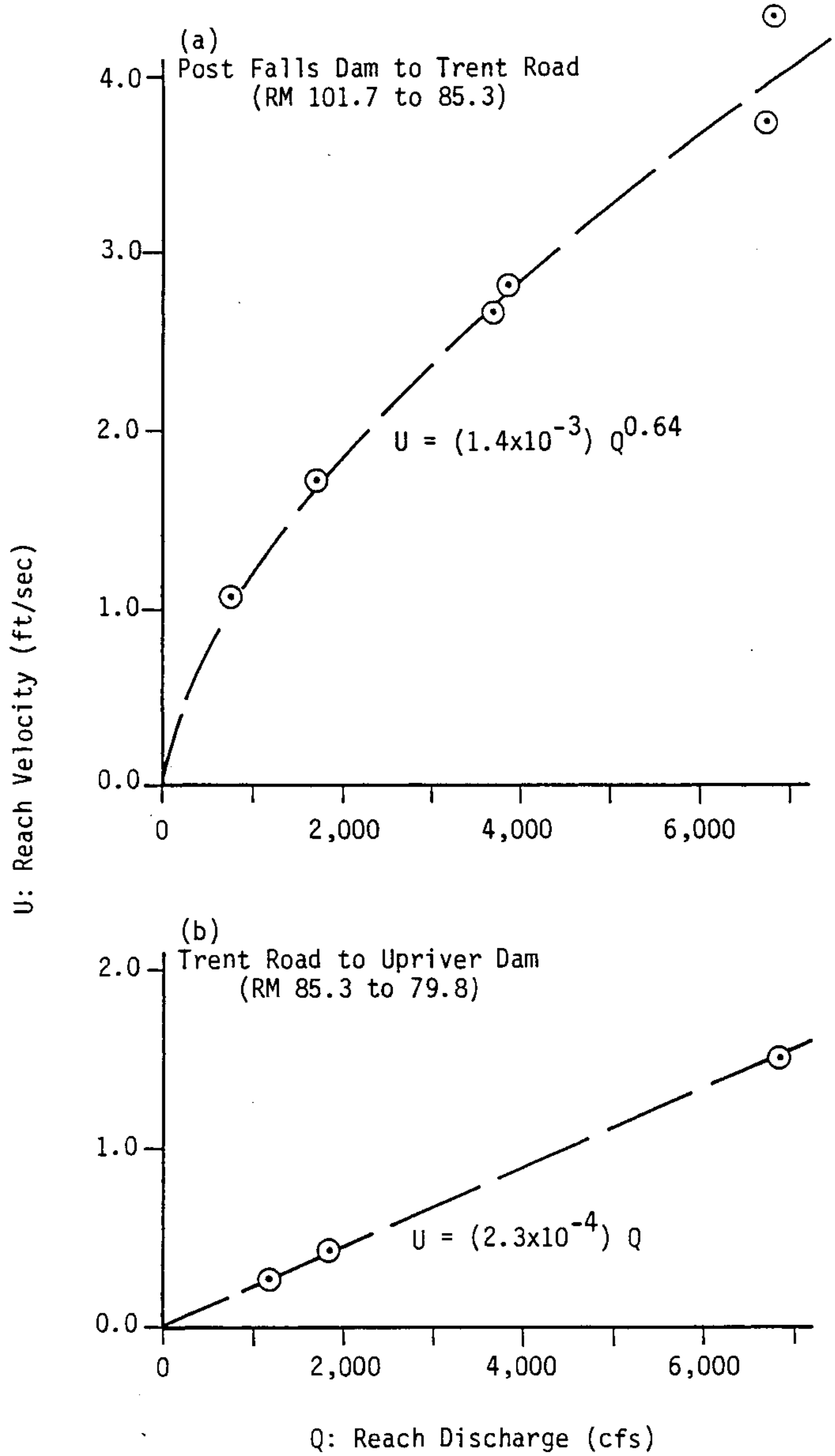


FIGURE C-5

Velocity Versus Discharge for the Spokane River Between Upriver Dam (RM 79.8) and Post Street (RM 74.1)

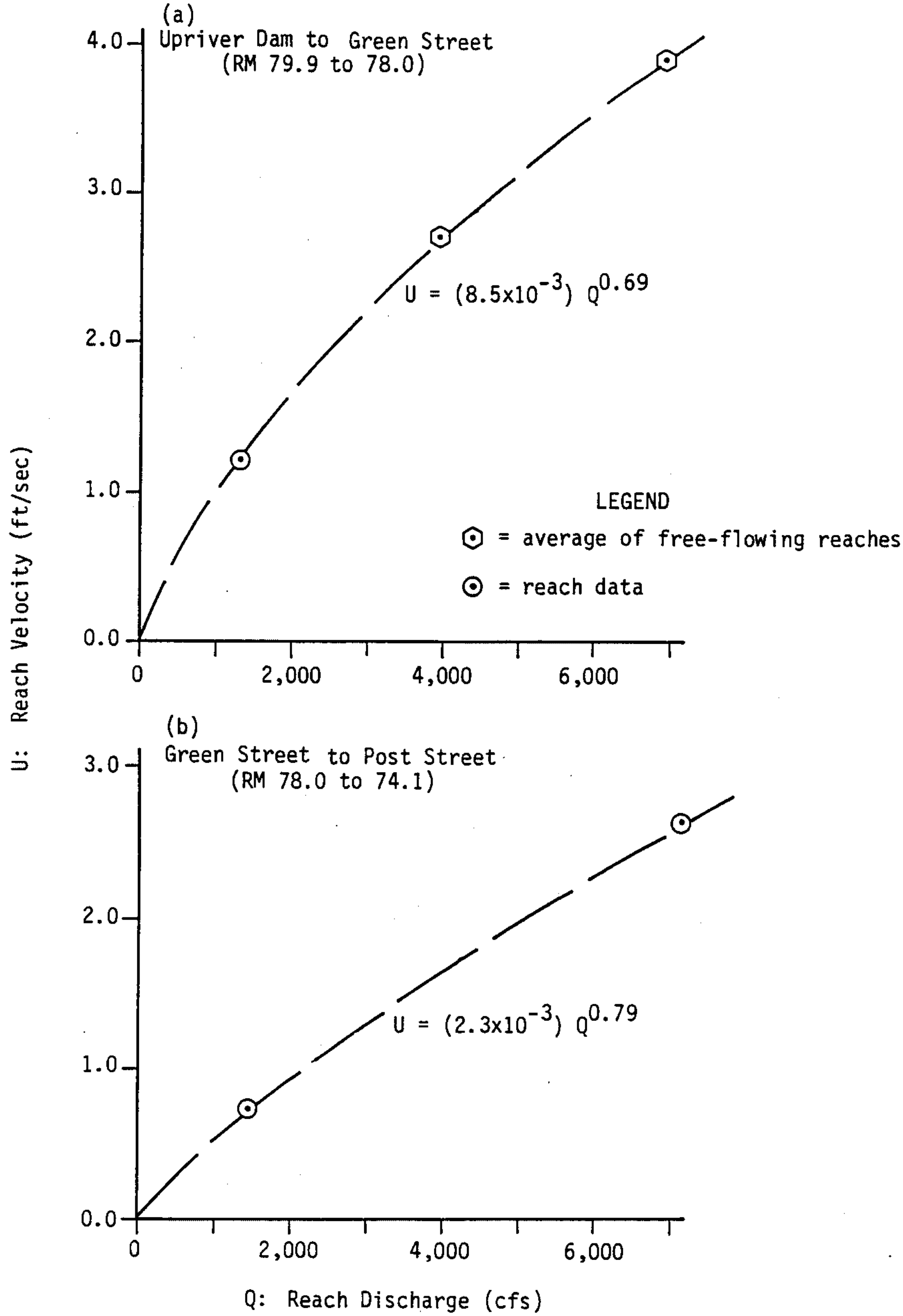


FIGURE C-6

Velocity Versus Discharge for the Spokane River Between
Post Street (RM 74.1) and Nine Mile Dam (RM 58.1)

