APPENDIX C
Modeling and Water/Nutrient Budget Methods and Assumptions

METHODS AND ASSUMPTIONS USED TO DEVELOP THE WATER BUDGET, PHOSPHORUS BUDGET AND THE LAKE RESPONSE MODEL

This appendix describes the methods and assumptions used to develop the water and phosphorus budgets for Lake Sawyer and the lake response model. The results of model calibration are also presented.

WATER BUDGET

Data used in the water budget consisted of streamflow collected at the mouth of Rock and Ravensdale Creeks, lake stage, precipitin, evaporation, and the lake outflow. Groundwater was estimated based on water budget calculations. Due to budget constraints this technique was used to solve groundwater flows because all other inflows and outflows were known (see Chapter 5). The approach utilized to obtain monthly averages was to perform a continuous hydrologic simulation of the lake's basin using the Hydrologic Simulation Program -Fortran (HSPF) model.

Land cover changes discussed in Chapter 2, were developed by King County Surface Water Management as follows:

* Current conditions were based on GIS analysis of aerial photography from the summers of 1989 and 1992 and corrections based on field observations.
* Future conditions were determined using a combination of land use zoning as presented in the Tahoma/Raven Heights Community Plan and Update, the King County Sensitive Areas Ordinance, mapping of urban growth boundaries , and the City of Black Diamond's Comprehensive Plan, and Annexation areas.

Changes in land cover are summarized in **Table E-1**. As the Lake Sawyer watershed is developed, forest land cover is expected to significantly decrease and be converted to residential communities and impervious areas. This land cover scenario assumes no net loss of wetland areas to future development.

Table E-1: Distribution of Land Cover Types

Numbers are in hectares (ha) *

Land Cover Type	Current Conditions	Future Conditions
Forest	2319	**950**
Residential**	310	**1509**
Impervious	2	**312**
Wetland	167	167

* acre x 0.405 = hectare

** residential = single, medium, high density, and multi-family.

A summary of the data, calibration, and results discussed in Chapter 5.0 follows. Overall, precipitation measured during the 1994-1995 study period was generally lower than the 1989-1990 and also below average for every month based on the maen values recorded at Landsburg (**Figure E-1**). Streamflow data was used in the HSP-F model and simulated versus gaged mean daily flows were calibrated (see **Figures E-2 and E-3**) for both Ravensdale and Rock Creek. Lake stage was also used to calibrate the model and was able to track measured changes within a few percent over the period of record (see **Figure E-4**). The match of simulated to measured discharge over the outlet weir of Lake Sawyer was also considered good (see **Figure E-5**).

Discharge of water from the lake is primarily (67%) over the outlet weir structure. Additionally, another significant loss is through seepage (30%) and lastly 3% is lost through evaporation from the lakes' surface (see **Table E-2**). Compared to the previous study by WSDOE (1989-1990) (see **Table E-3**), the only significant difference with the current study is in the apportioning of outflow between Covington Creek and lake seepage.

