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LAKE SAWYER - BLACK DIAMOND WASTE LOAD ALLOCATION EVALUATION

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ABSTRACT

The Black Diamond Wastewater Treatment Facility (WWTF) discharges treated sewage to a wetland, which drains to Rock Creek and then Lake Sawyer. Total phosphorus concentrations in Lake Sawyer increased following start-up of the WWTF. The observed increase in whole-lake total P content corresponds closely to the estimated loading currently discharged from the WWTF. The condition of Lake Sawyer is predicted to reach a eutrophic state in the future (2010) if discharges from the Black Diamond WWTF continue at existing or currently permitted levels of treatment. Diversion of WWTF discharge from the Rock Creek/Lake Sawyer system would probably return the condition of the lake to the mesotrophic (threshold eutrophic) condition that existed prior to WWTF start-up. An in-lake total P criterion of 25 ug P/L is recommended for protection of lake water quality.

INTRODUCTION

The City of Black Diamond in King County presently operates a wastewater treatment facility (WWTF) which discharges to a natural wetland. Discharge of effluent to the marsh was designed to utilize natural processes in order to remove nutrients (nitrogen and phosphorus). The wetland drains into Rock Creek, which in turn enters Lake Sawyer (Figure 1).

The natural wetland component of the WWTF was considered innovative by the Environmental Protection Agency (EPA) and funded under the Innovative and Alternative Grants Program. Construction began in the early 1980s, and the wetland portion of the WWTF has subsequently failed to meet design removals of phosphorus (R.W. Beck, 1985; Environmental Resources Management, 1986). Increased loading of phosphorus to Lake Sawyer resulting from WWTF discharges to the wetland system has been postulated to result in increased intensity of algal blooms. The lake is currently classified as mesotrophic to eutrophic (Brenner and Davis, 1988). The EPA has recommended that a waste load allocation study be performed in order to determine the amount of phosphorus that must be removed by the Black Diamond WWTF system in order to protect the water quality of Lake Sawyer.

BACKGROUND

Lake Sawyer lies within the Big Soos Creek sub-basin of the Green River drainage. Lake Sawyer's drainage basin covers 13 mi^2 at the outlet, Covington Creek (Figure 1). Various physical descriptions of the lake are listed in Table 1. The lake lies primarily in glacial drift with peat and muck areas to the south (McConnell, Bortleson, and Innes, 1976). The 1973 bathymetric map shows the southern quarter of the lake to be shallower than the middle and northern areas (Figure 2). The two major inflow streams, Rock and Ravensdale Creeks, and an extensive wetland area enter at the southern end. Another small wetland lake drains (subsurface) to the northeast corner of Lake Sawyer. The lake outlet, Covington Creek, leaves the lake from the central western shore. Lake level is controlled by a concrete dam constructed in 1952. Annual extremes of water level generally range about four feet. Single-family residences and developed open-space occupy 85 percent of the shoreline (McConnell, Bortleson, and Innes, 1976).

The city of Black Diamond (population estimated at 1,300) lies approximately one mile south of Lake Sawyer along Rock Creek (Figure 1). It is a residential community with a few commercial and institutional establishments and no major industrial development. However, the now inactive coal mines in and around the town were a major industry. Historically, wastewaters from the city were treated by individual septic tank systems or by one of five community septic tank systems (KCM, 1979). All of the community septic systems and many individual systems had experienced failures during the 1970s, resulting in deterioration of Rock Creek and Ginder Creek water quality. Health concerns over sewage inputs to Rock Creek and Ginder Creek were one impetus for design and construction of a wastewater treatment system. It was not generally believed that the lake water quality would worsen because of the increased wastewater treatment afforded by the new facility. In 1983, a new WWTF was put into service: a two-cell aerated lagoon using wetland dispersal for nutrient and solids removal.

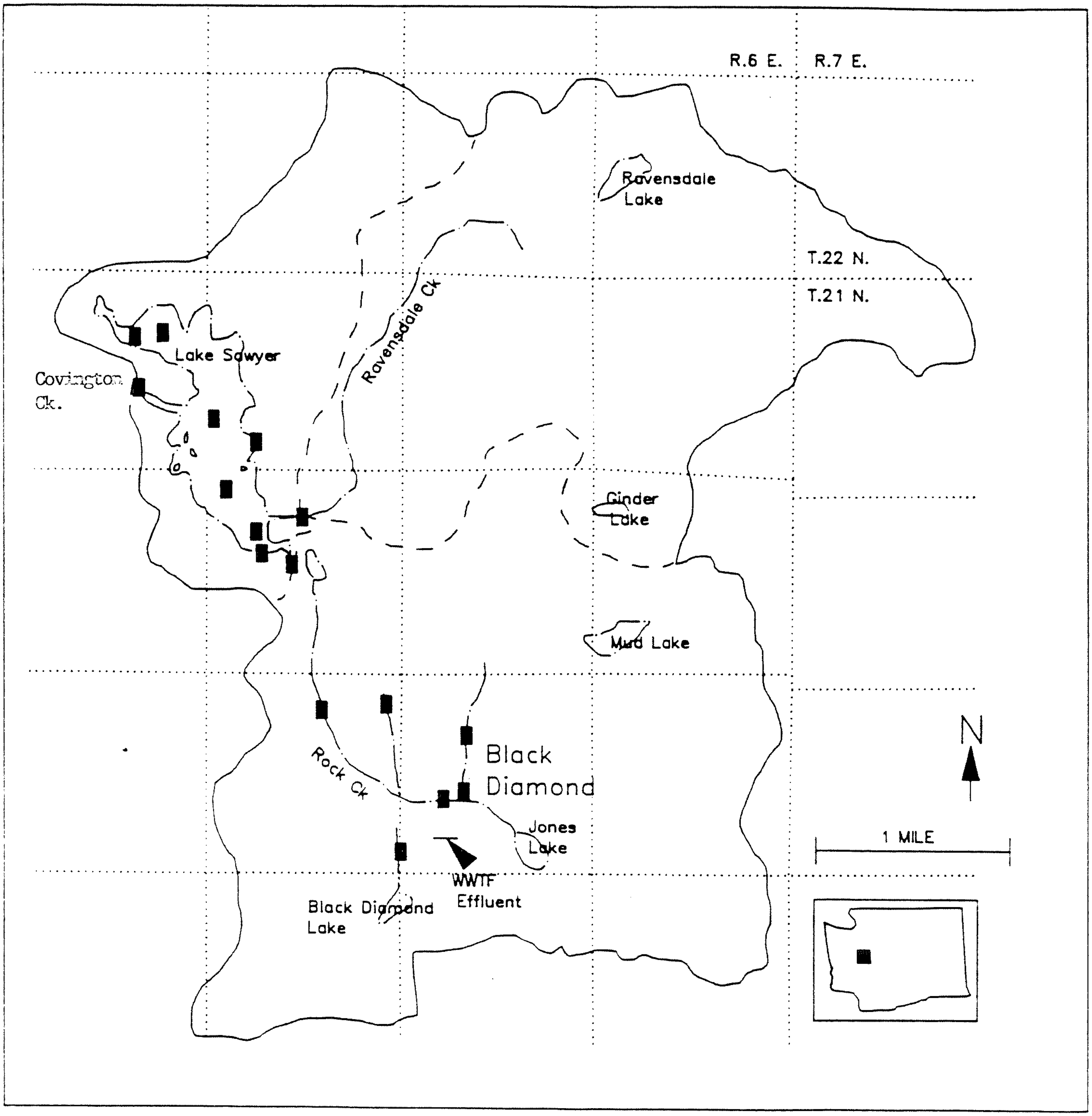

Figure 1. Map of Lake Sawyer drainage basin showing major sub-drainage areas for Ravensdale and Rock Creeks and Ecology monitoring stations (1989 ongoing studies).

Table 1. Physical characteristics of Lake Sawyer (after McConnell *et al.*, 1976).

Parameter	English Unit	Metric Units
Drainage area	13 sq. mi.	34 sq. km.
Altitude	495 ft.	151 m.
Surface area[1]	280 acres	1.13 sq. km.
Lake volume[1]	7,000 ac. ft.	8.6 mill.cu.m.
Mean depth	25 ft.	7.62 m.
Maximum depth	58 ft.	18 m.
Shoreline length	36,000 ft.	11 km.

1) Area was digitized from USGS Black Diamond Quadrangle map. Lake volume was computed from digitized contour intervals from McConnell *et al*. (1976) map scaled to lake surface area from USGS quadrangle map.

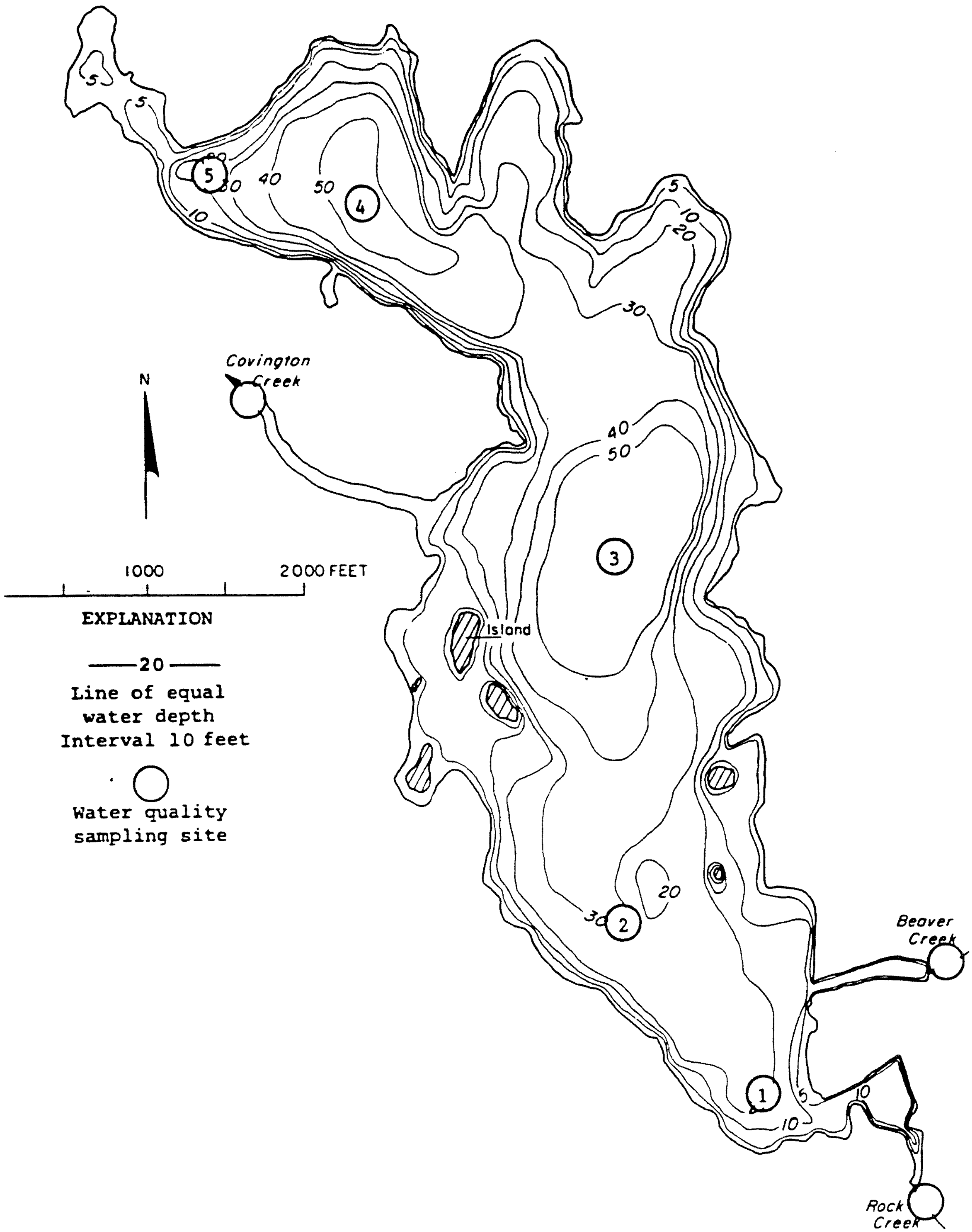

Figure 2. Lake Sawyer bathymetry and Ecology sampling stations.

The Black Diamond WWTF discharges to a natural wetland that discharges to Rock Creek and then Lake Sawyer. The WWTF effluent enters the wetland system approximately 1.8 miles upstream from Lake Sawyer. The wetland area surrounding the 0.9 mile of creek between the WWTF line and the Morganville Bridge at river mile 0.9 is a complex convergence zone for several tributaries to Rock Creek: Black Diamond Lake Creek, Morganville marsh drainage, and Ginder Creek.

Ravensdale Creek, also known as Beaver Creek, flows into Lake Sawyer about 0.25 mile north of the Rock Creek inlet (Figure 2). Ravensdale Creek drains the primarily forested area east of the lake (Figure 1). A quarry, sawmill, and the small town of Ravensdale are located near Ravensdale Lake at the head of the drainage.

Several groups have monitored the water quality of the lake and points in the watershed since the early 1970s. Most monitoring has centered on the Black Diamond WWTF and the Rock Creek wetland area, and on the lake. Unfortunately, these efforts were not comprehensive and analyses relating watershed inputs and lake water quality are not available. A summary of the past Municipality of Metropolitan Seattle (Metro), Ecology, private consultants, and USGS sampling locations, dates, parametric coverage, and depth intervals is shown in Figure 3 and Table 2. Data from each source are listed in Appendix A, B, and C.

METHODS

Waste Loading Evaluations

The loading evaluation for nutrient inputs to Lake Sawyer was based on the calculation procedures presented by Mancini *et al.* (1983). The methods may be summarized as follows:

- Morphometric data describing lake volume, surface area, mean depth, and drainage area were calculated using published maps of bottom contours (McConnell, Bortleson and Innes, 1976) and drainage basin topography (USGS Quadrangle maps).

- Six years of continuous monitoring by the USGS (Williams and Pearson, 1985) were used to estimate the average annual outflow rate from the lake.

- The average annual total phosphorus loading from all sources was determined using a steady-state mass balance model. Estimation of total P loads to the lake before and after start-up of the WWTF were based on existing data describing whole lake content of P. This method provided an estimate of the increase in loading that occurred following WWTF start-up which could be compared with direct measurements of nutrient export from the facility.

- Predicted changes in lake water quality resulting from effluent quality changes or diversion from Rock Creek were made.

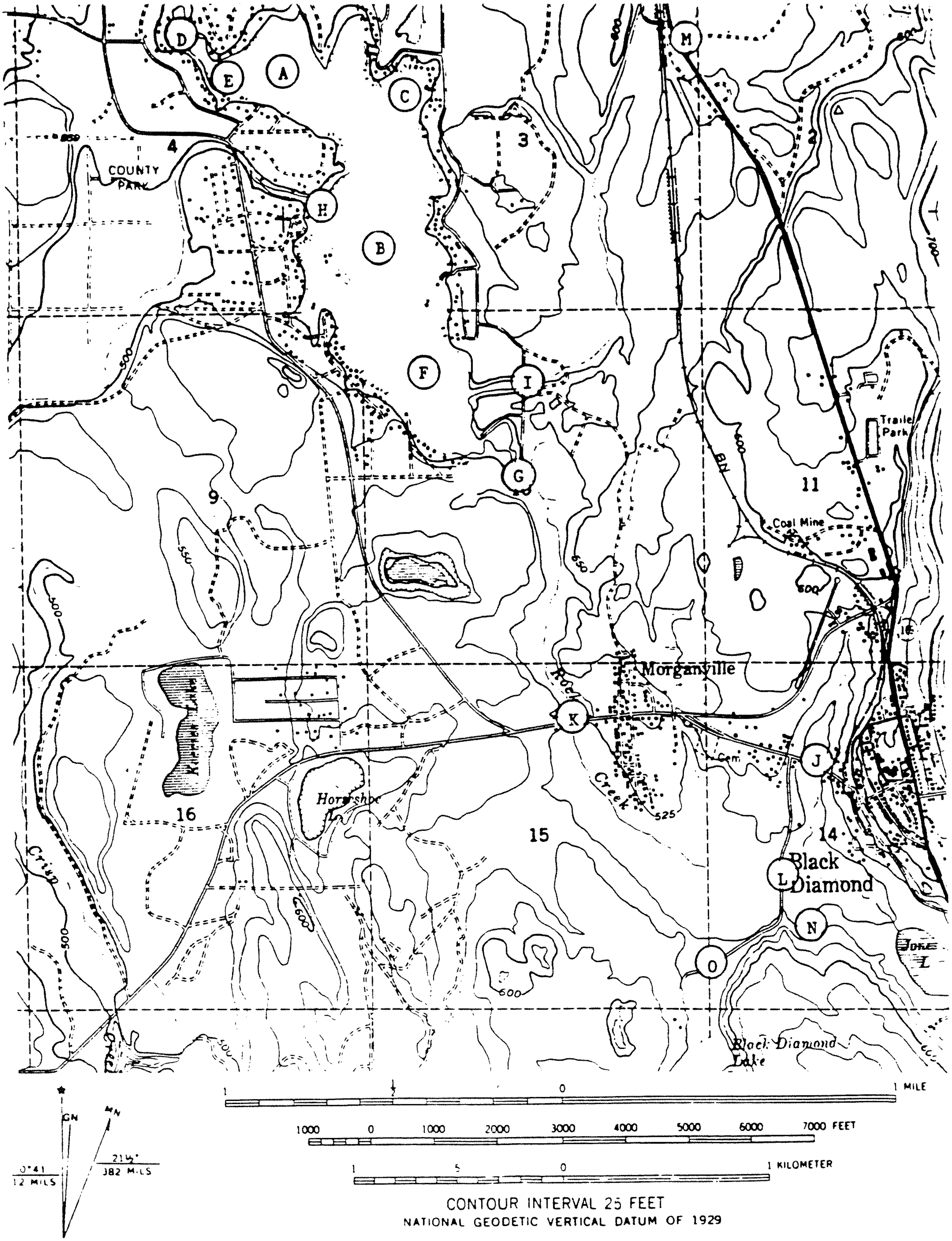

Figure 3. Historical monitoring sites in the Lake Sawyer basin (see Table 2 for description of sites).

Table 2. Historical water quality sampling activities pertinent to evaluation of eutrophication in the Lake Sawyer drainage basin.

Organization	Year(s)	Area	Site[1]	Depth[2]	Parameters
Metro	71,72,73,79,80, 83,84,85,86,	Lake	A	1,5,10,15	secchi,temp,pH,DO,turb,cond,alk,chla,pheao, NH_3-N,NO_2+NO_3-N,SRP,TP*,coliform
	71,72,79,80	Lake	B	1,8,16	Same as above
	71,72,73	Lake	C	1	Same as above, but no chla,or SRP
	71,72,73	Lake	D	1	Same as above
	71,72,73	Lake	E	1	Same as above
	85	Lake	F	1	Same as above
	72,73,79	Rock Cr.	G	S	Same as above with SRP
	72,73	Cov'tonCr.	H	S	Same as site C
	85	Rock Cr.	G	S	Coliform, NO_3, NH_3, TP, SRP, pH, cond
	85	Rav'aleCr.	I	S	Coliform, NO_3, NH_3, TP, SRP, pH, cond
USGS	53-59,60-75	Cov'tonCr.	H	-	Gage height
	73	Lake	B	1,16	secchi,temp,pH,DO,turb,cond,alk,chla,pheoa, NH_3-N,NO_2+NO_3-N,SRP,TP*,coliform,Si,CA, Fe,Mn,Na,K,HCO_3,CO_3,Org.N,color,TOC,hard,TSS
WA Ecology	72,78	Ginder Cr.	J	S	DO,temp,coliform,NO_2,NO_3,NH_3,BOD,COD, spec.cond.,pH,TP,SRP,solids,MBAS
Kramer, Chin & Mayo, Inc.	80,81,82	Rock Cr.	G,K,L	S	Discharge,TP,SRP,NO_2,NO_3,TKN
		Rav'aleCr.	M	S	Discharge,TP,SRP,NO_2,NO_3,TKN
R.W. Beck, Inc.	85	Rock Cr.	N,O	S	Discharge,TP,SRP,NO_2,NO_3,TKN,BOD,TSS
City of Black Diamond	83 to present	Rock Cr.	K	S	Discharge,TP,SRP,NO_3,NO_2,NH_3

*) All phosphorus data were reported as hydrolyzable P prior to 1975.
1) Site codes refer to Figure 3 sites
2) Depth of 'S' is surface sample

Uncertainty Analysis

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

Statistical techniques which describe the effects of contributing uncertainties are broadly categorized as error propagation methods. For this report, we have utilized a first-order uncertainty methodology. The theory and application of first-order uncertainty analysis techniques have been described by Reckhow and Chapra (1983), Cornell (1973), and Lettenmaier and Richey (1979). Briefly, the technique is based upon the assumption that parameter variations can be propagated about the first derivative (i.e., first order) of a function relative to those variables which make up the function. In general, for any calculated quantity Y which is derived from measured parameters denoted by X:

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

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

$$\mathrm{Var}(Y) = \sum_{i=1}^{n} [(\delta Y/\delta X_i)^2 \, \mathrm{Var}(X_i)]$$

The quantity $(\delta Y/\delta X_i)^2$ describes the sensitivity of the calculated value (Y) to changes in each measured parameter (X_i) which describes the function. Unless otherwise stated herein, parameter estimates are presented as the mean values plus or minus ($\pm$) the standard error (SE) of the mean (Zar, 1974). A summary of error propagation formulas for some simple algebraic functions is presented in Appendix D.

RESULTS AND DISCUSSION

The trophic condition of a lake is determined by nutrient inputs and the assimilation properties of the lake. Evaluation of nutrient input and output (nutrient budget) rates provides a powerful decision-making tool when coupled with mass balance predictive models. Predicted changes in nutrient concentration, and the corresponding degree of eutrophication, can thereby be evaluated for various scenarios of development or wastewater management.

Water Budget

The water budget for Lake Sawyer can be described as:

$$(1) \qquad \frac{dV}{dt} = Q_{in} - Q_{out} + PA_S - E_V A_S$$

where (units: L = length, M = mass, T = time):

$\frac{dV}{dt}$ = Change in lake volume $[L^3/T]$

Q_{in} = Surface and ground water inflows $[L^3/T]$

Q_{out} = Total outflow $[L^3/T]$

P = Precipitation $[L/T]$

A_S = Lake surface area $[L^2]$

E_V = Lake evaporation rate $[L/T]$

Assuming change in lake storage over a long-term average period is negligible,

$$(2) \qquad Q_{in} = Q_{out} - PA_S + E_V A_S$$

The lake outlet was continuously gauged by the USGS between 1953 and 1960 (Williams and Pearson, 1985). The average annual outlet discharge during this period was 26.5 ± 2.8 cfs, based on six complete years of data. A summary of the annual water budget for Lake Sawyer is presented in Table 3. Lake Sawyer is rapidly flushed due to a relatively large drainage area (and, therefore, inflow rate) in comparison with lake volume. The flushing rate averages 2.7 lake volumes per year, which corresponds to a water residence time (i.e. the average time required to replace the entire lake volume) of 0.37 years, or less than five months. Ground water inflow and outflow are not included in the present water budget due to lack of existing data. If ground water outflow is substantial, then the flushing rate may be even more rapid than that presented herein.

Phosphorus Mass Balance Models

The principle algal nutrients, nitrogen (N) and phosphorus (P), generally control the biological productivity of aquatic systems, and thus indirectly determine a wide range of important water quality characteristics (OECD, 1982; Welch, 1980). The control each nutrient exerts within the lake system can be evaluated by the ratios of nitrogen to phosphorus. Nitrogen-to-phosphorus ratios above 17:1 (by mass) indicates that algal productivity is limited by phosphorus (Forsberg, 1980). Phosphorus is most often the limiting nutrient in freshwater systems, and this is assumed to be the case in Lake Sawyer (see later discussions). Nitrogen can also become limiting seasonally, especially if large amounts of wastewater enter the system (Welch, 1980).

Table 3. Average annual water budget summary for Lake Sawyer

Water Budget Component	Annual Discharge (cfs) Mean ± SE
Outflow[1]	26.5 ± 2.8
Precipitation[2]	1.9 ± 0.2
Evaporation[3]	0.8 ± 0.2
Inflow[4]	25.4 ± 2.8

1) Based on USGS data from 1953-60 (Williams and Pearson, 1985).

2) Source: Gladwell and Mueller, 1967. Precipitation equals 55 ± 6 inches/year.

3) Source: WSU, 1968. Pan evaporation equals 32 inches/year, with an assumed pan coefficient of 0.7 and estimated standard error of ± 30%.

4) Total of surface and net subsurface inflow calculated by difference in the water budget equation, assuming long-term storage changes are equal to zero.