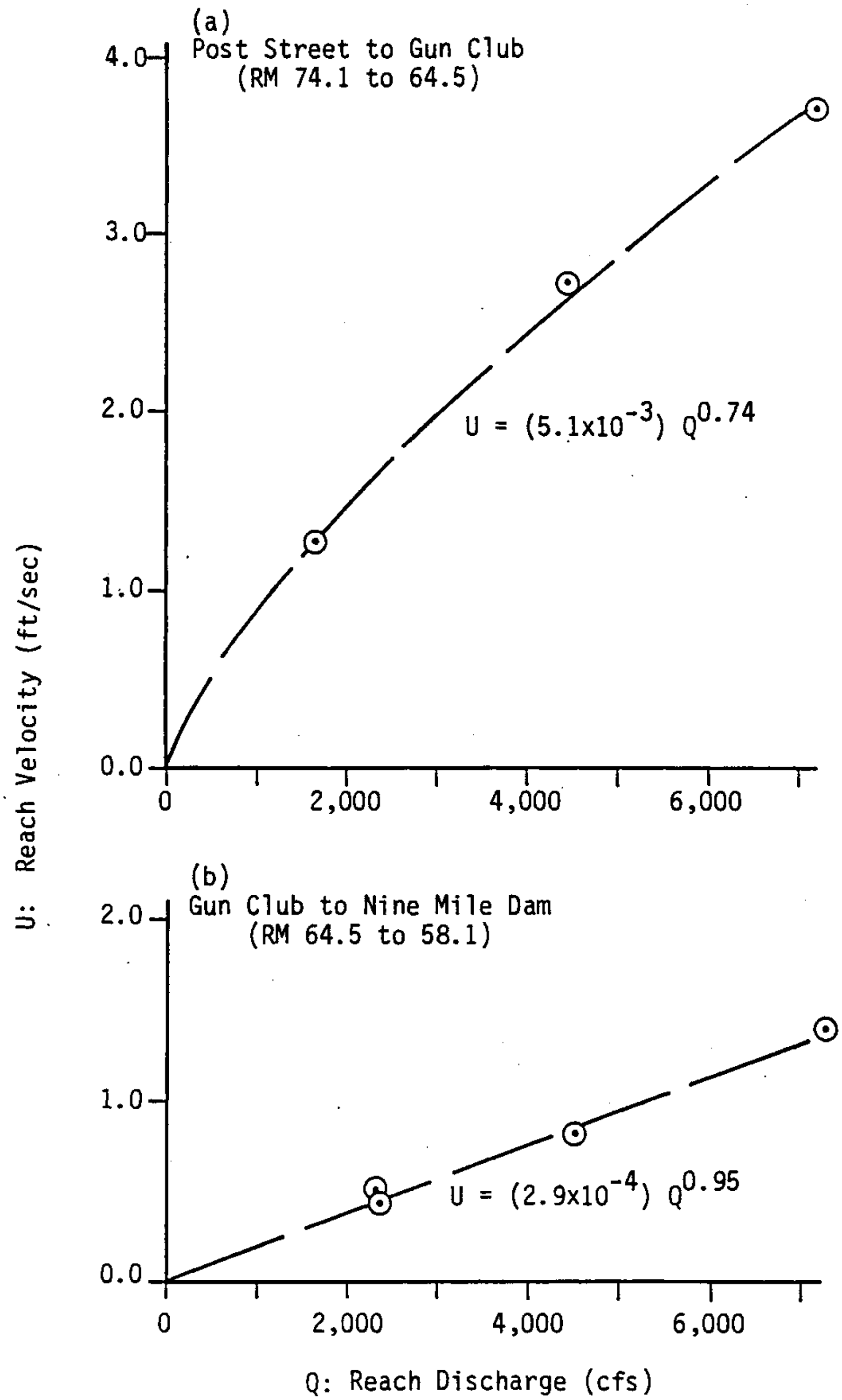


TABLE C-5

Average Daily Discharge Measurements (cfs) at Gaging Stations on Days During the Four Dye Studies

DATE	POST FALLS	OTIS ORCHARD	TRENT RD.	UPRIVER DAM	GREEN ST.	MONROE ST.	SPOKANE GAGE	HANGMAN CR.	SPOKANE WTP
January 23, 1968	3770	3710					3800	322	40
January 24, 1968	4130	4040					4240	236	
January 25, 1968	4170	4070					4260	194	
April 24, 1968	7140	6790					7420	48	
April 25, 1968	6640	6370					6970	46	
September 23, 1980	1760	1700					2010	8.2	
September 24, 1980	1750	1700					1970	7.8	
September 25, 1980	1760	1700					1960	7.1	
October 7, 1980	1780	1720					1990	6.8	50
October 8, 1980	1780	1720					1990	6.8	
October 9, 1980	1780	1720					2000	6.5	
August 27, 1984	1040			1075	1550	1382	1520	24	54.1
August 28, 1984	1040						1530	24	54.1
August 30, 1984	1050	824-1276					1490	23	
August 31, 1984	936	915	1209				1480	24	
September 1, 1984	1040		1334	1094			1530	25	
September 2, 1984	1050		1334	1100			1520	25	
September 7, 1984	1730						2130	25	54
September 8, 1984	1730						2130	26	54

TABLE C-6

Summary of Cross-Sectional Area Measurements, Reach Volume, and Area Estimations for Lake Couer D'Alene to Post Falls Dam

RIVER MILE (mile)	SOURCE	SURVEY DATE	STAGE (ft)	WIDTH (m)	MEASURED CROSS-SECTION AREA TO STAGE (m2)	ESTIMATED CROSS-SECTION AREA TO STAGE = 27.72 ft (m2)	REACH AREA (m)	REACH PLAN AREA (thousand m2)	REACH VOLUME (thousand m3)
111.0	EPA, 1980	12- 5-78	23.56	182	306	538	1609	294	866
110.4	EPA, 1980	12- 5-78	23.56	198	299	550	563	111	310
110.4	USGS, 1981	6- 9-80	28.04	222	643	622	563	125	350
109.6	USGS, 1981	8-25-80	27.75	155	574	572	1287	200	737
108.8	USGS, 1981	8-25-80	27.75	156	595	594	804	126	477
108.6	EPA, 1980	12- 5-78	23.56	148	326	515	724	107	372
107.9	EPA, 1980	12- 5-78	23.56	198	408	659	1046	207	690
107.3	USGS, 1981	8-26-80	27.75	222	766	764	1046	232	799
106.6	EPA, 1980	12- 5-78	23.56	148	435	623	885	131	552
106.2	USGS, 1981	8-26-80	27.75	197	834	832	885	175	736
105.5	EPA, 1980	12- 5-78	23.56	148	462	651	804	119	523
105.2	USGS, 1981	8-27-80	27.72	128	643	643	885	113	569
104.4	EPA, 1980	12- 5-78	23.56	198	688	939	1287	255	1209
103.6	EPA, 1980	12- 5-78	23.56	243	891	1200	724	176	869
103.5	USGS, 1981	8-27-80	27.72	139	956	956	241	33	230
103.3	EPA, 1980	12- 5-78	23.56	248	907	1221	563	139	688
102.8	EPA, 1980	12- 5-78	23.56	198	843	1095	563	111	616
102.6	USGS, 1981	8-28-80	27.68	244	1579	1582	241	59	381
102.5	EPA, 1980	12- 5-78	23.56	347	1239	1679	724	251	1216
101.7				0	0	0	643	0	0
TOTAL							16092	2972	12200