Figure E-1
Comparison of
Antecedent and
Study Period Monthly Precipitation

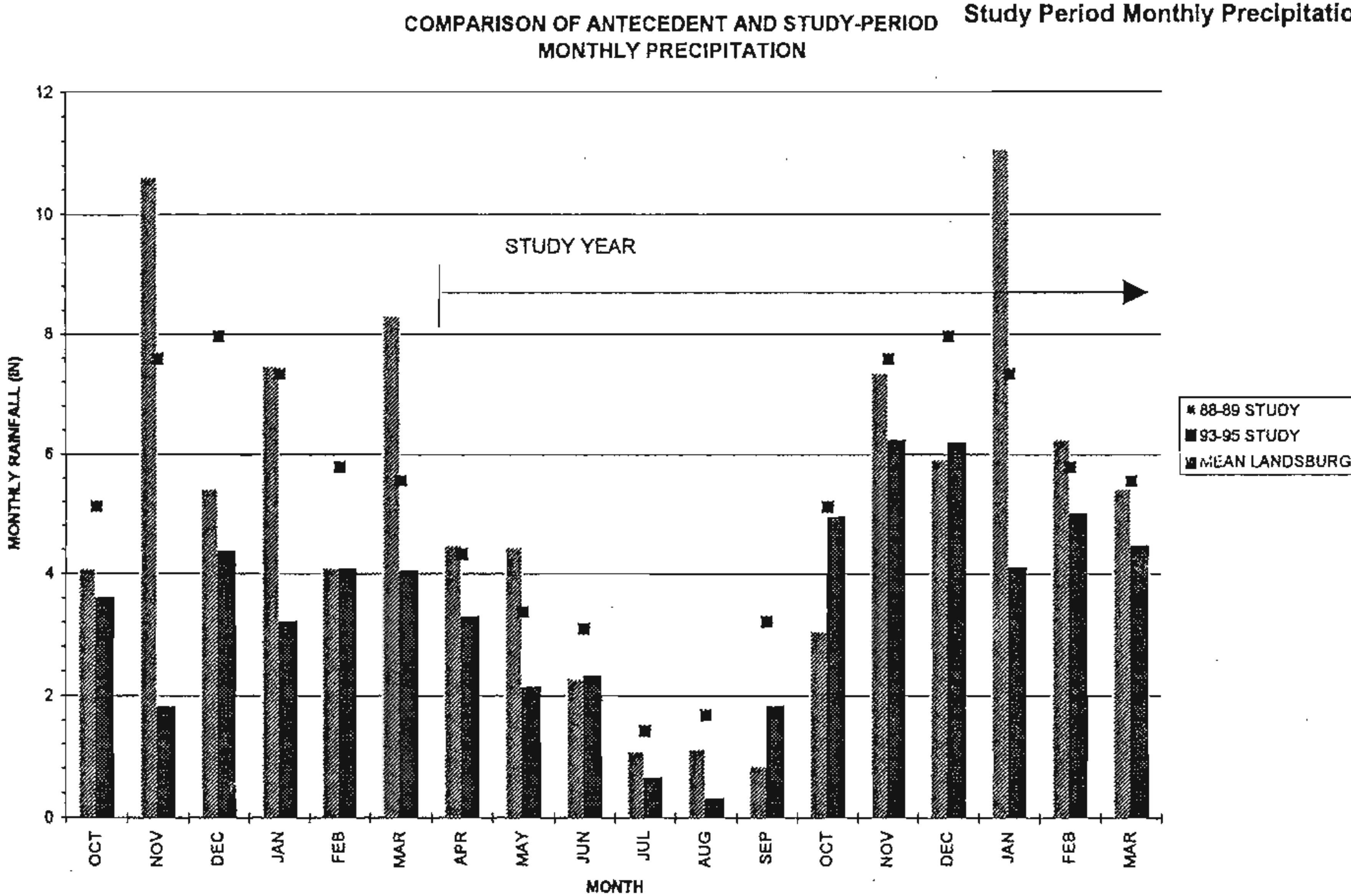


Figure E-2
Ravensdale Creek
Calibration

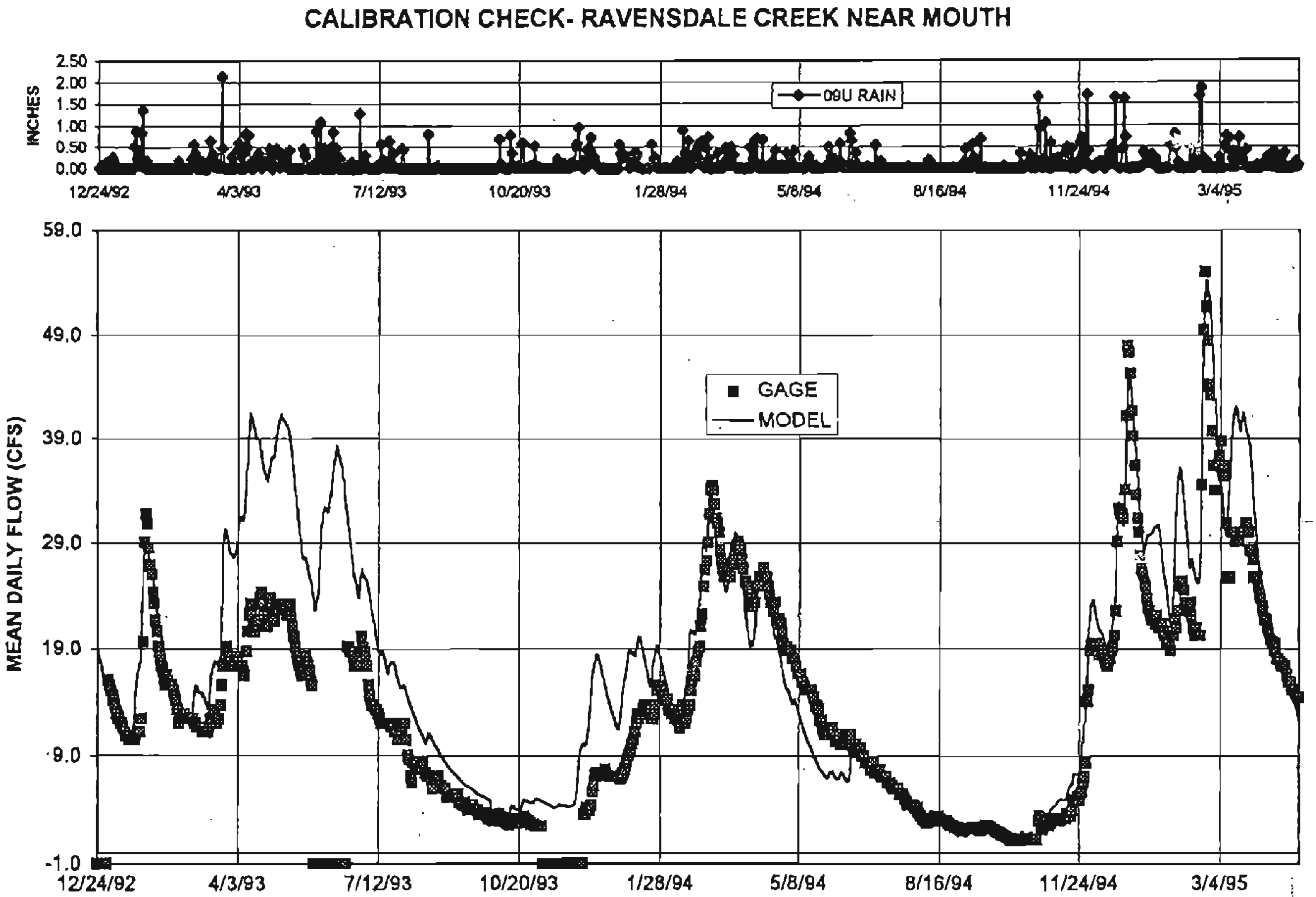


Figure E-3
Rock Creek
Calibration

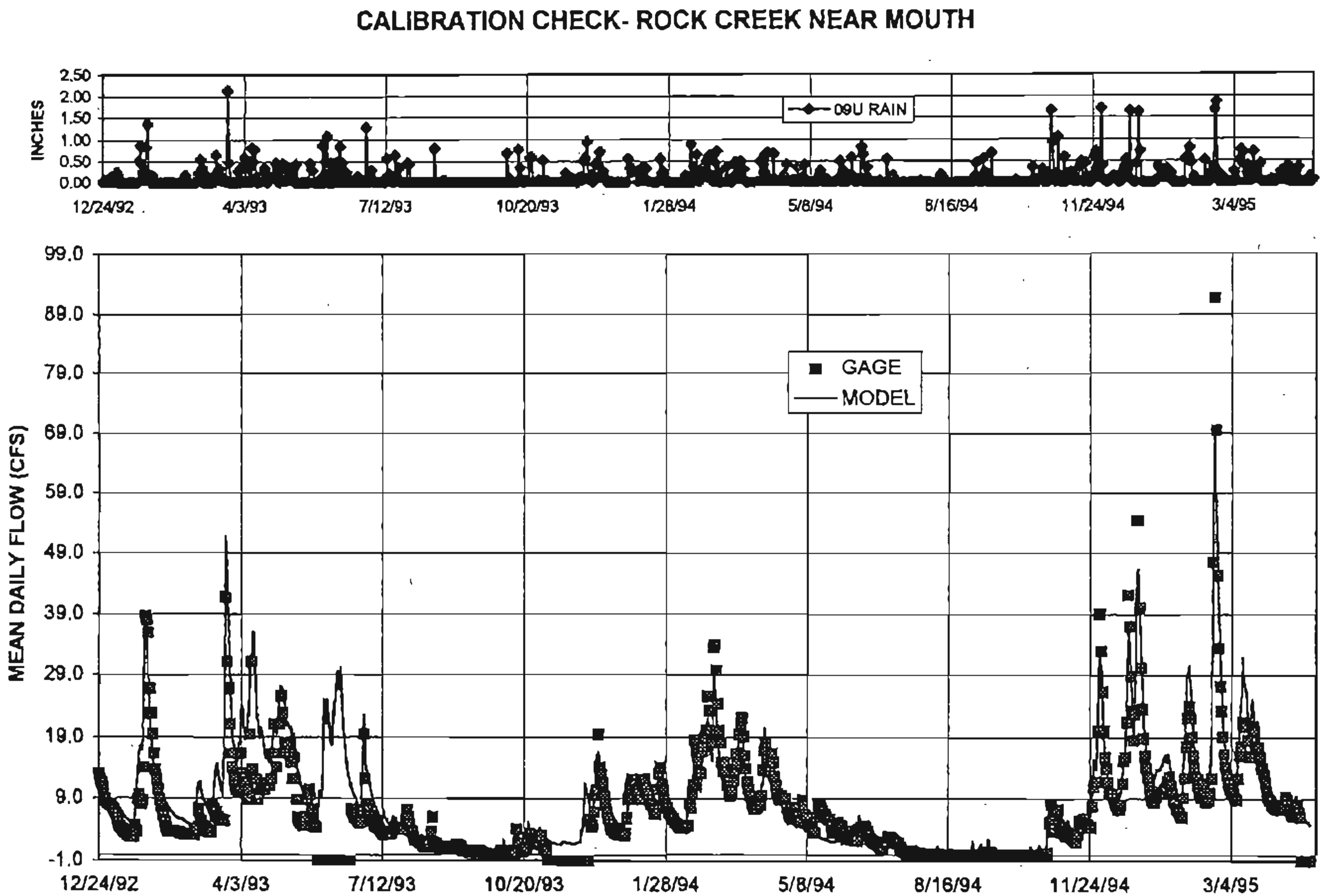


Figure E-4
Lake Sawyer Stage
Calibration

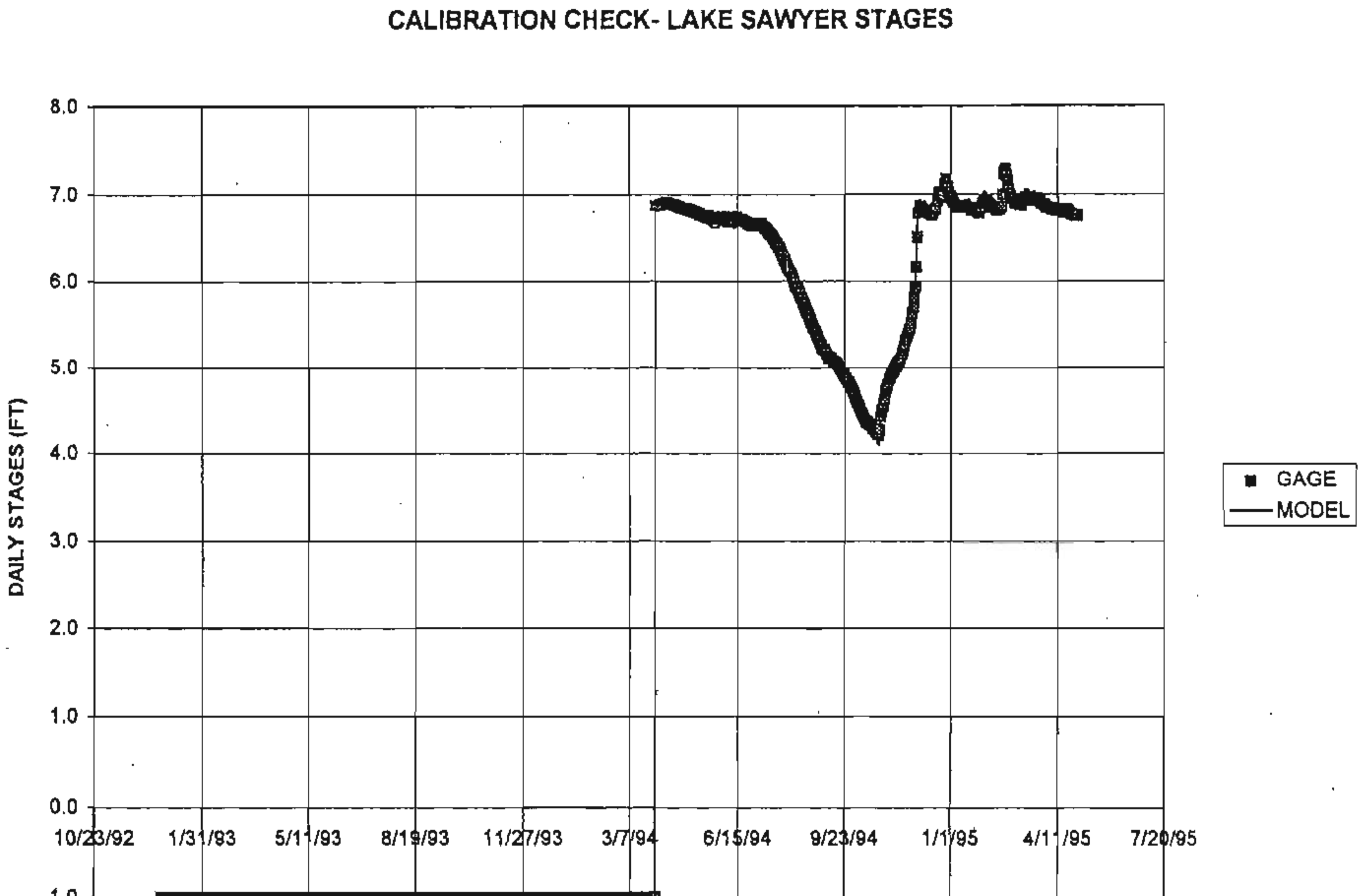
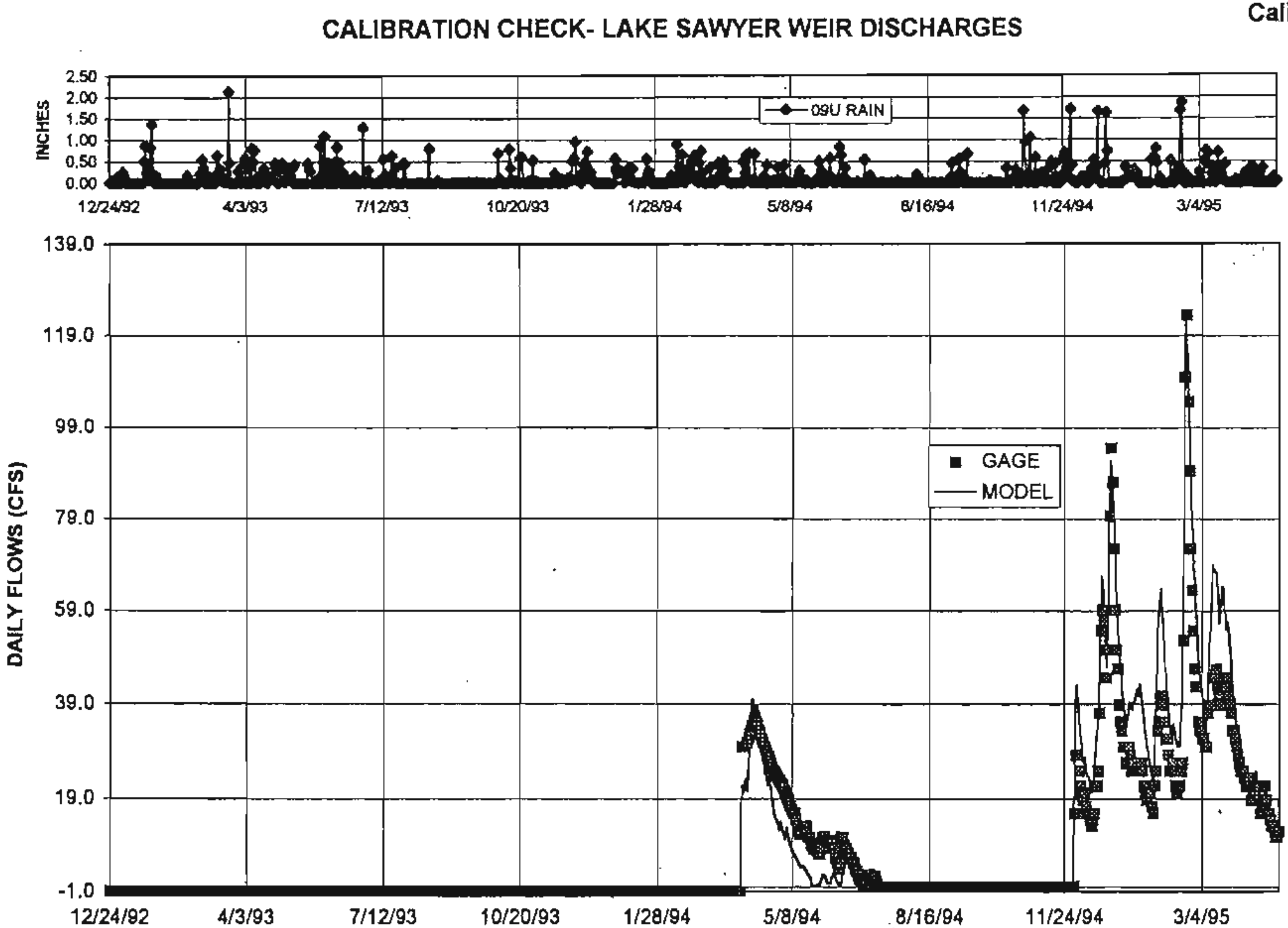


Figure E-5
Lake Sawyer Weir Outlet
Covington Creek
Calibration



MONTHLY AND ANNUAL WATER BALANCE FOR LAKE SAWYER DURING STUDY PERIOD

	OUTFLOWS		-	INFLOWS				+	STORAGE CHANGE	=	RESIDUAL[5] GWATER
	EVAPORATION[1]	+	COVINGTON CREEK[2]	ROCK CREEK	+	RAVENSDALE CREEK	+	DIRECT DRAINAGE[3]	+	RAINFALL[4]		
	(CFS)		(CFS)	(CFS)		(CFS)		(CFS)		(CFS)	(CFS)	(CFS)

	EVAPORATION (CFS)	COVINGTON CREEK (CFS)	ROCK CREEK (CFS)	RAVENSDALE CREEK (CFS)	DIRECT DRAINAGE (CFS)	RAINFALL (CFS)	STORAGE CHANGE (CFS)	RESIDUAL GWATER (CFS)
Jan-94	0.25					1.34		
Feb-94	0.25					1.71		
Mar-94	0.55					1.69		
Apr-94	0.80	29.51	10.11	23.24	0.53	1.38	-0.01	-4 96
May-94	1.26	12.77	5.48	14.45	0.12	0.89	-0 01	-6.93
Jun-94	1.47	5.85	2.78	9.58	0.13	0.97	-0.02	-6.16
Jul-94	1.76	0.45	1.02	5.76	0.04	0.27	-0.08	-4 95
Aug-94	1.47	0.00	0.02	2.85	0.02	0.12	-0.14	-1.68
Sep-94	0.88	0.00	0.08	2.13	0.10	0.76	-0 09	-2 28
Oct-94	0.42	0.00	1.09	1.52	0.28	2 07	0.00	-4.54
Nov-94	0.25	0.00	6.58	4.75	0.35	2.61	0 30	-13.74
Dec-94	0.21	37.04	21.12	26.24	0.99	2.60	0 08	-13.62
Jan-95	0.25	26.50	10.54	23.46	0.66	1.72	-0.01	-9.64
Feb-95	0.25	45.94	22.02	30.48	0.81	2.10	0.01	-9.20
Mar-95	0.55	37.36	14.85	29.92	0.72	1.87	-0 01	-9.47
Apr-95	0.80	18.62	7.46	18.20	0.24	0.64	-0.02	-7.15
May-95	1.26							
Jun-95	1.47							
STUDY YEAR MEAN	0.80	16.46	7.93	14.81	0 38	1 39	0.00	-7.26
ANN. TOT. INCHES ASSUMES 300 AC	24 83	508.09	244.87	457.13	11.82	42.76	-0.04	-223 91
TOTAL IN LK VOLUMES ASSUMES 7000 AC-FT	1.06	21.80	10.50	19.61	0.51	1.83	0.00	-9.61

[1] EVAPORATION DATA ARE BASED ON THE NOAA PUYALLUP CLASS A PAN USING A COEFFICIENT OF 0.75. SOURCE OF VALUES USED IN 3/91 DOE STUDY ARE UNKNOWN, BUT THEY ARE 35% SMALLER THAN OUR CURRENT ESTIMATE.

[2] FLOWS ARE BASED ON A BROAD-CRESTED WEIR EQUATION ASSUMING A COEFFICIENT OF DISCHARGE OF 3.0, AN EFFECTIVE WEIR LENGTH OF 70 FEET, AND A POWER OF 1 5 ON HEAD ABOVE THE WEIR CREST IN FEET. THE HEAD WAS BASED ON LAKE LEVEL MEASUREMENTS AT THE DAVIES RESIDENCE AND A 4/25/95 SURVEY BY BLOEDEL AND DUTTON THAT TIED THE STAFF GAGE TO THE WEIR CREST. THIS RATING IS PROBABLY BETTER THAN THE ONE BASED ON STREAM GAGING BELOW THE OUTLET WEIR, ALTHOUGH TWO METHODS ARE WITHIN A FEW PERCENT OF EACH OTHER FOR THE LARGEST DAILY DISCHARGES.

[3] DIRECT DRAINAGE REPRESENTS THE LIMITED AMOUNT OF SURFACE RUNOFF AND INTERFLOW THAT COMES FROM IMPERVIOUS AND GRASS AREAS ADJACENT TO THE LAKE. AMOUNTS REPRESENT 80% RUNOFF COEFFICIENT FOR 50 ACRES OF IMPERVIOUS THROUGHOUT THE YEAR PLUS 50% RUNOFF FROM GRASS FOR THE NOVEMBER THROUGH APRIL PERIOD.

[4] NOTE THAT PRECEDING MONTHS AND THE STUDY YEAR REFLECT DROUGHT CONDITIONS. THIS MAY ACCOUNT FOR SOME DIFFERENCES IN THE ESTIMATE OF NET GROUNDWATER FLOW FROM LAKE SAWYER BETWEEN THE CURRENT STUDY AND THE 3/91 DOE STUDY.