The general equation for a phosphorus mass balance in a lake is expressed as follows (Reckhow and Chapra, 1983):

(3) $$V\frac{dP}{dt} = W - Q_{out}P - V_sA_sP$$

where

$V\frac{dP}{dt}$ = Change in lake P content [M/T]

W = External load of P [M/T]

Q_{out} = Outflow discharge rate $[L^3/T]$

V_s = Apparent P settling velocity [L/T]

P = Lake P concentration $[M/L^3]$

A_s = Lake surface area $[L^2]$

The steady state solution of the phosphorus budget equation is as follows (Reckhow and Chapra, 1983):

(4) $$P = \frac{W}{V_sA_s + Q_{out}} = \frac{L}{V_s + q_s}$$

where

L = Areal load of P $[M/L^2/T]$

q_s = Areal water loading [L/T]

V_s = Apparent P settling velocity [L/T]

This form of the phosphorus budget equation is generally recommended as the basic predictive model for performing waste load allocations for lakes (Mancini *et al.*, 1983), and results from the assumption that the sediments are an areal sink. Therefore, the rate of phosphorus deposition should be a function of sediment area (Chapra, 1975). The apparent P settling velocity (V_s) describes the net settling velocity of P over the lake surface area (A_s). Values of V_s ranging from 10 to 16 m/y have been reported. Mancini *et al.* (1983) recommend using 12.4 m/y for V_s if local data are not available. Instead of assuming a constant value common to all lakes, Rechkow and Chapra (1983) proposed an empirical modification of equation 4, using a function of q_s to determine V_s, so that:

(5) $$P = \frac{L}{11.6 + 1.2\, q_s}$$

Various other derivations of the phosphorus model (equation 3) are commonly used to predict lake phosphorus concentrations. Among the most widely applied versions are those proposed by Vollenweider (1976) and Larsen and Mercier (1976), which Mancini *et al.* (1983) have shown to be mathematically identical to each other:

(6) $$P = \frac{L}{z(\rho + \rho^{0.5})} = \frac{L}{q_s + z\rho^{0.5}}$$

where ρ = lake flushing rate $[T^{-1}]$

z = mean depth [L]

Each of the commonly used derivations of the steady-state P mass balance may be rearranged to estimate the total maximum permissible P load which would correspond to an acceptable in-lake P concentration. The three alternative models (equations 4, 5 and 6) discussed above are summarized in Table 4.

The Reckhow and Chapra (1983) model (equation 5) was based on data from 47 north temperate lakes, and is reported to have an uncertainty of ± 30 percent. Additionally, the nutrient, hydrological and climatic conditions of Lake Sawyer are within the range of the database used to derive this model. In contrast, the other two models were developed from fewer north temperate lakes with primarily oligotrophic characteristics (Reckhow and Chapra, 1983). Therefore, of the three models, equation 5 is the most appropriate predictive tool for Lake Sawyer. However, when the three loading models (Table 4) are compared using Lake Sawyer data (q_s = 21 m/y; $\rho = 2.7\ y^{-1}$), the results are not significantly different (with 95 percent confidence) from each other (Table 5). Therefore, since a) all three models yield essentially the same mean predicted values, and b) model uncertainties are reported by Reckhow and Chapra, equation 5 was selected to best derive permissible and predicted phosphorus loads for Lake Sawyer.

Historical Lake Water Quality and Nutrient Loading

Metro has collected samples from the lake at several different locations intermittently since 1971. Their efforts have been directed at characterizing trophic status and watching long-term trends in water quality (Brenner and Davis, 1988). Some complaint-response samples have been taken in the past (Davis, personal communication[1], 1989).

USGS maintained a gauge on Covington Creek at Lake Sawyer from 1953 to 1960, and recorded lake stage height until 1975 (USGS, 1975). They also collected some lake quality data in 1973 (Figure 4) as part of a cooperative monitoring program with Ecology (McConnell, Bortleson, and Innes, 1976).

The data collected by Metro and USGS since the early 1970s indicate the lake usually undergoes stratification and hypolimnetic oxygen depletion in the central and northern basins in the late spring through mid-fall. The thermocline usually forms somewhere between 5 and 10 meters (16 to 33 feet). Dissolved oxygen concentrations in the hypolimnion fall rapidly to 1 to 2 mg/L between June and July. Hypolimnetic waters usually become anoxic by August

1 Joanne Davis, Municipality of Metropolitan Seattle, 1989

Table 4. Summary of commonly used models for estimating phosphorus loads to lakes (all loads $gP/m^2/year$).

Model Reference	Loading Equation[1]
Reckhow and Chapra (1983)	$L = P\ (11.6 + 1.2\ q_s)$
Mancini _et al_. (1983)	$L = P\ (12.4 + q_s)$
Vollenweider (1976) and Larsen and Mercier (1976)	$L = P\ (q_s + z\rho^{0.5})$

1) q_s = areal water load (m/y);

z = mean depth (m);

ρ = flushing rate (y^{-1});

L = areal P load corresponding to in-lake concentration;

P = in-lake P concentration

Table 5. Comparison of models and calculation of phosphorus loads to Lake Sawyer corresponding to oligotrophic and eutrophic[1] thresholds.

Parameter	Units	Mean	± Std Err
Reckhow and Chapra (1983):			
Oligotrophic Threshold (P=10 ug/L)	g P/m2/year	0.368	± 0.110
	# P/day	2.5	± 0.8
Eutrophic Threshold (P=20 ug/L)	g P/m2/year	0.736	± 0.221
	# P/day	5.0	± 1.5
Mancini *et al.* (1983):			
Oligotrophic Threshold (P=10 ug/L)	g P/m2/year	0.334	--
	# P/day	2.3	--
Eutrophic Threshold (P=20 ug/L)	g P/m2/year	0.668	--
	# P/day	4.6	--
Vollenweider (1976); Larsen and Mercier (1976):			
Oligotropic Threshold (P=10 ug/L)	g P/m2/year	0.330	--
	# P/day	2.3	--
Eutrophic Threshold (P=20 ug/L)	g P/m2/year	0.660	--
	# P/day	4.5	--

1) The threshold between mesotrophic and eutrophic generally ranges from total P of 20 to 35 ug P/L in P-limited lakes, and is a function of individual lake response and investigator interpretation (OECD, 1982).

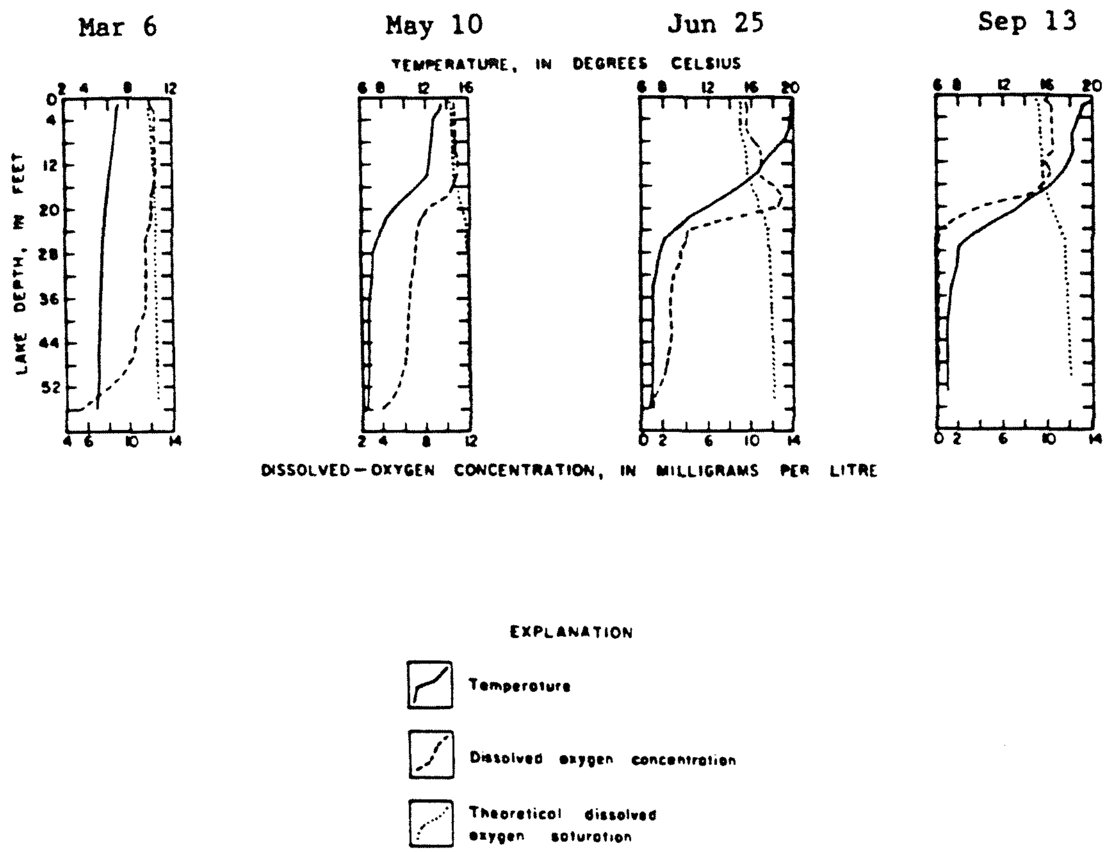

Figure 4. Dissolved oxygen and temperature profiles in Lake Sawyer, 1973 (McConnel, Bortleson and Innes, 1976).

(Figure 4). In 1973 the oxygen-depleted water included nearly half of the lake's volume. Hypolimnetic oxygen depletion is usually related to the decay of algae, or decay of organic materials originating in the watershed. The rate of oxygen depletion has been correlated to trophic status and nutrient loading in lakes (Welch and Perkins, 1979).

Metro investigators have used chlorophyll *a*, total phosphorus, and transparency data to evaluate the trophic condition of lakes in King County (Brenner and Davis, 1988). Historically, Lake Sawyer has exhibited an overall mesotrophic state according to these indicators (Figure 5). Summer chlorophyll *a* concentrations and transparency values have usually been in the oligotrophic and mesotrophic area of Metro's classification system. Winter phosphorus concentrations have usually indicated eutrophic or mesotrophic tendencies. A trend toward improving or declining water quality is not readily apparent from the Metro summaries, although the most recent data have shown a tendency toward more frequent and intense algal blooms (Appendix A).

The lack of an apparent trend in existing summaries of in-lake total phosphorus may be partly due to inclusion of data which are not comparable in earlier years of study. Metro's phosphorus data from 1971 to 1973 are not reported as total P, and were based on a different chemical technique than the total P analysis which was used from 1979 to the present (Brenner, personal communication, 1989)[2]. The USGS was independently sampling Lake Sawyer and reported total P in 1973. Comparisons of USGS and Metro data for the same time period suggest that Metro's earlier hydrolyzable P data are not comparable to total P data (Table 6). Therefore, the following trend analysis (Figure 6) excludes the 1971 to 1973 Metro data.

Only whole water column observations (i.e. samples spaced between the surface and lake bottom) were included in the summaries presented in Table 6 and Figure 6 in order to characterize changes in whole-lake content of total phosphorus. Also, the recent long-term average total P concentration excludes data collected during the WWTF start-up period (1983) because of the time required for the lake to reach a new equilibrium condition in response to changed loading. Because of a relatively rapid flushing rate, Lake Sawyer is predicted to reach 90 percent of a new equilibrium condition within approximately six months of a change in phosphorus loading. Therefore, data from 1984-89 would be expected to represent an approximate steady-state average for the existing lake condition.

The 1973-80 USGS and METRO data used to describe whole lake total P prior to WWTF start-up contain observations collected during oxic and anoxic condtions. The average of all of these observations, as shown in Table 6, was 20 ±3 ug P/L. Exclusion of data collected during anoxic conditions resulted in an average of 19 ±5 ug P/L for this period, which is not significantly different from the average of all data (oxic and anoxic). Therefore, the overall average (20 ± 3 ug P/L was chosen to compare pre- and post-WWTF conditions, even though the post-WWTF data were collected only during oxic conditions (Appendix A).

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2 Bob Brenner, Municipality of Metropolitan Seattle, 1989.

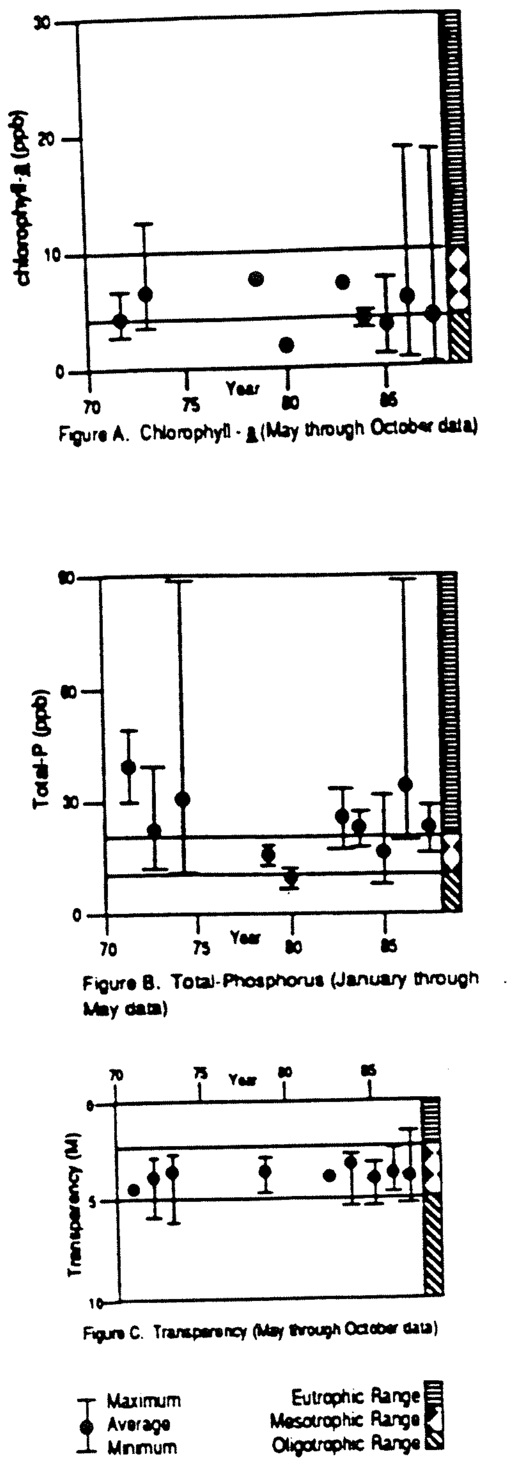

Figure 5. Metro summary of chlorophyll (a), total phosphorus (b), and transparency (c) in Lake Sawyer (Brenner and Davis, 1988).

Table 6. Summary of historical total P and total N data. Volume weighted averages for whole lake concentrations (ug/L).

Data Source	Time Period	< Total P > mean ± SE,n	< Total N > mean ± SE,n	TN:TP
USGS	1973	23.4 ± 7.0, 4	579 ± 134, 4	25
Metro[1]	1971-73	33.7 ± 3.2, 38	--- ---	--
Metro, USGS[2]	1973-80	20.4 ± 3.2, 10	--- ---	--
Metro, Ecology[3]	1984-89	30.7 ± 7.5, 12	625 ± 10, 2	27
TROPHIC STATE CRITERIA[4]				
Oligotrophic		<10	<150	--
Mesotrophic		10-20	150-300	--
Eutrophic		20-50	>300	--
Hypereutrophic		>50	---	--

1) Metro phosphorus analyses for the 1972-73 period were not "total P" - a "hydrolyzable" P value is reported with an accuracy of ± 10 ug/L.

2) Metro data from 1971-73 excluded because of inconsistent method and apparent bias.

3) 1983 Metro data were excluded due to WWTF start-up in January, 1983.

4) Nitrogen criteria are tentative, and only applicable if nitrogen is the limiting nutrient (Mancini et al., 1983). The threshold between mesotrophic and eutrophic generally ranges from total P of 20-35 ug/L in P-limited lakes, and is a function of individual lake response.

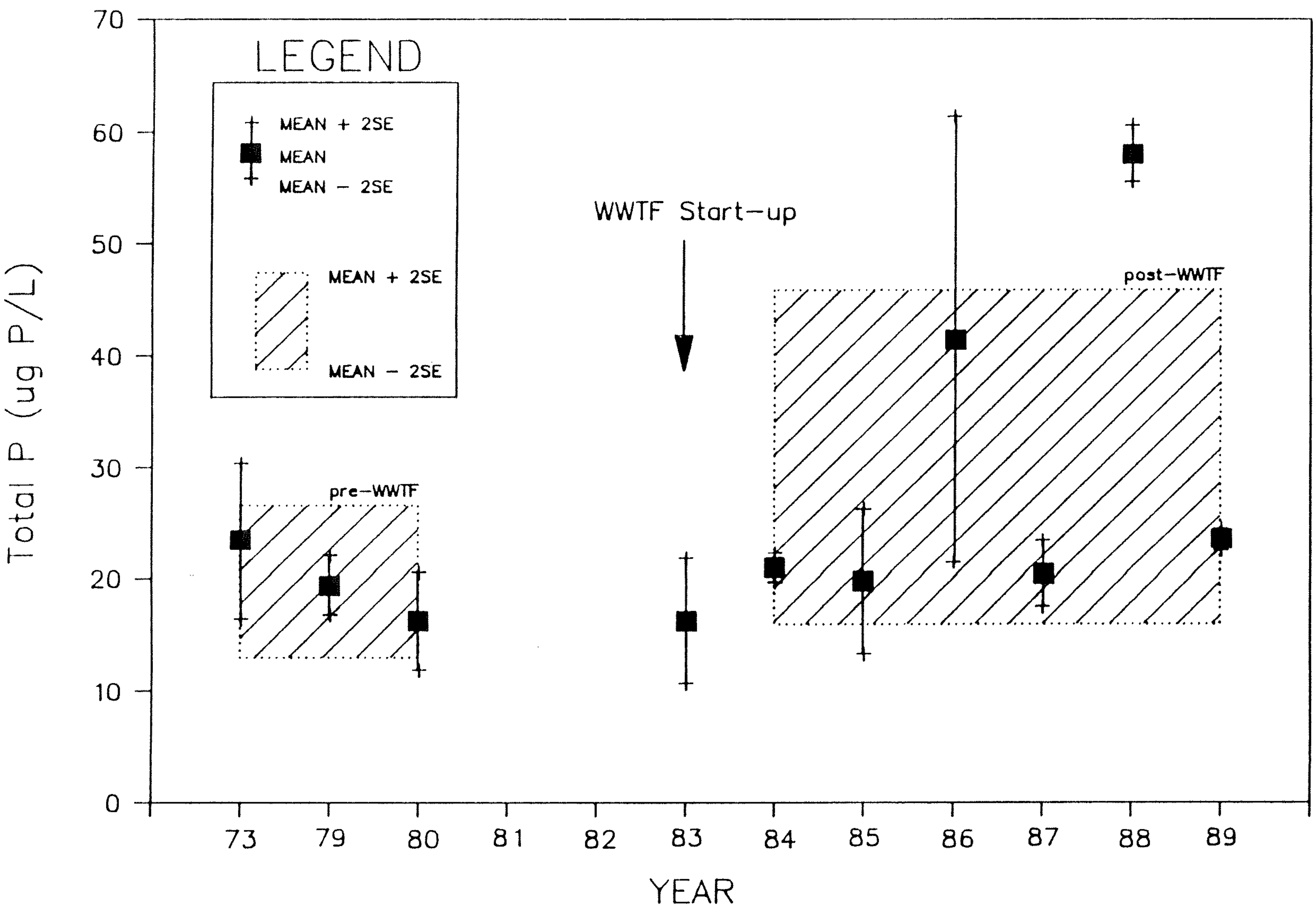

Figure 6. Comparison of whole-lake total P before and after discharge of effluent from the Black Diamond WWTF. Data from 1983 were excluded from the post-WWTF average because of the time required for the lake to reach a new equilibrium with changed loading.

Comparison of whole-lake total P data collected before and after start-up of the Black Diamond WWTF reveal an apparent increase of approximately 10 ± 8 ug P/L (Table 7; Figure 6). Loading was estimated by substituting the observed whole lake total P concentrations into the Reckhow and Chapra loading equation (Table 7). The concentration increase corresponds to an increased load to the lake of approximately 2.6 ± 2.2 #P/day following the WWTF start-up.

The available data suggest that, overall, productivity in Lake Sawyer is limited by phosphorus. Ratios of total N to total P were generally greater than 25:1 (by mass) in the USGS studies (McConnell *et al.*, 1976) and ongoing Ecology investigations (Table 6). Therefore, increases or decreases in phosphorus loading to the lake would be expected to result in corresponding increases or decreases in algal productivity and biomass. Since phosphorus is the limiting nutrient, control of nitrogen loads to the lake would not be expected to influence water quality to the same extent as phosphorus controls. Therefore, the influence of changing phosphorus loads on lake trophic status is examined in greater detail below.

Black Diamond Wastewater Treatment Facility

Facility History

Prior to 1982, about 35 percent of the Black Diamond population was served by three community septic systems. All other residents were on individual systems. All the community systems and some of the individual systems had experienced failures in the 1970s (KCM, 1979). Ecology staff had documented the consequent water quality deterioration of Ginder and Rock Creeks (Thielen, 1978; Devitt, 1972). Health authorities were highly concerned (KCM, 1979).

Planning for improvement of the waste treatment facilities began in 1967 and continued through the 1970s (KCM, 1979). Lagoon and wetland treatment was the preferred alternative selected from among five system designs presented in the 1979 wastewater facility plan and environmental assessment (KCM, 1980). The lagoon and wetland design as first proposed contained the following features:

- Two-stage extended aeration basin
- Chlorine contact chamber
- Two 3.5-acre controlled (artificial) marsh ponds
- Discharge to Rock Creek via the natural wetland

Objections from the U.S. Fish and Wildlife Service, Friends of the Earth, Seattle Audubon Society, Washington Department of Game, and National Marine Fisheries Service concerning one or more of the design features, especially construction of the artificial marsh ponds, resulted in proposal of a modified design (KCM, 1981). The new design substituted distribution of wastewater to the natural riparian wetland along Rock Creek for the artificial marsh ponds. The design qualified for USEPA innovative and alternative (I & A) funding.

Table 7. Summary of calculated total P loads corresponding to measured in-lake concentrations.

Parameter	Units	Mean	±	Std Err
CALCULATED PHOSPHORUS LOADS CORRESPONDING TO IN-LAKE CONCENTRATIONS				
Prior to start-up of WWTF (1973-80)				
Whole lake total P concentration	ug P/L	20.4	±	3
Estimated total P load	g P/m2/year	0.751	±	0.254
	# P/day	4.9	±	1.7
After start-up of WWTF (1984-89)				
Whole lake total P concentration	ug P/L	30.7	±	8
Estimated total P load	g P/m2/year	1.130	±	0.437
	# P/day	7.7	±	3.0
Net increase after WWTF start-up				
Whole lake concentration increase	ug P/L	10.3	±	8
Estimated total load increase	g P/m2/year	0.379	±	0.321
	# P/day	2.6	±	2.2

As an I & A system, the WWTF would also be eligible for 100 percent modification or removal funding if it failed to meet NPDES permit limits within two years of operation.

After start-up, the WWTF did not meet its NPDES permit requirements. Evaluations by R.W. Beck (1985) and ERM (1986) confirmed the facility was not meeting designed nutrient treatment levels. The WWTF was subsequently declared to be a failed I & A project. Appendix E contains a detailed summary of the work leading up to the determination of the facilities failure. Determination of facility failure allows environmental concerns to be re-evaluated in consideration of present and future design conditions.

WWTF Nutrient Loads

The ability of natural wetlands to assimilate nutrient loads from wastewater is a function of the loading rate and wetland treatment area. At low loading rates (1-5 g $P/m^2/y$), natural wetlands have been reported to remove substantial quantities of P from domestic wastewater (Nichols, 1983). The ability of natural wetlands to remove wastewater P generally decreases rapidly at higher loading rates (> 10 g $P/m^2/y$; Nichols, 1983). Phosphorus loading rates to the natural wetland from the Black Diamond WWTF currently are relatively high [14 g P/m^2/year, assuming an 11-acre contact area (Appendix E)] and are expected to be considerably higher in the future (41 g P/m^2/year at the WWTF design flow assuming existing effluent P concentrations). Since the adsorption/precipitation mechanism for P retention is not a limitless sink, high P loadings similar to the existing and future load from the Black Diamond WWTF can saturate the capacity of the wetland soils to remove P and lead to reduced or insignificant treatment efficiency.

Average flows from the Black Diamond WWTF are presented in Table 8. Plant flows since start-up of the facility (1983-88) have averaged 0.106 MGD. The planning period considered in the facilities plan extends to the year 2010 (Brown and Caldwell, 1988), at which time projected average annual flows are expected to reach 0.307 MGD.

Influent total P loads to the Black Diamond WWTF averaged 6.9 ± 0.4 #P/day between 1983 and 1988 (Table 9). Substantial removal (40 - 50%) of both total phosphorus and nitrogen has been observed in the lagoon system based on comparison of historical influent and effluent data (Table 9). Nutrient loading to the Rock Creek wetland system from the WWTF has averaged 3.8 ± 0.3 # P/day of total phosphorus and 15 ± 1.6 #N/day of total nitrogen between 1983 and 1988 (Table 9).

Calculated phosphorus loading from the WWTF based on effluent discharge and concentration (3.8 ±0.3 # P/day) is similar to the loading required to explain the observed increase in whole-lake total P following WWTF start-up (2.6 ± 2.2 # P/day; see Table 7). The close agreement between these independently calculated values suggests that the steady-state mass balance model accurately represents Lake Sawyer, and that the observed increases in whole-lake total P are a result of loading from the Black Diamond WWTF. Comparison of these values suggests that approximately two-thirds of the WWTF effluent load to the Rock Creek wetland system is reaching Lake Sawyer, assuming the post-WWTF increase in lake

Table 8. Black Diamond WWTF plant influent flows.