The average velocity within the Coeur d'Alene to Post Falls Dam reach was assumed to be a linear function of discharge as measured at the USGS gage near Post Falls, Idaho. Therefore the volume of this impoundment was assumed to be a constant value which could be estimated for any given stage condition. The average travel time, from RM 111.7 to 101.7, during the nine sampling surveys was approximately 4.1 days (Table C-7). Since travel time in this reach is relatively long, an iterative averaging procedure was used for estimating the representative discharge conditions and travel times for each sampling survey. The representative average volume and discharge was determined as the average condition over the estimated travel time from Lake Coeur d'Alene to Post Falls Dam. Given the observed fluctuation in stage and discharge, this averaging procedure was considered to yield the most representative travel time estimates of water parcels sampled at Post Falls.

The velocity-discharge relationship for the river reach between RM 64.6 and 58.1 is corroborated by an estimate of the reach volume conducted by EPA (Yearsley, personal communication) which, when volume is assumed constant, yields a relationship between reach velocity as a linear function of discharge of:

$$U = (2.2 \times 10^{-4})Q$$

where: U = average velocity (ft/sec)
Q = average discharge (CFS)

The power curve fit to the dye study data shown in Figure C-6b yields a similar relationship where:

$$U = (2.9 \times 10^{-4})Q^{0.95}$$

For typical low flow discharge values of interest, the two independent equations yield velocity predictions that agree to within about 10%, which adds support to the validity of the time-of-travel estimates.

Travel Time Estimates

The travel time of a parcel of water in the Spokane River was found to be strongly dependent upon discharge, as would be expected. The relationship between travel time and discharge is presented in Figure C-7. A log-log regression of travel time as a function of discharge was found to best fit the data ($r^2 = 0.9996$). Interestingly, at the low flow condition of interest in the present study, greater than 50 percent of the travel time in the Spokane River between Lake Coeur d'Alene and Nine Mile Dam (RM 111.7 to 58.1) is estimated to occur in the first 10 river miles between Lake Coeur d'Alene and Post Falls Dam (RM 111.7 to 101.7) due to the large volume of this impoundment reach (Figure C-7).

The average physical characteristics of specific reaches during the 1984 study period are presented in Table C-8. The average travel time through the entire river system (Coeur d'Alene to Nine Mile Dam) during the study period was 7.4 days. Nearly 85 percent of the residence time of water in the Spokane River occurred in pool reaches formed by the hydropower dams.

TABLE C-7

Average Stage, Discharge, Volume, and Travel Time for the Spokane River from Lake Couer D'Alene to Post Falls Dam

DATE	# DAYS[1] POOLED	MEAN STAGE (ft)	MEAN POST FALLS DISCHARGE (cfs)	REACH VOLUME (thousand m3)	TRAVEL TIME (days)
7-17-84	3	27.97	2470	12426	2.05
7-30-84	3	27.94	2097	12400	2.41
8- 7-84	5	27.93	1106	12392	4.58
8-13-84	6	27.94	969	12400	5.23
8-20-84	8	27.94	691	12400	7.33
8-27-84	6	27.87	1005	12335	5.01
9- 4-84	5	27.70	1083	12182	4.59
9-10-84	3	27.44	1730	11947	2.82
9-24-84	3	26.82	1763	11384	2.63
AVERAGE		27.72	1434	12208	4.07

[1] The number of daily average values included in the mean stage and discharge estimates. The total number of days pooled includes the day of sampling plus the required number of preceeding days which must be included to approximately represent the average reach volume and travel time for a parcel of water traveling between Lake Couer D'Alene and Post Falls Dam.

TABLE C-8

Average Physical Characteristics Within Each Reach

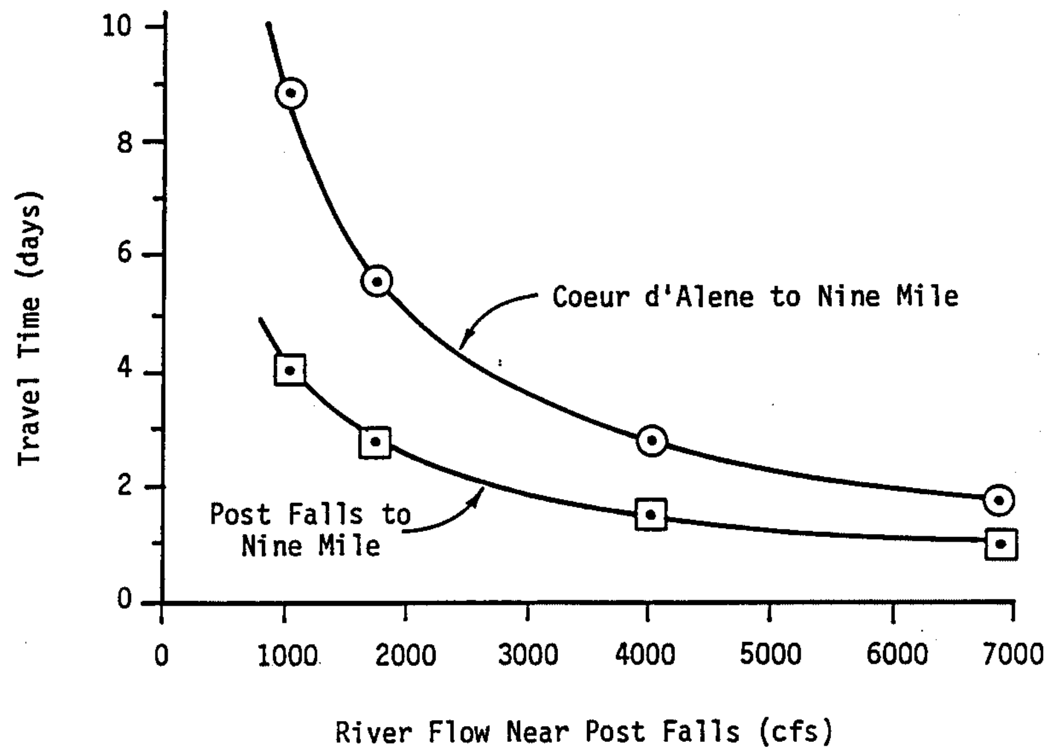
During the 1984 Study Period

Reach	Length (km)	Width (m)	Depth[a] (m)	Discharge[b] (cfs)	Velocity (cm/sec)	Travel Time (hours)
CDA-HI	7.2	182	3.3	1,448	6.0	39.8
HI-PF	7.9	188	4.9	1,437	4.4	58.1
PF-ST	9.2	54	1.7	1,387	43.4	5.9
ST-HA	4.8	54	1.6	1,315	42.0	3.2
HA-BA	4.2	54	1.6	1,293	41.5	2.8
BA-SU	4.2	54	1.6	1,293	41.5	2.8
SU-TR	4.0	55	1.7	1,496	45.8	2.4
TR-UP	8.9	81	5.1	1,572	10.9	22.8
UP-GR	2.9	56	1.9	1,734	45.2	1.8
GR-PO	6.3	71	2.8	1,932	27.9	6.2
PO-FW	6.9	57	2.2	1,934	42.9	4.5
FW-RA	3.5	57	2.3	2,041	44.7	2.2
RA-GC	4.8	57	2.3	2,112	45.9	2.9
GC-SM	4.2	79	3.3	2,187	24.0	4.8
SM-NM	6.3	181	3.2	2,175	10.6	16.4
	85.3					176.6 (7.4 days)