[5] THE NET GROUNDWATER CALCULATION SUGGESTS THAT THE LAKE WAS CONTINUOUSLY DISCHARGING MORE GROUNDWATER THAN IT WAS RECEIVING IN EVERY MONTH DURING THE STUDY. THIS IS CONSISTENT WITH EARLIER FINDINGS (DOE,1991 AND HART-CROWSER, 1990) USING A HYDRO-GEOLOGIC APPROACH (DARCY'S LAW CRUDELY APPLIED USING PUMP TEST AND WATER LEVEL DATA). THEY CONCLUDED GROUNDWATER OUTFLOWS ARE FROM 5 TO 80 TIMES AS LARGE AS INFLOWS AND THAT OUTFLOWS AVERAGED APPROXIMATELY 4 0 CFS

PHOSPHORUS BUDGET AND LAKE RESPONSE MODEL

The steps taken to develop and apply the phosphorus budget and lake response model were:

1. Develop a phosphorus budget and a lake response model for the study year.
2. Calibrate a lake response model using the phosphorus data collected in the study year.
3. Use the calibrated lake model to represent water quality conditions in the lake under a year with average rainfall.
4. Use the model to predict conditions in the lake under future conditions, based on zoning (See Chapter 5 for discussion).
5. Use the lake response model to predict the response to restoration techniques, both in-lake and watershed controls (See Chapter 7 for discussion).

PHOSPHORUS BUDGET DEVELOPMENT

The purpose of a phosphorus budget is to identify and quantify the major sources of phosphorus to a lake from the watershed as well as the lake itself (for example, phosphorus released from lake sediments). The phosphorus budget for Lake Sawyer was developed by combining the water budget developed by the HSPF runoff model (as described in Chapter 5) with phosphorus concentration data measured in this study. For those sources not directly measured, such as septic tanks, loading estimates were based on data from other studies.

Watershed and in-lake sources of phosphorus to Lake Sawyer included in the phosphorus budget were:

- Tributary areas (surface runoff, groundwater, and interflow) Three major subbasins drain to Lake Sawyer: Rock Creek subbasin, Ravensdale Creek subbasin, and Lake Sawyer subbasin.
- Wetlands.
- Septic tanks.
- Atmospheric deposition (dryfall and precipitation).
- Aquatic macrophytes.

- Lake sediment release and diffusion across the thermocline.

Losses of phosphorus from Lake Sawyer included in the phosphorus budget were:

- Surface outflow
- Groundwater discharge
- Sedimentation to the lake bottom

Sources of Phosphorus

Tributary Areas

Phosphorus levels measured in the streams were used to approximate average phosphorus (P) concentrations in each hydrologic component (surface water, interflow, groundwater, and runoff) from each land use type (i.e., forested, grass, wetland, or impervious). This was accomplished by: assessing the components of streamflow during monitoring events to find times that flow is dominated by one hydrologic component, finding an average P concentration during these times for each hydrologic component, and then using these values to estimate other P values.

For example, Lake Sawyer Station IN6 was assumed to represent a basin that is primarily forested. During most of the monitored events, the HSPF output indicated that the flows at this station predominantly arose from interflow. These events were used to estimate the average P concentration in forested interflow water. Using this interflow concentration, the observed P concentration in the stream, and the quantities of interflow and surface flow in the stream as estimated from the data generated by the HSPF model, the average P concentration in forested surface flows was determined. The determination was made by minimizing the difference between the flow-weighted predicted P concentrations and the flow-weighted measured concentrations for all of the monitoring dates. Using a similar process and building on these results, approximate P concentrations were estimated for all of the hydrologic components for each land use type (**Table E4**).

Table E4
Average Phosphorus Concentrations (µg/L) Assumed for Land Types in the Lake Sawyer's Watershed

	Forest	Grass	Wetland	Impervious
Surface Runoff	50	58	70	235
Interflow	38	35	50	—
Groundwater	10	10	10	—

As shown in **Table E4**, P concentration in surface runoff from impervious surface areas is the highest at 235 µg/L. Runoff from wetland areas also had slightly greater P concentrations than either forest or grassland areas, with an average concentration of 70 µg/L. This compares to concentrations of 50–58 µg/L in surface runoff from forest and grassland areas.

These average P concentrations were then checked by comparing the flow-weighted predicted P concentrations at other monitoring stations with the measured P concentrations. To find the daily loading to Lake Sawyer from these sources, the concentrations were multiplied by the hydrologic contributions from each basin as predicted by the HSPF model.

Wetlands

Although the average P concentrations described above seemed to perform well for most sites, the flows downstream of two wetland areas (Rock Creek and Ravensdale Creek subbasins) seemed to be affected by processes occurring within those wetlands. To mimic the impacts of these wetlands, two different data treatments were required. Unfortunately, there was insufficient data to adequately characterize the mechanisms involved, so empirical functions were developed to represent these loading processes. The methods used to produce empirical functions for both Rock Creek and Ravensdale Creek subbasins are described below.

In the Rock Creek subbasin, wetlands in the lower portion of the basin seemed to provide a significant net loading to the flows running through them and subsequently to the lake. Such a source of P is not surprising since this is the area that had previously received sewage treatment plant effluent. This loading did not appear to be constant throughout the year, but instead fluctuated seasonally. To represent this seasonal fluctuation, a sinusoidal loading function was introduced to represent the wetland loads from this area.

The second area affected by wetland processes was Ravensdale Creek subbasin. There is a large wetland area in the headwaters of this creek, and the data indicate P release occurs in the wetland beginning around May 1. The outflow from the wetland would have elevated levels of P, but the effects of this release would diminish with time. Assuming an increase in wetland P concentrations on May 1 and exponential decay rate in the P concentrations through the rest of the year, The water leaving the wetland (assumed to be the water entering as defined by the HSPF model output) was combined with the downstream flow inputs to find a predicted streamflow P concentration. The concentrations (and thereby the P loading) predicted, using this model of the system, seem to represent the measured values reasonably well.

The total loading from each subbasin was calculated by adjusting the predicted loading using the average component concentration method described previously, by the changes contributed by the wetlands. In the Rock Creek subbasin, the total daily loading is the component loading plus the wetland loading function. In the Ravensdale Creek subbasin, the in-stream concentrations are adjusted by the amount of flow and concentration of P leaving the wetlands, so the effect is contained within the adjusted flow concentration value. The concentration multiplied by the flow gives the P loading to Lake Sawyer.

Septic Tanks

There are approximately 1,000 septic tanks in the watershed. Of these, 246 are immediately adjacent to the lakeshore and may discharge directly to Lake Sawyer. It was assumed that any loading outside of the lake's immediate vicinity would be transported via a stream to the lake and so would have been taken into account as part of the tributary input calculations. However, the 246 septic tanks immediately adjacent to the lakeshore could discharge directly to the lake and so were considered as a second potential loading source.

The P loading to each septic system was assumed to be 0.01 kg P/day, based on a per capita waste generation of four grams P/day (**EPA 1980**) and an average occupancy rate of 2.5 people per household. Phosphorus removal in properly working septic systems occurs primarily in the drainfield. Working systems provide some P loading, but failing systems do not allow drainfield removal. Due to the age of many of the septic systems in this area, and the fact that many were not designed for year-round use, 10 percent were assumed to be failing. (Note: for future conditions, it was assumed that the failure rate would increase to 15 percent because the systems would be older). Properly functioning systems were assumed to undergo P removal in the septic tank (25 percent) and then again in the drainfield (an additional 94 percent). Failing systems were assumed to undergo only septic tank removal (25 percent).

Atmospheric Inputs

Atmospheric P loading to Lake Sawyer was assumed to occur at a constant rate of 3.9×10^{-4} kg/acre/day (**Reckhow and Chapra 1983**).

Aquatic Macrophytes

In the macrophyte survey performed in this study, the plants density in the macrophyte stands in Lake Sawyer was found to be approximately 200 mg P/m^2. Based on past observations and the contour map of the lake bottom, it was estimated that 37 percent of the lake surface could contain macrophyte growth. Macrophyte senescence was assumed to provide a three-month source of uniform loading starting on August 1, during which 80 percent of the phosphorus in the plants would be released to the water column.

Sediment Release and Diffusion Across the Thermocline

Although sediment P release can occur during both aerobic or anaerobic conditions, anaerobic release is typically the most significant. For the purpose of modeling, sediment release rate during non-stratified (aerobic) conditions and in the epilimnion was assumed to be zero. Anaerobic release was calculated by determining the amount of release necessary to obtain the observed hypolimnetic P concentrations given the other inputs and outputs. The calculated value was found to be 15 $mg/m^2/day$. When computing the nutrient budget, the sediment release contribution was calculated as the sum of the amount diffused across the thermocline (as described below) and the amount in the hypolimnion released to the whole lake at over-turn (early December).

The amount of phosphorus in the hypolimnion that becomes available for primary productivity in the overlying waters of the epilimnion, is largely controlled by the rate of diffusion across the thermocline. The rate of diffusion depends on the differences in temperature between the hypolimnion and epilimnion and the duration of stratification. Temperature profiles taken during lake monitoring, indicated the lake was thermally stratified from June 1 to December 1. The anaerobic sediment phosphorus release was assumed to begin on June 15. During stratification, it was assumed that the diffusion rate of P from the hypolimnion to the epilimnion occurred at a rate of 0.69 cm/day based upon the apparent heat transfer across the thermocline during the period of stratification **(Reckhow and Chapra 1983)**. Also, P sedimentation for the portion of the epilimnion overlying the hypolimnion was assumed to reach the hypolimnion and reflect a net loss of phosphorus from the epilimnion.

Losses of Phosphorus

Surface Outflow

The loss of phosphorus from the surface outflow (Covington Creek) was estimated as the product of the volume-weighted epilimnion phosphorus concentrations and the modeled lake outflow.

Groundwater Outflow

Phosphorus loss associated with groundwater discharge from the lake was estimated as the product of the groundwater discharge volume as determined by the hydrologic budget and the volume-weighted hypolimnetic phosphorus concentration. During the non-stratified period, the hypolimnetic phosphorus concentration was equal to the whole-lake average phosphorus concentration.

Sedimentation

Phosphorus loss to the sediments was determined by a combination of in-lake observations, literature values, and phosphorus calibration steps. A single sedimentation value of 0.053 m/day was found to be effective in predicting in-lake phosphorus concentrations over the course of the year. For comparison, sedimentation rates reported by Reckhow and Chapra (1983) range from 0.05 to 0.60 m/day.

LAKE RESPONSE MODEL CALIBRATION AND RESULTS

Following the development of the phosphorus budget, a mass-balance numerical model—the lake response model—was calibrated to volume-weighted phosphorus concentrations (epilimnion, hypolimnion, and whole-lake) in the lake. The results of the calibration are presented in **figures E6, E7, and E8**. The calibrated model was then used to assess the seasonal response of Lake Sawyer to changes in phosphorus loading associated with the changes in watershed land use and the application of restoration measures (See Chapter 7 for a detailed discussion).

REFERENCES

Reckhow, K.W. and Chapra, S.C.

1983 Engineering Approaches for Lake Management, Vol 1. Data Analysis and Empirical Modeling.

United States Environmental Protection Agency (EPA)