Month	1983[1]	1984[1]	1985[2]	1986[2]	1987[2]	1988[3]	1983-88 Monthly Average
	<-------------- Average Monthly Flow (mgd) ------------->						
Jan	0.158		0.089	0.140	0.130	0.102	0.124
Feb	0.121	0.124		0.141	0.116	0.126	0.126
Mar		0.119	0.086	0.130	0.150	0.144	0.126
Apr	0.079	0.104	0.096	0.099	0.115	0.147	0.107
May	0.078	0.123	0.089	0.111	0.085	0.129	0.103
Jun	0.075	0.094	0.093	0.099		0.111	0.094
Jul	0.091	0.075	0.067	0.079		0.081	0.079
Aug	0.068	0.064	0.067	0.066	0.083	0.077	0.071
Sep	0.082	0.065	0.070	0.082	0.058	0.082	0.073
Oct	0.069		0.084	0.071	0.055	0.105	0.077
Nov	0.144	0.139		0.167	0.062	0.210	0.144
Dec	0.127	0.290	0.130	0.122	0.095	0.147	0.152
Avg[4]	0.101	0.116	0.095	0.109	0.094	0.122	0.106
Std Err[5]							0.005

1) source: ERM (1986)
2) source: Brown and Caldwell (1988)
3) source: NPDES reports
4) where data for a month are missing, monthly average was used to compute annual average
5) standard error of annual averages

Table 9. Summary of Black Diamond WWTF waste stream characteristics, 1983 to present.

Parameter	Units	Mean	±	SE
INFLUENT				
Flow	mgd	0.106	±	0.005
Total P				
-Concentration	mg P/L	7.8	±	0.2
-Load	#P/day	6.9	±	0.4
Total N				
-Concentration	mg N/L	30.7	±	3.7
-Load	#N/day	27.2	±	3.5
Inorganic N				
-Concentration	mg N/L	21.0	±	1.0
-Load	#N/day	18.6	±	1.2
EFFLUENT				
Total P				
-Concentration	mg P/L	4.3	±	0.2
-Load	#P/day	3.8	±	0.3
Total N				
-Concentration	mg N/L	17.4	±	1.6
-Load	#N/day	15.4	±	1.6
Inorganic N				
-Concentration	mg N/L	12.6	±	3.1
-Load	#N/day	11.1	±	2.8
LAGOON TREATMENT EFFICIENCY				
Total P	% removal	45%	±	5%
Total N	% removal	43%	±	9%
Inorganic N	% removal	40%	±	16%

total P is due entirely to WWTF input and not, in part, to increases in other sources (e.g. nonpoint sources, internal loading).

Four scenarios of WWTF nutrient loading were considered for evaluation of lake water quality response: 1) existing condition, 2) future (2010) discharge with existing nutrient removal efficiency, 3) future (2010) discharge with currently permitted nutrient removal efficiency, and 4) future (2010) discharge with technologically feasible removal of phosphorus and nitrogen assuming advanced waste treatment processes are utilized. A summary of Black Diamond WWTF nutrient loading to Lake Sawyer via Rock Creek is presented in Table 10. Future (2010) loading of phosphorus is expected to be nearly triple the existing load if no improvements in nutrient removal efficiency are implemented. Advanced waste treatment would result in future phosphorus loads to Lake Sawyer which are nearly two-thirds of the existing load. Future nitrogen loads would be nearly triple existing loads if no improvements in removal are implemented, and nearly double existing loads if permitted removals are adhered to or if advanced waste treatment is utilized.

Tributary Water Quality

Data collected during 1980-82 from Rock Creek (at the Morganville Bridge) and Ravensdale Creek (KCM, 1982) provide a direct estimate of nutrient loading to Lake Sawyer prior to start-up of the Black Diamond WWTF. Both total phosphorus and total nitrogen show significant relationships between concentration and flow (Figure 7). Total P in Rock Creek was significantly higher than Ravensdale Creek, while total N concentrations were not significantly different between creeks. Rock Creek also showed a significant tendency toward increasing total P with decreasing flow. This suggests a relatively constant input, possibly related to failing community septic systems or other nonpoint sources within the drainage area. Nutrient concentrations in Ravensdale Creek probably provide an indication of background conditions from undeveloped land in the Lake Sawyer basin.

Nutrient concentrations in Rock Creek following start-up of the Black Diamond WWTF are documented by three sources of data: 1) city of Black Diamond NPDES monitoring at the Morganville Bridge from 1983 - 1988, 2) R.W. Beck (1985) investigations of wetland treatment efficiency in 1985, and 3) Ecology sampling in 1989. Unfortunately, flow data for the entire record of NPDES monitoring by the city of Black Diamond are either unreliable or unreported (R.W. Beck, 1985). The R.W. Beck and Ecology data sets provide flow measurements concurrent with water quality sampling and were therefore used to determine the nutrient loading estimates.

A summary of nutrient loads measured from tributaries to Lake Sawyer is presented in Table 11. Total phosphorus loads from Rock Creek were significantly elevated following start-up of the WWTF. Nutrient loads in Rock Creek upstream from the WWTF input did not appear to decrease significantly following WWTF start-up, which suggests that non-point nutrient loads within the basin have not changed substantially as a result of sewering. However, nutrient loads from Rock Creek sources upstream from the WWTF are not well documented for the period following WWTF start-up, but will be determined during the ongoing diagnostic study

Table 10. Summary of Black Diamond WWTF nutrient loading to the Rock Creek wetland system for alternative scenarios of discharge and treatment.

Scenario	Discharge (mgd)	< Total P > Effluent Concentration (mg/L)	Load (#P/day)	< Total N > Effluent Concentration (mg/L)	Load (#N/day)
1. Existing (1983-88) condition	0.106	4.3	3.8	17	15
2. Future (2010) discharge with existing nutrient removal efficiency	0.307	4.3	11	17	44
3. Future (2010) discharge with permitted nutrient removal efficiency[1]	0.307	3.9	10	11	28
4. Future (2010) discharge with advanced waste treatment[2]	0.307	1.0	2.6	10	26

1) Effluent concentrations estimated based on average annual reduction of influent concentrations for phosphorus and nitrogen of 50% and 65%, respectively.

2) Effluent concentrations estimated based on maximum feasible level of advanced waste treatment (Brown and Caldwell, 1988).

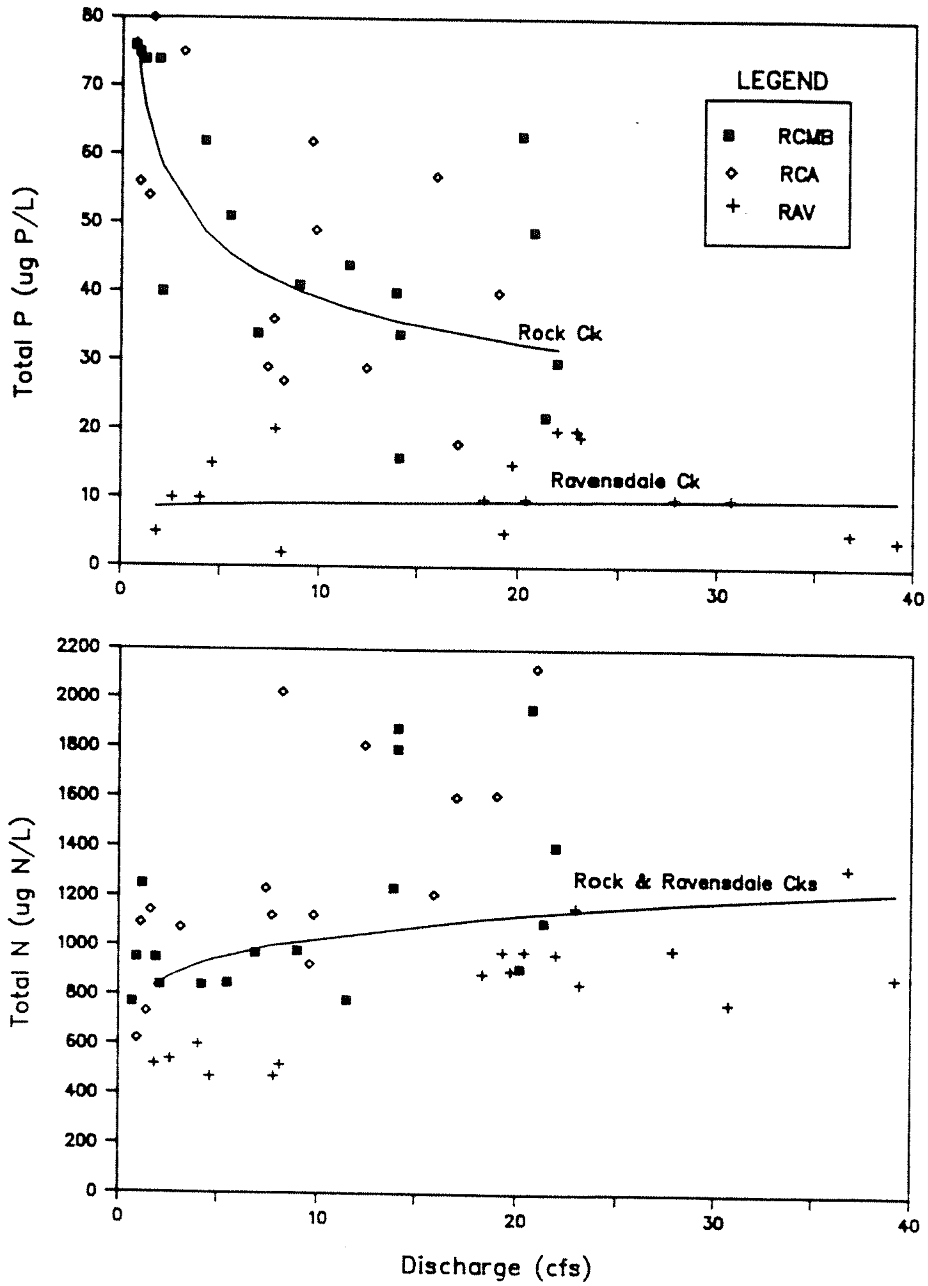

Figure 7. Relationships between total P, total N and discharge in Rock Ck at the Morganville Bridge (RCMB), Rock Ck at Abrams Road (RCA), and Ravensdale Ck (RAV) prior to start-up of the Black Diamond WWTF (1980-82).

Table 11. Summary of total P and total N loads measured in tributaries of Lake Sawyer.

	Total P (#P/day) mean ± SE,n	Total N (#N/day) mean ± SE,n
Rock Creek at Morganville Bridge		
- 1980-82 (KCM, 1982)	2.1 ± 0.4, 17	70 ± 16, 17
- 1985 (R.W. Beck, 1985)	8.1 ± 2.1, 5	20 ± 5, 5
- 1989 (Ecology)	7.8 ± 0.6, 2	124 ± 2, 2
Rock Creek at Abrams Road		
- 1980-82 (KCM, 1982)	1.5 ± 0.4, 17	66 ± 17, 17
- 1985 (R.W. Beck, 1985)	0.4 ± 0.1, 5	12 ± 2, 5
- 1989 (Ecology)	2.2 ± 0.4, 2	132 ± 6, 2
- 1980-89 (All data)	1.3 ± 0.6, 24	60 ± 18, 24
Ravensdale Creek		
- 1980-82 (KCM, 1982)	1.1 ± 0.2, 17	92 ± 18, 17
- 1989 (Ecology)	0.9 ± 0.2, 2	83 ± 13, 2
- 1980-89 (All data)	1.1 ± 0.3, 19	91 ± 22, 19

by Ecology. Nutrient loads from Ravensdale Creek have remained fairly constant over the period of record, which is consistent with the low level of development in that sub-basin.

Nonpoint Phosphorus Loads

In addition to point source loading from the Black Diamond WWTF, nonpoint sources also contribute to the total nutrient load to Lake Sawyer. The important nonpoint sources include background inputs from undeveloped land, and diffuse inputs from developed land use, septic systems, and atmospheric deposition.

Average annual nutrient loads from the Rock Creek and Ravensdale Creek sub-basins may be estimated directly based on historical water quality monitoring of the creeks and the Black Diamond WWTF (Table 12). The average annual load to Lake Sawyer between 1984 and 1989, from all sources combined, was estimated using the steady-state mass balance model with the observed whole-lake total P concentration. Direct atmospheric P deposition to the lake surface was assumed equal to 35 ± 15 kgP/Km^2/yr (Reckhow and Chapra, 1983). The remaining local nonpoint total P load, from sources including nearshore septic systems and residential land use, was estimated based on the difference between the model estimate of total loading, and all other directly estimated loading sources (Table 12). An estimate of 1.7 ± 3.7 #P/day results as the local nonpoint source input (e.g., septic systems), although the uncertainty is relatively high.

An alternative method of computing local nonpoint total P loading is by direct estimation from published export coefficients describing similar settings, and estimates of developed land area. An estimated 300 acres of residential land area surround the lake shore within a radius of 1000 feet. At a typical land use export coefficient of 190 ± 110 kg P/km^2/year (Reckhow and Chapra, 1983) the nonpoint total P load from residential land use (e.g., lawn fertilizing, impervious area wash off) is estimated to be 1 ± 1 #P/day.

An estimated 1100 people use nearshore septic systems, based on the number of homes in the watershed within 1000 feet of the lake shore (310 homes with an assumed occupancy of 3.5 people/home). The direction of ground water flow around the lake shore is not certain based on currently available information. However, the predominant direction of ground water movement is toward the west (Brown and Caldwell, 1988). Therefore, septic systems on the western shore may not discharge toward the lake. For the purpose of estimating septic system loading, it is assumed that 50 to 100% (75% ± 25%) of the nearshore homes discharge septic system wastewater toward the lake. Soil retention of phosphorus is likely to be rather low due to the course texture of the predominantly gravelly Everett-series soils. It is assumed that 0 to 50% (25% ± 25%) of the phosphorus discharged from each septic system is immobilized in the soil beneath the drainfield. The resulting estimate of total P loading to Lake Sawyer from nearshore septic systems, based on the assumptions above and an assumed phosphorus load to septic systems of 1.5 kgP/cap/yr (Uttormark *et al.*, 1974), is 2 ± 2 #P/day.

Local nonpoint total P loading therefore is estimated to be 3 ± 3 #P/day from nearshore septic systems and residential land use. This quantity is not significantly different from the indirect estimate based on the total P budget in Table 12 (1.7 ± 3.7 #P/day). Both the direct and

Table 12. Summary of annual total phosphorus budget for Lake Sawyer for existing condition.

	Total P (#P/day) Mean ± SE
Rock Creek	
- Black Diamond WWTF[1]	2.6 ± 2.2
- Background & nonpoint	2.1 ± 0.4
- Rock Creek Total	4.7 ± 2.2
Ravensdale Creek	1.1 ± 0.2
Atmospheric Deposition[2]	0.2 ± 0.1
Total Lake Sawyer Load[3]	7.7 ± 3.0
Local Nonpoint Load[4]	1.7 ± 3.7

1) Loading to Lake Sawyer from the Black Diamond WWTF is based on the observed in-lake P increase, which suggests that 68% ± 58% of the WWTF effluent load to the wetland system reaches the lake.

2) from Reckhow and Chapra (1983) atmospheric deposition assumed to be 35 ± 15 $Kg/Km^2/yr$

3) from steady-state mass balance model for post-WWTF whole-lake average total P concentration (Table 7)

4) Residual non-point load estimated as total load minus atmospheric, Ravensdale Ck., and Rock Ck. loads. This category includes all loading sources not within the Rock Creek or Ravensdale Creek sub-basin or directly deposited to the lake surface (e.g. nearshore septic systems and residential non-point loading).

indirect estimates of local nonpoint loading suggest that this category of input may be as large as the current point source input from the Black Diamond WWTF. However, nonpoint sources, in general, are more difficult to control than point source inputs due to their diffuse nature. Furthermore, point source inputs are expected to increase substantially, as the WWTF reaches its design capacity (Table 10). Nonpoint sources may not increase substantially since the nearshore region of the lake is nearly developed with residential land use, and further development will probably occur at a relatively large distance from the lake shore. However, nonpoint sources should be recognized as a significant component of the total P load. Any increases in nonpoint loading due to increased development in the watershed would be expected to result in corresponding increases in Lake Sawyer total P concentration and acceleration of eutrophication.

The indirectly calculated quantity of local nonpoint total P loading (1.7 ± 3.7 #P/day) represents the total residual of unmeasured or unaccounted loading sources. Therefore, in addition to local nonpoint loading, this quantity also reflects internal loading from lake sediments and other internal processes. The comparison of indirectly calculated (1.7 ± 3.7 #P/day; Table 12) and directly calculated (3 ± 3 #P/day) quantities of local nonpoint total P loading suggests that internal loading may not be significant, since the unmeasured residual of the total P budget can be explained by directly estimated local nonpoint loading. However, since the uncertainties are relatively high, internal loading may be a substantial source of phosphorus. Nevertheless, the rate of internal loading is accounted for in the phosphorus budget (Table 12) and lake response predictions which follow since total loading is based on the equilibrium of in-lake total P with all sources of external and internal loading.

Response of Lake Sawyer to Changed Phosphorus Loading

Existing lake phosphorus data reflect the influence of all present sources of loading to Lake Sawyer. For the period following start-up of the WWTF (1984 - 89), six years of observations represent the steady-state condition of the lake in response to point source inputs, nonpoint loading from background and developed land use, and internal loading or recycling of phosphorus. In order to calculate the response of Lake Sawyer to changes in phosphorus loading with the least uncertainty, the existing lake data and the steady-state model (equation 5) can be used together to evaluate the impact of forecasted loading changes (Reckhow and Chapra, 1983). An example of the technique used to predict Lake Sawyer total P concentrations, including uncertainty, is presented in Appendix F.

Table 13 presents a summary of predicted Lake Sawyer total P concentrations for incremental loading changes associated with various scenarios of WWTF discharge and treatment. The existing condition of the lake is described by the average whole-lake total P concentration observed between 1984 and 1989 (31 ± 8 ug P/L). This concentration is the result of the equilibrium with the point source total P input, and the additional local nonpoint loading and tributary background. The future (2010) condition of the lake was predicted for four alternative scenarios of WWTF discharge and treatment: 1) future (2010) discharge with existing total P removal; 2) future (2010) discharge with currently permitted total P removal; 3) future (2010) discharge with feasible advanced treatment for total P removal; and 4) complete diversion of wastewater from the Rock Creek system.

Table 13. Summary of predicted Lake Sawyer total P concentrations for incremental loading changes associated with various scenarios of WWTF discharge and treatment.

	Black Diamond WWTF Effluent Total P Load (# P/day)	Increment of Changed Loading[1] (# P/day)	Increment of Changed Lake Sawyer Total P Conc[2] (ug P/L)	Resulting Lake Sawyer Total P Conc (ug P/L)
EXISTING CONDITION (1984-89)	3.8	--	--	31 ± 8
FUTURE CONDITION (2010)				
Current Treatment Efficiency	11.0	4.9 ± 4.2	20 ± 18	51 ± 20
Permitted Treatment Efficiency	10.0	4.2 ± 3.6	17 ± 16	48 ± 17
Feasible Advanced Treatment Efficiency[3]	2.6	-0.8 ± 0.7	-3 ± 3	27 ± 8
Complete Diversion	0.0	-2.6 ± 2.2	-11 ± 10	20 ± 12
TROPHIC STATE CRITERIA (ug P/L)				
Oligotrophic	--	--	--	<10
Mesotrophic[4]	--	--	--	10-20
Eutrophic[4]	--	--	--	20-50
Hypereutrophic	--	--	--	>50

1) Incremental increase or decrease from existing (1984-89) level of point source loading assuming 68% ± 58% of the WWTF effluent P is transported to Lake Sawyer.

2) Incremental increase or decrease from existing (1984-89) whole-lake total P.

3) Feasible advanced treatment assumed to produce effluent total P concentration of 1 mg P/L.

4) The threshold between mesotrophic and eutrophic generally ranges from 20-35 ug P/L, which is a function of individual lake response.

Predicted lake response to future discharges (Table 13) at present or currently permitted total P removal efficiencies indicate a substantial enrichment (in-lake P >50 ug P/L). Changes of this magnitude would probably represent a substantial degradation in quality from the existing condition (see below). Implementation of advanced waste treatment would probably result in some improvement over the existing condition. Complete diversion of wastewater would result in the greatest potential improvement to the lake, and is predicted to return the lake to the condition that existed prior to start-up of the WWTF.

The predictions for future Lake Sawyer total P presented in Table 13 are based on the assumption that loading sources other than the WWTF will remain at their current (1984-89) level. If, as is likely, some increases in nonpoint loading occur in the future, then the actual future lake concentrations will probably be somewhat higher than those presented in Table 13.

Total Maximum Daily Phosphorus Loading

The management goal for Lake Sawyer is to minimize the eutrophication process. Although trophic descriptions (e.g., eutrophic, mesotrophic) have no absolute meaning, they are generally used by many lake investigators and managers to denote the nutrient "status" of a waterbody, or describe the effects of nutrients on water quality (OECD, 1982). Consequently, several attempts have been made to relate descriptive trophic terms to specific boundary values for key water quality parameters. The most rigorous attempt at such a classification scheme was presented by OECD (1982). The scheme is based on a probabilistic evaluation of an extensive limnological data base collected from lakes and reservoirs throughout the northern temperate zone. An example of the resultant probability distribution of trophic status based on the most highly correlated parameter--in-lake total P--is presented in Figure 8. The overlap between trophic categories is substantial, and attests to the subjective nature of trophic classifications.

Numerous fixed boundaries have been proposed to delineate the subjective trophic classifications (OECD, 1982; Mancini *et al.*, 1983; EPA, 1974; Brezonik, 1976; Dobson *et al.*, 1974; Wetzel, 1983). Table 14 presents a summary of the more commonly used relationships between lake phosphorus concentration, trophic state, and lake use for north temperate lakes. As a practical management goal, OECD (1982) recommends that for water uses which do not require high purity conditions (e.g., drinking water), achievement of a mid-mesotrophic condition should generally provide adequate protection against impacts to important water uses such as recreation and fisheries production. EPA (1986) reached a similar conclusion in recommending that in-lake total P concentrations less than 25 ug P/L should generally protect against undesirable water quality conditions associated with eutrophy. From Table 14 it is apparent that total P concentrations between 20 and 35 ug P/L represent the approximate boundary between mesotrophic and eutrophic designations, and should represent the approximate upper limit of acceptable enrichment before water quality degradation becomes apparent.

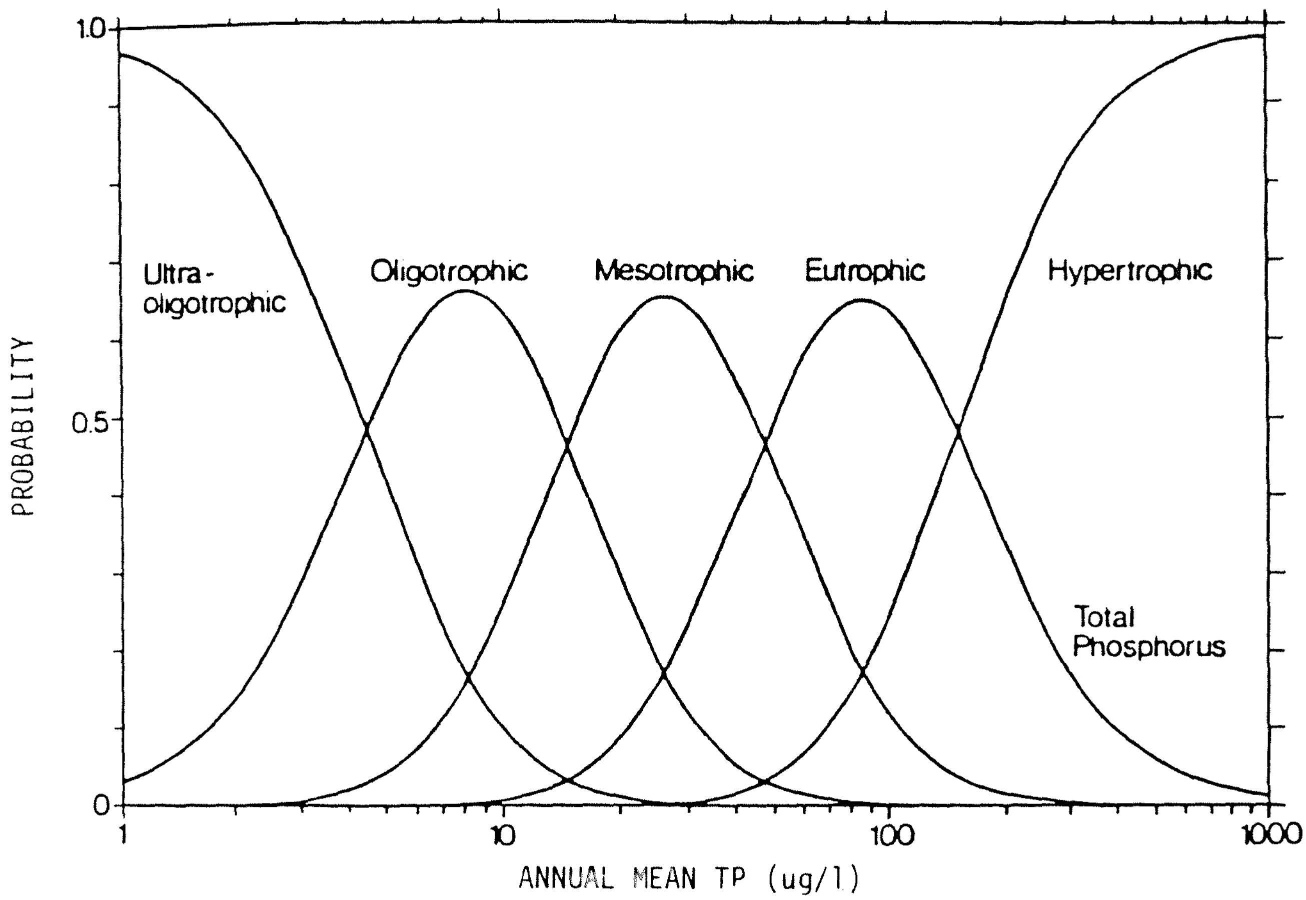

Figure 8. Probability distribution of trophic categories relative to average total phosphorus concentrations (OECD, 1982).