[a] calculated based upon discharge, velocity, and width data.
[b] m^3/sec = 0.02832 * cfs

FIGURE C-7

Relationship Between Travel Time Through the Study Area and River Discharge Near Post Falls



The sampling of the Spokane River was designed to be "time-of-travel" between Stateline Bridge and Trent Rd. (RM 96.0 to 85.3), and between Monroe Street and Seven Mile Bridge (RM 73.4 to 62.0). The schedule for "time-of-travel" sampling was based on preliminary interpretation of velocity-discharge relationships since the present low flow dye study had not been conducted until after the initiation of sampling. Therefore, the accuracy of the sampling schedule was re-evaluated in light of the present velocity-discharge relationships. These relationships are based on all dye study information collected to date and are therefore considered to be the present best estimates of river velocity for specific discharge conditions.

The inital time-of-travel estimate used in the sampling design was found to be within 1.2 hours of the re-evaluated estimate for the entire river segment between Stateline Bridge and Trent Road (RM 96.0 to 85.3). Each sampling station was occupied for a period of approximately 2 hours during time-of-travel sampling, therefore the error in initially estimated travel time for this reach is considered negligible.

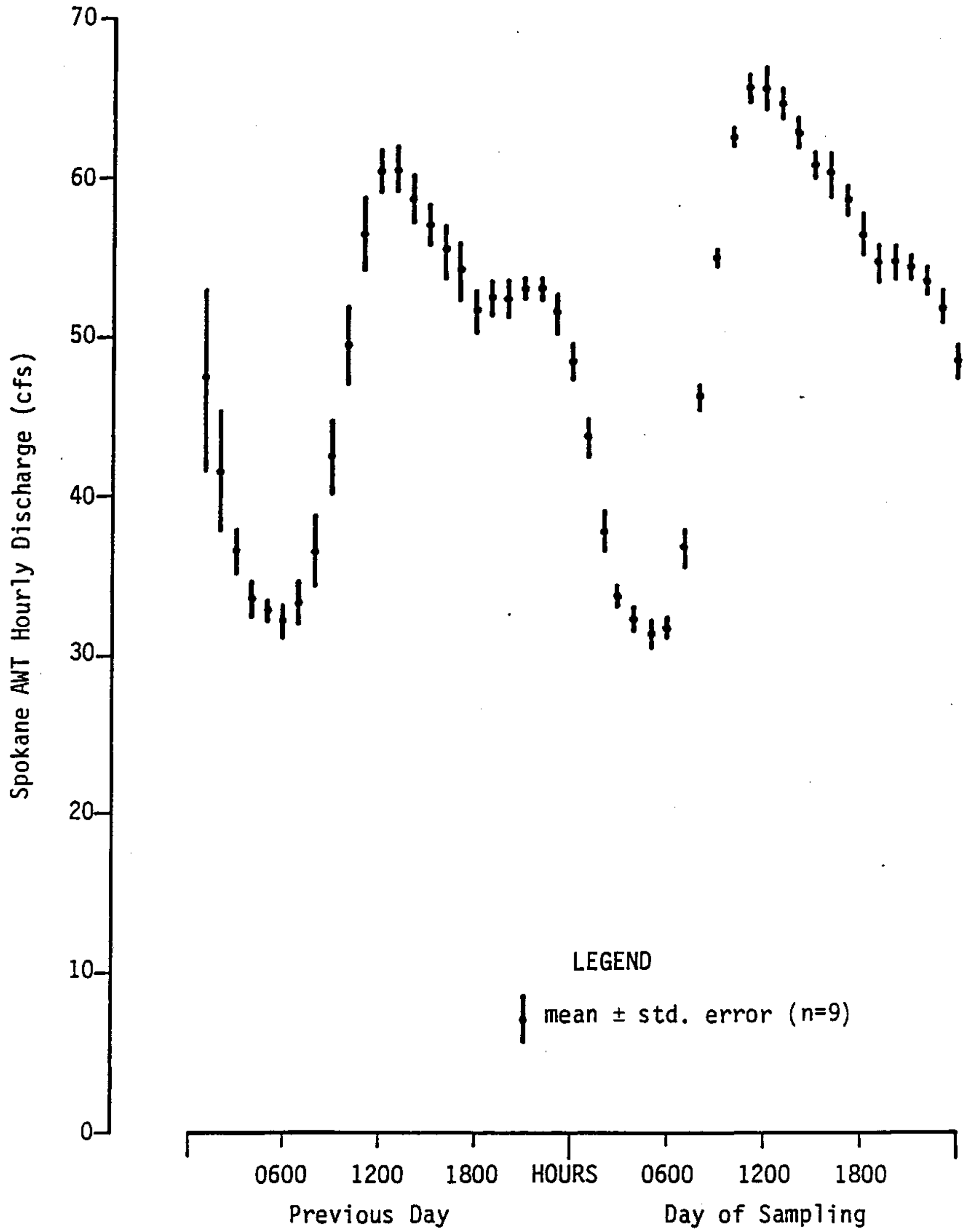
A larger discrepancy of 2 to 4 hours between initially estimated and re-evaluated time-of-travel was found between Monroe Street and Seven Mile Bridge (RM 73.4 to 62.0). Nearly all of the error in travel time initially estimated for this river segment is estimated to occur as a result of initially underestimating the travel time in the lower portion between the Spokane AWT and Seven Mile Bridge (RM 67.4 to 62.0). The initial estimate of travel time for the upper portion between Monroe Street and the Spokane AWT was found to be within approximately 0.2 hours of the re-evaluated best estimate for the range of flows sampled.

Convection and Dispersion of Spokane AWT Effluent

The Spokane AWT effluent discharge is characterized by significant diurnal fluctuations (Figure C-8). Therefore, substantial diurnal fluctuations in AWT effluent dilutiuon may be an important consideration in evaluating the phosphorus mass balance. In general, the sampling of the Spokane River between the Spokane AWT and Seven Mile Bridge was initially designed as "time-of-travel" or plug-flow. In addition, the plug-flow sampling of this reach generally began with Spokane AWT sampling between 11:00 and 13:00 hours, which corresponds to peak hours of discharge (Figure C-8). Also, since travel times between the Spokane AWT and Seven Mile Bridge were initially underestimated by about 2 to 4 hours, the river conditions sampled at Seven Mile Bridge were influenced by much lower Spokane AWT discharges which probably occurred between about 08:00 and 10:00 hours. Even if the travel time used for sampling this reach had been correct, the process of dispersion would have caused a decrease in concentration within a water parcel followed down-river, starting with peak Spokane AWT influence. Therefore, two important processes - convection and dispersion - contribute to a probable overestimation of attenuation immediately below the Spokane AWT, if no correction of the present sampling data is made for travel time biases and dispersion.