Figure E6

Lake Sawyer Epilimnetic P Concentration-1994/95

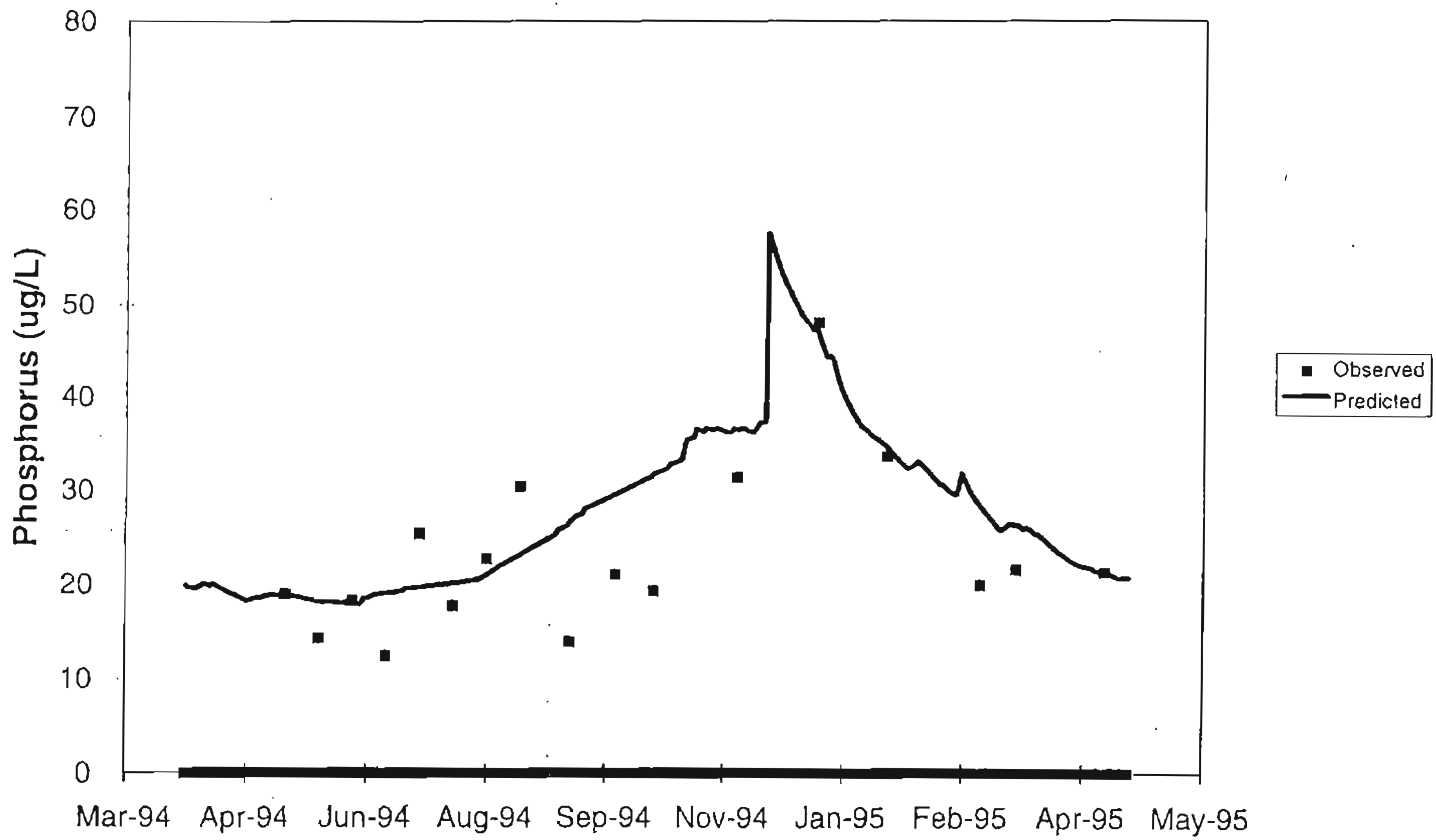


Figure E7

Lake Sawyer
Whole Lake Average P Concentration -94/95

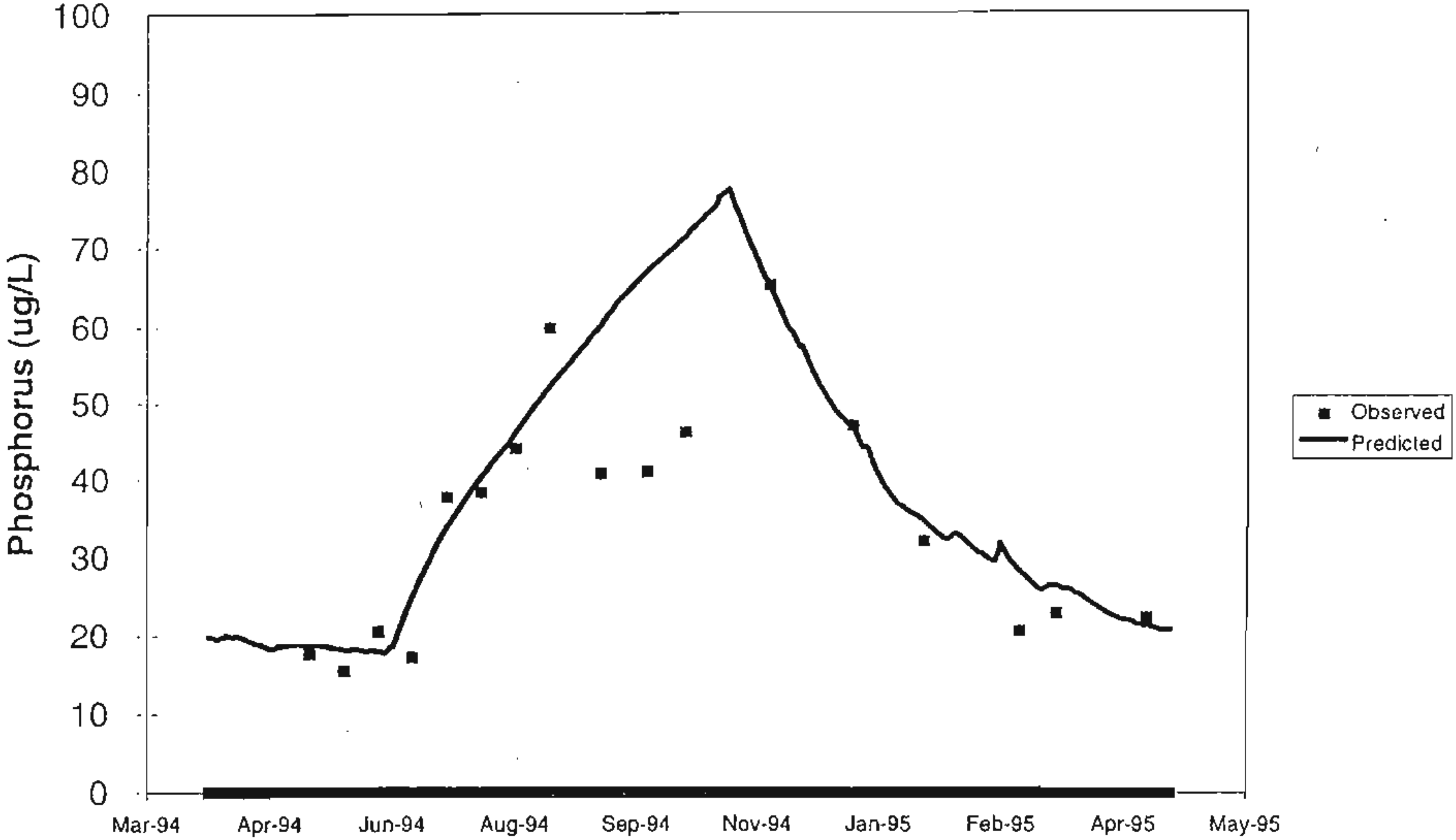
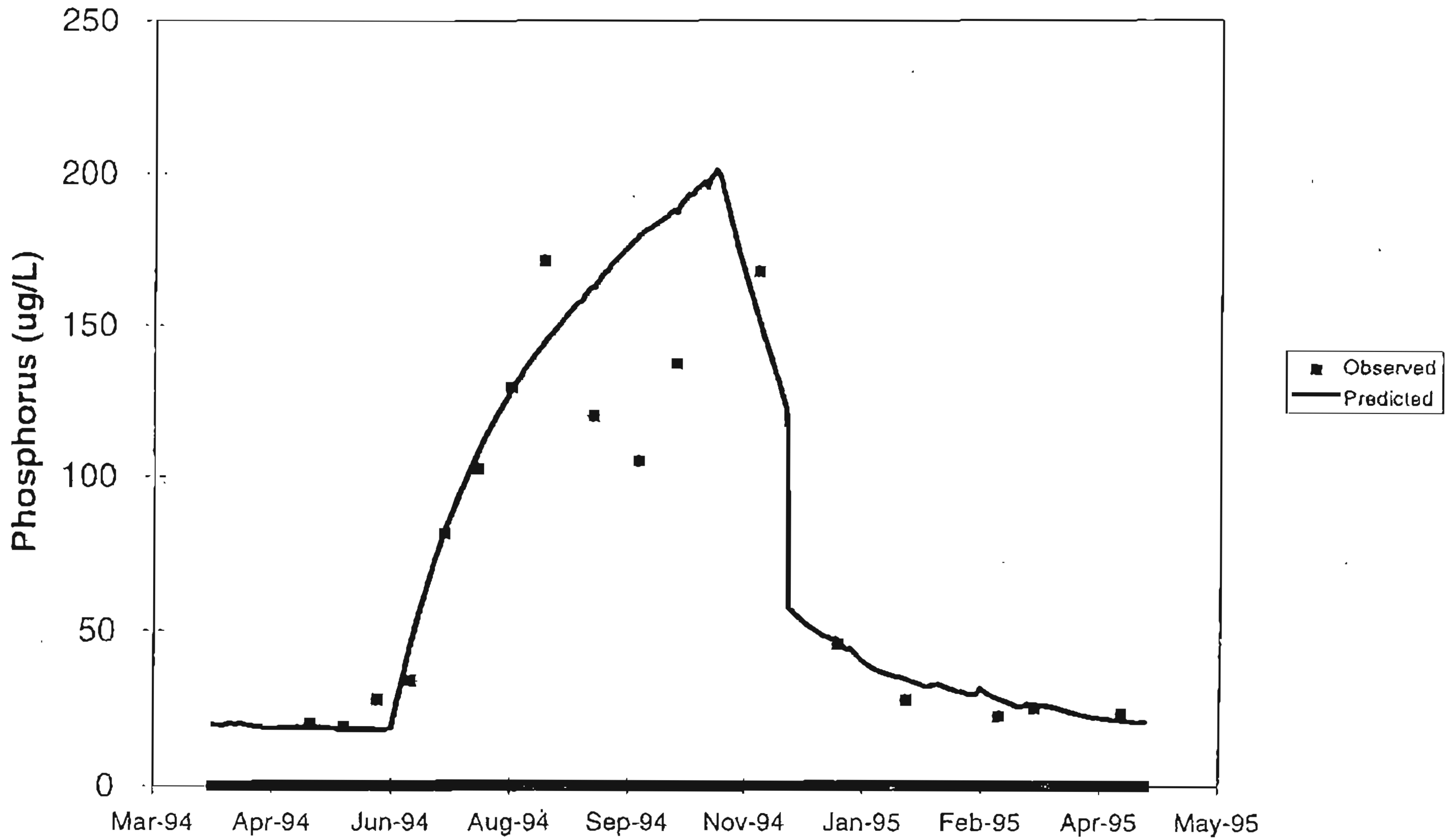


Figure E8

Lake Sawyer Hypolimnetic P Concentration - 1994/95



1980 Design Manual for On-site Wastewater Treatment and Disposal Systems. Office of Water Program Operations. Washington D.C.

APPENDIX D
Aquatic Plant Management Plan

Lake Sawyer Aquatic Plant Management Plan

Aquatic Plant Management Goals

The stated lake management goal that addresses the aquatic plant problem is; "To control the growth of macrophytes to levels that provide optimum recreational uses of the lake including fishing, swimming, boating and others." This goal is refined further, to " prevent the growth of and balance unnatural and unhealthy macrophytes like Eurasian watermilfoil." Most of the existing plant coverage in Lake Sawyer already meets the aquatic plant management goals. Although, the lake has a well-mixed plant community and the plants are confined to the nearshore area, plants are becoming more abundant and wide-spread over time. A few problem areas associated with shallow areas (especially bays) provide the focus for plant control needs.

Other lake management goals are aimed at reducing lake phosphorus concentrations and controlling algae blooms. Reductions in phosphorus and resultant increased water clarity can result in improved growth conditions for aquatic macrophytes. The amount of reduction predicted from implementing the recommended plan (watershed controls and treatment of Rock Creek inflow with alum) is not expected to cause large shifts in aquatic plant habitat. Therefore, this aquatic plant control strategy addresses existing lake conditions.

There are a number of advantages and disadvantages associated with aquatic plant populations that should be considered in addition to the stated management goals. Aquatic plants provide: 1) important habitat for wildlife especially fish and waterfowl, 2) shoreline protection through buffering the effects of wave action and resultant shoreline erosion, and 3) a natural balance for control of algae populations. Disadvantages of aquatic plants are primarily associated with their growth pattern. Those plants that grow up to the lake surface in dense mats cause navigation problems for motorboats, sailboats, and swimmers, and can cause fishing difficulties. These dense mats may also cause problems for wildlife. Depending upon plant type, they can result in low dissolved oxygen concentrations and may also be too dense to allow effective fish predation. To the extent that it can, the aquatic plant control strategy should provide a proper balance between these advantages and disadvantages while meeting management goals.

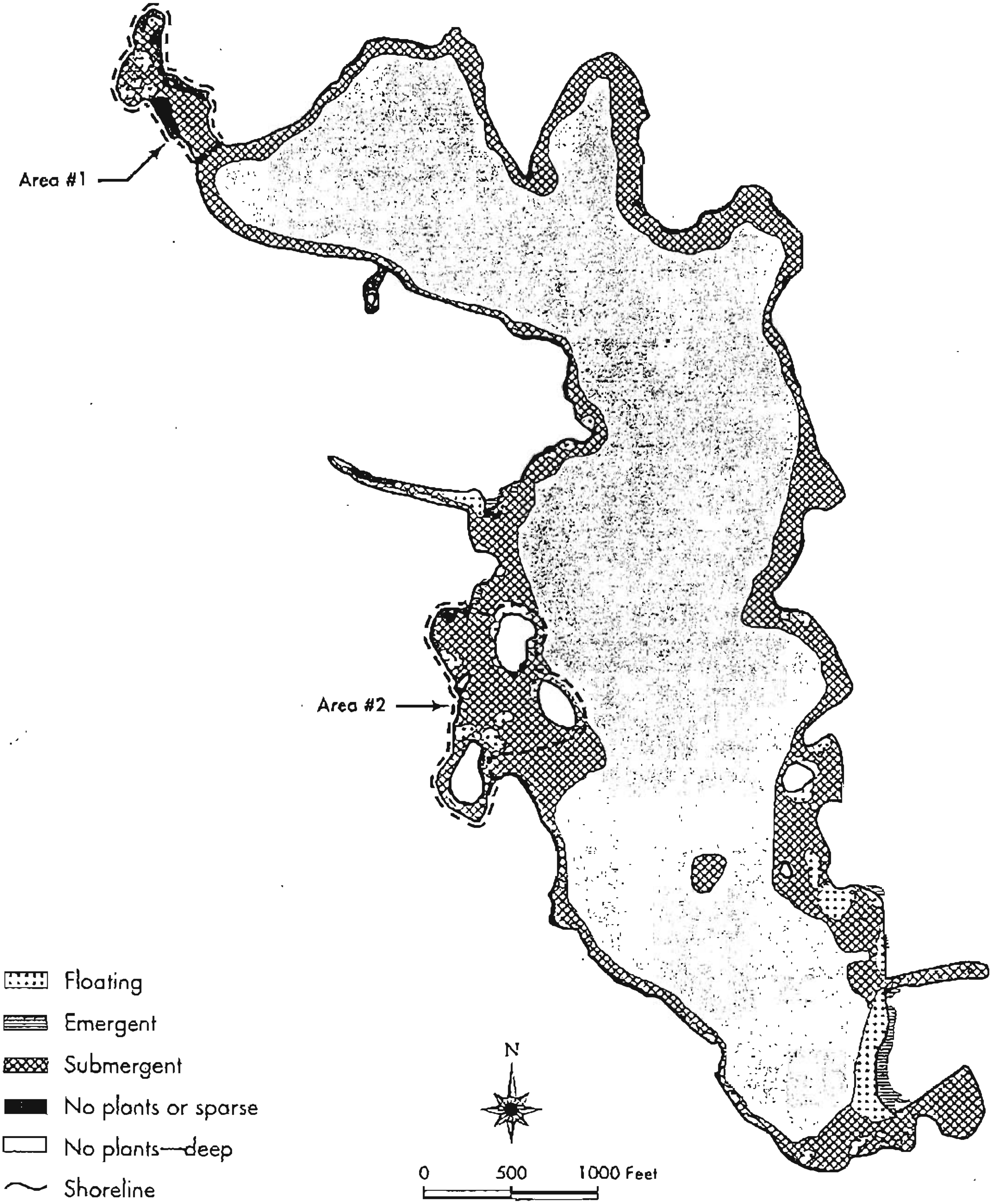
Aquatic Plant Control Objectives

Plant control objectives consisted of developing specific strategies for control of identified problem areas, and providing lakeside residents with some flexibility for long-term maintenance and monitoring of the plant populations. The following objectives were selected for development of the control strategy:

1) Control of aquatic plants in the shallow bay located in the northwest corner of the lake (Area #1, Figure H-1). The plant community consists largely of a mix of two non-native species: White water lily and Eurasian watermilfoil. This area consists of approximately 4 acres of Eurasian Watermilfoil and 2 acres of white water lily.