Table 14. Summary of proposed relationships among phosphorus concentration, trophic state and lake use for north temperate lakes.

In-Lake Total P (ug P/L)			
Mancini et al. (1983)[1]	OECD (1982)	Trophic State	Lake Use
<10	<10	Oligotrophic	Suitable for water-based recreation and propagation of cold water fisheries, such as trout. Very high clarity and aesthetically pleasing.
10-20	10-35	Mesotrophic	Suitable for water-based recreation but often not for cold water fisheries. Clarity less than oligotrophic lake.
20-50	35-100	Eutrophic	Reduction in aesthetic properties diminishes enjoyment from body contact recreation. Generally very productive for warm water fisheries.
>50	>100	Hypereutrophic	A typical "old-aged" lake in advanced succession. Some fisheries, but high levels of sedimentation and algae or macrophyte growth may be diminishing open water surface area.

1) Hypereutrophic category suggested by Reckhow and Chapra (1983).

Prior to start-up of the WWTF, the whole-lake total P concentration was approximately 20 ± 3 ug P/L. This would place Lake Sawyer at the threshold of a eutrophic designation, but still within the mesotrophic range of OECD (1982). Following WWTF start-up, the average concentration of P increased to 31 ± 8 ug P/L. Metro (Brenner and Davis, 1988) and local residents have reported a noticeable decline in overall water quality, with more frequent and more intense algal blooms. The post-WWTF total P concentration, while still within the threshold range between mesotrophic and eutrophic designations, represents a substantial enrichment to a more eutrophic state. The analysis of lake response to projected future WWTF loadings, indicates that much greater increases are likely if discharges continue at present or currently permitted treatment levels. These concentrations would place Lake Sawyer in a eutrophic and degraded condition.

If a mesotrophic in-lake criterion is chosen for protection of Lake Sawyer [e.g., 25 ug P/L as an upper limit, as suggested by EPA (1986) and adopted by Ecology in WAC 173-201-080 (105), Patmont *et al.*, (1987), for protection of Long Lake], the future WWTF load is projected to raise the total P concentration of the lake above an acceptable limit, even if technologically feasible advanced waste treatment processes are implemented. Therefore, in consideration of all available information, continuation of point source phosphorus inputs from the Black Diamond Wastewater Treatment Facility should not be permitted.

Lake Sawyer is predicted to recover to an acceptable mesotrophic condition if wastewater diversion is implemented. However, the equilibrium condition of the lake following diversion is likely to be a threshold between mesotrophic and eutrophic states. Therefore, increases in nonpoint loading which may occur in the future with increases in watershed development may bring the lake to a eutrophic condition. Consequently, any future development within the basin should incorporate best management practices (BMPs) to minimize nonpoint phosphorus inputs to the lake.

CONCLUSIONS AND RECOMMENDATIONS

- Phosphorus is the nutrient which most limits algal productivity in Lake Sawyer. Therefore, management of phosphorus loading is likely to exert the greatest control on the trophic condition of the lake.

- A net increase in whole-lake total phosphorus from 20 ± 3 to 31 ± 8 ug P/L was observed in the lake following start-up of the Black Diamond WWTF. The condition of the lake prior to the WWTF start-up was mesotrophic to eutrophic. The current condition of the lake is more eutrophic, with more frequent and intense algal blooms.

- The observed increase in whole-lake total P content corresponds closely to the estimated loading currently discharged from the Black Diamond WWTF. Excessive loading of the natural wetland soils probably results in the poor removal of wastewater P loads in the wetland system.

- Future (2010) loading of total P from the Black Diamond WWTF is expected to increase to nearly three times the current load if phosphorus removal efficiencies remain the same, or are limited to currently permitted levels. Implementation of feasible advanced waste treatment would result in future (2010) loading of approximately two thirds of the existing effluent total P load.

- Local nonpoint loading from nearshore septic systems and residential land use may be as high as the current point source load from the Black Diamond WWTF. However, nonpoint loading is diffuse, and therefore, more difficult to control than point sources. Also, local nonpoint source loading may not increase substantially in the future, since the nearshore region of the lake is nearly developed with residential land use, and further development will probably occur at a relatively large distance from the lake shore.

- The condition of Lake Sawyer is predicted to reach a eutrophic state in the future (2010) if discharges from the Black Diamond WWTF continue at existing or currently permitted levels of treatment. Implementation of feasible advanced treatment would probably cause an improvement over the existing condition of the lake, even at future (2010) plant flows. However, the lake would probably still remain in a eutrophic condition with implementation of advanced treatment.

- Diversion of the Black Diamond WWTF discharge from the Rock Creek/Lake Sawyer system would probably return the condition of the lake to the mesotrophic (threshold eutrophic) condition that existed prior to WWTF start-up, and prevent the substantial degradation that is likely if discharge continues. Diversion is the only alternative evaluated which is likely to result in an improved trophic state in comparison with the existing condition.

- An in-lake total P criterion of 25 ug P/L should be adopted to protect a mesotrophic condition in the lake. All future development within the Lake Sawyer watershed should incorporate best management practices to minimize nonpoint source loading of phosphorus from construction activities and land use.

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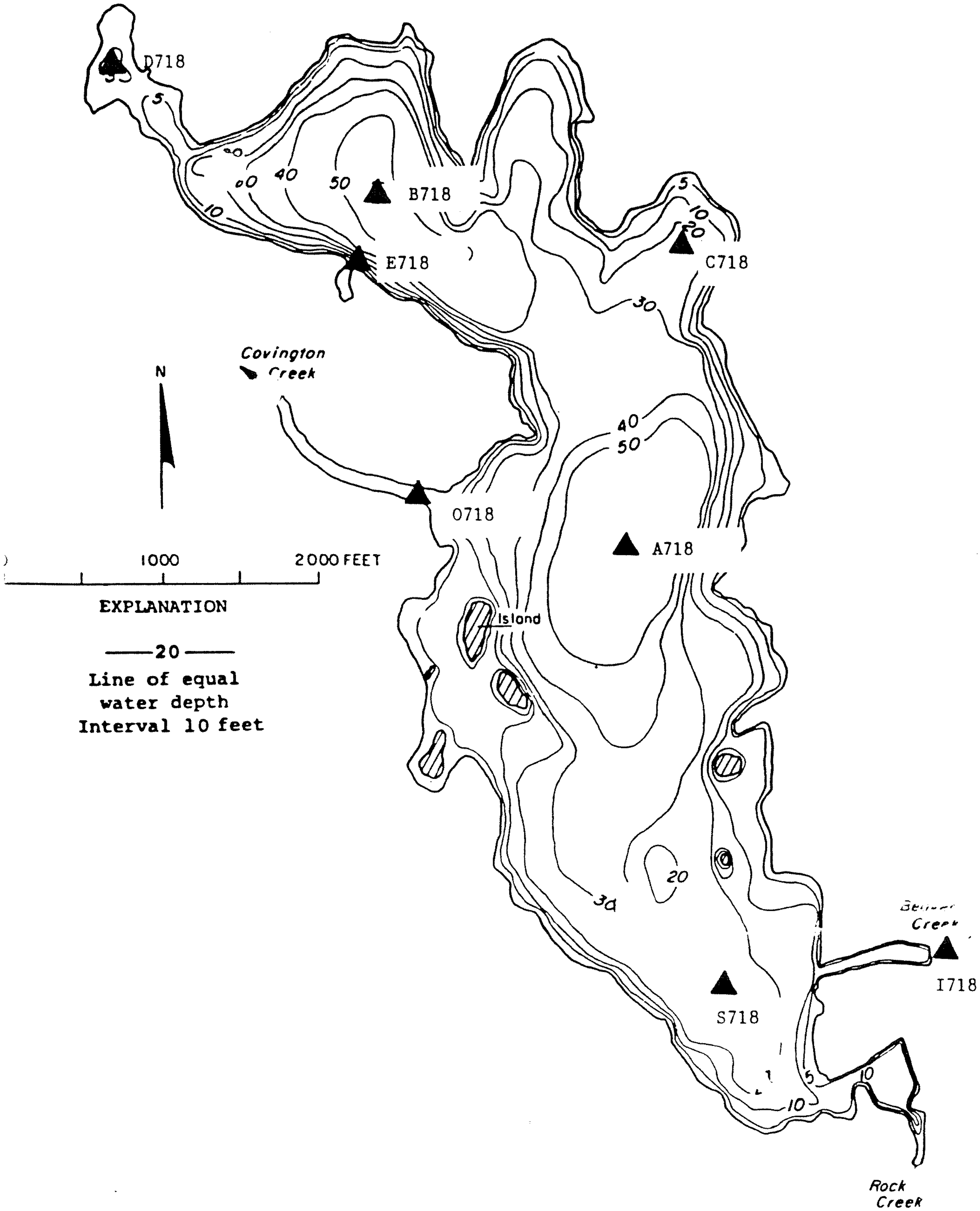
APPENDIX A

METRO DATA

(Source: Bob Brenner, Municipality of Metropolitan Seattle, personal communication, 1989)



Location of Metro sampling stations (▲).

Appendix A. Metro Data

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25°C)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Diss. Inorganic N (mgN/L)
A718	25-Mar-71	1	4.1	7.1	10.1	7.3		130	0.01	0.82		0.05					0.830
A718	25-Mar-71	5		6.5	11.1	7.6		130	0.01	0.84		0.05					0.850
A718	25-Mar-71	10		5.4	10.8	7.6		128	0.02	0.84		0.03					0.860
A718	25-Mar-71	15		5.2	10.6	7.4		129	0.03	0.74		0.03					0.770
A718	25-Mar-71	16		5.2	5.5			139									
A718	24-Aug-71	1	4.5	24	9.7	7.4		103	0.01	0.01		0.04					0.020
A718	24-Aug-71	5		19	13.9	7.9		200	0.01	0.01		0.04					0.020
A718	24-Aug-71	10		11.5	1.8	7.4		144	0.01	0.44		0.06					0.450
A718	24-Aug-71	15		11.5	0.3	7		107	0.22	0.28		0.16					0.500
A718	16-Feb-72	1	2	4.5	11.5	6.6	2.2	110	0.01	0.8		0.01					0.810
A718	16-Feb-72	5		4.9	11.7	6.6	1.5	110	0.01	0.82		0.01					0.830
A718	16-Feb-72	10		4.9	11.6	6.7	1.2	110	0.01	0.8		0.04					0.810
A718	12-Apr-72	1	4	9	11.6	7.2	2.1	115	0.01	0.76		0.01		2.5			0.770
A718	12-Apr-72	6		9.2	12.2	7.5	3.5	115	0.01	0.72		0.02					0.730
A718	12-Apr-72	12		7.4	10.4	7.4	1.7	117	0.01	0.76		0.01					0.770
A718	13-Apr-72	1	4.1	10.1	11.4	7.1	2	113	0.01	0.76		0.02		5.9			0.770
A718	13-Apr-72	6		9.9	10.7	7.1	2.4	120	0.01	0.7		0.01					0.710
A718	13-Apr-72	12		9.8	9.6	7.1	3.7	115	0.02	0.76		0.02					0.780
A718	17-May-72	1	4.7	16	10.6	7.3	1.9	133	0.01	0.48		0.02		2.1			0.490
A718	17-May-72	5		9	12.1	7.4	2.2	135	0.01	0.48		0.03					0.490
A718	17-May-72	10		9	9.2	7.2	2.3	132	0.01	0.64		0.01					0.650
A718	17-May-72	15		8.1	7.3	7	1.8	298	0.01	0.64		0.01					0.650
A718	24-Jul-72	1	3.2	21.5	9.5	8.5	1.1	112	0.01	0.01		0.04		2			0.020
A718	24-Jul-72	5		16	13.5	8.6	1.5	120	0.01	0.04		0.01					0.050
A718	24-Jul-72	10		11	4.3	7.2	2	58	0.03	0.49		0.06					0.520
A718	24-Jul-72	15		10	1.7	7.2	2.6	113	0.02	0.48		0.06					0.500
A718	07-Aug-72	1	3.5	25	9.2	8.1	0.8	140	0.01	0.01		0.03		2			0.020
A718	07-Aug-72	5		20	13.6	8.6	1.3	140	0.03	0.01		0.03					0.040
A718	07-Aug-72	10		16	2.8	7.2	1.1	138	0.02	0.29		0.01					0.310
A718	07-Aug-72	15		11	1.7	8	1.1	130	0.03	0.49		0.01					0.520
A718	21-Aug-72	1	4	21	9.4	8.4	1.4	142	0.01	0.03		0.02		1.7			0.040
A718	21-Aug-72	5		20.5	9.9	8.4	1.2	145	0.01	0.02		0.01					0.030
A718	21-Aug-72	10		13	4.1	7.1	1	138	0.02	0.41		0.03					0.430
A718	21-Aug-72	15		11	0.7	6.8	1.2	160	0.04	0.44		0.02					0.480
A718	18-Sep-72	1	6	17.8	9.8	7.6	0.4	150	0.04	0.01		0.01		2.1			0.050
A718	18-Sep-72	5		16	9.2	7.1	0.7	145	0.02	0.05		0.01					0.070
A718	18-Sep-72	10		11.5	0.5	6.6	1	148	0.01	0.16		0.01					0.170
A718	18-Sep-72	15		10	1.5	6.4	3	149	0.04	0.34		0.03					0.380
A718	03-Oct-72	1	4.1	14.9	10.4	6.7	0.8	110	0.01	0.03		0.01		5.7			0.040

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25°C)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
A718	03-Oct-72	5		14.5	10.2	6.8	0.7	108	0.01	0.04		0.01					0.050
A718	03-Oct-72	10		11.2	2.1	6.9	1	112	0.03	0.16		0.02					0.190
A718	03-Oct-72	15		9.8	1	6.7	4.5	114	0.11	0.2		0.05					0.310
A718	16-Oct-72	1															
A718	17-Oct-72	1	4.7	12.8	9.2	6.2	0.7	132	0.01	0.02		0.02		2.6	50		0.030
A718	17-Oct-72	5		12.8	9.1	6.1	0.7	130	0.01	0.04		0.02			51		0.050
A718	17-Oct-72	10		10.5	1.4	6	1	208	0.08	0.14		0.04			52		0.220
A718	17-Oct-72	15		9	0.1	6	3	132	0.16	0.12		0.06			53		0.280
A718	31-Oct-72	1	4.5	10.5	8.4	7.3	0.8	147	0.02	0.04		0.04		2	52		0.060
A718	31-Oct-72	5		10	8.4	7.4	0.9	149	0.02	0.02		0.02			49		0.040
A718	31-Oct-72	10		9.4	8.2	7.3	0.9	152	0.03	0.04		0.02			51		0.070
A718	31-Oct-72	15		9	1.2	6.8	4.3	200	0.17	0.04		0.06			50		0.210
A718	13-Nov-72	1	3.9	9	8.8	7.7	0.7	145	0.05	0.04		0.05		1.6	57		0.090
A718	13-Nov-72	5		9.8	8.4	7.5	0.8	150	0.04	0.06		0.04			55		0.100
A718	13-Nov-72	10		9.7	8.4	7.2	0.7	145	0.04	0.04		0.03			50		0.080
A718	13-Nov-72	15		9.5	8	6.9	2.4	150	0.06	0.02		0.05			49		0.080
A718	28-Nov-72	1	3.7	7.5	8.1	6.9	0.7	131	0.07	0.06		0.04		4.4	46	20	0.130
A718	28-Nov-72	5		7.8	7.9	6.8	0.8	135	0.08	0.06		0.05			45		0.140
A718	28-Nov-72	10		7.8	7.9	6.7	1	120	0.06	0.04		0.04			45		0.100
A718	28-Nov-72	15		7.8	7.8	6.7	0.7	135	0.07	0.04		0.06			45		0.110
A718	26-Dec-72	1	4.6	4.8	11.2	7.2	0.8	140	0.07	0.14		0.04		5.1	49	20	0.210
A718	26-Dec-72	5		4.9	11	7.2	1.1	165	0.06	0.18		0.05			48		0.240
A718	26-Dec-72	10		5	10.8	7.3	0.8	146	0.07	0.18		0.05			48		0.250
A718	26-Dec-72	15		5.1	11.2	7.4	0.8	150	0.05	0.16		0.05			49		0.210
A718	09-Jan-73	1															
A718	10-Jan-73	1	3.2	2.1	12.3	7.2	0.7	142	0.05	0.54		0.03		2.8	44	20	0.590
A718	10-Jan-73	5		2.1	12.3	7.2	1	140	0.05	0.48		0.05			44		0.530
A718	10-Jan-73	10		2.1	12.4	7.1	0.8	139	0.08	0.48		0.04			44		0.560
A718	10-Jan-73	15		2.3	12.2	7.1	1.9	150	0.41	0.48		0.04			44		0.890
A718	17-Jan-73	1	5.4	2.5	12.3	7.3	0.6	152	0.14	0.52		0.05		2.6	43	20	0.660
A718	17-Jan-73	5		2.9	12.2	7.3	0.6	156	0.02	0.54		0.06			43		0.560
A718	17-Jan-73	10		3.1	11.9	7.2	0.7	160	0.02	0.56		0.05			42		0.580
A718	17-Jan-73	15		3.2	11.8	7.3	2.5	162	0.02	0.58		0.05			43		0.600
A718	07-Feb-73	1	3.5	2.3	12	7.1	0.8	190	0.03	0.56		0.04			48	20	0.590
A718	07-Feb-73	5		2.5	12.2	7	0.6	176	0.04	0.56		0.04			48		0.600
A718	07-Feb-73	10		3	12.4	7	0.8	182	0.02	0.54		0.03			48		0.560
A718	07-Feb-73	15		3.4	12.5	7.4	0.7	170	0.02	0.62		0.04			48		0.640
A718	22-Feb-73	1	3.6	6	13	7.1	1	130	0.01	0.23		0.02			46	20	0.240
A718	22-Feb-73	5		6.8	12.9	7.1	1	130	0.01	0.21		0.04			46		0.220
A718	22-Feb-73	10		6.7	12.8	7	0.7	130	0.01	0.21		0.03			44		0.220

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^oC)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^oC)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity (mgCaCO$_3$/L)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
A718	22-Feb-73	15		6.4	12.7	7	3.4	135	0.05	0.22		0.13			44		0.270
A718	08-Mar-73	1	5.3	8	12.5	6.9	0.5	129	0.01	0.64		0.04		3.8	42		0.650
A718	08-Mar-73	5		7.1	11.1	6.9	0.8	164	0.02	0.66		0.04			42		0.680
A718	08-Mar-73	10		6.4	9.1	6.8	1	135	0.02	0.66		0.04			41		0.680
A718	08-Mar-73	15		6.4	8.8	6.8	0.9	143	0.01	0.62		0.04			41		0.630
A718	21-Mar-73	1	3.9	7.3	12	7.1	0.5	130	0.01	0.72		0.02		12	45	20	0.730
A718	21-Mar-73	5		7.8	11.8	7	1	134	0.01	0.72		0.03			44		0.730
A718	21-Mar-73	10		7	11.6	7.1	1	138	0.02	0.68		0.02			44		0.700
A718	21-Mar-73	15		7.8	11	7	1.2	140	0.02	0.68		0.03			44		0.700
A718	02-Apr-73	1	4.6	9.5	12.2	7.1	0.6	133	0.01	0.72		0.03		2.6	44	20	0.730
A718	02-Apr-73	5		8.8	12.1	7	0.8	133	0.02	0.72		0.06			44		0.740
A718	02-Apr-73	10		6.8	10.5	7	1.5	134	0.04	0.72		0.07			44		0.760
A718	02-Apr-73	15		6.1	9.5	7.1	1.2	138	0.04	0.72		0.05			44		0.760
A718	19-Apr-73	1	4.2	11.2	11.2	7.1	0.8	131	0.01	0.48		0.05		4.7	44	20	0.490
A718	19-Apr-73	5		9.6	11	7.3	2.5	135	0.01	0.56		0.04			44		0.570
A718	19-Apr-73	10		7.5	9.1	7.1	0.7	137	0.02	0.58		0.05			44		0.600
A718	19-Apr-73	15		6.8	8.4	7.2	1.7	136	0.02	0.56		0.06			44		0.580
A718	30-Apr-73	1	5.3	12.9	11.3	7.3	0.4	160	0.03	0.36		0.02		2.5	44	20	0.390
A718	30-Apr-73	5		12.4	10.4	7.1	0.6	140	0.03	0.36		0.03			40		0.390
A718	30-Apr-73	10		9.3	9.2	7.3	1	140	0.03	0.47		0.03			43		0.500
A718	30-Apr-73	15		8.7	7.7	7.2	0.8	140	0.03	0.48		0.02			42		0.510
A718	14-May-73	1	6.1	17.2	11	7.3	0.5	148	0.02	0.32		0.02		3.4	44	20	0.340
A718	14-May-73	5		17.3	10.7	7	0.7	141	0.01	0.36		0.01			40		0.370
A718	14-May-73	10		17	10.7	7.1	0.7	141	0.02	0.4		0.02			41		0.420
A718	14-May-73	15		13.5	9.1	7.1	1	143	0.02	0.32		0.02			41		0.340
A718	31-May-73	1	3.9	17	11.4	7.3	0.6	140	0.02	0.24		0.01		8.6	43	20	0.260
A718	31-May-73	5		13	11	7.1	0.8	150	0.01	0.28		0.01			41		0.290
A718	31-May-73	10		8.2	5.8	7.2	0.6	140	0.01	0.56		0.01			42		0.570
A718	31-May-73	15		7.6	5	7.1	1	150	0.02	0.52		0.01			41		0.540
A718	09-Jun-73	1															
A718	11-Jun-73	1															
A718	26-Jun-73	1	4.9	20	9.8	7.1	0.6	140	0.01	0.12		0.03		6.1	40	20	0.130
A718	26-Jun-73	5		18.2	9.7	7	0.8	260	0.01	0.12		0.04			39		0.130
A718	26-Jun-73	10		11	6.5	6.8	1.9	150	0.01	0.44		0.03			39		0.450
A718	26-Jun-73	15		9.5	2.9	6.8	1.1	150	0.01	0.48		0.06			39		0.490
A718	10-Jul-73	1	3.1	22.5	10.3	7.9	0.6	230	0.01	0.04		0.03		3.1	53	20	0.050
A718	10-Jul-73	5		22.8	10.3	9	1.8	170	0.01	0.02		0.02			60		0.030
A718	10-Jul-73	10		14	9	6.7	1.8	190	0.01	0.24		0.02			50		0.250
A718	10-Jul-73	15		10.7	2.1	6.6	1.8	150	0.01	0.4		0.02			50		0.410
A718	24-Jul-73	1	2.9	21.2	10.2	7.6	0.8	170	0.01	0.01		0.01		7.2	50	20	0.020