FIGURE C-8

Mean Hourly Spokane WTP Discharge for the Nine Sampling Days and Their Respective Previous Days



A mathematical model of the convection and dispersion of Spokane AWT effluent in the Spokane River between the Spokane AWT and Nine Mile Dam was based on conventional one-dimensional finite difference procedures (Bella and Dobbins, 1968). The convection of a substance in a parcel of water may be approximated during each finite difference time increment as:

$$L(n,T + \Delta T) = L(n-1,T)$$

where: L = concentration of a conservative tracer
n = river segment
T = time
ΔT = time increment

The above equation applies to convection when cross-sectonal area and velocity are assumed to be constant along the river reach being modeled. In addition, the condition of $U\Delta T = \Delta X$ must be met in order to avoid the effects of artificial numerical dispersion, where ΔX represents the length of a given segment within the river reach being modeled and U represents velocity (Bella and Dobbins, 1968). In the case of the Spokane River, a time increment of 1 hour was found to yield satisfactory results.

The effect of dispersion on a water parcel was mathematically modeled as (Bella and Dobins, 1968):

$$L(n,T + \Delta T) = L(n,T) + [L(n+1, T) - 2L(n,T) + L(n-1, T)] \; D\Delta T/(\Delta x)^2$$

where: D = dispersion coefficient.

The dispersion coefficient (D), cross-sectional area, and velocity were assumed to be uniform over the length of river between the Spokane AWT to Nine Mile Dam.

The relationship between the dispersion coefficient and discharge is presented in Figure C-9 for the reach between the Spokane AWT and Nine Mile Dam (RM 67.4 to 58.1). The total travel time between RM 67.4 and 58.1 was estimated by two velocity-discharge equations; velocity between RM 67.4 and 64.6 was assumed to be represented by the equation for RM 74.1 to 64.6 (Figure C-6a). The remainder from RM 64.6 to 58.1 was assumed to be represented by the relationship shown in Figure C-6b. The transition from riffle to pool apparently occurs in the vicinity of RM 64.6.

The average reach discharge, travel time, and velocity is presented for RM 67.4 to 58.1 in Table C-9 for the nine sampling surveys. The average travel time between Spokane AWT and Nine Mile for the nine surveys is approximately 26.2 hours. Of the total travel time, approximately 90 percent occurs between RM 64.6 and 58.1. The uncertainty in the estimated travel time for this segment based on the power curve regression (Figure C-6b) represents a standard error of approximately 1.7 hours for the average measured reach discharge of 2158 cfs.

TABLE C-9

Average Discharge, Travel Time, Velocity, and Dispersion for the Spokane River from the Spokane AWT to Nine Mile Dam

	AVERAGE REACH[1] DISCHARGE (cfs)	TRAVEL TIME RM 67.4-64.6 (hours)	TRAVEL TIME RM 64.6-58.1 (hours)	TRAVEL TIME RM 67.4-58.1 (hours)	AVERAGE VELOCITY (ft/sec)	AVERAGE DISPERSION (ft2/sec)
JULY 17, 1984	3266.6	1.95	14.83	16.79	0.8121	424
JULY 30	2845.0	2.17	16.91	19.08	0.7145	365
AUGUST 7	1806.3	3.04	26.06	29.10	0.4686	253
AUGUST 13	1778.0	3.07	26.44	29.52	0.4619	251
AUGUST 20	1457.3	3.56	31.95	35.52	0.3839	224
AUGUST 27	1709.6	3.17	27.45	30.62	0.4453	245
SEPTEMBER 4	1734.0	3.13	27.08	30.22	0.4512	247
SEPTEMBER 10	2350.0	2.50	20.28	22.79	0.5984	307
SEPTEMBER 24	2476.3	2.40	19.30	21.71	0.6282	321
AVERAGE	2158.1	2.78	23.37	26.15	0.5516	293

[1]The estimated average discharge between the Spokane AWT and Nine Mile Dam

The dispersion coefficient appropriate to each sampling survey was estimated by a linear regression of the logarithm of measured dispersion coefficients as a function of reach discharge (Figure C-9). The uncertainty of this estimate for the range of flows encountered during the nine surveys was estimated as the root mean squared deviation of the observations from the regression line. The standard error of the estimated dispersion coefficient was therefore approximately plus or minus 137 ft^2/sec. This standard error (and that of the travel time estimate) determined the precision of the finite difference model (see below). The accuracy of the model was verified by simulating the September 7, 1984 dye injection (Figure C-10).

Based on hourly variations in AWT effluent discharge measured at the plant and using the finite difference model described above, the diurnal fluctuation in the volumetric fraction of effluent at Nine Mile Dam was estimated for each sampling date. Results of this output for a high flow (July 17) and low flow (August 20) sampling day are presented in Figures C-11 and C-12. These data reveal that the diurnal flow pattern at the Spokane AWT is apparent at Nine Mile Dam and significant sampling biases could thus be introduced at this site depending upon the particular flow and sampling conditions.

The results of the convection/dispersion model were used to estimate the representative Spokane AWT discharge that actually influenced the river at Nine Mile Dam <u>at the time of sampling</u>. As expected, the actual representative Spokane AWT discharge was found to be significantly lower ($P<0.001$) than the initially sampled efluent discharge intended for time-of-travel sampling between the Spokane AWT and Seven Mile Bridge. In addition, the representative Spokane AWT dischage at Nine Mile Dam was significantly higher ($P<0.05$) than the mean daily average. These data (Table C-10) illustrate that a substantial sampling bias existed between the original time-of-travel and Nine Mile Dam sampling data which prevents a direct comparison of information from these stations. Therefore, P mass balances between Spokane AWT and Nine Mile Dam should be based on representative Spokane AWT discharges, estimated by the convection/dispersion model (Table C-10), rather than instantaneous time-of-travel or daily average values.