Figure AP1

Aquatic Plant Problem Areas in Lake Sawyer



2) Control of aquatic plants in the shallow western shoreline area (south of the lake outlet), which contains three small islands (Area #2, Figure H-1). This area is approximately 17 acres and consists primarily of different species of pondweed and coontail.

3) Establish a conservancy zone(s) to preserve natural areas and provide wildlife habitat.

4) Allow for some long-term flexibility in selecting additional control zones and controlling small plant stands adjacent to swimming and docking areas.

5) Provide for long-term monitoring of aquatic plant beds and invasion of new exotic aquatic plants.

An objective to control or eliminate milfoil in the lake was also considered. Although milfoil was found in transects throughout the lake, it was the dominant submerged plant in only two locations: the shallow bay located in the northwest corner of the lake (area #1) and another much smaller bay located in the northeast quadrant of the lake. Milfoil has been found in Lake Sawyer since the early 1970s, and has apparently dominated the plant community during many years. The current decrease in the population could indicate that natural controls have finally come into play and the existing mixed plant community represents expected future conditions. Since milfoil has been existing in the lake for over 20 years, it is unlikely that drastic changes in the amount and type of milfoil beds will be observed in the near future. Therefore, with the exception of Area #1, no specific control objective was deemed necessary for lakewide control of this plant.

Permitting Considerations

The following section describes some of the permitting issues and needs that must be considered when selecting aquatic plant control techniques. At present, King County has no formal working definition for lakes, and does not differentiate lakes from wetlands. Therefore, three different local codes may apply to work being done within a lake's shoreline: the Shorelines Management Code, the Environmentally Sensitive Areas Code, and Grading Permit codes.

Chapter 25 of the King County Code (the Shoreline Management Code) implements Washington's Shoreline Management Act of 1971. Shoreline areas in King County are designated as either natural, conservancy, rural, or urban environments. These designations are used to differentiate shoreline areas based on geographical, hydrological, topographical, or other features. Different management objectives and practices are applicable for each wetland type. The provision of the Shoreline Management Code (K.C.C. 25), when in conflict with the Environmentally Sensitive Areas Code (K.C.C. 21A.24), defers to the code which provides more protection to the shoreline or sensitive area. In the case of lake shorelines, which have been designated by the King County Wetlands Inventory as Class 1 or 2 lacustrine systems, shoreline or aquatic plant management activities must meet the conditions of K.C.C. 21A.24. No development shall be undertaken by any person on the state's shorelines unless such development is consistent with the policy of the Shoreline Management Act. Substantial development is defined as any development in which the total cost or fair market value exceeds $2,500, or any development that materially interferes with the normal public use of the state's water or shorelines. The development definition includes such activities as construction, dredging, drilling, dumping, filling, removal of materials, and building bulkheads.

Based on these definitions and the interpretation of the shorelines code, aquatic plant management activities that are not prohibited by K.C.C. 21A.24 and are exempted by K.C.C.16.82 (see discussion below)can be performed after a shoreline exemption review is completed and granted for the activity (4-6 weeks). Purple Loosestrife removal has been the aquatic plant management activity most commonly performed with a shorelines exemption. Given the similarity designation of Eurasian watermilfoil as a noxious weed, it would be expected that removal projects totaling less than $2,500 could be similarly exempted.

King County Code 16.82 regulates clearing and removal of vegetation, excavation, grading and earthwork construction, and other related activities. The intent of this regulation is to protect public health and safety. For all projects and activities involving clearing or grading, including aquatic vegetation removal and management, a grading permit must be obtained from the King County Department of Development and Environmental Services (DDES). King County Code 16.82.050 details the exceptions to this requirement and includes an allowance for the removal of noxious weeds.

The purpose of the Environmentally Sensitive Areas chapter of the zoning code (K.C.C.21.A.24) is to implement the goals and policies of the Washington State Environmental Policy Act. Aquatic plant management activities for lakes designated as lacustrine wetland systems must comply with the wetlands regulations associated with K.C.C. 21A.24.

In combination, the King County Shoreline Management, grading, and Environmentally Sensitive Areas codes constrain aquatic plant management activities for lacustrine wetland systems. Noxious weeds removal projects are the most easily permitted aquatic plant management activity. For other more complex aquatic plant management issues, including removal of white/pink water lilies, implementation of integrated aquatic plant management plant recommendations, and the testing and evaluation of new aquatic plant control techniques, the combination of the three codes potentially make aquatic plant management illegal (depending upon the interpretation of the activity). At the very least it makes it more costly due to additional permits and reviews.

King County SWM staff members are currently working with King County DDES staff to explore options and assess whether code revisions are an appropriate long-term solution for aquatic plant management activities.

Summary of Aquatic Plant Control Alternatives

Different plant control techniques are, more or less, feasible depending upon the size of the area that needs controlling. Some techniques are more appropriate for controlling large areas, such as extensive beds of milfoil or the entire lake, while others are better suited for smaller areas. Initially, all available control options were considered for the lake. Due to the size of Lake Sawyer and the generally good condition of the existing plant community, however, relatively small treatment areas were selected for control. Techniques appropriate for these areas are described in this section. (Discussion and comparison of large area control techniques are included in this appendix. For each of these techniques, Table H-1 contains comparison information that addresses costs, duration of control, intensity, and other criteria.

<u>Techniques Appropriate for Small Control Areas</u>

Hand Cutting

Hand cutting is a manual method of cutting the stems of aquatic plants (submerged and floating-leaved) close to the sediment surface. Two tools that can be effective for plant control include the Water Weed Cutter and the Lake Weed Shaver (McComas 1993). The Water Weed Cutter has a V-shaped, straight-edge blade that cuts a 3-foot path. It is best used by throwing it from the shore or dock and pulling it back with a jerky motion. The Lake Weed Shaver has a straight-edge blade that cuts a 6-foot path. Because of its weight, it is best used by dragging it behind a boat. To be most effective, both tools should be used before the plants become very dense, and the blade must be routinely sharpened.

Cut fragments of some plants will re-root and grow in new areas, and these fragments should be removed to prevent regrowth and to deter aesthetic impacts from floating debris and onshore decay of the plant material. Cut fragments float and are best removed with a modified fish seine that encircles small working areas or is positioned down-wind of the working area. The net should have at least a 1-inch mesh so that it will not trap small fish.

There are no depth limitations for these tools; therefore, this method could include any portion of the lake plant beds. However, since it requires manual labor, it is best suited for small patches of plants that may be hindering lake access. Because plant roots and tubers are not removed using these tools, the duration of control is comparatively low. The frequency of application depends on water depth; monthly cuts will maintain deep areas, but more frequent cuts may be necessary for areas less than 3 feet deep.

Equipment costs are low: $100 for the Water Weed Cutter, $200 for the Lake Weed Shaver, and $500 for a modified fish seine. Assuming that two of each tool are purchased, with a seine for each, the total cost would be $2,600, discluding labor provided by property owners. The primary advantage of hand cutting is the low cost. The primary drawback is the high amount of labor required to provide adequate control. Although these control techniques have a short longevity, they are moderately reliable and moderately effective for achieving what they are designed for. These techniques typically require a shoreline exemption for removal of noxious weeds. Removal of native vegetation is not a permittable activity in designated wetland areas (i.e. lake shorelines).

Weed Rolling

The Weed Roller is a relatively new product that controls aquatic plant growth by periodically disturbing the lake bottom. The drive head is typically mounted to the end of a dock in water depths of up to 8 feet. It slowly rotates a string of three aluminum tubes that repeatedly roll over a broad arc on the lake bottom. Each 6-inch by 10-foot tube is connected with a flexible coupler to follow the bottom contour.

The Weed Roller converts 110-volt household current to 24-volt direct current (DC), and covers up to a 270° sweep in 15 minutes. According to the manufacturer, adequate control is typically achieved by operating the Weed Roller continuously overnight once every week or two during the growing season.

Table H-1. Comparison matrix of aquatic plant control alternatives for small areas. (L=Low, M=Medium, H=High)

	Treatment Cost	Reliability	Longevity	Effectiveness	Disadvantages[1]	Advantages
SMALL AREA						
Physical Controls						
Handcutting	$2600	M	L	M	•Labor intensive •Need to remove cuttings	•Allows site specific control •Provides shoreline owners with an aid
Bottom Barrier	$35000/acre	M	M-H	M-H	• Expense •Annual maintenance	•Can be fairly long lasting •No chemical concerns •Ability to control specific area
Rotovation	$1,700/acre	L-M	L-M	M	•Sediment disruption may promote invasive species •Low longevity for cost	•Disrupts roots for longer control •No chemical concerns •Removes plant matter
Diver Dredge	$4,000/acre	L	M-H	H	•Expense •Sediment disruption •Water quality concerns	•Removes roots and tubers for longer control •No chemical concerns •Removes plant matter
Chemical Control						
Sonar pellets[2]	$2,000/acre	M-H	M-H	M	•Addition of chemicals to natural environment	•Low cost •Low toxicity
Aquathol	$500/acre	M-H	L	M	•Addition of chemicals to natural environment •Short duration of control	•Low cost
Rodeo[3]	$300/acre	M-H	M	M	•Addition of chemicals to natural environment	•Low cost •Kills entire plant for longer control

(1) All of these techniques may required local and/or state permits.
(2) Used for controlling milfoil.
(3) Use for controlling lilies.

Since a power source and structural support is required to operate the weed roller, the control zone is limited to area directly adjacent to docks. King County Surface Water Management Division tested use of the Weed Roller at two sites and found it was effective although also high maintenance, since removed plants should be collected each day (**R. Storer, pers. comm.**).

A complete unit with accessories sells for approximately $2,500. Advantages of the Weed Roller include the high degree of control and the fact that it will control all plant types within its path. The main drawback is its expense and limited area of control. The Weed Roller requires hydraulic approval from the Washington Department of Fish and Wildlife, and a shorelines exemption review from King County DDES. Due to the site specific use of the weed roller, its benefit is received only by the immediate property owner. A lake community club or several neighbors could purchase a Weedroller unit and shore it during the growing season.

Bottom Barriers

Bottom barriers are manufactured sheets of material that are anchored to the lake bottom to prevent plants from growing, similar to weed barriers commonly used in lawn and garden activities. Several bottom covering materials have been used with varying degrees of success. A woven polyester material such as Texel® is one of the most effective bottom barriers because it is durable and it provides efficient exchange of gas produced from decaying organic matter (roots). It is typically installed in the winter, when plants are not present, by unrolling 30x50-foot sections and anchoring them with sand bags spaced 10 feet apart. Bottom barriers should be maintained on an annual basis to ensure adequate coverage and anchoring. Bottom barriers can be relocated to other areas after 2 years if sediment accumulation is not excessive. Re-installation may be necessary to control encroachment in areas adjacent to dense growth.

There are no limits to the control zone for bottom barriers. They are effective in deep (as well as shallow) water and do not have special requirements that eliminate their use in different areas. The control zone would be defined by the number of 30*50 foot sections installed. Furthermore, they can be used to control submerged plants as well as emergents, such as lilies. Control intensity and duration vary, depending on sediment accumulation and encroachment from adjacent areas. If properly installed and maintained annually, bottom barriers can provide a high level of control for five years or more.

The cost of applying bottom barriers is approximately $0.80 per square foot, or $35,000 per acre. Annual maintenance costs are estimated to be $5,000 per acre. The primary advantage of bottom barriers is the high level of control and the ability to be very selective about the control area. The main disadvantage is the high cost per acre controlled. Treatment longevity could be considered moderate to high, depending upon the level of maintenance. They are moderately reliable, but apparently more reliable for submerged plants than floating-leaved varieties. They can be highly effective with proper installation and maintenance. Bottom barriers require hydraulic approval from the Washington Department of Fish and Wildlife and a shorelines exemption review by King County DDES.

Rotovation

This method involves "tilling" the sediment to a depth of 4-6 inches, which dislodges plants and plant roots. At a minimum, rotovation will result in decreased plant densities and growth impairment through the following growing season, although in some cases improvements can last for 2 to 3 years. If done repeatedly over several years, the effectiveness period may be extended. The regrowth period is related to both depth and proximity of nearby plant beds. Rotovation is best done during winter or spring to reduce plant regrowth potential, which also reduces the impact associated with the increased turbidity.

The advantages of this method are that it does not interfere with peak recreational use of the lake, it can be scheduled so as not to impact fish spawning, and it provides relatively long-term control. The main disadvantage is the cost ($1,200-1,700/acre). Sediment disruption can also result in the release of nutrients to the water column which can result in water quality concerns. The method does create plant fragments but, as stated earlier, this is considered a minor problem in Lake Sawyer, where milfoil can be found throughout the lake. It is also not recommended for sediments that contain high metals or other contaminants, since it may release these contaminants into the water column. This is not expected to a problem in Lake Sawyer, however, rotovation can be expected to have a low-to-moderate longevity and reliability, and high effectiveness. Rotovation would require an HPA from WDFW, a temporary water quality modifications permit from WDOE, and a shorelines review from KCDDES. Additionally, a Section 404 permit, obtained from the U.S. Army Corps of Engineers, may be required.