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^oC)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^oC)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
A718	24-Jul-73	5		21.2	11.2	7	1.4	180	0.01	0.01		0.01			49		0.020
A718	24-Jul-73	10		13.9	5.1	6.8	1.1	290	0.02	0.24		0.01			48		0.260
A718	24-Jul-73	15		9.2	1	6.6	1.2	160	0.02	0.34		0.01			45		0.360
A718	07-Aug-73	1	3.9	22	9.5	7.4	0.7	160	0.01	0.01		0.02		2.6	44	20	0.020
A718	07-Aug-73	5		20.6	11.8	7.2	1.2	160	0.02	0.01		0.03			42		0.030
A718	07-Aug-73	10		11	2.1	6.9	1.2	240	0.02	0.34		0.02			41		0.360
A718	07-Aug-73	15		14	0.6	6.6	1.1	160	0.01	0.38		0.03			40		0.390
A718	21-Aug-73	1	4.1	22	9.8	8.3	0.8	150	0.01	0.01		0.02		7.6	52	20	0.020
A718	21-Aug-73	5		21	9.2	7.7	0.9	150	0.01	0.01		0.02			50		0.020
A718	21-Aug-73	10		11.2	2.9	7.2	1.4	140	0.01	0.2		0.05			48		0.210
A718	21-Aug-73	15		11	0.8	6.7	3	140	0.06	0.28		0.05			46		0.340
A718	06-Sep-73	1	3.6	19.9	10	8.3	0.7	150	0.01	0.01		0.01		6.1	57	20	0.020
A718	06-Sep-73	5		17.2	9.8	7.9	0.9	140	0.01	0.01		0.02			54		0.020
A718	06-Sep-73	10		10.9	1.8	7.6	0.9	150	0.04	0.18		0.02			52		0.220
A718	06-Sep-73	15		11.5	0.8	7.1	1	150	0.04	0.16		0.01			51		0.200
A718	18-Sep-73	1	4.7	17.4	11.5	8.4	0.4	150	0.01	0.01		0.03		2	54	20	0.020
A718	18-Sep-73	5		17.2	10.1	7.3	0.9	270	0.01	0.01		0.02			48		0.020
A718	18-Sep-73	10		14	3.7	7.5	1.1	150	0.02	0.16		0.04			49		0.180
A718	18-Sep-73	15		8	1.1	7.2	2.6	160	0.08	0.18		0.06			48		0.260
A718	02-Oct-73	1		16.7	9.8	8.3	0.6	150	0.02	0.01		0.03		4.4	56	20	0.030
A718	02-Oct-73	5		15.9	9.6	7.4	0.8	150	0.01	0.01		0.03			53		0.020
A718	02-Oct-73	10		9.4	4.2	6.8	1.9	160	0.1	0.02		0.06			51		0.120
A718	02-Oct-73	15		9.6	1	7	1.8	230	0.12	0.01		0.06			52		0.130
A718	12-Oct-73	1															
A718	16-Oct-73	1	4.3	14.9	9	7.7	0.6	150	0.01	0.01		0.02		2.1	53	20	0.020
A718	16-Oct-73	5		14.9	8.8	7.2	0.6	150	0.01	0.01		0.02			51		0.020
A718	16-Oct-73	10		10.7	3.4	6.6	0.6	140	0.09	0.01		0.05			50		0.100
A718	16-Oct-73	15		10.5	0.4	6.9	0.6	150	0.24	0.01		0.1			51		0.250
A718	30-Oct-73	1	4	12.2	9.7	7.4	0.6	140	0.01	0.01		0.02		1.5	51	20	0.020
A718	30-Oct-73	5		12.1	9.3	7.1	1.3	150	0.01	0.01		0.02			49		0.020
A718	30-Oct-73	10		9.6	1.4	7	1.1	140	0.15	0.02		0.07			49		0.170
A718	30-Oct-73	15		8.9	0.5	7.2	1.5	150	0.22	0.01		0.11			50		0.230
A718	15-Nov-73	1	3.9	8.5	8.8	7.4	0.7	140	0.02	0.02		0.06		5.6	54	20	0.040
A718	15-Nov-73	5		8.2	8.7	7.2	0.8	140	0.03	0.01		0.04			55		0.040
A718	15-Nov-73	10		8	8.6	7.2	1	140	0.03	0.02		0.05			53		0.050
A718	15-Nov-73	15		9	8.8	7.3	0.8	270	0.03	0.02		0.05			54		0.050
A718	27-Nov-73	1	4.4	6.6	9.3	7.3	1.5	140	0.06	0.04		0.07		7.4	52	20	0.100
A718	27-Nov-73	5		7	9.2	7.2	2.7	150	0.05	0.04		0.06			51		0.090
A718	27-Nov-73	10		7	9.1	6.8	3.2	150	0.04	0.04		0.06			50		0.080
A718	27-Nov-73	15		7	9	7	2.1	130	0.05	0.18		0.06			50		0.230

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^{o}C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm $25^{o}C$)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
A718	13-Dec-73	1	4.5	6	9.9	7.2	1.5	140	0.05	0.12		0.05		1.5	54	20	0.170
A718	13-Dec-73	5		5.8	9.8	7	2.8	150	0.05	0.11		0.05			52		0.160
A718	13-Dec-73	10		5.8	9.7	7.1	1.4	130	0.05	0.12		0.05			53		0.170
A718	13-Dec-73	15		5.8	9.7	6.9	0.9	150	0.05	0.13		0.05			51		0.180
A718	27-Dec-73	1	4.9	5.6	10.3	6.9	0.7	120	0.03	0.33		0.05		12.6	50	20	0.360
A718	27-Dec-73	5		5.4	10	6.8	1	120	0.03	0.33		0.04			49		0.360
A718	27-Dec-73	10		5.4	10.1	6.6	1.1	120	0.02	0.32		0.05			48		0.340
A718	27-Dec-73	15		5.4	9.9	6.8	1.5	130	0.02	0.31		0.04			49		0.330
A718	15-May-79	1	3	16.2	11.2	7.8		123			0.016		0.001	7.5		10	
A718	15-May-79	8		8.2	8.4	6.8		122			0.015		0.001				
A718	15-May-79	16		7.2	6.6	6.8		123			0.013		0.001				
A718	18-Jul-79	1	3.3	23.8	9.6	7.9					0.008		0.004	0.5		10	
A718	18-Jul-79	8		11.8	8.8	6.9					0.012		0.002				
A718	18-Jul-79	16		8.9	1.3	6.6					0.017		0.001				
A718	19-Sep-79	1	5	20.2	9.7	8.5		138			0.018		0.006	1.1		10	
A718	19-Sep-79	8		14.3	7.9	7.7		140			0.029		0.008				
A718	19-Sep-79	16		7.8	0.2	7.2		147			0.109		0.069				
A718	14-Nov-79	1	3.5	9.1	8.4	7.5		134			0.012		0.003			10	
A718	14-Nov-79	8		9	8.7	7.4		135			0.012		0.005				
A718	14-Nov-79	16		7	0.1	6.9		143			0.184		0.178				
A718	14-Jan-80	1	3.3	4	11.2	7.2		128			0.022		0.007	7.7		10	
A718	14-Jan-80	8		4.2	11.3	7.2		124			0.021		0.006				
A718	14-Jan-80	16		4.2	11.1	7.2		128			0.017		0.03				
A718	11-Mar-80	1	4	7.1	12	7.5		135			0.01		0.003	1.7		10	
A718	11-Mar-80	8		6	12	7.5		136			0.005		0.004				
A718	11-Mar-80	16		5	10.8	7.5		140			0.011		0.006				
A718	28-Mar-83	1	4.5	9.1	11.9	7.7		112			0.022			6.67			
A718	28-Mar-83	5		8.9	11.3	7.7		115			0.023						
A718	28-Mar-83	10		7	10.1	7.9		121			0.017						
A718	28-Mar-83	15		6.4	8.7	7.6		122			0.03						
A718	31-Aug-83	1	4.1	21.3	9	7.9		155			0.009			3.2			
A718	31-Aug-83	5		16.5	9.1	7.2		148			0.79						
A718	31-Aug-83	10		7.9	0.5	6.9		106			0.021						
A718	31-Aug-83	15		8	0.5	7.5		110			0.049						
A718	01-Feb-84	1	3		10.9	7.2		110			0.019			3.2			
A718	01-Feb-84	5			11.2	7.2		115			0.024						
A718	01-Feb-84	10			11.3	7.2		106			0.023						
A718	01-Feb-84	15			11.4	7.2		120			0.023						
A718	29-Feb-84	1	3.8	6.6	11.8	7.4		109			0.017			3.74			
A718	29-Feb-84	5		6	11.5	7.3		110			0.018						

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25°C)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
A718	29-Feb-84	10		5.9	11.3	7.3		106			0.026						
A718	29-Feb-84	15		5.8	11	7.3		108			0.02						
A718	28-Feb-85	1	3.5	4.4	11	7.2		82			0.029			3.47			
A718	28-Feb-85	5		4.2	11.1	7.1		81			0.032						
A718	28-Feb-85	10		4.1	10.4	7		83			0.014						
A718	28-Feb-85	15		4.3	10.2			86			0.021						
A718	07-Mar-85	1	4	5.1	11.6	7.5		106			0.011			5.07			
A718	07-Mar-85	5		5.3	10.5	7.3		88			0.016						
A718	07-Mar-85	10		5.3	10.3	7.2		93			0.011						
A718	07-Mar-85	15		5.3	10.3	7.2		93			0.015						
A718	06-May-85	1	3.6	12.8							0.008			7.34			
A718	20-May-85	1	3.6	17.8							0.015			6.2			
A718	03-Jun-85	1	3.3	17.2							0.017			4.37			
A718	18-Jun-85	1	4.2	20							0.009			3.2			
A718	10-Jul-85	1	4.8	23.3							0.009			1.6			
A718	05-Aug-85	1	4.6	21.7							0.005			1.6			
A718	20-Aug-85	1	4.5	21.7							0.008			2.14			
A718	02-Sep-85	1	5.5	19.4							0.022			2.25			
A718	23-Sep-85	1	4.9	16.1							0.012			1.63			
A718	07-Oct-85	1	4.6	13.9							0.007			3.2			
A718	20-Oct-85	1	5.2	12.2							0.011			2.9			
A718	27-Feb-86	1	4.1	6.2	11.8	7		147			0.052			4.54			
A718	27-Feb-86	5		6	11.4	7.1		147			0.096						
A718	27-Feb-86	10		5.9	11.3	7.1		151			0.023						
A718	27-Feb-86	15		5.6	11.2	7.3		150			0.022						
A718	06-Mar-86	1	4.2	8.5	11.5	6.6		138			0.026			3.47			
A718	06-Mar-86	5		6.5	11.5	6.7		139			0.019						
A718	06-Mar-86	10		5.4	11.1	6.7		144			0.02						
A718	06-Mar-86	15		5.7	10.7	6.8		145			0.021						
A718	20-May-86	1	2.3	15.6							0.01			7.37			
A718	01-Jun-86	1	2.3	22.8							0.016			4.7			
A718	16-Jun-86	1	4.2	20							0.004			3.52			
A718	08-Jul-86	1	4	21.1							0.005			3.52			
A718	21-Jul-86	1	4.6	21.1							0.006			1.47			
A718	05-Aug-86	1	4.3	21.1							0.011			1.6			
A718	17-Aug-86	1	5	21.7							0.005			1.91			
A718	06-Sep-86	1	4.2	20.6							0.001			2.14			
A718	22-Sep-86	1	4.2	16.1							0.013			4.27			
A718	04-Oct-86	1	4	15							0.018			2.67			
A718	22-Oct-86	1	4.8	12.2							0.011			18.82			

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^{o}C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm $25^{o}C$)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
A718	26-Feb-87	1	3.2	4.7	10.9	7.2		145			0.02			6.17			
A718	26-Feb-87	5		4.7	10.5	7.1		142			0.026						
A718	26-Feb-87	10		4.7	10.1	7		142			0.024						
A718	26-Feb-87	15		4.6	9.5	7		140			0.019						
A718	12-Mar-87	1	3	7.7	12.1	7.8		140			0.019			7.05			
A718	12-Mar-87	5		7.4	11.9	8		130			0.02						
A718	12-Mar-87	10		6	10	7.8		130			0.016						
A718	12-Mar-87	15															
A718	05-May-87	1	5.2								0.028			17.62			
A718	02-Jun-87	1	2	16.7							0.017			11.75			
A718	15-Jun-87	1	1.8	17.8							0.014			12.34			
A718	29-Jun-87	1	3	24.4													
A718	21-Jul-87	1	2.6	20							0.008			4.11			
A718	03-Aug-87	1	3.8	21.1							0.005			1.76			
A718	16-Aug-87	1	4.5	18.9							0.01			1.17			
A718	07-Sep-87	1	5.6	20.6							0.01			0.59			
A718	20-Sep-87	1	6.3	17.2							0.017			0.88			
A718	06-Oct-87	1	5	17.2							0.011			2.94			
A718	19-Oct-87	1	4.3	13.9							0.017			3.13			
A718	24-Feb-88	1	2.3	6.5	13.1	7.7		140			0.027			19.76			
A718	24-Feb-88	5		6.3	13.2	7.8		140			0.027						
A718	24-Feb-88	10		6	12.6	7.7		140			0.173						
A718	24-Feb-88	15		6	10	7.3		140			0.027						
A718	09-Mar-88	1	1.6	7	12.9	7.9		144			0.059			12.92			
A718	09-Mar-88	5		6	12.5	7.8		144			0.059						
A718	09-Mar-88	10		6	12.4	7.6		145			0.048						
A718	09-Mar-88	15		6	11	7.4		145			0.046						
A718	02-May-88	1	2	11.1							0.022			1.85			
A718	16-May-88	1	3	16							0.068			4.99			
A718	06-Jun-88	1	3.2	17							0.009			6.46			
A718	21-Jun-88	1	3	21.1							0.015			1.47			
A718	05-Jul-88	1	3	17.2							0.009			2.94			
A718	19-Jul-88	1	3.1	20							0.01			0.59			
A718	01-Aug-88	1	3.7								0.01			1.04			
A718	15-Aug-88	1	5.5	20							0.03			1.38			
A718	19-Sep-88	1	5	16.7							0.011			2.64			
A718	03-Oct-88	1	5.5	16.7							0.012			1.47			
A718	16-Oct-88	1	5.5	14.4							0.019			0.01			
B718	25-Mar-71	1	2.6	6.8	9.4	7.3		130									
B718	24-Aug-71	1		24.1		7.2		104	0.01	0.01		0.04					0.020

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^{o}C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^{o}C)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity (mgCaCO$_3$/L)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
B718	16-Feb-72	1	2	5	11.3	6.8	1.3	110	0.01	0.96		0.01					0.970
B718	13-Apr-72	1	4.6	10	11.3	7.1	1.9	112	0.01	0.74		0.02					0.750
B718	17-May-72	1		16.6	10	7.2	1.6	145	0.01	0.46		0.03					0.470
B718	15-May-79	1	4	17	11	7.9		126			0.013		0.001	5.9			
B718	15-May-79	8		8.2	8.8	7		123			0.009		0.001				
B718	15-May-79	16		7.2	6.8	6.8		124			0.012		0.001				
B718	18-Jul-79	1	4.6	24.8	9.7	8.3					0.01		0.002	0.5		10	
B718	18-Jul-79	8		13	8	7					0.02		0.002				
B718	18-Jul-79	16		8.9	1.8	6.7					0.017		0.002				
B718	19-Sep-79	1	4.7	20.2	9.8	8.7		135			0.012		0.002	2.4		10	
B718	19-Sep-79	8		14.9	8	7.8		140			0.028		0.007				
B718	19-Sep-79	16		8	0.2	7.3		140			0.029		0.013				
B718	14-Nov-79	1	3.3	9	8.8	7.5		136			0.01		0.004			10	
B718	14-Nov-79	8		9	8.8	7.5		135			0.019		0.004				
B718	14-Nov-79	16		7	0.2	6.9		143			0.143		0.143				
B718	14-Jan-80	1	3.6	3.9	11.3	7.2		122			0.026		0.003	5.6		22	
B718	14-Jan-80	8		4.1	11	7.3		126			0.025		0.002				
B718	14-Jan-80	16		4.1	11	7.3		127			0.029		0.005				
B718	11-Mar-80	1	4	6.5	12.2	7.5		120			0.008		0.005	2.9		10	
B718	11-Mar-80	8		5.5	11.9	7.5		125			0.013		0.006				
B718	11-Mar-80	16		5	11.5	7.5		129			0.008		0.007				
C718	25-Mar-71	1	2	7	10	7.3		138									
C718	24-Aug-71	1		24		7.2		111	0.01	0.01		0.05					0.020
C718	16-Feb-72	1	3.5	4.2	11.5	6.9	1.5	120	0.01	0.84		0.04					0.850
C718	12-Apr-72	1	3.1	9.9	11.8	7.5	1.9	115	0.01	0.76		0.01					0.770
C718	13-Apr-72	1	4.6	10.2	11.4	7.1	2.6	190	0.01	0.76		0.02					0.770
C718	17-May-72	1	4.6	16.4	10.4	7.2	1.8	105	0.01	0.48		0.01					0.490
C718	24-Jul-72	1	3.1	21.5	9.3	9.4	1.7	151	0.02	0.01		0.02					0.030
C718	07-Aug-72	1	3.5	24.5	9.1	8.1	0.7	135	0.01	0.01		0.01					0.020
C718	21-Aug-72	1	4.4	21	9.6	8.4	0.6	140	0.01	0.01		0.02					0.020
C718	18-Sep-72	1	5.4	18	9.4	7.8	0.4	145	0.01	0.02		0.01					0.030
C718	03-Oct-72	1	4.1	14.9	10.1	7.1	0.5	111	0.01	0.01		0.02					0.020
C718	17-Oct-72	1	4.9	12.9	9.5	6.4	0.7	138	0.02	0.02		0.02			53		0.040
C718	31-Oct-72	1	4.2	10.4	9	7.1	0.7	148	0.02	0.02		0.03			48		0.040
C718	13-Nov-72	1	3.7	9.2	8.9	7.3	1.2	103	0.03	0.04		0.03			51		0.070
C718	28-Nov-72	1	4.4	7.8	8.5	6.7	0.5	140	0.05	0.06		0.04			45	20	0.110
C718	26-Dec-72	1	4.2	5	11.1	7.3	1.1	132	0.05	0.24		0.05			48	20	0.290
C718	10-Jan-73	1	3.2	2.1	12.1	7.4	0.7	235	0.04	0.52		0.04			46	20	0.560
C718	17-Jan-73	1	4.4	2.5	12.3	7.1	0.6	140	0.02	0.56		0.05			42	20	0.580
C718	07-Feb-73	1	3.7	2.5	12.5	7.1	1	165	0.02	0.56		0.04			47	20	0.580

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^oC)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^oC)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity (mgCaCO$_3$/L)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
C718	22-Feb-73	1	3.9	6	12.9	6.9	0.5	132	0.01	0.21		0.01			43	20	0.220
C718	09-Mar-73	1	4.4	8.6	12.4	7	0.5	127	0.01	0.66		0.02			42	20	0.670
C718	21-Mar-73	1	3.7	7.5	12.1	7	0.6	134	0.01	0.7		0.03			44	20	0.710
C718	02-Apr-73	1	4.9	9.1	11.9	7.1	1	134	0.01	0.7		0.04			44	20	0.710
C718	19-Apr-73	1	4.4	10.9	11.1	7.2	0.5	133	0.03	0.5		0.03			44	20	0.530
C718	30-Apr-73	1	5.7	13.5	11.2	7	0.5	140	0.02	0.4		0.02			40	20	0.420
C718	14-May-73	1	4.9	19	10.8	7.2	0.6	142	0.02	0.36		0.02			42	20	0.380
C718	31-May-73	1	4.1	17.3	10.7	7	0.6	140	0.02	0.24		0.01			40	20	0.260
C718	26-Jun-73	1	4.9	20	9.9	7	0.5	150	0.01	0.12		0.02			39	20	0.130
C718	10-Jul-73	1	4.1	22.8	10.1	7.7	0.6	180	0.01	0.18		0.02			51	20	0.190
C718	24-Jul-73	1	2.9	21.5	10	7.4	0.7	140	0.01	0.01		0.01			49	20	0.020
C718	07-Aug-73	1		21.3	10.6	7.3	1	190	0.03	0.04		0.02			44	20	0.070
C718	21-Aug-73	1		21	9.8	7.9	0.7	150	0.01	0.01		0.02			51	20	0.020
C718	06-Sep-73	1	3.5	19.8	10.1	8.2	0.6	150	0.01	0.01		0.01			56	20	0.020
C718	18-Sep-73	1	5.4	17.4	10	8.1	0.5	210	0.01	0.01		0.03			53	20	0.020
C718	02-Oct-73	1	4.9	16	9.6	8.2	0.9	150	0.03	0.01		0.03			55	20	0.040
C718	16-Oct-73	1	3.9	15	9	7.6	0.6	150	0.01	0.01		0.02			53	20	0.020
C718	30-Oct-73	1	3.9	13.5	9.7	7.3	1.5	160	0.01	0.01		0.02			51	20	0.020
C718	15-Nov-73	1	4.1	8.2	7.4	7.4	0.7	140	0.03	0.01		0.04			54	20	0.040
C718	27-Nov-73	1	3.9	6.9	9.4	7.3	2.2	140	0.05	0.05		0.06			52	20	0.100
C718	13-Dec-73	1	3.9	5.8	10	7.3	0.8	140	0.04	0.17		0.05			54	20	0.210
C718	27-Dec-73	1	4.9	5.6	10.2	6.9	0.8	130	0.02	0.32		0.04			50	20	0.340
D718	25-Mar-71	1		7.5	10.1			129									
D718	24-Aug-71	1		22.8		8.2		103	0.01	0.01		0.04					0.020
D718	16-Feb-72	1	1.4	4.9	12.1	7	1.8	100	0.01	0.52		0.01					0.530
D718	12-Apr-72	1		9.8	12.1	7.6	4.1	111	0.01	0.62		0.01					0.630
D718	13-Apr-72	1		10.1	11.8	7.2	3.2	184	0.01	0.76		0.01					0.770
D718	17-May-72	1		16	10.3	7.4	4.9	122	0.03	0.4		0.01					0.430
D718	24-Jul-72	1		21	10.7	8.5	0.8	110	0.02	0.02		0.03					0.040
D718	07-Aug-72	1		24	9.9	8.7	2	140	0.01	0.01		0.01					0.020
D718	21-Aug-72	1		20	9.4	8.7	1.5	140	0.02	0.06		0.01					0.080
D718	18-Sep-72	1		18	9.9	7.9	0.4	148	0.01	0.01		0.01					0.020
D718	03-Oct-72	1		14.8	11.6	6.9	0.7	110	0.01	0.01		0.02					0.020
D718	17-Oct-72	1		11.5	10.5	6.5	1	130	0.01	0.02		0.02			52		0.030
D718	31-Oct-72	1		8.6	9.1	7.2	0.7	155	0.01	0.08		0.02			49		0.090
D718	13-Nov-72	1		7.9	9.6	7.3	1.5	145	0.03	0.04		0.02			51		0.070
D718	28-Nov-72	1		6	8.7	6.6	0.7	135	0.04	0.04		0.04			44	20	0.080
D718	26-Dec-72	1		5.2	11.5	7.4	1.6	160	0.05	0.04		0.05			42	30	0.090
D718	10-Jan-73	1		1.4	12.7	7.1	0.8	179	0.04	0.38		0.04			44	24	0.420
D718	17-Jan-73	1		1.9	12.4	7.3	0.8	135	0.02	0.36		0.03			43	20	0.380

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^oC)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^oC)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
D718	07-Feb-73	1		1.9	12.4	7.2	5	274	0.01	0.48		0.03			48	20	0.490
D718	22-Feb-73	1		6.5	12.7	6.7	1.2	135	0.01	0.21		0.02			42	20	0.220
D718	08-Mar-73	1		7.2	11.6	6.9	0.7	130	0.01	0.54		0.05			42		0.550
D718	21-Mar-73	1		7.9	12.2	7.1	1	131	0.02	0.56		0.02			45	20	0.580
D718	02-Apr-73	1		9.6	12.1	7.1	1.3	132	0.02	0.56		0.05			44	20	0.580
D718	19-Apr-73	1		10.4	11	7.1	1	131	0.01	0.4		0.04			43	20	0.410
D718	30-Apr-73	1		12.8	11	7.3	1	140	0.03	0.32		0.02			44	20	0.350
D718	14-May-73	1		18.4	10.6	7.2	1.3	142	0.02	0.28		0.02			42	20	0.300
D718	31-May-73	1		17.2	11.5	7.2	1.6	140	0.03	0.2		0.02			42	20	0.230
D718	26-Jun-73	1		19.5	9.8	7.1	2	260	0.02	0.12		0.04			39	20	0.140
D718	10-Jul-73	1		22.5	11.1	8.7	0.6	140	0.01	0.11		0.01			53	20	0.120
D718	24-Jul-73	1		20.5	9.8	7.6	0.9	250	0.01	0.02		0.01			50	20	0.030
D718	07-Aug-73	1		22.2	9.7	7.2	0.8	160	0.01	0.01		0.01			44	20	0.020
D718	21-Aug-73	1		21	11.1	7.8	1.9	140	0.02	0.01		0.03			50	20	0.030
D718	06-Sep-73	1		19.2	10.4	8.4	0.7	150	0.01	0.01		0.01			57	20	0.020
D718	18-Sep-73	1		17.5	10.3	8.2	0.9	140	0.01	0.01		0.02			53	20	0.020
D718	02-Oct-73	1		19	10.7	8.2	4.4	130	0.02	0.01		0.03			55	20	0.030
D718	16-Oct-73	1		14.8	11.7	7.7	2.7	130	0.01	0.01		0.02			54	56	0.020
D718	30-Oct-73	1			10.3	7.3	2.7	140	0.01	0.01		0.02			51	100	0.020
D718	15-Nov-73	1		6.8	11.2	7.5	2.1	130	0.01	0.08		0.03			54	25	0.090
D718	27-Nov-73	1		5.4	9.3	7.1	1.4	140	0.01	0.02		0.05			51	20	0.030
D718	13-Dec-73	1		5	11	7.1	1.4	130	0.02	0.1		0.04			52	20	0.120
D718	27-Dec-73	1		3.9	10.3	6.7	1.1	120	0.02	0.17		0.04			48	20	0.190
E718	25-Mar-71	1		6.6	9.8	7.4		135									
E718	24-Aug-71	1		23.4		6.8		148	0.01	0.01		0.05					0.020
E718	16-Feb-72	1	2.9	4.2	11.7	7.1	1.7	120	0.01	0.82		0.02					0.830
E718	13-Apr-72	1		10.1	11.6	7.2	1.6	155	0.01	0.76		0.01					0.770
E718	17-May-72	1		17	10.9	7.2	1.7	135	0.01	0.44		0.02					0.450
E718	18-Sep-72	1		18	9.6	7.7	0.5	162	0.01	0.01		0.01					0.020
E718	03-Oct-72	1	3.1	14.9	9.9	7.5	0.5	112	0.01	0.02		0.01					0.030
E718	17-Oct-72	1	4.6	12.9	9.5	6.5	0.6	140	0.01	0.06		0.03			52		0.070
E718	31-Oct-72	1	4.3	10.4	8.3	7.1	0.7	152	0.03	0.04		0.02			47		0.070
E718	13-Nov-72	1	4	9.1	8.6	7.4	0.8	155	0.05	0.04		0.03			51		0.090
E718	28-Nov-72	1	3.9	7.8	7.8	6.8	0.8	200	0.08	0.04		0.05			45	20	0.120
E718	26-Dec-72	1	4.9	4.8	11.1	7.3	0.7	150	0.05	0.16		0.05			48	20	0.210
E718	10-Jan-73	1	3.2	1.5	11.1	7.2	0.7	141	0.05	0.48		0.03			44	20	0.530
E718	17-Jan-73	1	4.9	2.5	12.3	7.1	0.6	140	0.02	0.52		0.04			42	20	0.540
E718	07-Feb-73	1	3.9	2.5	12.8	7	0.7	162	0.02	0.66		0.04			47	20	0.680
E718	22-Feb-73	1		6	13	7	0.5	131	0.01	0.26		0.02			44	20	0.270
E718	09-Mar-73	1	2.2	8.4	12.6	6.7	0.4	126	0.01	0.62		0.02			41	20	0.630