FIGURE C-9

Average Dispersion Versus Discharge From the Spokane AWT to Nine Mile Dam

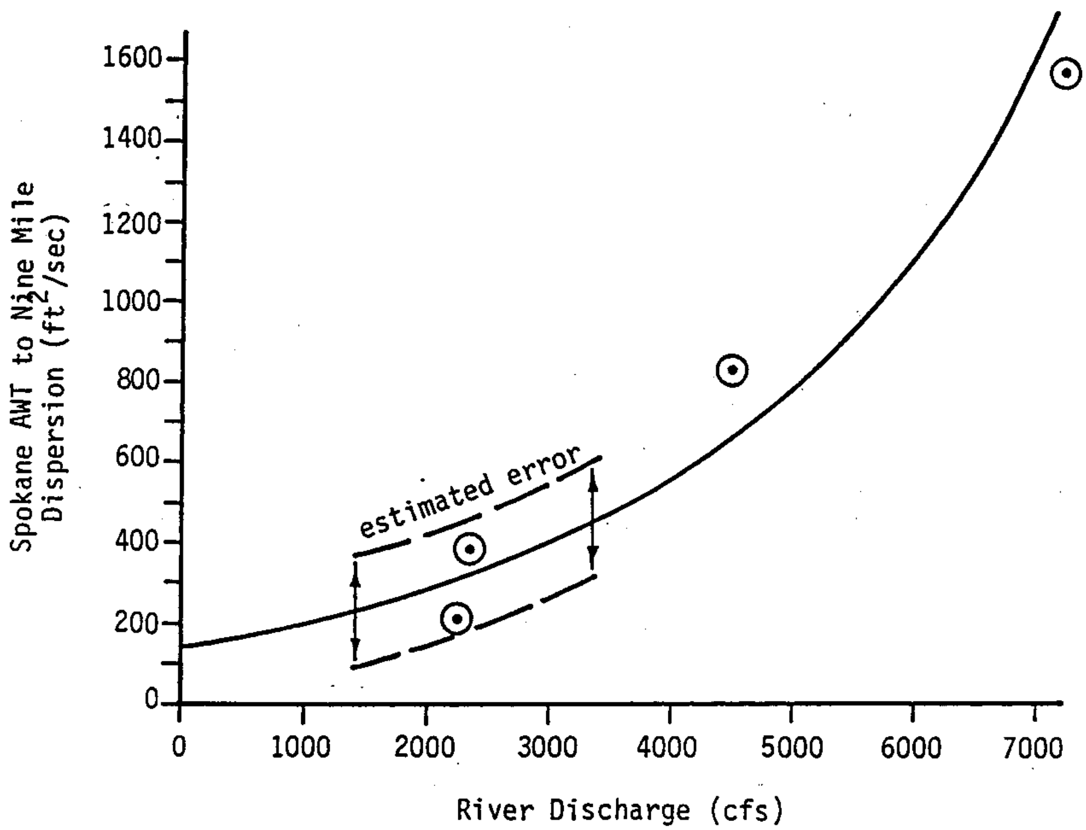


FIGURE C-10

Observed and Modeled Dye Injection, Spokane STP to Nine Mile Dam

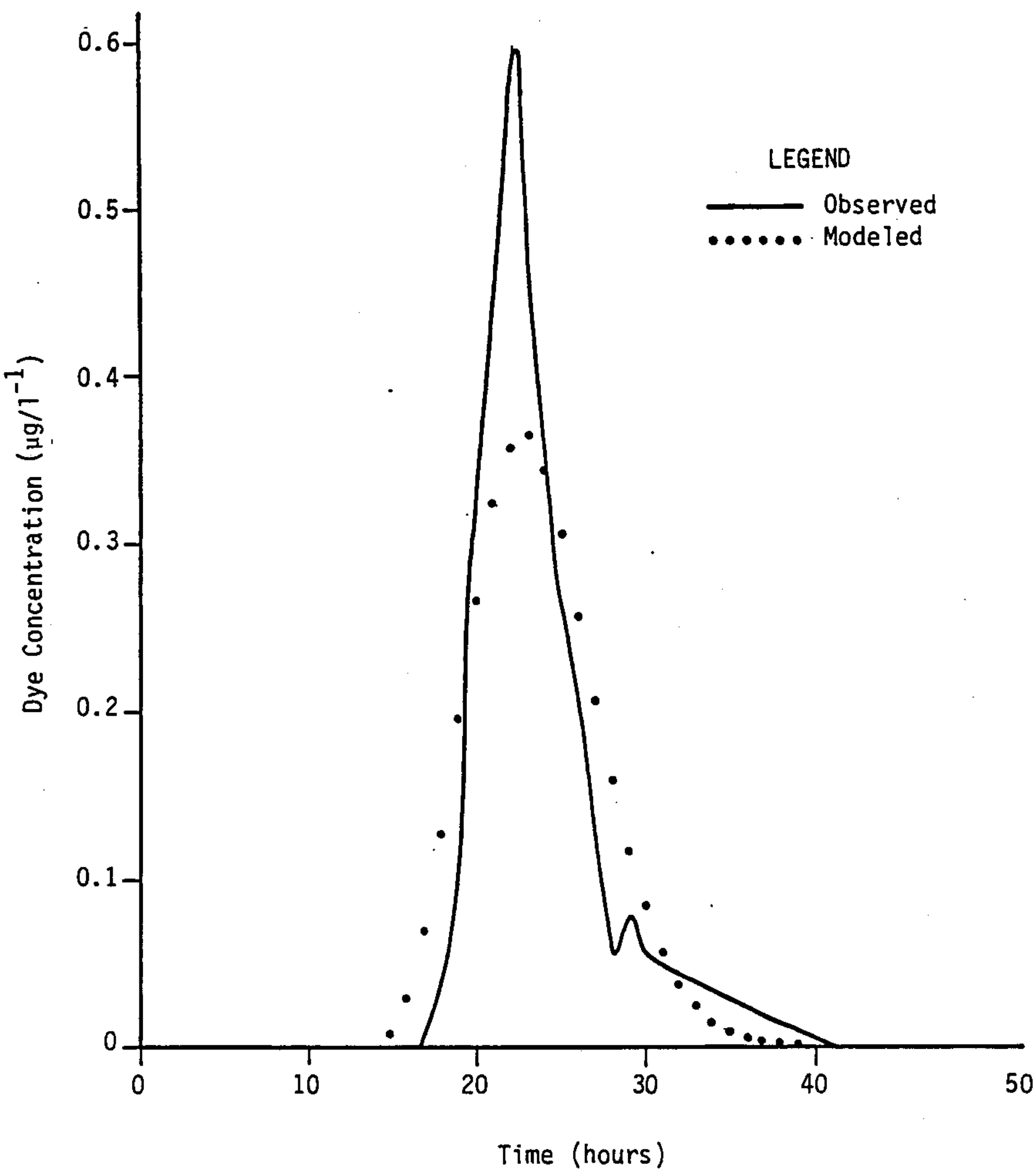


FIGURE C-11

Percent Spokane WTP Effluent at Nine Mile Dam

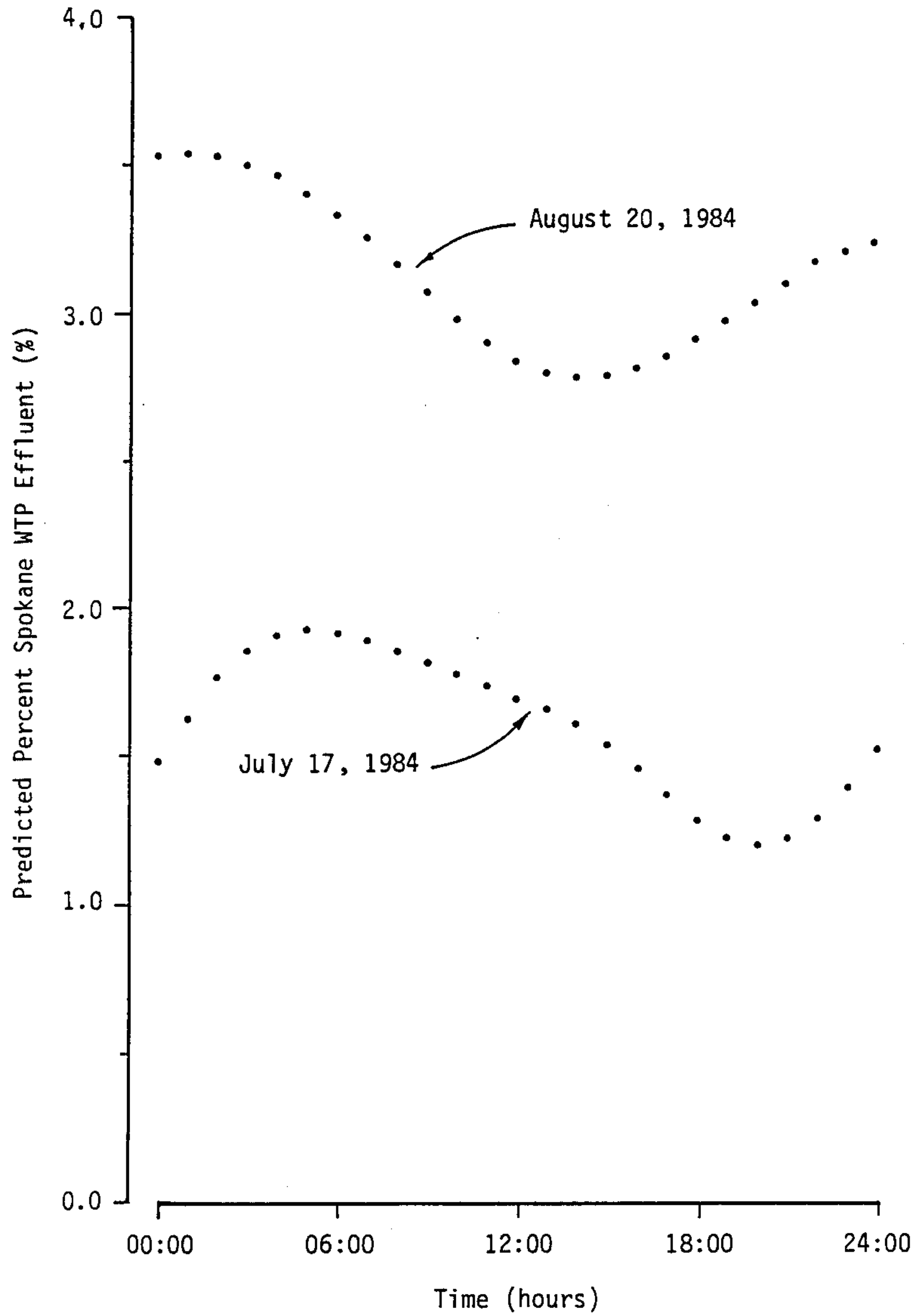


FIGURE C-12

Predicted Initial Concentration of Total Phosphorus at Nine Mile Dam Assuming Total Phosphorus is Conservative Between Spokane AWT and Nine Mile Dam

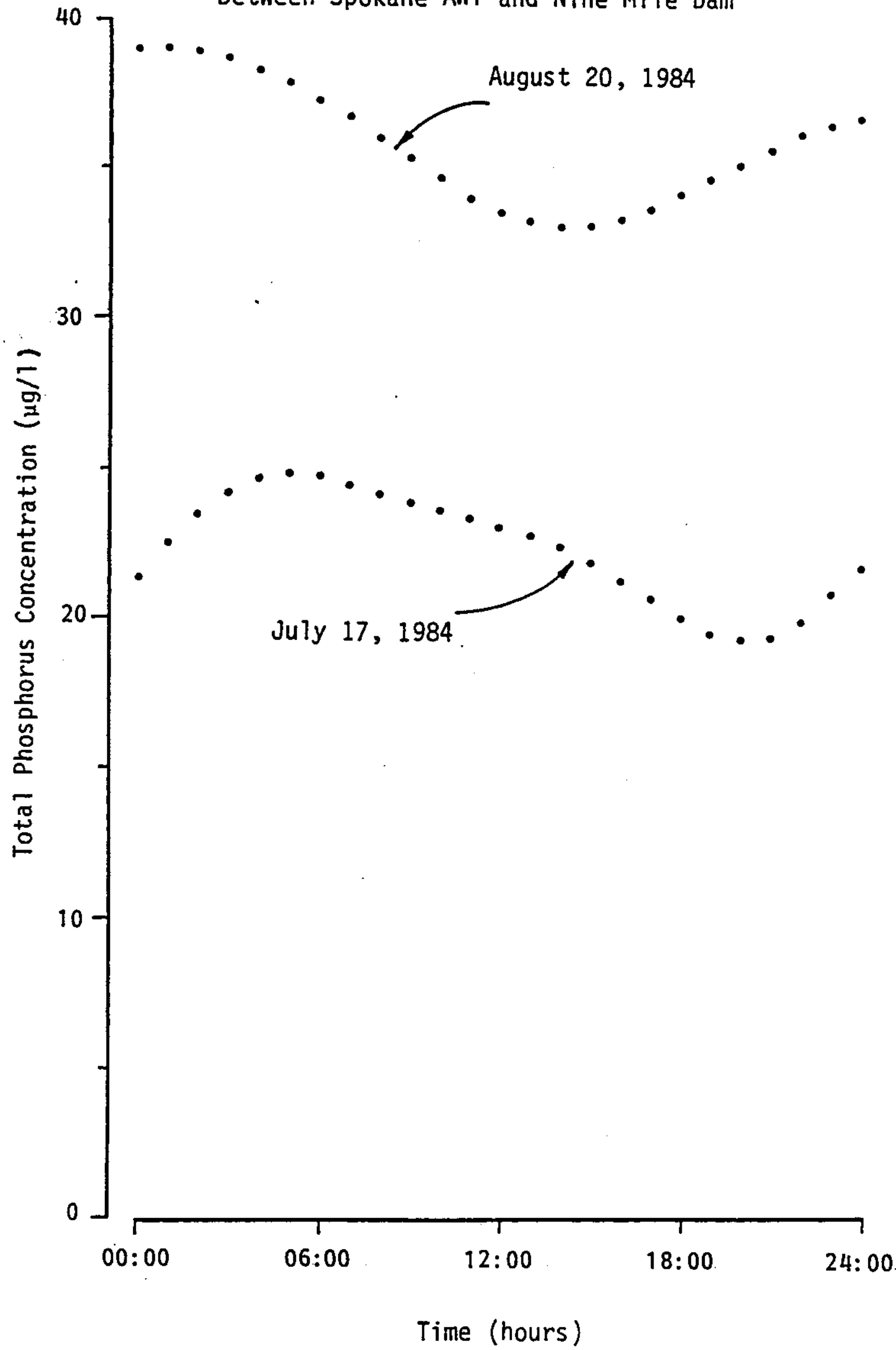


TABLE C-10

Spokane AWT Discharge at the time of AWT Sampling and Estimated AWT Discharge Representative of Nine Mile Dam Sampling Conditions

	Initial Spokane AWT Discharge at Sampling (cfs)	Representative "AWT Discharge" at Nine Mile Sampling (cfs)	Difference (cfs)
7-17-84	64.11	46.82+/-0.35	17.29
7-30-84	67.83	51.11+/-0.87	16.72
8-7-84	62.04	63.56+/-1.67	-1.52
8-13-84	65.19	53.17+/-0.26	12.02
8-20-84	60.84	43.28+/-2.15	17.56
8-27.84	61.65	48.71+/-0.32	12.94
9-4-84	63.01	49.77+/-1.37	13.24
9-10-84	60.70	49.28+/-0.63	11.42
9-24-84	58.24	54.88+/-0.95	3.36
MEAN	62.62	51.18+/-0.95	11.45
S.E.			2.35 (P<.001)

APPENDIX D

Analysis of Historical Phosphorus Data in the Spokane River Relative to P Attenuation

(data from Gibbons et al., 1982; Singleton and Joy, 1982; and Yearsley, 1982)

Table D-1

Steady-state analysis of phosphorus attenuation within

the upper Spokane River[a]; June-October, 1980-81 (n=20 surveys)