Diver Operated Suction Dredge

A portable, barge-mounted dredge with a suction head is operated by SCUBA divers who essentially "vacuum" up sediments and root material that they physically dislodge. The plant/sediment slurry material is then carried back to the barge via hoses operated by the diver. The plant material is first separated from the sediment slurry and then removed to an offshore site for disposal. The sediment slurry is typically returned to the lake. Costs are much lower than traditional dredge operations because there are no disposal costs except those associated with the comparatively small amount of vegetation.

There are a number of advantages associated with diver dredging. Most important is that the method is site specific and can be species specific. Thus, beneficial plants can be retained. The effects of the treatment should last a fairly long time. Plants may begin to return the following year; lilies and other tubers would begin to invade from the edge and work in, but depending upon the size of the treatment area it would take 3-4 years for them to reach the areal extent and density of pre-treatment conditions. The main disadvantage is that it is labor intensive and, therefore, relatively expensive. Unit costs for suction dredging range from $1,100 to more than $2,000 per day. Assuming a daily rate of 0.5 acres at $2,000 per day, the annual cost for controlling 10 acres is $40,000. Suction dredging is a fairly new tool for lakes and has a low reliability. The removal of plants and roots and ability to be quite selective about control areas, make it a highly effective tool, however, diver dredging would require an HPA, a temporary water quality modifications permit, and a shorelines review.

Herbicides

A number of herbicides are effective for use in controlling small areas. Sonar in pellet form can be used to avoid the whole-lake applications usually required for the liquid form to work. The pellets remain in the area needing control instead of moving into the rest of the lake. Thus, these pellets can be used to achieve local control in protected bays or along shoreline patches. Because the pellets work best when they are directly on the vegetation, three separate applications can be used to achieve a higher level of control. This type of application can be expected to cost approximately $2,000 per acre (**RMI, personal communication**) and would be similar in terms of longevity, reliability, and effectiveness to diver-dredging operations.

Another herbicide that can be used to treat small areas of submerged vegetation is Aquathol. This is a contact herbicide that does not kill the roots. Therefore application would need to occur every year to keep the plants under control. Application costs are approximately $500/acre and are considerably lower than for the sonar pellets (**RMI, personal communication**). Although the EPA has recently lifted lake use restrictions for Aquathol, State regulations require an 8 day waiting period between application and lake recreational use.

A last herbicide that might be effectively used to treat milfoil, but will not affect most other submerged plants and can be used for spot treatments is "Trichlopyr", fast acting systemic herbicide. This herbicide is in the process of being reviewed for registration by the EPA, so it will be a year or more before it could potentially be approved for use in Washington State (**Hamel, K. Personal Communication**). Assuming Trichlopyr becomes registered for use, as is predicted, this herbicide could be used to "spot treat" patches of milfoil that recover from, for example, a Sonar treatment. No information is available on the application costs for this herbicide. It is expected to be comparable in cost to Sonar, but will not need to be applied to the same extent and therefore may provide a more cost-effective treatment.

Glyphosate is the recommended herbicide for waterlily control. Glyphosate is a systemic herbicide that is applied to the leaves of actively growing waterlilies. Glyphosate is formulated as Rodeo® or Pondmaster®. The herbicide is rapidly absorbed by the leaves and translocated throughout the entire plant, including the roots (tubers). Wilting and yellowing of plants occurs within 7 days, followed by browning and death. Complete control may require a second treatment in the following year. Submerged plants are typically not affected by a glyphosate treatment.

Duration of control varies with depth and distance to nearest lily bed. Encroachment from adjacent stands of lilies will begin immediately and be most efficient in nearshore areas. The primary advantage of glyphosate treatments are the low cost coupled with relatively long-term control of the plants. It is considered to have a very low toxicity to aquatic animals and comes with no swimming or fishing use restrictions. Treatment costs average $300 per acre. Since it is a systemic herbicide and can kill the entire plant, treatment longevity can be 3-4 years. Reliability and effectiveness are also high. However, it is a chemical control method and therefore there are implied concerns associated with the use of toxins in natural environments. Other than chemical use concerns, the primary drawback of glyphosate use is the water quality impact from the release of nutrients by decaying vegetation. There is also concern associated with the possibility of affecting non-target plants from drift of the applied herbicide.

All herbicide treatments require a temporary modification of water quality standards permit from the Washington Department of Ecology and a shorelines review by King County DDES.

DESCRIPTION OF LARGE AREA AQUATIC PLANT CONTROL TECHNIQUES

Large Area Control Techniques

The most commonly used techniques for controlling a large surface area of plants are; harvesting, herbicides, and grass carp. Shoreline dredging, although hardly a commonly used technique, is also a technique for controlling large areas of plant biomass. Water column drawdown and use of water column dyes are also large scale techniques, however, due to their general ineffectiveness in this part of the country, they are not described here.

Shoreline Dredging

Dredging, or removing accumulated sediments has typically been used to either deepen a lake, or to remove nutrient laden sediments for water quality improvement. It can also be used to control the amount and type of aquatic plant habitat present. This is based on the fact that different plant types have fairly defined water depth preferences. Therefore, if sediments are removed (causing deeper water) plant types will change accordingly and the extent (width) of the plant bed will decrease. To use the southwestern shoreline of Lake Sawyer as an example; Under existing conditions the demarcation for the outward extent of the aquatic plant bed is near the 10 foot depth contour and extends 50-75 feet from the shore. If through a dredging project 2 feet of material was removed from the entire 0-10 foot depth zone, the various depth zones would continue to exist, but they would be in much narrower bands and the overall width of the aquatic plants would be decreased by 15-20%. Thus a dredge project has the advantage of decreasing the total acreage of prime plant habitat, while retaining a variety of plant habitats, but in more compressed (narrower) bands along the lake. Since plant habitat would remain there would be no decrease in water clarity, and there may be some improvement in overall water quality due to the removal of nutrient laden sediments from the lake. Dredging will not help the non-native aquatic plant problem, since it would cause removal of all plant types. In fact, general disruption of plant beds may result in a competitive advantage to invasive/non-native species such as Eurasian watermilfoil.

Unfortunately, dredging is probably the most expensive restoration technique. The costs range from $5-13.00/cu.yd for the dredging and dewatering with possible additional costs associated with dredge spoil disposal and a dredge design report. Assuming 3 feet of material is removed from 50 surface acres, the cost could range from 1.8 to 3.5 million dollars. All costs would occur during the first few years of the project, thus there would be no additional costs over the long-term(20 year cost estimates).

Assuming a sedimentation rate of 0.32 cm/yr (0.13 inches/yr) (Ecology, 1991), every 1 foot of sediment removed could be equated to removing approximately 92 years of accumulation, two feet of material would equate to 184 years of accumulation and etc. Likewise, assuming at least 1 foot of material would need to re-accumulate before plant habitat was affected, it would take almost 100 years for the lake to re-accumulate the sediment. This results in a duration for control of almost 100 years for every foot of material removed. In the matrix, dredging is rated high for longevity, low for reliability (since it is not a technique that has been used enough to have an established record for affect), and high for effectiveness, because plant habitat is actually being altered and decreased.

Mechanical Harvesting

This method entails cutting or "mowing" the plants below the water surface, similar to mowing a lawn. The tops are removed from the plants to a depth of 5 to 8 feet below the water surface. (The width and depth of the cut is dependent upon the type of harvester used.) Harvesting must occur at least twice each summer to maintain plant height to an acceptable level. The main advantages of harvesting are the immediacy of the control and the fact that plant material that would normally add to the lakes nutrient load is removed from the lake. The main disadvantages are that it is a slow process with a short duration of control. Assuming 2 acres can be harvested each day and assuming approximately 24 acres of submerged plants would be harvested in Lake Sawyer, it would require 12 days of harvesting twice each summer, for a total of 24 days. Another concern associated with harvesting is that plant fragments are left behind that can cause infestation of new areas. This is especially a concern with milfoil. Since milfoil is already spread throughout Lake Sawyer, its colonization of new habitat area is not a significant concern. The cost per acre for harvesting has been estimated at $500-$870 (Envirovision, 1994), resulting in a total cost range for 24 acres twice per season of $12,000-$20,880.00 per year, or $240,000-$418,000 over twenty years.

Harvesting has been used extensively in the Puget Sound Region since the early 1980's. However, its popularity has greatly decreased in past years due to the high cost associated with operations and maintenance and the fact that is expensive over the long-term, yet provides no long-term solution to the problem. Harvesting is rated high for reliability, (due to its extensive record of use in the area), low for longevity, and low for effectiveness.

Herbicides

A number of herbicides are now approved for controlling aquatic plants in the State of Washington. The most effective herbicide for control of Eurasian watermilfoil is fluridone (formulated as Sonar®), because it kills both the plant and the roots, therefore providing lasting control or even eradication of the plant. It also impacts many other submerged plants and to a lesser extent can affect floating-leaved plant types. One of the problems posed by treatment with fluridone is that because it is a systemic herbicide (it must be taken up by the plants) to get a proper application a specific concentration must be maintained in the water for a period of 8 weeks. This can require as many as four whole-lake applications spread over the 8 week period. It has been estimated that an entire lake treatment of liquid Sonar with repeated applications over an 8 week period would cost approximately $255,000 assuming maximum application (**RMI, personal communication**). The purpose of this type of application is to eradicate milfoil from the lake. Many native plants would also be affected but would expected to recolonize habitat fairly quickly.

Conversely, fluridone can be applied in a higher concentration, one time application throughout the lake. It would not result in eradication of the milfoil, but it would greatly reduce the plants (and other submerged plants) for a 2-4 year period. The cost of this type of application has been estimated at $97,000.00 (**RMI, personal communication**). Use of sonar and other herbicides available for treating smaller control areas is described in a following section.

The effects of fluridone treatment become noticeable within 7 to 10 days of application, with complete control often requiring 60-90 days, and repeated applications. Because it kills the plant and roots it has a relatively long control duration; four to five years. Extensive studies have indicated that with proper application there is no risk to human health from fluridone use and it has a low level of toxicity to fish and other wildlife. The main disadvantages of the liquid Sonar (aside from those that are implied by use of any chemical pesticide in natural environments) is that because it is slow-acting it must be applied to large areas (five acres or more) to be effective and may be best used as a whole-lake treatment. Therefore, it can not be used to target specific zones and impacts beneficial submersed plants as well as nuisance plants. Another important disadvantage is that the plants that die result in immediate release of nutrients to the lake during the critical early summer time period. (Proper timing of application can help to reduce the amount of plant material that is available to decompose.) Large-scale Sonar treatments can be expected to provide a moderate longevity depending upon application, and moderate to high reliability and effectiveness.

Grass Carp

Grass carp are plant-consuming fish native to China and Siberia. Sterile (triploid) grass carp are raised in the southeast US for lake-wide control of submerged aquatic plants. Known for their high growth rates and wide range of food preference, these fish can control certain nuisance aquatic plants under the right circumstances. Stocking rates depend on climate, water temperature, type and extent of plant species, and other site-specific conditions. In 1990, Washington state adopted grass carp regulations that require the following conditions:

- Only sterile (triploid) fish can be planted,
- Inlets and outlets must be screened to prevent fish from getting into other water bodies,
- To insure sufficient vegetation is retained for fish and wildlife habitat, stocking rates are defined by WDFW based on the current planting model,
- Lakes with public access require a lake restoration study.

Effectiveness of grass carp in controlling aquatic plants was once thought to depend on feeding preferences and metabolism. However, more recent research in Washington State has indicated that the fish will eventually eat most submerged plants, and initial plant preference is not an issue (**Bonar, S. personal communication**). The primary advantage of grass carp is that it can be a low cost option if a lake restoration study has already been performed and if inlets and outlets can be easily screened. Primary drawbacks are that effects are unpredictable and that all beneficial plants may be removed, resulting in serious impacts to fish and wildlife.

Costs range from $50 to $2,000 per acre, at stocking rates ranging from 5 to 200 fish per acre and average cost of $10 per fish. Assuming 70 total acres of submerged plant habitat, stocking would cost $3,500 to $140,000. Based on recent stocking rates used in Washington State, a rate of 25 fish per acre, or $20,000 is probably a reasonable estimate. Lake Sawyer poses another problem for grass carp stocking; screening would be required on both inflows and the outflow to insure the carp could not invade other areas. Since salmon migrate through the lake, the screens would have to be specially designed to allow this movement. Design and installation can be expensive. Additional costs could be as high as $200,000 for inlet and outlet screening required by the fish planting permit. Follow-up stocking would also need to occur approximately every 5 years to replace fish lost through mortality. Assuming $5,000 is spent every five years on replacement, the 20-year cost estimate is $235,000. In addition to a game fish planting permit, hydraulic project approval is required by WDFW.

Although it can take 4-5 years for the carp to reach the desired level of control, once this has been reached, control can last for 10 years beyond the initial stocking and of course longer if carp lost through mortality are replaced. Consequently, the longevity of this treatment is high. It is not considered very reliable since there are still relatively few studies where long-term affects are known. It is also rated low in effectiveness due to the inability to obtain a desired level of control. (These projects have a tendency to be either unsuccessful or result in total eradication of the plant community with coincident changes in fish and wildlife communities.)

RECOMMENDED AQUATIC PLANT CONTROL PLAN

The aquatic plant community in Lake Sawyer already meets many of the identified functions described previously. It is a well-mixed community of plants, there is a variety of wildlife habitat types present, and it is apparently causing only minor impacts to recreational activities except in isolated areas. Also, due to the lake's size, any whole-lake treatment will be expensive. Consequently, this plan focuses on identified problem areas, while allowing some flexibility by lakeside residents in selecting other areas for control. It also recommends establishment of conservancy zones for protection. Figure H-2 identifies the treatment area and recommended conservancy zones.