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^oC)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^oC)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
E718	21-Mar-73	1		7.3	12	7.1	0.7	134	0.01	0.68		0.03			45	20	0.690
E718	02-Apr-73	1		9.4	12.1	7	0.4	136	0.02	0.68		0.05			44	20	0.700
E718	19-Apr-73	1		11.1	11.2	7.3	0.5	130	0.02	0.5		0.04			44	20	0.520
E718	30-Apr-73	1		12.9	11.6	7.2	0.4	140	0.02	0.4		0.03			42	20	0.420
E718	14-May-73	1	2.9	18.1	10.9	7.3	0.9	141	0.02	0.32		0.02			43	20	0.340
E718	31-May-73	1	4.1	17.5	10.8	7.1	0.6	140	0.02	0.28		0.01			41	20	0.300
E718	26-Jun-73	1	4.3	20	9.8	7.3	1	150	0.01	0.12		0.03			41	20	0.130
E718	10-Jul-73	1		21.8	10.3	7.6	0.8	280	0.01	0.02		0.03			54	20	0.030
E718	24-Jul-73	1	2.9	21.5	9.9	7.4	0.9	150	0.01	0.01		0.01			49	20	0.020
E718	07-Aug-73	1	3.9	22.4	9.4	7.4	0.6	150	0.01	0.01		0.02			44	20	0.020
E718	21-Aug-73	1	3.8	21.5	9.9	8.2	0.9	150	0.01	0.01		0.02			52	54	0.020
E718	06-Sep-73	1		19.8	10	8.3	0.6	150	0.01	0.01		0.01			56	20	0.020
E718	18-Sep-73	1		18	10.6	8	0.6	150	0.01	0.01		0.03			52	20	0.020
E718	02-Oct-73	1	3.5	16	9.5	8	0.9	140	0.01	0.01		0.03			54	20	0.020
E718	16-Oct-73	1	3.9	14.7	9	7.5	1.3	160	0.02	0.01		0.02			52	20	0.030
E718	30-Oct-73	1	4.1	13.3	9.6	7.4	0.7	150	0.01	0.01		0.02			52	20	0.020
E718	15-Nov-73	1	3.9	8.3	8.7	7.3	0.6	140	0.03	0.01		0.05			54	20	0.040
E718	27-Nov-73	1	4	5.2	9.6	7.3	5.4	150	0.04	0.03		0.07			53	20	0.070
E718	13-Dec-73	1		5.9	10.8	7.3	0.9	140	0.05	0.16		0.05			54	20	0.210
E718	27-Dec-73	1	4.9	5.5	10.3	7	0.7	130	0.03	0.33		0.04			51	20	0.360
I718	24-Jul-72	1	3.2	22	7.3	8.4	0.9	120	0.01	0.01		0.03					0.020
I718	07-Aug-72	1		24	9	8.2	0.8	135	0.01	0.01		0.04					0.020
I718	21-Aug-72	1		21	9.5	8.2	0.7	142	0.01	0.01		0.02					0.020
I718	18-Sep-72	1		18	9.5	7.7	0.4	149	0.01	0.01		0.01					0.020
I718	03-Oct-72	1		15	10	7.5	1	115	0.01	0.02		0.01					0.030
I718	17-Oct-72	1		12.8	9.7	6.4	0.6	135	0.02	0.02		0.02			52		0.040
I718	31-Oct-72	1		10.3	9.1	7.3	0.7	147	0.02	0.04		0.01			51		0.060
I718	13-Nov-72	1		9.3	9.4	7.2	0.8	150	0.01	0.06		0.03			50		0.070
I718	28-Nov-72	1		7.4	9.3	6.9	0.5	135	0.06	0.04		0.04			46	20	0.100
I718	26-Dec-72	1		7.9	11	7.1	0.9	160	0.02	0.54		0.04			36	20	0.560
I718	10-Jan-73	1		2.2	12.4	7.2	1.7	175	0.01	1.16		0.05			44	20	1.170
I718	17-Jan-73	1		1.2	11.3	7.2	0.2	164	0.01	1.08		0.04			42	20	1.090
I718	07-Feb-73	1		3.1	12.3	6.9	0.3	194	0.01	0.7		0.04			40	20	0.710
I718	22-Feb-73	1		6.8	11.7	7.1	0.6	135	0.01	0.16		0.01			46	20	0.170
I718	09-Mar-73	1		7.9	12.7	6.8	0.6	131	0.01	0.64		0.02			42	20	0.650
I718	21-Mar-73	1		7.4	11.6	7	0.4	117	0.01	0.6		0.03			44	20	0.610
I718	02-Apr-73	1		9.1	11.8	6.9	0.5	134	0.01	0.6		0.05			43	20	0.610
I718	19-Apr-73	1		10.3	11.4	7.1	0.5	137	0.02	0.48		0.05			44	20	0.500
I718	30-Apr-73	1		13.6	11.3	7.1	0.3	140	0.02	0.39		0.03			41	20	0.410
I718	14-May-73	1		18	10.8	7.1	1	141	0.02	0.36		0.02			41	20	0.380

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^{o}C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^{o}C)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
I718	31-May-73	1		18	10.2	7.1	0.6	140	0.02	0.24		0.01			41	20	0.260
I718	26-Jun-73	1		20	10	7	1.3	270	0.01	0.04		0.05			39	20	0.050
I718	10-Jul-73	1		23.3	9.9	7.2	0.6	300	0.01	0.04		0.02			52	20	0.050
I718	24-Jul-73	1		22	9.6	7.2	0.8	270	0.01	0.03		0.01			48	20	0.040
I718	07-Aug-73	1		22.5	9.6	7.4	1	160	0.01	0.01		0.02			44	20	0.020
I718	21-Aug-73	1		22	10	7.8	0.7	150	0.01	0.01		0.04			50	20	0.020
I718	06-Sep-73	1		19.3	10.3	8.3	0.6	150	0.01	0.01		0.02			56	20	0.020
I718	18-Sep-73	1		18	10.1	8.4	0.5	150	0.04	0.01		0.02			55	20	0.050
I718	02-Oct-73	1		16.2	9.6	8.1	0.8	140	0.01	0.01		0.03			54	20	0.020
I718	16-Oct-73	1		15	8.9	7.7	1.1	310	0.01	0.02		0.02			53	20	0.030
I718	30-Oct-73	1		13	9.3	7.5	1.1	200	0.01	0.01		0.03			51	20	0.020
I718	15-Nov-73	1		8.1	8.9	7.3	1.1	200	0.02	0.05		0.05			57	27	0.070
I718	27-Nov-73	1		6.9	9	7.1	1.5	110	0.02	0.43		0.06			51	20	0.450
I718	13-Dec-73	1		5	11	7.2	0.3	140	0.01	0.8		0.04			54	20	0.810
I718	27-Dec-73	1		5.6	9.6	6.8	0.3	130	0.01	1.08		0.04			49	20	1.090
I718	19-Sep-79	1		15.8	3.1	7.4		375			0.097		0.043			74	
I718	14-Nov-79	1		3	10.8	7.6		295			0.03		0.013			33	
O718	13-Apr-72	1		10.2	11.8	7.2	2.5	270	0.01	0.72		0.02					0.730
O718	17-May-72	1		16.6	9.8	7.2	2.6	123	0.01	0.44		0.01					0.450
O718	24-Jul-72	1		21.5	9.1	8.6	1.3	117	0.01	0.01		0.03					0.020
O718	07-Aug-72	1		24	9.2	8.2	1.4	136	0.01	0.01		0.02					0.020
O718	21-Aug-72	1		21.1	9.2	8.4	0.7	152	0.01	0.01		0.01					0.020
O718	18-Sep-72	1		17.9	9.9	7.7	0.4	146	0.01	0.03		0.01					0.040
O718	03-Oct-72	1		14.7	9.6	7.6	0.6	120	0.01	0.11		0.02					0.120
O718	17-Oct-72	1		12	10	6.5	1	135	0.01	0.02		0.03			52		0.030
O718	31-Oct-72	1		9.8	9.5	7.2	0.7	155	0.03	0.04		0.02			51		0.070
O718	13-Nov-72	1		8.9	9.2	7.4	0.6	160	0.05	0.04		0.02			51		0.090
O718	28-Nov-72	1		7.8	8.5	6.8	0.8	140	0.03	0.04		0.03			45	20	0.070
O718	26-Dec-72	1		4.8	10.8	7.3	0.8	185	0.05	0.2		0.05			48	20	0.250
O718	10-Jan-73	1		1.5	12.8	7.3	1.1	146	0.06	0.56		0.04			45	20	0.620
O718	17-Jan-73	1		2.3	12.2	7.2	0.7	188	0.02	0.52		0.05			42	20	0.540
O718	07-Feb-73	1		2.9	12.5	7	0.7	245	0.01	1		0.04			47	20	1.010
O718	22-Feb-73	1		6.2	12.9	6.8	0.6	129	0.01	0.19		0.02			42	20	0.200
O718	09-Mar-73	1		8.8	11.3	6.9	0.5	120	0.02	0.7		0.04			42	20	0.720
O718	21-Mar-73	1		7.9	12	7	0.5	160	0.01	0.9		0.02			44	20	0.910
O718	02-Apr-73	1		9.7	12.2	7	0.7	134	0.01	0.9		0.06			44	20	0.910
O718	19-Apr-73	1		10.8	11	7.2	0.6	137	0.03	0.5		0.04			44	20	0.530
O718	30-Apr-73	1		13.3	11.4	7	0.4	140	0.05	0.4		0.02			41	20	0.450
O718	14-May-73	1		18	10.4	7.2	0.7	141	0.02	0.32		0.02			42	20	0.340
O718	31-May-73	1		17.3	11	7	0.8	150	0.03	0.24		0.01			40	20	0.270

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25°C)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
0718	26-Jun-73	1		20	10.2	7.2	0.4	160	0.01	0.12		0.04			31	20	0.130
0718	10-Jul-73	1		24	10.1	7.4	0.9	380	0.01	0.02		0.02			52	20	0.030
0718	24-Jul-73	1		22	9.9	7.3	0.8	340	0.01	0.01		0.01			49	20	0.020
0718	07-Aug-73	1		23	9.8	7.3	0.7	150	0.01	0.02		0.02			44	20	0.030
0718	21-Aug-73	1		22	10.7	8	1	150	0.01	0.01		0.02			52	20	0.020
0718	06-Sep-73	1		19.8	9.8	8	1.5	170	0.01	0.01					55	21	0.020
0718	18-Sep-73	1		18	11.1	8.1	0.6	180	0.01	0.01		0.02			53	20	0.020
0718	02-Oct-73	1		16	10.4	8	1	140	0.01	0.01		0.02			54	20	0.020
0718	16-Oct-73	1		15	9.5	7.6	0.8	150	0.01	0.03		0.02			53	20	0.040
0718	30-Oct-73	1		12.2	10.3	7.3	1.3	150	0.01	0.01		0.02			51	20	0.020
0718	15-Nov-73	1		8.2	9.3	7.3	0.8	200	0.02	0.01		0.05			55	20	0.030
0718	27-Nov-73	1		6.9	9.6	7.2	2.4	190	0.04	0.05		0.06			51	20	0.090
0718	13-Dec-73	1		5.6	9.9	7	1.4	170	0.04	0.22		0.05			52	20	0.260
0718	27-Dec-73	1		5.5	10	6.8	2.4	140	0.03	0.36		0.05			49	20	0.390
S718	19-May-85	1	3.5	16.7							0.006			6.53			
S718	10-Jul-85	1	4.2	23.3							0.013			2.14			
S718	04-Aug-85	1	4.3	21.1							0.004			2.49			
S718	20-Aug-85	1	4.2	21.5							0.005			2.94			
S718	02-Sep-85	1	5.3	20							0.015			0.01			
S718	23-Sep-85	1	4.8	16.7							0.023			1.72			
S718	07-Oct-85	1	4.3	13.9							0.011			2.88			
S718	20-May-86	1	3	15.6							0.016			8.01			
S718	01-Jun-86	1	2.5	23.9							0.015			4.99			
S718	16-Jun-86	1	4.1	19.4							0.01			4.7			
S718	08-Jul-86	1	3.8	21.1							0.019			3.52			
S718	21-Jul-86	1	4.3	22.2							0.007			1.76			
S718	05-Aug-86	1	4.6	22.2							0.015			2.14			
S718	17-Aug-86	1	5.3	21.1							0.007			2.29			
S718	06-Sep-86	1	4.5	20							0.009			1.42			
S718	22-Sep-86	1	3.8	16.7							0.01			3.92			
S718	04-Oct-86	1	3	15.6							0.018			9.61			
S718	02-Jun-87	1	2	16.1							0.017						
S718	15-Jun-87	1	2	17.8							0.014			7.64			
S718	29-Jun-87	1	2.6	26.1													
S718	03-Aug-87	1	3.3	21.1							0.005			0.59			
S718	16-Aug-87	1	3.8	19.4							0.013			0.88			
S718	07-Sep-87	1	5.1	20.6							0.013			0.59			
S718	20-Sep-87	1	5	17.2							0.012			0.59			
S718	06-Jun-88	1	3	17							0.02			10.09			
S718	21-Jun-88	1	3.2	22.2													

Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^oC)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^oC)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
O718	26-Jun-73	1		20	10.2	7.2	0.4	160	0.01	0.12		0.04			31	20	0.130
O718	10-Jul-73	1		24	10.1	7.4	0.9	380	0.01	0.02		0.02			52	20	0.030
O718	24-Jul-73	1		22	9.9	7.3	0.8	340	0.01	0.01		0.01			49	20	0.020
O718	07-Aug-73	1		23	9.8	7.3	0.7	150	0.01	0.02		0.02			44	20	0.030
O718	21-Aug-73	1		22	10.7	8	1	150	0.01	0.01		0.02			52	20	0.020
O718	06-Sep-73	1		19.8	9.8	8	1.5	170	0.01	0.01					55	21	0.020
O718	18-Sep-73	1		18	11.1	8.1	0.6	180	0.01	0.01		0.02			53	20	0.020
O718	02-Oct-73	1		16	10.4	8	1	140	0.01	0.01		0.02			54	20	0.020
O718	16-Oct-73	1		15	9.5	7.6	0.8	150	0.01	0.03		0.02			53	20	0.040
O718	30-Oct-73	1		12.2	10.3	7.3	1.3	150	0.01	0.01		0.02			51	20	0.020
O718	15-Nov-73	1		8.2	9.3	7.3	0.8	200	0.02	0.01		0.05			55	20	0.030
O718	27-Nov-73	1		6.9	9.6	7.2	2.4	190	0.04	0.05		0.06			51	20	0.090
O718	13-Dec-73	1		5.6	9.9	7	1.4	170	0.04	0.22		0.05			52	20	0.260
O718	27-Dec-73	1		5.5	10	6.8	2.4	140	0.03	0.36		0.05			49	20	0.390
S718	19-May-85	1	3.5	16.7							0.006			6.53			
S718	10-Jul-85	1	4.2	23.3							0.013			2.14			
S718	04-Aug-85	1	4.3	21.1							0.004			2.49			
S718	20-Aug-85	1	4.2	21.5							0.005			2.94			
S718	02-Sep-85	1	5.3	20							0.015			0.01			
S718	23-Sep-85	1	4.8	16.7							0.023			1.72			
S718	07-Oct-85	1	4.3	13.9							0.011			2.88			
S718	20-May-86	1	3	15.6							0.016			8.01			
S718	01-Jun-86	1	2.5	23.9							0.015			4.99			
S718	16-Jun-86	1	4.1	19.4							0.01			4.7			
S718	08-Jul-86	1	3.8	21.1							0.019			3.52			
S718	21-Jul-86	1	4.3	22.2							0.007			1.76			
S718	05-Aug-86	1	4.6	22.2							0.015			2.14			
S718	17-Aug-86	1	5.3	21.1							0.007			2.29			
S718	06-Sep-86	1	4.5	20							0.009			1.42			
S718	22-Sep-86	1	3.8	16.7							0.01			3.92			
S718	04-Oct-86	1	3	15.6							0.018			9.61			
S718	02-Jun-87	1	2	16.1							0.017						
S718	15-Jun-87	1	2	17.8							0.014			7.64			
S718	29-Jun-87	1	2.6	26.1													
S718	03-Aug-87	1	3.3	21.1							0.005			0.59			
S718	16-Aug-87	1	3.8	19.4							0.013			0.88			
S718	07-Sep-87	1	5.1	20.6							0.013			0.59			
S718	20-Sep-87	1	5	17.2							0.012			0.59			
S718	06-Jun-88	1	3	17							0.02			10.09			
S718	21-Jun-88	1	3.2	22.2													

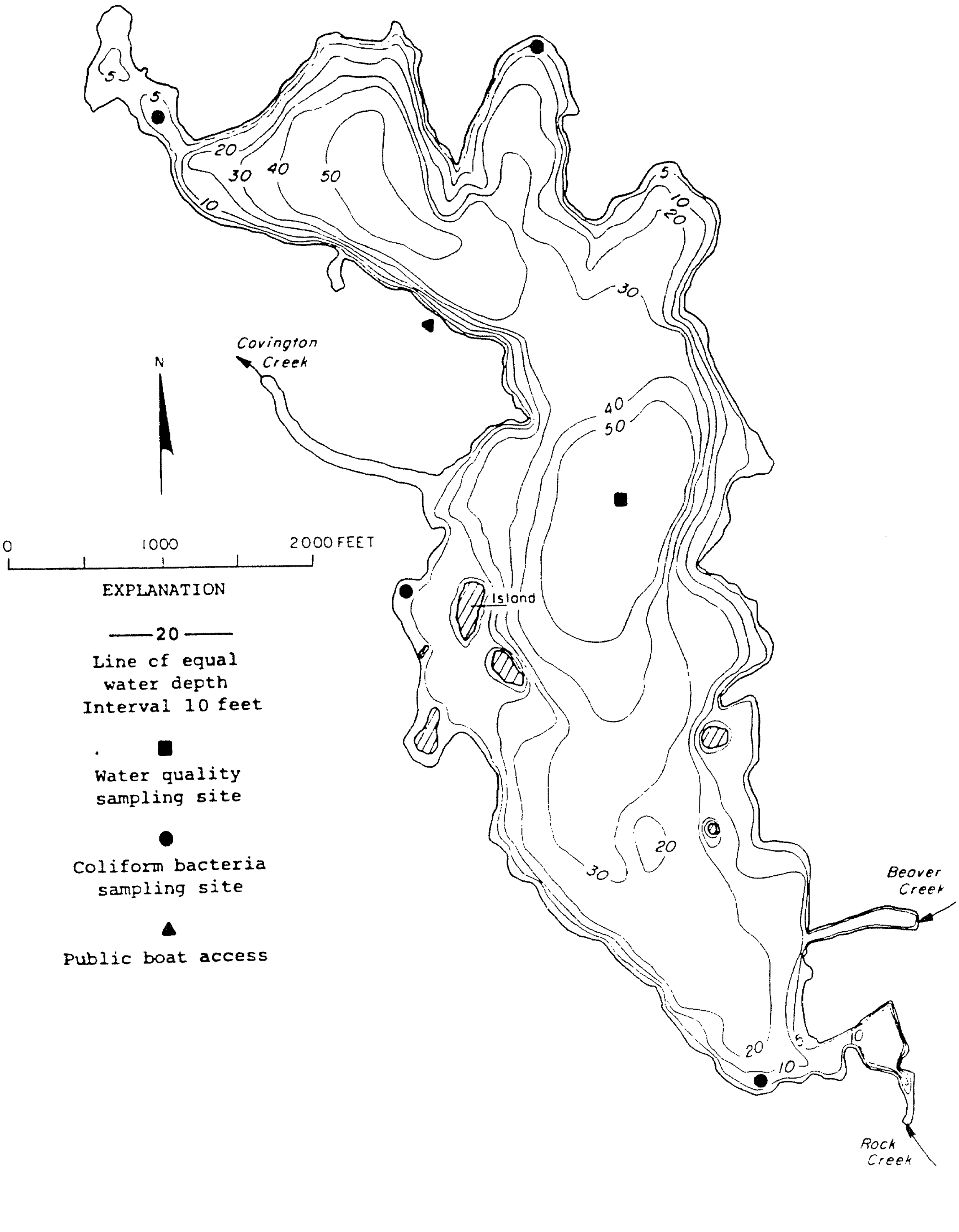
Appendix A. (continued)

Metro Station ID	Date	Depth	Secchi Disk (m)	Temperature (^{o}C)	Dissolved Oxygen (mg/L)	pH (SU)	Turbidity (NTU)	Specific Conductance (umhos/cm 25^{o}C)	Ammonia N (mg N/L)	Nitrite+Nitrite N (mgN/L)	Total P (mgP/L)	Hydrolyzable P (mgP/L)	Soluble Reactive P (mgP/L)	Chlorophyll a (ug/L)	Alkalinity ($mgCaCO_3/L$)	Fecal Coliform (CFU/100ml)	Dissolved Inorg. N (mgN/L)
S718	05-Jul-88	1	2.4	16.7							0.01			3.52			
S718	19-Jul-88	1	3.2	20.6							0.014			1.17			
S718	01-Aug-88	1	3.3								0.013						
S718	15-Aug-88	1	5	19.4							0.014			2.42			
S718	19-Sep-88	1	4.2	16.7							0.017			1.76			
S718	03-Oct-88	1	5.3	16.7							0.013			1.17			
S718	16-Oct-88	1	5	14.4							0.022			1.76			
RCLS	22-May-85					7.13		275	0.04	0.067	0.141		0.144				0.107
RAV	22-May-85					7.18		112	0.001	0.359	0.015		0.005				0.360
RCLS	04-Jun-85				2.53				0.028	0.038			0.152			16	0.066
RAV	04-Jun-85				9.92				0.001	0.388			0.003			4	0.389

APPENDIX B

U.S. GEOLOGICAL SURVEY DATA

(Source: McConnell *et al.*, 1976)



Location of USGS sampling stations.