		Phosphorus Flux (kg P/day); mean ± one standard error			
		Q[b]:600 - 1,300 cfs	Q:1,300 - 2,000 cfs	Q:2,000 - 8,000 cfs	Q:8,000 - 15,000 cfs
Inputs:	soluble reactive P	30. ± 5.	39. ± 5	34. ± 5.	60. ± 14.
	soluble non-reactive P	17. ± 3.	22. ± 5	37. ± 6.	131. ± 33.
	particulate P	19. ± 3.	41. ± 16	122. ± 46.	379. ± 93.
	Total P	66. ± 3.	102. ± 15.	192. ± 50.	569. ± 119.
Outputs:	soluble reactive P	9. ± 5.	13. ± 3.	10. ± 3.	38. ± 18.
	soluble non-reactive P	13. ± 2.	10. ± 4.	28. ± 13.	117. ± 49.
	particulate P	12. ± 5.	47. ± 8.	175. ± 38.	503. ± 143.
	Total P	34. ± 5.	70. ± 9.	212. ± 34.	658. ± 184.
Residual[c]:	soluble reactive P	-21. ± 7.*	-26. ± 6.**	-24. ± 6.*	- 22. ± 23.
	soluble non-react. P	- 4. ± 4.	-11. ± 6.	- 9. ± 14.	- 14. ± 59.
	partaiculate P	- 7. ± 6.	+ 6. ± 18.	+53. ± 59.	+124. ± 171.
	Total P	-32. ± 6***	-31. ± 18.	+20. ± 61.	+ 89. ± 219.

a.) RM 94.1 (above Harvard Rd.) to RM 72.6 (below Latah Creek).

b.) "Q" refers to discharge at RM 100.7 (below Post Falls Dam).

c.) Negative residual signifies in-river loss (i.e. attenuation); positive residual signifies in-river gain. "*" denotes significant residual at P <.05; "**": P <.01; "***": P <.001.

APPENDIX E

Historical Discharge Data Collected by USGS in the Spokane River, 1913-1983

HISTORICAL SUMMARY OF JUNE-NOVEMBER AVERAGE DISCHARGES IN THE SPOKANE RIVER BASIN
(all units in cubic feet per second)

YEAR	Estimated Lake Coeur d' Alene Outflow	Rathdrum Canal Diversion	Spok. Vall Farm Co. Diversion	Post Falls	Harvard Road	Trent Road	Green Street	Spokane	Hangman Creek	Estimated Spokane STP Effluent	Gun Club	Nine Mile Dam	Little Spok. R. at Dartford	Little Spok. R. at Mouth	Change in Long Lake Contents (Jun-Nov)	Long Lake Outflow
River Mile	111.7	106.6	101.7	100.7	93.6	85.2	78.0	72.9	72.4	67.4	64.6	58.1		56.3		33.9
1913	5752	0	64	5688				6121		24				438		
1914	2390	0	65	2325				2676		24						
1915	2139	0	74	2065				2459		24						
1916	5982	0	79	5903				6375		24						
1917	6466	0	71	6395				6956		24						
1918	2489	0	76	2413				2873		24						
1919	2385	0	80	2305				2809		24						
1920	3133	0	87	3046				3536		24						
1921	2827	0	96	2731				3485		24						
1922	3003	0	96	2907				3654		25						
1923	3532	0	118	3414				4106		25						
1924	1567	0	131	1436				1932		26						
1925	2615	0	132	2483				3183		26						
1926	2033	0	134	1899				2341		26						
1927	7097	0	136	6961				7503		27						
1928	2389	0	140	2249				3043		27						
1929	1879	0	123	1756	1756			2299		28			117			
1930	1576	0	124	1452	1492			1920		28			97			
1931	1302	0	141	1161	1144			1557		28			89			
1932	3772	0	146	3626	3722			4480		28						
1933	6132	0	138	5994	5869			6603		28						
1934	1724	0	145	1579	1558			2222		28						
1935	2689	0	156	2533	2511			3385		29						
1936	1933	0	151	1782	1742			2543		29						
1937	2496	0	150	2346	2290			2959		29						
1938	2339	0	158	2181	2096			2807		29						
1939	1664	0	154	1510	1493			2062		29						2825
1940	1432	0	152	1280	1273			1863		29						2644
1941	2165	0	140	2025	1968			2507		30						3226
1942	2534	0	146	2388	2319			2852		31						3632
1943	3562	0	149	3413	3398			4144		32						4947
1944	1473	0	145	1328	1257			1832		33						2489
1945	2357	0	144	2213	2177			2878		34						3610
1946	2935	18	143	2774	2775			3487		34						4282
1947	2690	26	152	2512	2456			3152		35			150			3966
1948	5082	25	133	4924	4739	5503		5711	103	36		6334	302	540	58	6905
1949	2221	32	142	2047	1960	2524	2953	2911	21	37	3141	3264	173	425	53	3568
1950	6388	27	150	6211	5957	6653	7230	7171	50	38	7365		218	457	121	7873
1951	2664	31	151	2482	2229	2858	3178	3175	31	39	3314		207	452	-6	4041
1952	2286	31	141	2114	2009	2500		2818	26	39			207		16	3573
1953	3474	30	140	3304	3165	3609		3901	34	40			202		6	4764
1954	4543	22	127	4394	4273			4989	27	40			183		30	5699
1955	5296	29	149	5118	4994			5714	43	41			183		8	6235
1956	4000	27	150	3823	3724			4687	32	41			216		-11	5500
1957	3168	26	147	2995	3022			3846	45	42			185		35	4594
1958	2597	29	143	2425	2358			3186	27	42			179		10	3880
1959	5084	29	139	4916	4772			5469	45	43			218		1	6350
1960	2963	29	142	2792	2754			3590	24	31			242		-4	4323
1961	3078	33	147	2898	2840			3703	17	35			205		0	4421
1962	2833	31	144	2658	2609			3369	20	31			190		7	4004
1963	1525	34	149	1342	1316			1991	18	41			166		-8	2535
1964	5431	23	138	5270	5204			5936	19	42			173		15	6591
1965	3085	27	136	2922	2923			3687	27	36			172		3	4401
1966	1812	30	67	1715	1717			2221	13	34			142		5	2952
1967	3696	31	9	3665	3626			4080	24	38			160		8	4875
1968	3199	28	0	3171	3059			3382	16	42			143		4	4125
1969	2689	30	0	2659	2538			3123	34	42			180		2	3894
1970	3796	31	0	3765	3655			4213	25	42			171		6	4969
1971	4736	26	0	4710	4472			5157	72	44			183	437	3	5931
1972	4887	27	0	4860	4632			5429	20	43			161	393	4	6022
1973	1829	30	0	1799	1722			2056	20	46			133	368	-7	2691
1974	6460	29	0	6431	6218			7258	36	48			229	453	3	7783
1975	5133	26	0	5107	4980			5702	43	48			225	449	56	6492
1976	3160	25	0	3135	3054			3666	25	50			184	443	2	4484
1977	1662	27	0	1635	1557			1946	12	43			123	408	0	2548
1978	2645	22	0	2623	2580			2992	26	53			157	444	4	3821
1979	2137	23	0	2114	2079			2484	13	48			123	383	-2	3202
1980	3083	21	0	3062	2987			3360	43	50			150	450	6	4155
1981	3361	21	0	3340	3161			3618	29	50			171	414	-4	4393
1982	3920	23	0	3897	3614			4220	25	51			165	465	10	4922
1983	3234	17	0	3217	2963			3701	63	49			224	507	3	4492