Area #1

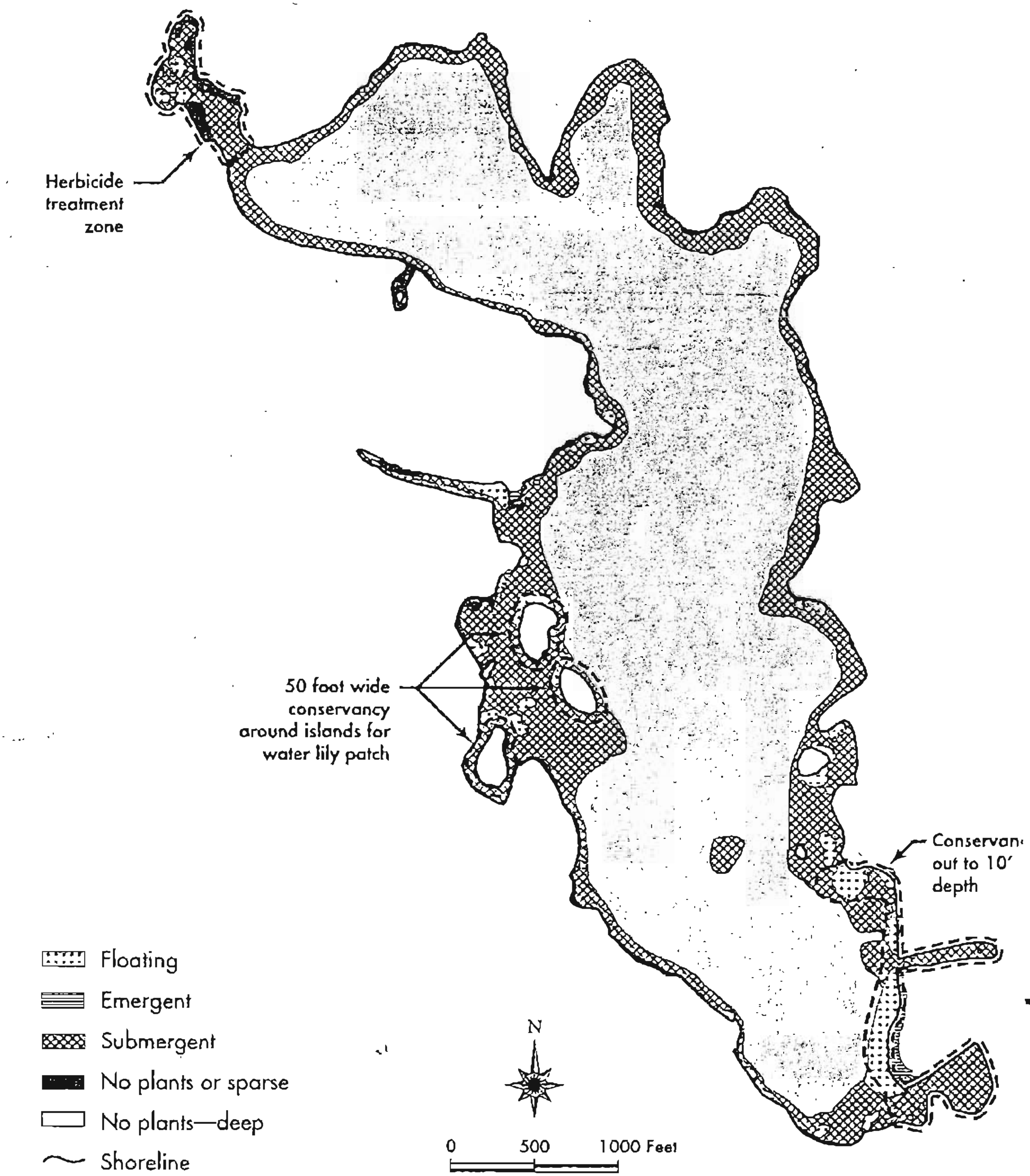
The shallow bay in the northwest corner of the lake has been repeatedly identified as a problem area. The plant community consists largely of a mix of two non-native species: White water lily and Eurasian watermilfoil. This combination is notoriously poor, making even boating access difficult. A number of scenarios were considered for treatment of this area, including: diver-dredging or rotovation of the entire area, and a combination of diver dredging and follow-up herbicide applications. Scenarios that included diver-dredging or rotovation were always considerably more expensive that herbicide treatments, even when twenty-year treatment costs were considered. Furthermore, the disruption of the sediments by these methods would likely favor re-invasion by milfoil instead of native pondweeds. For these reasons these scenarios were not selected.

Sonar pellets are recommended for treatment of the milfoil. Treatment would consist of three applications over the first summer to achieve maximum die-off of the milfoil and open the entire area to new plant types. If a mixed-plant community returns to the bay, it is suggested that spot treatments with sonar pellets or Trichlopyr be used on remaining milfoil beds. If a well-mixed population is eventually achieved, but use of this bay continues to be hampered by plants, use of the herbicide Aquathol every 1-2 years (as needed), would represent the most cost-effective approach to long-term herbicide control strategy. The goal is to eventually eliminate the milfoil and allow replacement by native species that do not have the same nuisance characteristics as milfoil. Assuming four acres of submerged plants are treated, three treatments with Sonar pellets would cost approximately $8,000 (**RMI, personal communication**). Allowing for treatment of an additional acre the following year with either pellets or Trichlopyr would cost an additional $2,000. Future annual treatments with Aquathol would cost approximately $2,000 per year, assuming a total of 4 acres of submerged plants are treated each year.

Rodeo (glyphosate) is recommended for treatment of the waterlily. Due to the shallow nature of the bay, removal of the milfoil will allow invasion of much of this opened habitat by waterlily, if coincident steps are not taken to control this plant, too. It is recommended that the treatment be designed to remove large beds of waterlily and allow navigational channels, while leaving a few patches to provide habitat and edge effect for fish and wildlife. It is expected that the bay will need to be re-treated to control lilies every 3-4 years. Estimating that there are currently 2 acres of lilies in the bay, the cost for this control would be $600 per treatment.

Figure AP2

Aquatic Plant Control Zones in Lake Sawyer



Although it is not an action item selected for this plan, lake residents may want to consider re-dredging this bay, over the long-term. Although dredging is expensive, it is the only alternative that will allow continued use of the bay without a permanent program of herbicide treatment.

Area #2

The second treatment objective was the shallow area containing the three islands located along the western shore. Due to the extensive shallow nature of this shoreline, it can be expected to have plant problems, even if currently that is not the case. Apparently this area has not been identified as a critical problem area at this time. Therefore, no specific treatment has been selected for control of plants in this area. Residents may choose to prioritize this area for treatment during their annual review of aquatic plant treatment needs (see below). Portions of this treatment area have been identified as conservancy zone, as described below.

Establishment of Conservancy Zones

Conservancy zones are set aside to preserve natural areas and wildlife habitat. No treatment or plant control activities would be allowed in these areas unless a newly invasive critical species, such as hydrilla (Hydrilla verticillata), was found there. It is recommended that the area near the lake's two (Ravensdale and Rock Creeks), be designated as a conservancy zone. The conservancy area would consist of the small bays out to the 10 foot depth contour, extend approximately 500 feet, to the north of Ravensdale Creek, and to the first residence located along the shore to the south of where Rock Creek enters the lake. Conservancy zones should also be established around existing islands, leaving a 50 foot wide buffer around the edge of each island, with the exception of the area immediately adjacent to island docks. The isolated patch of waterlily located between the three island clusters along the western shore should also be retained. This can easily be navigated around, and by retaining it, another habitat structure type is retained within this small bay. A 50-foot treatment buffer around this patch should be maintained as well (this buffer should be established to keep the patch from growing larger; if a herbicide was used right up to the patch's edge it would provide lilies with an advantage in colonizing the newly opened area and the bed would grow even larger, which is not the intent of retaining the bed).

Long-term Flexibility and Control

Long-term flexibility is provided through a combination of equipment, treatment allowance, and establishment of an advisory committee. These are included to provide community club members and lake residents access to different control methods, flexibility to allow normal changes in the aquatic plant communities, and a mechanism for overseeing implementation of this plan.

Plant Control Advisory Committee

A plant control advisory committee would be established to oversee long-term implementation of this plan. Each year the committee would review aquatic plant concerns, decide whether treatment is warranted, and select areas to be treated based on defined criteria. The reliance on herbicides for long-term control of lake aquatic plant problems means that Lake Sawyer will become a managed system that will need some continual attention. Establishing a plant control advisory committee will be a method of insuring long-term tracking and implementation of this plan.

Annual Treatment Allowance

In addition to the herbicide treatments described above, a maximum of four additional acres of plants can be treated each year at the discretion of an established plant control advisory committee. The selection of the controlled acres would be based on criteria set by this advisory committee on prioritizing areas needing control. A maximum of $8,000 is set aside for this annual treatment allowance. This would include either use of Rodeo for waterlily or Sonar pellets (or trichlopyr if it becomes approved for use in Washington) for submerged plants. This would provide an additional element of control for problem areas without removing large portions of habitat at any one time (this would allow treatment of the portions of area #2 if it was selected as a treatment site).

Tools for Control of Small Areas

The purchase of hand operated equipment for removal of waterlily and submerged plants is recommended. These tools would provide property owners with a more efficient method for controlling nuisance patches of plants found near their docks. The fact that each resident would need to supply the labor for their removal, would reduce concerns associated with removing too much of the lake plant habitat. Although they would not be funded as part of this plan, use of weedrollers, bottom barrier, and other non-chemical, small area control techniques would also be approved for lakeside residents who choose to employ them.

Long-term Monitoring Plan

A long-term monitoring program is needed to both provide the plant control advisory committee with information to use in determining annual treatment needs, and as a means of tracking possible entry of new exotic aquatic plants to the lake. Monitoring would be performed on an annual basis by a cadre of trained volunteers. Each volunteer would be responsible for patrolling 500 meters of shoreline during either the months of July or August each year. Patrolling would consist of using a submersible viewing scope to examine plant beds. Volunteers would boat along the outer edge of the plant bed, making notes on the plant types observed, extent of the plant bed, density, and whether it appears to have noticeably changed since the previous year. Every 100 meters a transect from the outer edge of the plant bed to the shore would be done, collecting plant samples with a rake wherever the plant community changes to check the plant community composition. The only cost associated with this program would be in producing a simple training guide and the initial training of the volunteers. The guide would describe how the sampling should be done and provide illustrations and descriptions of the most common plants currently found in Lake Sawyer, as well as those exotic plants volunteers would also need to recognize. Training and production of this guide is estimated to cost $2,000. Alternatively, King County's Lake Stewardship Program has an aquatic plant management element. Depending upon future funding, this program could provide training for volunteers to identify and map aquatic plants in Lake Sawyer. A cost for this is included in Table H-2 in order to provide a conservative (worse case) estimate of implementation costs.

The need to develop and implement plans for controlling aquatic plants in lakes is recognized by the WSDOE through their establishment of a funding mechanism for these projects. Funds can be obtained for either development of a plan for controlling aquaitc plants, or for implementing a plan already approved by the agency. Guidelines for producing these plans are outlined in their manual **(Gibbons, M. et al., 1994)**. The following aquatic plant control plan was developed to meet most of the requirements of this program. Assuming the plan is approved by Ecology, it will be available open certified implementation funds could be acceptable

Estimated Cost of Recommended Plant Control Strategy

Table H-2, summarizes the estimated costs for implementing this plant control strategy. The estimated cost for the first (and most expensive) year is $21,200, the 20-year cost is estimated at $215,200, for an annual average cost of $10,760.00.

The intent of this strategy is not to rid the lake of milfoil, but to control it at a level where it is not hindering recreational use or upsetting the natural balance of the plant community. Lake Sawyer itself lends evidence to the theory that the more plant communities are manipulated, the more advantage is given to the non-native invasive plants. This plan specifically addresses identified problem areas, while allowing long-term flexibility for lakeside residents in controlling nuisance plant populations and meeting WDFW limitations for plant removal.

Table H-2. Estimated Costs for Implementation of the Aquatic Plant Control Plan for Lake Sawyer.

Task/Year	1	2	3	4	5	10	20
Small Bay/Milfoil Contrl							
Sonar Pellets	8000	0	0	0	0	8000	8000
Follow-up Treatments	0	0	2000	0	0	2000	2000
Contingency/Aquathol	0	0	0	0	2000	6000	16000
Small Bay/Lilies Control							
Rodeo Treatments	600	0	0	600	0	2400	4800
General Plant Control							
Equipment	2600	0	0	0	0	5200	10400
Treatment Allowance	8000	8000	8000	8000	8000	80000	160000
Monitoring	2000	0	0	0	0	2000	
Committee	0	0	0	0	0	0	
Conservancy Zones	0	0	0	0	0	0	
TOTAL	21,200	8000	10000	8600	10000	105,600	201,200

REFERENCES

Resource Management Inc. (Written Communication from T. McNabb. 30 November 1995).

Hamel, Kathy. Washington Department of Ecology. (Phone Communication. 28 November 1995).

APPENDIX E
Public Access Inventory

Lake Sawyer and its Watershed
Draft Management Plan

Public Access Inventory

Lake Sawyer's main beneficial uses include boating, fishing, swimming, aesthetics, and picnicking. Public access to these uses is provided via the public boat launch contained within King County's Lake Sawyer Park.