APPENDIX C

MISCELLANEOUS WATER QUALITY DATA

Key to Miscellaneous Data Codes

Source
KCM = KCM, 1982
BD = City of Black Diamond NPDES data
ERM = ERM (1986) summary
RWBECK = RW Beck (1985) data
ECOLOGY = Dept. of Ecology data (this study)

Station

RCMB = Rock Creek at Morganville Bridge
RCA = Rock Creek at Abrams Road
RAV = Ravensdale Creek
WTP-EFF = Lagoon effluent from Black Diamond WWTF
WTP-INF = Influent pump station to Black Diamond WWTF
BDLC = Black Diamond Lake Creek
RCLS = Rock Creek at lake shore
MM = Morganville marsh surface outflow
PS = Palmer spring

Appendix C. Miscellaneous Water Quality Data

SOURCE	STATION	DATE	FLOW (cfs)	TP (mgP/L)	DIN (mgN/L)	TN (mgN/L)
KCM	RCMB	04-Aug-80	0.7	0.076	0.239	0.773
KCM	RCMB	18-Sep-80	1.9	0.074	0.256	0.952
KCM	RCMB	15-Oct-80	1.2	0.074	0.764	1.252
KCM	RCMB	08-Dec-80	22.0	0.030	1.147	1.405
KCM	RCMB	27-Jan-81	11.5	0.044	0.696	0.784
KCM	RCMB	04-Mar-81	20.2	0.063	0.432	0.914
KCM	RCMB	01-Apr-81	9.0	0.041	0.445	0.983
KCM	RCMB	30-Apr-81	6.9	0.034	0.454	0.974
KCM	RCMB	21-May-81	4.2	0.062	0.643	0.843
KCM	RCMB	31-Aug-81	0.9	0.075	0.179	0.954
KCM	RCMB	07-Oct-81	13.9	0.040	0.434	1.240
KCM	RCMB	11-Nov-81	2.1	0.040	0.375	0.842
KCM	RCMB	09-Dec-81	20.8	0.049	1.276	1.962
KCM	RCMB	12-Jan-82	14.1	0.034	1.281	1.883
KCM	RCMB	10-Feb-82	14.1	0.016	1.347	1.797
KCM	RCMB	17-Mar-82	21.4	0.022	1.006	1.100
KCM	RCMB	23-Apr-82	5.5	0.051	0.592	0.852
KCM	RCA	04-Aug-80	0.9	0.056	0.192	0.623
KCM	RCA	18-Sep-80	1.4	0.054	0.343	0.733
KCM	RCA	15-Oct-80	1.1	0.074	0.519	1.093
KCM	RCA	08-Dec-80	19.0	0.040	1.353	1.611
KCM	RCA	27-Jan-81	9.8	0.049	0.857	1.127
KCM	RCA	04-Mar-81	15.9	0.057	0.679	1.211
KCM	RCA	01-Apr-81	7.7	0.036	0.616	1.125
KCM	RCA	30-Apr-81	7.4	0.029	0.794	1.234
KCM	RCA	21-May-81	9.6	0.062	0.787	0.927
KCM	RCA	31-Aug-81	1.6	0.080	0.209	1.143
KCM	RCA	07-Oct-81		0.040	0.627	1.370
KCM	RCA	11-Nov-81	3.1	0.075	0.416	1.074
KCM	RCA	09-Dec-81	21.0		1.405	2.125
KCM	RCA	12-Jan-82	12.4	0.029	1.370	1.811
KCM	RCA	10-Feb-82	8.2	0.027	1.546	2.026
KCM	RCA	17-Mar-82	17.0	0.018	1.216	1.603
KCM	RCA	23-Apr-82		0.040	0.538	1.053
KCM	RAV	04-Aug-80	4.0	0.010	0.389	0.602
KCM	RAV	18-Sep-80	2.6	0.010	0.356	0.541
KCM	RAV	15-Oct-80	1.8	0.005	0.407	0.521
KCM	RAV	08-Dec-80	27.8	0.010	0.942	0.989
KCM	RAV	27-Jan-81	19.7	0.015	0.828	0.902
KCM	RAV	04-Mar-81	30.7	0.010	0.675	0.771
KCM	RAV	01-Apr-81	18.3	0.010	0.775	0.891
KCM	RAV	30-Apr-81	19.3	0.005	0.901	0.981
KCM	RAV	21-May-81	23.2	0.019	0.901	0.851
KCM	RAV	31-Aug-81	7.8	0.020	0.384	0.474
KCM	RAV	07-Oct-81	8.1	0.002	0.420	0.520
KCM	RAV	11-Nov-81	4.6	0.015	0.354	0.471
KCM	RAV	09-Dec-81	22.0	0.020	0.823	0.972
KCM	RAV	12-Jan-82	20.4	0.010	0.852	0.981

Appendix C. (continued)

SOURCE	STATION	DATE	FLOW (cfs)	TP (mgP/L)	DIN (mgN/L)	TN (mgN/L)
KCM	RAV	10-Feb-82	36.8	0.005	1.207	1.322
KCM	RAV	17-Mar-82	39.2	0.004	0.745	0.881
KCM	RAV	23-Apr-82	23.0	0.020	0.784	1.161
BD	RCMB	07-Nov-84		1.200	0.270	
BD	RCMB	20-Nov-84		1.000	0.520	
BD	RCMB	16-Jan-85		0.500	0.810	
BD	RCMB	24-Jan-85		0.850	0.670	
BD	RCMB	14-Feb-85		0.500	0.720	
BD	RCMB	14-Mar-85		0.700	0.560	
BD	RCMB	28-Mar-85		0.500	0.700	
BD	RCMB	11-Apr-85		0.300	0.460	
BD	RCMB	25-Apr-85		0.600	0.210	
BD	RCMB	09-May-85		0.800	0.170	
BD	RCMB	23-May-85		0.800	0.170	
BD	RCMB	12-Jun-85		0.900	0.140	
BD	RCMB	27-Jun-85		0.500	0.130	
BD	RCMB	17-Jul-85		1.000	0.160	
BD	RCMB	31-Jul-85		0.600	0.090	
BD	RCMB	01-Aug-85		0.600	0.100	
BD	RCMB	15-Aug-85		0.800	0.150	
BD	RCMB	05-Sep-85		1.400	0.590	
BD	RCMB	18-Sep-85		2.400	3.000	
BD	RCMB	02-Oct-85		0.500	0.070	
BD	RCMB	16-Oct-85		0.500	0.190	
BD	RCMB	14-Nov-85		0.120	0.520	
BD	RCMB	15-Jan-86		0.200	0.330	
BD	RCMB	29-Jan-86		0.300	0.830	
BD	RCMB	12-Feb-86		1.000	0.870	
BD	RCMB	27-Feb-86		0.600	0.660	
BD	RCMB	04-Mar-86		0.500	0.620	
BD	RCMB	17-Mar-86		0.700	0.460	
BD	RCMB	09-Apr-86		0.800	0.560	
BD	RCMB	23-Apr-86		0.500	0.340	
BD	RCMB	03-May-86		1.000	0.290	
BD	RCMB	07-May-86		0.350	0.320	
BD	RCMB	18-May-86		0.650	0.240	
BD	RCMB	21-May-86		0.400	0.320	
BD	RCMB	03-Jun-86		1.000	0.300	
BD	RCMB	18-Jun-86		0.650	0.250	
BD	RCMB	02-Jul-86		1.500	0.210	
BD	RCMB	16-Jul-86			0.210	
BD	RCMB	30-Jul-86		1.800	0.210	
BD	RCMB	13-Aug-86		1.500	0.280	
BD	RCMB	27-Aug-86		1.000	0.640	
BD	RCMB	10-Sep-86		1.000	0.150	
BD	RCMB	29-Sep-86		0.450	0.360	
BD	RCMB	07-Oct-86		0.500	0.250	
BD	RCMB	21-Oct-86		1.000	0.330	
BD	RCMB	05-Nov-86		0.600	2.200	
BD	RCMB	18-Nov-86		0.950	0.700	

Appendix C. (continued)

SOURCE	STATION	DATE	FLOW (cfs)	TP (mgP/L)	DIN (mgN/L)	TN (mgN/L)
BD	RCMB	04-Dec-86		0.300	1.190	
BD	RCMB	18-Dec-86		0.250	0.850	
BD	RCMB	31-Dec-86		0.300	0.950	
BD	RCMB	10-Feb-87		0.800	1.690	
BD	RCMB	25-Feb-87		1.300	0.780	
BD	RCMB	04-Jun-87		1.200	0.630	
BD	RCMB	18-Jun-87		0.500	0.520	
BD	RCMB	16-Jul-87		0.600	0.090	
BD	RCMB	29-Jul-87		0.600	0.130	
BD	RCMB	13-Aug-87		1.500	0.180	
BD	RCMB	27-Aug-87		1.000	0.180	
BD	RCMB	10-Sep-87		1.000	0.220	
BD	RCMB	24-Sep-87		1.200	0.150	
BD	RCMB	08-Oct-87		0.500	0.180	
BD	RCMB	22-Oct-87		0.900	0.220	
BD	RCMB	04-Nov-87		0.800	0.290	
BD	RCMB	18-Nov-87		0.500	0.420	
BD	WTP-EFF	16-Apr-87		3.500	17.830	22.030
BD	WTP-EFF	07-May-87		5.400	8.210	14.510
BD	WTP-INF	07-Nov-84		5.400	19.090	
BD	WTP-INF	20-Nov-84		6.200	15.120	
BD	WTP-INF	16-Jan-85		8.000	17.720	
BD	WTP-INF	24-Jan-85		9.100	20.250	
BD	WTP-INF	14-Feb-85		5.300	18.670	
BD	WTP-INF	14-Mar-85		6.500	19.930	
BD	WTP-INF	28-Mar-85		5.700	18.560	
BD	WTP-INF	11-Apr-85		6.950	20.000	
BD	WTP-INF	25-Apr-85		7.300	20.190	
BD	WTP-INF	09-May-85		6.000	21.270	
BD	WTP-INF	23-May-85		7.000	20.200	
BD	WTP-INF	12-Jun-85		5.000	17.520	
BD	WTP-INF	27-Jun-85		8.400	18.870	
BD	WTP-INF	17-Jul-85		9.100	24.230	
BD	WTP-INF	31-Jul-85		9.900	34.960	
BD	WTP-INF	01-Aug-85		4.100	24.230	
BD	WTP-INF	15-Aug-85		10.100	35.520	
BD	WTP-INF	05-Sep-85		12.000	27.010	
BD	WTP-INF	18-Sep-85		9.500	24.650	
BD	WTP-INF	02-Oct-85		12.500	29.430	
BD	WTP-INF	16-Oct-85		11.500	28.030	
BD	WTP-INF	13-Nov-85		7.000	17.690	
BD	WTP-INF	15-Jan-86		5.000	20.820	
BD	WTP-INF	29-Jan-86		0.700	18.500	
BD	WTP-INF	12-Feb-86		7.600	20.220	
BD	WTP-INF	27-Feb-86		6.600	16.280	
BD	WTP-INF	04-Mar-86		11.000	20.960	
BD	WTP-INF	17-Mar-86		8.900	15.590	
BD	WTP-INF	09-Apr-86		7.400	22.720	
BD	WTP-INF	23-Apr-86		8.600	29.510	

Appendix C. (continued)

SOURCE	STATION	DATE	FLOW (cfs)	TP (mgP/L)	DIN (mgN/L)	TN (mgN/L)
BD	WTP-INF	03-May-86		7.500	32.540	
BD	WTP-INF	07-May-86		6.500	25.850	
BD	WTP-INF	18-May-86		7.700	33.960	
BD	WTP-INF	21-May-86		5.000	21.600	
BD	WTP-INF	03-Jun-86		7.500	32.540	
BD	WTP-INF	18-Jun-86		7.700	33.690	
BD	WTP-INF	02-Jul-86		6.500	27.140	
BD	WTP-INF	16-Jul-86		9.000	23.070	
BD	WTP-INF	30-Jul-86		8.900	31.770	
BD	WTP-INF	13-Aug-86		10.000	28.420	
BD	WTP-INF	27-Aug-86		11.000	8.830	
BD	WTP-INF	10-Sep-86		9.900	27.430	
BD	WTP-INF	29-Sep-86		10.000	37.800	
BD	WTP-INF	07-Oct-86		8.400	25.830	
BD	WTP-INF	21-Oct-86		11.000	27.240	
BD	WTP-INF	05-Nov-86		7.200	24.440	
BD	WTP-INF	18-Nov-86		5.000	17.010	
BD	WTP-INF	04-Dec-86		4.400	16.820	
BD	WTP-INF	18-Dec-86		7.840	22.750	
BD	WTP-INF	31-Dec-86		2.500	9.840	
BD	WTP-INF	10-Feb-87		6.900	26.360	
BD	WTP-INF	25-Feb-87		6.350	24.430	
BD	WTP-INF	04-Jun-87		8.900	22.440	
BD	WTP-INF	18-Jun-87		8.850	28.320	
BD	WTP-INF	16-Jul-87		8.500	26.480	
BD	WTP-INF	29-Jul-87		9.500	26.060	
BD	WTP-INF	13-Aug-87		9.000	30.230	
BD	WTP-INF	27-Aug-87		9.000	28.030	
BD	WTP-INF	10-Sep-87		9.500	23.880	
BD	WTP-INF	24-Sep-87		9.700	28.040	
BD	WTP-INF	08-Oct-87		9.800	28.310	
BD	WTP-INF	22-Oct-87		9.900	27.430	
BD	WTP-INF	04-Nov-87		8.500	27.710	
BD	WTP-INF	18-Nov-87		9.000	27.020	
ERM	WTP-INF	Jan-83				
ERM	WTP-INF	Feb-83		5.200	13.000	
ERM	WTP-INF	Mar-83				
ERM	WTP-INF	Apr-83				
ERM	WTP-INF	May-83		7.910	22.000	
ERM	WTP-INF	Jun-83		11.300	29.200	
ERM	WTP-INF	Jul-83		7.420	6.700	
ERM	WTP-INF	Aug-83		8.570	8.650	
ERM	WTP-INF	Sep-83		8.800	10.050	
ERM	WTP-INF	Oct-83		8.200	34.560	
ERM	WTP-INF	Nov-83		7.590	16.800	
ERM	WTP-INF	Dec-83		4.910	17.000	
ERM	WTP-INF	Jan-84		6.380	16.450	
ERM	WTP-INF	Feb-84		6.840	17.630	
ERM	WTP-INF	Mar-84		8.040	21.500	
ERM	WTP-INF	Apr-84		6.390	21.900	

Appendix C. (continued)

SOURCE	STATION	DATE	FLOW (cfs)	TP (mgP/L)	DIN (mgN/L)	TN (mgN/L)
ERM	WTP-INF	May-84		6.230	19.500	
ERM	WTP-INF	Jun-84		4.610	25.400	
ERM	WTP-INF	Jul-84		3.900	17.500	
ERM	WTP-INF	Aug-84		8.200	31.800	
ERM	WTP-INF	Sep-84		11.000	37.000	
ERM	WTP-INF	Oct-84				
ERM	WTP-INF	Nov-84		3.800	17.100	
ERM	WTP-INF	Dec-84		5.900	15.400	
ERM	WTP-INF	Jan-85		8.550	19.000	
ERM	WTP-INF	Feb-85		5.300	18.700	
ERM	WTP-INF	Mar-85		6.100	19.300	
ERM	WTP-INF	Apr-85		7.100	20.100	
ERM	WTP-INF	May-85		6.500	20.800	
ERM	WTP-INF	Jun-85		6.700	18.200	
ERM	WTP-INF	Jul-85		9.500	30.000	
ERM	WTP-INF	Aug-85		9.600	30.000	
ERM	WTP-INF	Sep-85		10.800	25.800	
ERM	WTP-INF	Oct-85		12.000	28.700	
ERM	WTP-INF	Nov-85		7.000	17.700	
ERM	WTP-INF	Dec-85		10.700	32.000	
ERM	WTP-INF	Jan-86		2.850	19.700	
ERM	WTP-INF	Feb-86		7.100	9.150	
ERM	WTP-INF	Mar-86		9.900	18.300	
ERM	WTP-INF	Apr-86		7.820	26.300	
ERM	WTP-INF	May-86		5.750	23.700	
ERM	RCMB	Jan-83				
ERM	RCMB	Feb-83		0.200	0.890	
ERM	RCMB	Mar-83				
ERM	RCMB	Apr-83				
ERM	RCMB	May-83		0.360	0.090	
ERM	RCMB	Jun-83		1.040	0.120	
ERM	RCMB	Jul-83		0.660	0.041	
ERM	RCMB	Aug-83		0.660	0.180	
ERM	RCMB	Sep-83		0.630	0.044	
ERM	RCMB	Oct-83		0.580	0.120	
ERM	RCMB	Nov-83		1.390	0.740	
ERM	RCMB	Dec-83		0.880	0.840	
ERM	RCMB	Jan-84		0.590	0.540	
ERM	RCMB	Feb-84		0.150	0.850	
ERM	RCMB	Mar-84		0.190	0.940	
ERM	RCMB	Apr-84		0.140	0.440	
ERM	RCMB	May-84		0.120	0.280	
ERM	RCMB	Jun-84		0.230	0.630	
ERM	RCMB	Jul-84		0.100	0.520	
ERM	RCMB	Aug-84		0.230	1.000	
ERM	RCMB	Sep-84		4.700	0.150	
ERM	RCMB	Oct-84				
ERM	RCMB	Nov-84		1.100	0.400	
ERM	RCMB	Dec-84		0.900	0.990	
ERM	RCMB	Jan-85		0.680	0.075	

Appendix C. (continued)

SOURCE	STATION	DATE	FLOW (cfs)	TP (mgP/L)	DIN (mgN/L)	TN (mgN/L)
ERM	RCMB	Feb-85		0.500	0.730	
ERM	RCMB	Mar-85		0.600	0.630	
ERM	RCMB	Apr-85		0.450	0.340	
ERM	RCMB	May-85		0.800	0.180	
ERM	RCMB	Jun-85		0.700	0.140	
ERM	RCMB	Jul-85		0.800	0.140	
ERM	RCMB	Aug-85		0.700	0.130	
ERM	RCMB	Sep-85		1.900	1.800	
ERM	RCMB	Oct-85		0.500	0.130	
ERM	RCMB	Nov-85		0.120	0.530	
ERM	RCMB	Dec-85		1.000	2.100	
ERM	RCMB	Jan-86		0.250	0.660	
ERM	RCMB	Feb-86		0.800	0.820	
ERM	RCMB	Mar-86		0.600	0.530	
ERM	RCMB	Apr-86		0.650	0.450	
ERM	RCMB	May-86		0.380	0.210	
RWBECK	WTP-INF	02-May-85		7.300	18.575	29.290
RWBECK	WTP-INF	09-May-85		7.400	0.404	30.790
RWBECK	WTP-INF	14-May-85		8.400	22.788	29.978
RWBECK	WTP-INF	23-May-85		9.300	15.062	45.742
RWBECK	WTP-INF	30-May-85		9.900	5.759	44.899
RWBECK	BDLC	02-May-85	0.8			
RWBECK	BDLC	09-May-85	0.7	0.041	0.010	0.390
RWBECK	BDLC	14-May-85	0.5	0.047	0.196	0.508
RWBECK	BDLC	23-May-85	0.2	0.116	0.108	0.887
RWBECK	BDLC	30-May-85	0.3	0.053	0.069	3.109
RWBECK	RCA	02-May-85	4.3	0.013	0.280	0.610
RWBECK	RCA	09-May-85	3.7	0.013	0.010	0.560
RWBECK	RCA	14-May-85	3.2	0.022	0.059	0.359
RWBECK	RCA	23-May-85	2.5	0.051	0.125	0.889
RWBECK	RCA	30-May-85	2.6	0.033	0.078	1.011
RWBECK	RCMB	02-May-85	9.1	0.100	0.120	0.420
RWBECK	RCMB	09-May-85	6.2	0.450	0.010	0.340
RWBECK	RCMB	14-May-85	7.0	0.140	0.083	0.373
RWBECK	RCMB	23-May-85	3.7	0.214	0.055	0.714
RWBECK	RCMB	30-May-85	8.7	0.230	0.133	0.853
ECOLOGY	RCLS	27-Feb-89	16.5	0.081		1.030
ECOLOGY	RCLS	27-Feb-89	16.5	0.081	0.770	1.010
ECOLOGY	RCLS	21-Mar-89	23.2	0.068		1.220
ECOLOGY	RCLS	21-Mar-89	23.5	0.069	0.788	1.100
ECOLOGY	RCLS	21-Mar-89	23.5	0.065		1.030
ECOLOGY	RCLS	11-Apr-89	19.8			
ECOLOGY	RCLS	11-Apr-89	19.8			
ECOLOGY	RCLS	11-Apr-89	19.5			
ECOLOGY	RCMB	27-Feb-89	14.3	0.092		1.320

Appendix C. (continued)

SOURCE	STATION	DATE	FLOW (cfs)	TP (mgP/L)	DIN (mgN/L)	TN (mgN/L)
ECOLOGY	RCMB	27-Feb-89	14.1	0.094	0.958	1.970
ECOLOGY	RCMB	21-Mar-89	20.4	0.076		1.300
ECOLOGY	RCMB	21-Mar-89	20.4	0.078	0.780	0.980
ECOLOGY	RCMB	21-Mar-89	20.9	0.074	0.795	1.020
ECOLOGY	RCMB	11-Apr-89	15.7			
ECOLOGY	RCMB	11-Apr-89	15.0			
ECOLOGY	RCMB	11-Apr-89	14.9			
ECOLOGY	RCA	27-Feb-89	14.4	0.025		1.630
ECOLOGY	RCA	27-Feb-89	14.4	0.021	0.998	1.920
ECOLOGY	RCA	21-Mar-89	22.5	0.021		1.100
ECOLOGY	RCA	21-Mar-89	22.5	0.020	0.994	0.940
ECOLOGY	RCA	21-Mar-89	23.7	0.021	0.980	1.000
ECOLOGY	RCA	11-Apr-89	14.2			
ECOLOGY	RCA	11-Apr-89	13.1			
ECOLOGY	RCA	11-Apr-89	14.4			
ECOLOGY	RAV	27-Feb-89	22.4	5.500		0.590
ECOLOGY	RAV	27-Feb-89	22.4	6.000	0.561	0.570
ECOLOGY	RAV	21-Mar-89	31.6	0.007		0.535
ECOLOGY	RAV	21-Mar-89	31.6	0.005	0.560	0.590
ECOLOGY	RAV	21-Mar-89	31.6	0.006		0.560
ECOLOGY	RAV	11-Apr-89	35.9			
ECOLOGY	RAV	11-Apr-89	34.9			
ECOLOGY	RAV	11-Apr-89	34.4			
ECOLOGY	MM	27-Feb-89	0.3	0.014		0.900
ECOLOGY	MM	27-Feb-89	0.3	0.014	0.578	0.885
ECOLOGY	MM	21-Mar-89	0.3	0.014		0.740
ECOLOGY	MM	21-Mar-89	0.3	0.014	0.347	0.770
ECOLOGY	MM	21-Mar-89	0.3	0.017		0.700
ECOLOGY	BDLC	27-Feb-89	1.1	0.022		0.810
ECOLOGY	BDLC	27-Feb-89	1.1	0.024	0.498	0.890
ECOLOGY	BDLC	21-Mar-89	2.4	0.023		0.770
ECOLOGY	BDLC	21-Mar-89	2.4	0.040	0.522	0.840
ECOLOGY	BDLC	21-Mar-89	2.4	0.030		0.890
ECOLOGY	PS	27-Feb-89	0.2	0.033		1.040
ECOLOGY	PS	27-Feb-89	0.2	0.052	1.059	0.970
ECOLOGY	PS	21-Mar-89	0.3	0.033		1.090
ECOLOGY	PS	21-Mar-89	0.3	0.034	1.444	1.010
ECOLOGY	PS	21-Mar-89	0.3	0.034		1.090

APPENDIX D

ERROR PROPAGATION FORMULAS

Simple Error Propagation Formulas. The following formulas represent application of the first-order error propagation technique to simple algebraic relationships between independent random variables. For all formulas, the quantity σ^2 represents the variance term (i.e. σ_z^2 = variance of z, σ_x^2 = variance of x, etc.); z is a function of random variables x and y; a and b are constants.

1. **Addition/Subtraction**

   Function: $z = ax+by$ or $z = ax-by$

   Variance: $\sigma_z^2 = (\delta z/\delta x)^2\sigma_x^2 + (\delta z/\delta y)^2\sigma_y^2 = a^2\sigma_x^2 + b^2\sigma_y^2$

2. **Multiplication**

   Function: $z = xy$

   Variance: $\sigma_z^2 = (\delta z/\delta x)^2\sigma_x^2 + (\delta z/\delta y)^2\sigma_y^2 = y^2\sigma_x^2 + x^2\sigma_y^2$

3. **Division**

   Function: $z = \frac{x}{y}$

   Variance: $\sigma_z^2 = (\delta z/\delta x)^2\sigma_x^2 + (\delta z/\delta y)^2\sigma_y^2$
   $= (1/y)^2\sigma_x^2 + (-x/y^2)^2\sigma_y^2$

APPENDIX E

EVALUATION OF WETLAND TREATMENT PERFORMANCE

The Wastewater Treatment Facility (WWTF) is located on Abrams Road on the southern edge of the city (Figures E-1 and E-2). The 270-acre wetland area extends along Rock Creek from Jones Lake along the south and west edges of the city to the Morganville Road bridge crossing. Several drainages from wetlands and lakes to the north (Mud Lake and Morganville marsh) and south (Black Diamond Lake) also converge on Rock Creek in this area, as do springs from flooded mine shafts.

Ecology authorized, under the 1980 NPDES permit, discharge limitations shown in Table E-1 for the Black Diamond WWTF (Ecology, 1980). Nitrogen and phosphorus limits are based on the percent reduction measured between the influent pump station and the Morganville Bridge. Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) limits are based on effluent from the lagoon to the wetland. The permit limitations were selected based on reasonable expectations for the technology utilized, rather than evaluation of the potential effect of discharges on water quality in Rock Creek and Lake Sawyer (ERM, 1986). Furthermore, the permit limitations were based on expectations for pollutant removal in harvested wetland wastewater treatment systems rather than the natural wetland system implemented (Cook and Brugger, 1986).

The wetland treatment portion of the Black Diamond WWTF distributes wastewater in the swamp, marsh, and wet coniferous areas west of Abrams Road (Figure E-1 and E-2). The original 1,500 feet of distribution pipe had ports approximately every 100 feet. The northern arm extended approximately 500 feet north of Rock Creek along Abrams Road, but was discontinued in 1988. The 1,000-foot western arm roughly follows the boundary between the wet coniferous forest and marsh communities and currently diffuses all of the WWTF effluent discharge.

R.W. Beck (1985) observed insignificant effluent phosphorus removal rates in the wetland system during their May 1985 survey. Average effluent nitrogen removal rates varied widely: total nitrogen (55 percent); total inorganic nitrogen (86 percent); and organic nitrogen (53 percent). Average removal rates of effluent BOD and TSS loads also were below acceptable permit rates (Table E-1).

The R.W. Beck (1985) study was criticized for incomplete characterization of the wetland water and nutrient budgets (ERM, 1986). Of the major components of the water and nutrient budgets, shown schematically in Figure E-3, inflows and outflows from the Palmer spring, Morganville marsh, precipitation, ground water, storage change and evapotranspiration, were unaccounted. Approximately 26 to 64 percent of the flow at the Morganville Bridge station was attributed to unknown sources in the R.W. Beck (1985) analysis.

The ongoing Ecology study of the wetland system includes characterization of nutrient removal in the wetland system, including all sources and losses identified in Figure E-3. Discharge measurements for three surveys and nutrient determinations for two surveys have been completed between February and April, 1989. The water balance for the three surveys is presented in Table E-2. Phosphorus and nitrogen mass balances are presented in Tables E-3 and E-4.

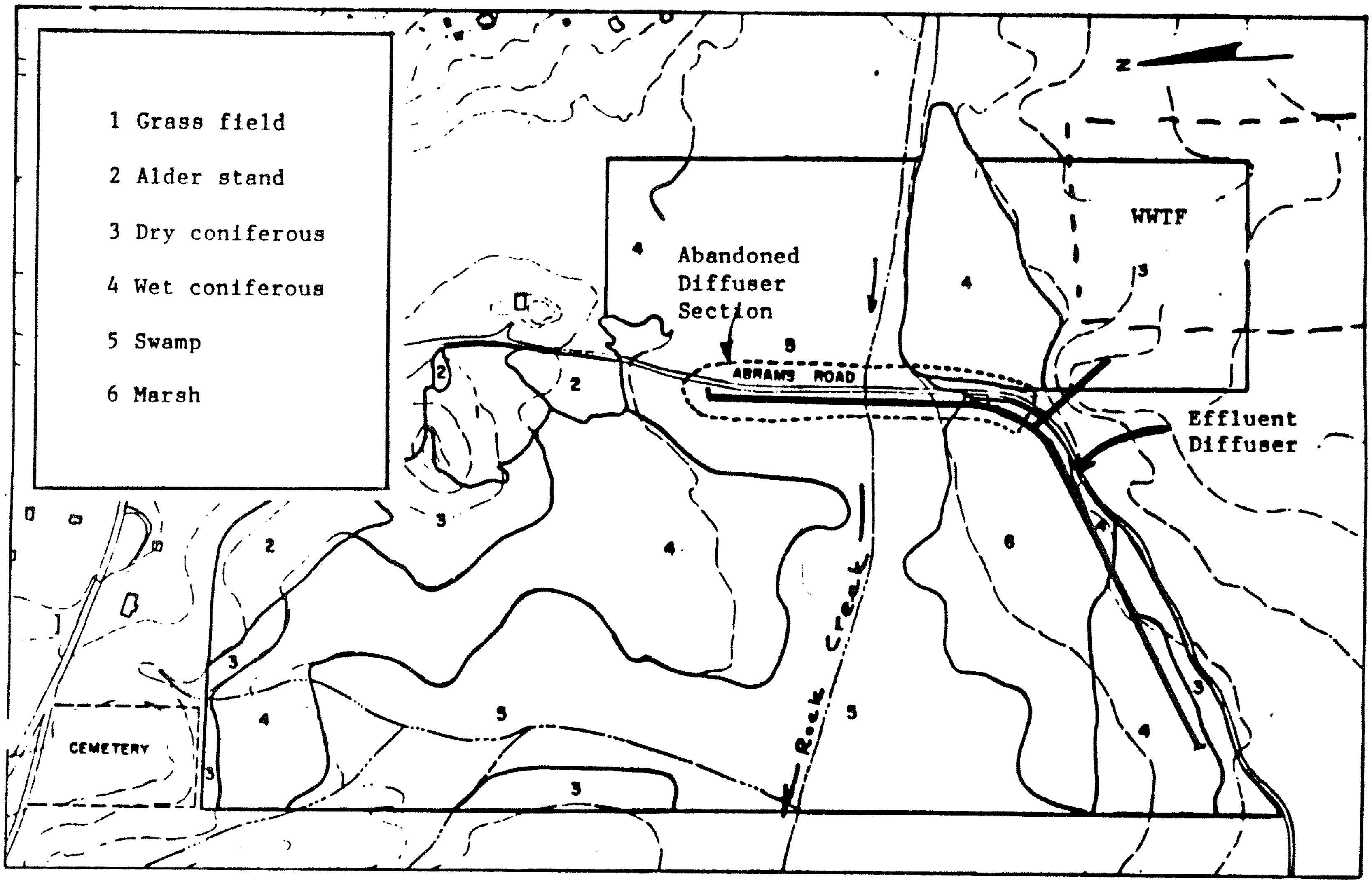


Figure E-1. Black Diamond WWTF wetland treatment layout and vegetative communities (after KCM, 1980).

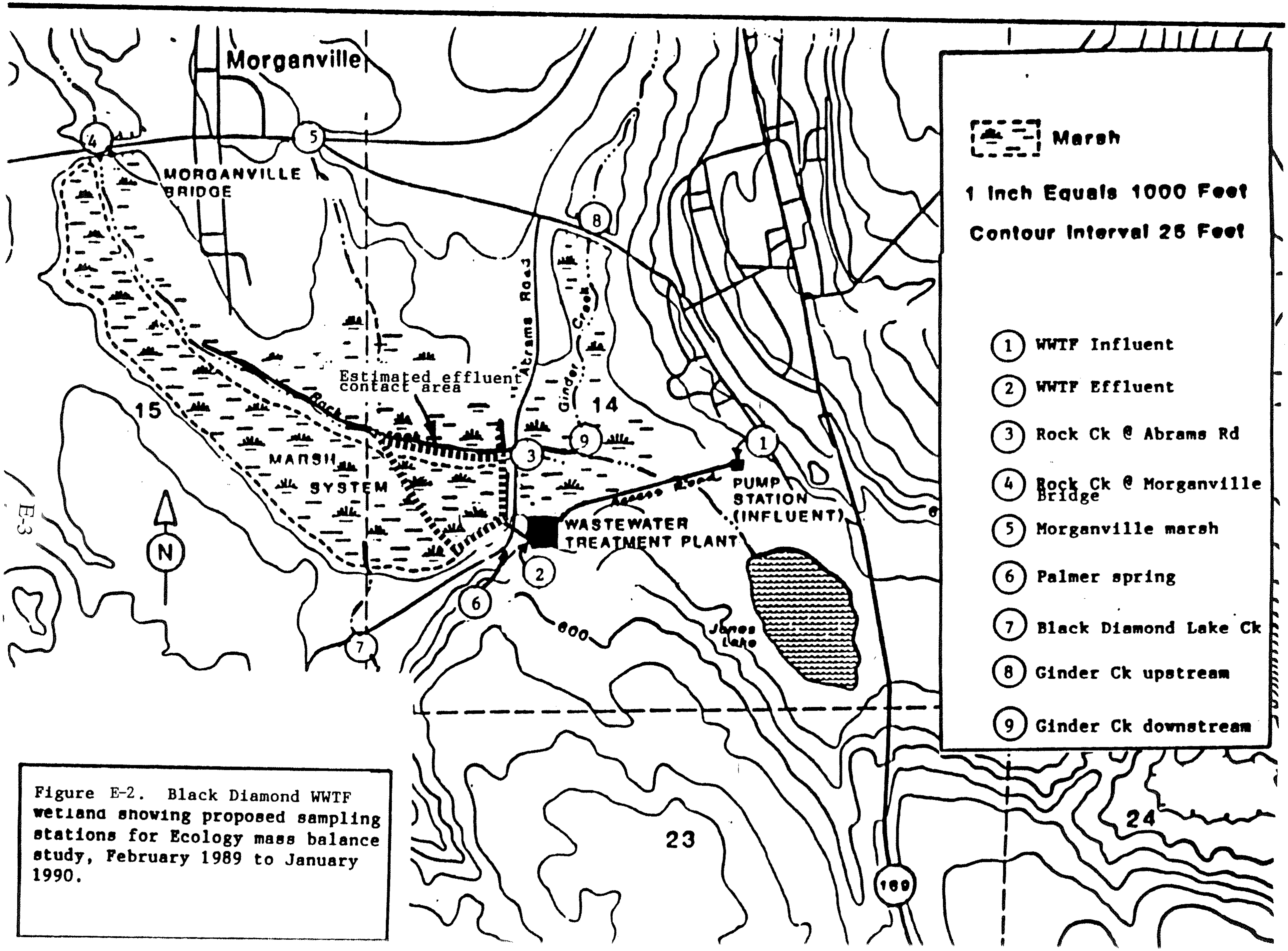


Figure E-2. Black Diamond WWTF wetland showing proposed sampling stations for Ecology mass balance study, February 1989 to January 1990.

Table E-1. Black Diamond WWTF effluent limitations based on NPDES permit (Ecology, 1980).

Permit No. WA-002996-3

FINAL EFFLUENT LIMITATIONS

Beginning on July 1, 1982 and lasting until the expiration date of this permit, the permittee is authorized to discharge wastewater treatment plant effluent to Rock Creek subject to the following limitations:

Monthly average flows are estimated at 0.15 MGD based on population estimates.

		EFFLUENT AND EFFICIENCY LIMITATIONS				
		Weekly Average		Monthly Average		
		Maximum Concentration	Maximum Quantity	Maximum Concentration	Maximum Quantity	Minimum Reduction
Biochemical Oxygen Demand (5-day)		45 mg/l	57 lbs/day	30 mg/l	38 lbs/day	85%
Total Suspended Solids		45 mg/l	57 lbs/day	30 mg/l	38 lbs/day	85%
Fecal Coliform Bacteria		400/100 ml	----	200/100 ml	----	----
(NO_3-N+NO_2-N+NH_3-N):	Summer	----	----	----	----	70%
	Winter	----	----	----	----	60%
Total Phosphorus:	Summer	----	----	----	----	60%
	Winter	----	----	----	----	40%
pH		Not outside the range 6.0 - 9.0				
Oils		No visible oils or greases				

The monthly and weekly averages of BOD and Suspended Solids are based on the arithmetic mean of the samples taken. The averages for Fecal Coliform are based on the geometric mean of the samples taken.

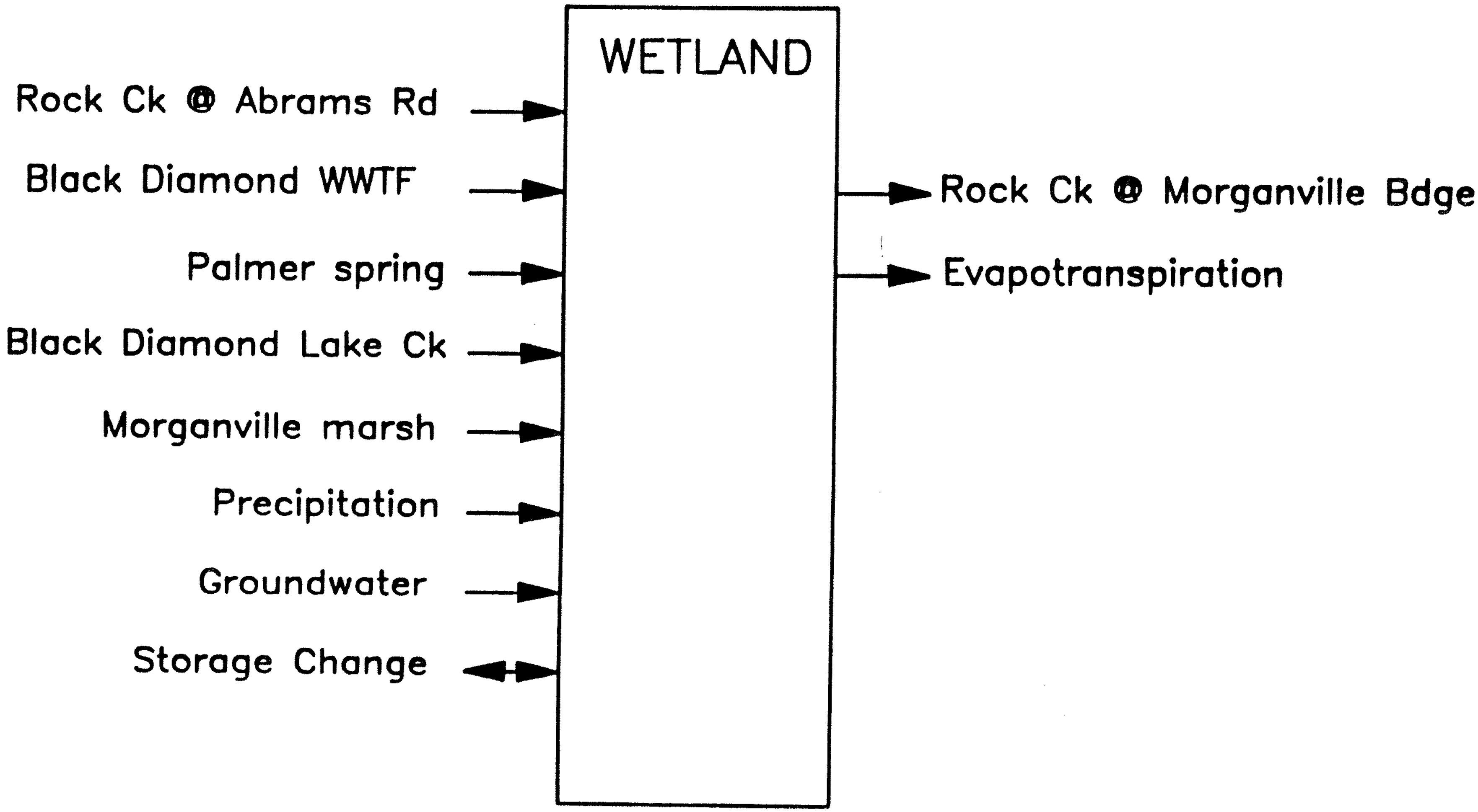


Figure E-3 . Schematic of the Black Diamond WWTF wetland water budget.

Table E-2. Summary of water budget for wetland intensive surveys, February, March, and April, 1989.

WATER BUDGET COMPONENT	Discharge (cfs) 27-Feb-89 Mean +/-	SE	21-Mar-89 Mean +/-	SE	11-Apr-89 Mean +/-	SE
INFLOWS OR SOURCES						
Black Diamond WWTF	0.2 +/-	0.0	0.3 +/-	0.0	0.3 +/-	0.0
Rock Ck @ Abrams Rd	14.4 +/-	1.4	22.9 +/-	2.3	13.9 +/-	1.4
Morganville marsh	0.3 +/-	0.0	0.3 +/-	0.0	0.2 +/-	0.0
Palmer spring	0.2 +/-	0.0	0.3 +/-	0.0	0.3 +/-	0.0
Black Diamond Lake Ck	2.4 +/-	0.2	2.5 +/-	0.3	1.1 +/-	0.1
Direct Precipitation	0.1 +/-	0.0	2.4 +/-	0.2	0.0 +/-	0.0
TOTAL INFLOWS	17.6 +/-	1.5	28.7 +/-	2.3	15.7 +/-	1.4
OUTFLOWS OR LOSSES						
Rock Ck @ Morganville Bdge	14.2 +/-	1.4	20.6 +/-	2.1	15.2 +/-	1.5
Evapotranspiration	0.1 +/-	0.0	0.2 +/-	0.0	0.2 +/-	0.0
TOTAL OUTFLOWS/LOSSES	14.3 +/-	1.4	20.8 +/-	2.1	15.4 +/-	1.5
CHANGE IN STORAGE (1)	-1.6 +/-	-0.2	6.5 +/-	0.7	-8.1 +/-	-0.8
NET GROUNDWATER INFLOW/OUTFLOW (2)	-4.9 +/-	2.0	-1.3 +/-	3.2	-8.4 +/-	2.2

1) Increaase in wetland volume if positive, decrease if negative.
2) Inflow if positive, outflow if negative.

Table E-3. Summary of total phosphorus budgets for intensive Rock Creek wetland surveys.

	Total Phosphorus Load (# P /day)					
	27-Feb-89			21-Mar-89		
NUTRIENT BUDGET COMPONENT	Mean	+/-	SE	Mean	+/-	SE
INFLOWS OR SOURCES						
Black Diamond WWTF	5.8	+/-	0.6	6.4	+/-	0.7
Rock Ck @ Abrams Rd	1.8	+/-	0.2	2.5	+/-	0.3
Morganville marsh	0.0	+/-	0.0	0.0	+/-	0.0
Palmer spring	0.0	+/-	0.0	0.1	+/-	0.0
Black Diamond Lake Ck	0.3	+/-	0.0	0.4	+/-	0.1
Direct Precipitation	0.0	+/-	0.0	0.3	+/-	0.1
TOTAL INFLOWS	8.0	+/-	0.7	9.7	+/-	0.7
OUTFLOWS OR LOSSES						
Rock Ck @ Morganville Bdge	7.1	+/-	0.7	8.4	+/-	0.9
Net Groundwater Loss	2.5	+/-	1.0	0.5	+/-	1.3
TOTAL OUTFLOWS/LOSSES	9.6	+/-	1.3	9.0	+/-	1.6
WETLAND RETENTION/EXPORT (1)	-1.6	+/-	1.4	0.8	+/-	1.7
WETLAND TREATMENT (2) EFFICIENCY (% removal)	-19%	+/-	18%	8%	+/-	17%

1) Retention within wetland if positive, export from nutrient stored within wetland if negative.

2) Treatment efficiencey calculated as 1-(outflows/inflows). Positive values indicate retention within wetland, negative values indicate export from stored nutrients within the wetland.

Table E-4. Summary of total nitrogen budgets for intensive Rock Creek wetland surveys.

	Total Nitrogen Load (# N /day)					
	27-Feb-89			21-Mar-89		
NUTRIENT BUDGET COMPONENT	Mean	+/-	SE	Mean	+/-	SE
INFLOWS OR SOURCES						
Black Diamond WWTF	24.6	+/-	2.5	22.4	+/-	2.9
Rock Ck @ Abrams Rd	137.8	+/-	17.8	125.1	+/-	14.9
Morganville marsh	1.6	+/-	0.2	1.1	+/-	0.1
Palmer spring	1.1	+/-	0.1	1.7	+/-	0.2
Black Diamond Lake Ck	11.1	+/-	1.2	11.2	+/-	1.3
Direct Precipitation	0.4	+/-	0.3	17.3	+/-	11.1
TOTAL INFLOWS	176.5	+/-	18.0	178.8	+/-	18.9
OUTFLOWS OR LOSSES						
Rock Ck @ Morganville Bdge	125.9	+/-	27.9	122.1	+/-	20.0
Net Groundwater Loss	43.7	+/-	20.1	8.0	+/-	18.8
TOTAL OUTFLOWS/LOSSES	169.6	+/-	34.4	130.1	+/-	27.4
WETLAND RETENTION/EXPORT (1)	7.0	+/-	38.8	48.7	+/-	33.3
WETLAND TREATMENT (2) EFFICIENCY (% removal)	4%	+/-	22%	27%	+/-	17%

1) Retention within wetland if positive, export from nutrient stored within wetland if negative.

2) Treatment efficiencey calculated as 1-(outflows/inflows). Positive values indicate retention within wetland, negative values indicate export from stored nutrients within the wetland.

The wetland surveys conducted by Ecology during February and March, 1989, generally support the conclusions made by R.W. Beck (1985). In general, phosphorus and nitrogen retention within the wetland system was insignificant. On average, total output of phosphorus exceeded total external inputs, although the difference was not significant. Average retention of nitrogen within the wetland was somewhat greater than phosphorus retention, although neither nutrient was significantly attenuated. The Ecology and R.W. Beck surveys of the wetland system indicate that the natural wetland portion of the system cannot be expected to significantly reduce phosphorus loads from the Black Diamond WWTF as it is presently designed.

Although the design report states that the wastewater contacts 130 acres of wetland (KCM, 1981), the actual contact area has never been determined. The 130 acres, it seems, includes all of the wetland areas inventoried during the ecological survey, as well as uninventoried areas downstream from the initial study area. However most of the wetland area, including portions north of Rock Creek and west of Black Diamond Lake Creek, does not appear to be potentially in contact with wastewater. This is in consideration of the effluent diffuser length and location (Figure E-2). Based on wetland topography and diffuser location, the actual effluent contact area appears to be about eleven acres.

APPENDIX F

UNCERTAINTY ANALYSIS EXAMPLE

Uncertainty Analysis Example

The following example presents the technique used to predict Lake Sawyer total P concentrations for various scenarios of future point source loading. In general, error propagation was computed using first-order uncertainty analysis techniques recommended by Reckhow and Chapra (1983) for evaluating incremental changes in phosphorus loading and in-lake response. The example presented is for the prediction of in-lake total P in the year 2010, assuming that feasible advanced waste treatment processes are implemented and the Black Diamond Wastewater Treatment Facility (WWTF) continues to discharge to the Rock Creek wetland system (Table 13).

The existing (1984-89) Lake Sawyer total P concentration is estimated to be 30.7 ± 7.5 μg P/L (Table 6). The future (2010) total P concentration is expected to change because effluent loading to the wetland is estimated to be 2.6# P/day, which represents a 1.2# P/day decrease from the existing (1984-89) effluent load of 3.8# P/day to the wetland. An estimated 68% ± 58% of the effluent load to the wetland actually enters Lake Sawyer, so that the decrease in future effluent load to the lake is estimated as follows:

$$\delta M_l = F\delta M_{wl} = (0.68)(1.2\# \text{ P/day}) = 0.8\# \text{ P/day}$$

where

δM_l = change in effluent total P load to the lake
F = fraction of effluent total P load to the wetland that reaches the lake = 68% ± 58%
δM_{wl} = change in effluent total P load to the wetland = 1.2# P/day

The estimated standard error of δM_l is calculated using first-order techniques as follows:

$$S_{\delta ml} = [\delta M^2_{wl} S^2_F]^{0.5} = [(1.2)^2(0.58)^2]^{0.5} = 0.7 \text{ \# P/day}$$

where

$S_{\delta ml}$ = standard error of δM_l
S_F = standard error of F

The change in loading to the lake will cause a corresponding change in the total P concentration, which can be predicted using equation 5:

$$\delta P = \frac{\delta L}{(11.6+1.2q_s)} = (K_1)(\delta L)$$

where

δP = increment of changed total P concentration (mg P/m^3)
δL = increment of changed areal total P load (mg P/m^2/y)
q_s = areal hydraulic load = 21 m/y
K_1 = $1/(11.6 + 1.2q_s)$ = 0.0272 (mg P/m^3) per (mg P/m^2/y)

The quantity K_1 represents the constant of proportionality between loading and in-lake concentration. For each unit change of loading of one mg P/m²/year, the in-lake total P is predicted to change by 0.0272 mg P/m^3 (note: units of mg P/m^3 are equivalent to μg P/L). This sensitivity of the lake to changed loading may also be predicted using units of # P/day for loading (δM_1), since:

$$\delta M_1 = \frac{(\delta L)(A)}{(365\ d/y)(453592\ mg/\#)}$$

where δM_1 = increment of changed total P load (# P/day) as above
A = lake surface area = 1.1×10^6 m².

Therefore, $\delta P = K_2 \delta M_1$

where
$$K_2 = K_1 \left[\frac{(365\ d/y)(453592\ mg/\#)}{A}\right]$$

$$= (0.0272)\left[\frac{(365)(453592)}{1.1 \times 10^6}\right]$$

$$= 4.1\ (mg\ P/m^3)\ per\ (\#\ P/day)$$

Therefore, the quantity K_2 represents a constant of proportionality specific to Lake Sawyer, which relates loading (# P/day) to in-lake total P concentration (mg P/m^3). For each unit change in loading of one # P/day, the lake concentration is predicted to change by 4.1 mg P/m^3. The constant of proportionality, which is the "model" which relates phosphorus loading to in-lake concentration, is estimated to have an uncertainty of ± 30 percent (Reckhow and Chapra, 1983). Therefore, the standard error (S_{k2}) of K_2 is estimated as:

$$S_{k2} = 0.3\ K_2$$
$$= (0.3)(4.1)$$
$$= 1.2\ (mg\ P/m^3)\ per\ (\#\ P/day).$$

The decrease in in-lake total P concentration which will result from a loading decrease of 0.8 ± 0.7 # P/day can now be estimated using the "model" presented above:

$$\delta P = K_2 \delta M_1$$
$$= (4.1)(0.8)$$
$$= 3.3\ mg\ P/m^3$$

The standard error of the predicted decrease in-lake total P is estimated using first-order analysis as follows:

$$S_{\delta p} = \left[(\delta M_1)^2(S_{k2})^2 + (K_2)^2(S_{\delta m1})^2\right]^{0.5}$$

$$= \left[(0.8)^2(1.2)^2 + (4.1)^2\ (0.7)^2\right]^{0.5} = 3.0 \text{ mg P/m}^3$$

Therefore, a concentration decrease of 3.3 ± 3.0 mg P/m^3 is predicted to result from the loading decrease of 0.8 ± 0.7 # P/day. The final step in predicting the future in-lake total P concentration (P_{2010}) is to subtract the predicted total P concentration change (3.3 ± 3.0 mg P/m^3) from the existing (1984-89) concentration (30.7 ± 7.5 mg P/m^3):

$$P_{2010} = 30.7 - 3.3 = 27 \text{ mg P/m}^3.$$

The standard error of P_{2010} is estimated using first-order analysis techniques as follows:

$$S_{p2010} = \left[(7.5)^2 + (3.0)^2\right]^{0.5}$$

$$= 8 \text{ mg P/m}^3.$$

Therefore, the predicted future (2010) concentration of total P in Lake Sawyer, assuming continued discharge from the WWTF using feasible advanced waste treatment processes, is 27 ± 8 mg P/m^3.