The boat launch is open all year, and until recently Lake Sawyer was the only lake in southeast King County open for fishing year-round. The boat launch is used heavily during the summer season, when on any given weekend 30-60 boating groups will use the boat ramp. Lake Sawyer serves as a migration corridor during winter high flow periods for coho salmon and steelhead trout. The Washington State Department of Fish & Wildlife (WSDFW) plants rainbow and cutthroat trout and kokanee when available on an annual basis. Warm water species that inhabit the lake include: large-mouth and small mouth bass, black crappie, yellow perch, pumpkinseed, sunfish and brown bullhead.

Currently, King County Parks Department has planned upgrades for the Park. The upgrades focus on bio-engineering for erosion control on the shoreline, provision of a floating pier at the boat-launch area and picnic tables near the west boundary of the property. This Park plan has been approved, but has not yet been funded.

In addition, King County and Black Diamond are proposing a new park at the south end of Lake Sawyer. The proposal envisions passive and active recreation, similar to Marymoor Park in north King County. The regional Green River to Cedar River Trail would bisect the proposed park. Activities to secure property - 54 acres - are expected to begin in 1997. Specific design is still ahead.

A public access inventory by element per the Washington State Department of Ecology's Centennial Clean Water Fund (CCWF) public access requirements follows.

1) **Park Identification Signs**

The WSDFW boat launch is currently signed at its entrance.

2) **Boat Launch**

There is an existing boat launch on Lake Sawyer located on the northwestern side via King County's Lake Sawyer Park. The launch isopen year-round.

3) **Parking Area**

Gravel and paved parking is provided at the park/boat launch for approximately 12 vehicles. The Upgrade Plan includes no additional parking.

4) **Garbage Receptacles**

A garbage receptacle is located at the boat launch and another near the portable toilet.. The Upgrade Plan includes 2 more.

5) **Picnic Area**

Currently, Lake Sawyer Park has no picnic tables. The Upgrade Plan includes 6 picnic tables near the west boundary of the Park.

6) **Sani-Kans or Portable Toilets**

Currently, Lake Sawyer Park has one seasonal Sani-Kan. The Upgrade Plan includes no more.

7) **Play Area**

Active play areas do not currently exist at Lake Sawyer Park. The Upgrade Plan includes none.

8) **Swimming Area**

Lake Sawyer Park currently has no formal swimming beach. The Upgrade Plan includes none.

9) **Fire Pits**

No fire pits are currently located within the park. The Upgrade Plan includes none.

10) **Permanent Restroom Facilities**

The park currently does not have permanent restroom facilities. The Upgrade Plan includes none.

11) **Potable Water Supply**

There are currently no potable water supplies at the park. The Upgrade Plan includes none.

12) **Fishing Pier/Floats**

Currently, there are no fishing piers or floats at the park/boat launch. The Upgrade Plan calls for a floating pier for boat-launching. Fishing could be conducted from this pier.

13) **Nature Trails**

There are no nature trails present in the park. The Upgrade Plan includes none.

Per the Washington State Department of Ecology's CCWF grant requirements, Phase II Lake Restoration Implementation projects which total less than $400,000 must provide items 1-6 (listed above) as the minimum requirement for public access. For lake restoration implementation projects between $400,000 and $800,000, items 1-9 must be provided. For lake projects greater than $800,000, public access elements 1-13 must be present.

With the completion of the upgrades approved for the existing park items 1 - 6 would be met, as well as item 12. Currently, there are no plans to supply any of the other elements at the existing park. It remains to be seen which elements, in addition to item 13, will be included in the design for the new park.

APPENDIX F
Total Maximum Daily Load (TMDL)

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
P.O. Box 47600 • Olympia, Washington 98504-7600
(360) 407-6000 • TDD Only (Hearing Impaired) (360) 407-6006

June 7, 1996

Mr. Jim Kramer
King County Surface Water Management
700 Fifth Ave, Suite 2200
Seattle, WA 98104

Dear Mr. Kramer:

Enclosed is the 1996 Clean Water Act Section 303(d) list and responsiveness summary that was submitted to the U.S. Environmental Protection Agency (EPA) on May 31. You had previously either submitted comments on the proposed list or requested a copy of the final submittal package.

The statute requires that EPA either approve or disapprove the list within 30 days after submittal. If the EPA disapproves the list, they must establish a different list. Appeals to the list that was submitted should be directed to EPA. The EPA Region 10 contact for the list review and approval is Alan Henning. His number is (206) 553-8293.

The Deparment of Ecology feels that the extensive public involvement in developing the list has resulted in a complete and accurate list of waters for which total maximum daily loads need to be established. Thank you for your interest and involvement. If you have any questions concerning the enclosed materials or the process, please feel free to call me at (360) 407-6482.

Sincerely,

Steve Butkus

Steve Butkus
Water Quality Program

SB:lb

Enclosure

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
P.O. Box 47600 • Olympia, Washington 98504-7600
(360) 407-6000 • TDD Only (Hearing Impaired) (360) 407-6006

May 31, 1996

Mr. Phil Millam
Water Division Director
U.S. Environmental Protection Agency - Region 10
1200 Sixth Avenue
Seattle, WA 98101

Dear Mr. Millam:

In accordance with federal regulations 40 CFR 130.7 and Section 303(d) of the Clean Water Act, the Department of Ecology submits the attached list of waters requiring establishment of Total Maximum Daily Loads (TMDLs). These waters have been selected after an extensive public participation process and numerous internal reviews by Ecology staff. A responsiveness summary of comments received and rationale for decisions is enclosed.

As required, those segments and parameters which have been identified as high priority for establishment of TMDLs are shown in underlined text. All other segments and parameters in the list not shown with underlined text have been identified as a medium priority for establishing TMDLs. These medium priority segments will be re-examined for their priority through the scoping process of our watershed approach to water quality management.

The segments and schedule of TMDLs that are under development or completed is shown in Appendix I of the responsiveness summary. Ecology is also committed to preventing waters from being placed on the list. As such, we are in the process of establishing many TMDLs for waters which are not on the current list.

If you have any questions or if we can clarify any of the information enclosed, please contact Steve Butkus of my staff at (206) 407-6482.

Sincerely,

Michael T. Llewelyn
Program Manager
Water Quality Program

MTL:SB:lmb
Enclosure

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue
Seattle, Washington 98101

February 12, 1993

Reply to
Attn of: WD-139

Michael T. Llewelyn, Program Manager
Water Quality Program
Washington Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

Re: Approval of Total Maximum Daily Load (TMDL) for Lake Sawyer (Waterbody Segment No. WA-09-9260)

Dear Mr. Llewelyn:

I am pleased to approve the following TMDL and associated wasteload and load allocations that were submitted by your Department to the Environmental Protection Agency (EPA) on March 9, 1992:

Waterbody Segment	Waterbody Name	TMDL Parameter
WA-09-9260	Lake Sawyer	Total Phosphorus

A TMDL has been established for Lake Sawyer that will ensure compliance with the state's narrative water quality standard for aesthetics. The TMDL will be implemented primarily through point source control. Effluent from the Black Diamond Wastewater Treatment Facility will be completely diverted from the Lake Sawyer watershed, in accordance with the wasteload allocation of zero.

By EPA's approval of this TMDL, it is now incorporated into the state's water quality management plan.

Sincerely,

Charles E. Findley
Director, Water Division

cc: Lynn Singleton, Ecology
Steve Butkus, Ecology
Will Kendra, Ecology

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue
Seattle, Washington 98101

FILE COPY

FEB 11 1993

Reply to
Attn of: WD-139

MEMORANDUM

SUBJECT: Recommendation for TMDL Approval
Lake Sawyer - Total Phosphorus

FROM: Amber Wong, Standards to Permits Specialist
Water Quality Section

TO: File

- TMDL submitted March 9, 1992

- TMDL package completed February 11, 1993

  - EPA Approval Checklist

  - Document 1: Transmittal letter

  - Document 2: TMDL document

  - Document 3: Diagnostic Study of Lake Sawyer - February 1989 through March 1990

  - Document 4: Lake Sawyer - Black Diamond Waste Load Allocation Evaluation - September 1989

  - Document 5: Public Participation, public notice and public hearing documentation

    5a. Minutes of the Lake Sawyer Waste Load Allocation Diagnostic Study Advisory Committee Meeting - March 8, 1989

    5b. Agenda for the Lake Sawyer Water Quality Modification or Replacement of the Black Diamond Wastewater Treatment Facility - February 1989

    5c. Focus - Lake Sawyer Water Quality (attached to 5b)

  - Document 6: NPDES Permit No. WA-002996-3, Town of

Black Diamond WWTP issued April 18, 1980, expired April 15, 1985

- Document 7: Letter from Oddvar K. Aurdal, Chief Grants Administration Section to Howard Botts, Mayor of Black Diamond on grant agreement for discharge interceptor dated June 25, 1991

Transmittal letter - Complete (see Document 1)

- states that TMDL has been established in accordance with Section 303(d)(1) of the Clean Water Act.
- **Review note: meets requirements**

Problem Assessment - Complete (see Document 4)

- The City of Black Diamond operates a wastewater treatment facility that discharges to a natural wetland. (The wetland drains into Rock Creek, which enters Lake Sawyer.) The wetland, which was funded under the Innovative and Alternative Grants Program, was designed to provide nutrient removal. The wetland portion subsequently failed to meet design removals of phosphorus, leading to an increased likelihood of eutrophic conditions. The TMDL/WLA study was undertaken to determine the amount of phosphorus that must be removed by the Black Diamond Treatment system to protect the water quality of Lake Sawyer.
- **Review notes: Identifies the problem parameter as phosphorus. Recognizes that there was a phosphorus load from septic systems prior to construction of the plant, but that the plant discharge is accelerating eutrophication.**

TMDL document - Complete (see Document 2)

- The TMDL is aimed at meeting the water quality standard for aesthetics.
- States that the goal is to maintain an average in-lake total phosphorus concentration of less than 16 μg/l. To meet this goal, the load capacity has been estimated to be 1.9 kg P/day.
- The Black Diamond WWTP has been given a WLA of 0 kg P per day.
- The load allocations for the tributaries to Lake Sawyer have been set at 1.4 kg P per day, which includes a

0.08 kg P per day allocation for uncertainty.

- The LA for internal loading is set at 0.54 kg P per day, which includes a 0.34 kg P day allocation for uncertainty.

- **Review note: Clearly identifies the load capacity for the TMDL, and links it to meeting the aesthetic standard. Concisely summarizes the implementation and monitoring followup. A construction grant from EPA has been awarded to the city to build an interceptor to take treated wastewater to the Seattle Metro-Renton treatment plant. References the supporting technical documents.**

Supporting Studies - Complete (see Documents 3 and 4)

- The TMDL was based on meeting the aesthetic standard for Lake Sawyer, which was interpreted as maintaining a mesotrophic condition in the lake. The "acceptable" level of risk of trophic degradation, based on previous regulatory policies and accepted scientific measures of certainty, was taken to be five (5) percent. The phosphorus TMDL was developed to meet this goal. This approach was also used in the Lake Chelan TMDL.

- Therefore, the 5% chance of eutrophic conditions represents an upper-limit in-lake total phosphorus concentration of about 16 μg/l. (pg 119, document 4). Removal of the treatment plant effluent was determined to meet this goal.

- **Review notes: Documentation gives basis for calculating the TMDL, and provides assurance that the goal of 16 μg/l will be met.**

Public participation - Complete (see Document 5)

- Focus sheet explains problem assessment process, and development of alternatives.

- Public meetings were held to discuss the modification or replacement of the Black Diamond facility.

- **Review notes: Adequate public participation.**

Enforceability - Complete (see Document 7)

- Documentation for the grant to construct the interceptor to the Metro-Renton plant, thereby eliminating the discharge to the lake.

- Review notes: Valid grant to document intent to remove the discharge.

<u>TMDL effectiveness plan</u> - Complete (see Document 2)

- The TMDL document indicates that water quality monitoring will be conducted by METRO.

- Review notes: Adequate monitoring to assess compliance with the TMDL.

<u>Recommendation, approve TMDL.</u>

ALW, 2/11/93

TOTAL MAXIMUM DAILY LOAD

Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

Developed pursuant to 40 CFR 130.7 and the Federal Clean Water Act

---

WATERBODY SEGMENT: WA-09-9260

Lake Sawyer

(outlet at TRS 21N-06E-04)

RECEIVING SYSTEM INFORMATION:

Basin: Duwamish-Green
County: King

TMDL PARAMETER:

Total Phosphorus

APPLICABLE RULES:

WAC 173-201-035(8)
WAC 173-201-045(5)(viii)

SOURCES COVERED BY THIS TMDL:

Allocation Type	Source Description
WLA	Black Diamond WWTP
LA	Tributaries to Lake Sawyer
LA	Internal Loading

TMDL:

The goal of maintaining an average in-lake total phosphorus concentration of 16 ug P/l has been identified in a technical study prepared by Ecology. This goal is expected to be achieved by setting the WLA of the Black Diamond WWTP to 0 kg P per day by removal of the discharge from the lake's main inflow. The loading capacity of total phosphorus to Lake Sawyer necessary to achieve this goal is estimated to be 1.9 kg P per day (715 kg P/yr). This estimated loading capacity is likely to be acheived from a LA to the tributaries of 1.4 kg P per day (which includes a 0.08 kg P per day allocation for uncertainty) and a LA from internal loading of 0.54 kg P per day (which includes a 0.34 kg P day allocation for uncertainty).

Technical Documents:

Carroll, J.V. and G.J. Pelletier. 1991. Diagnostic Study of Lake Sawyer, King County, Washington. Washington State Department of Ecology, Olympia, WA.

Pelletier, G.J. and J.W. Joy. 1989. Lake Sawyer - Black Diamond Waste Load Allocation Evaluation. Washington State Department of Ecology, Olympia, WA.

Public Participation:

Several advisory committee and public meetings have been held in conjunction of the Black Diamond WLA and Lake Sawyer Diagnostic studies. The final decision has been to reduce the WLA to zero through conveyance of the effluent to Seattle METRO's Renton WWTP.

Implementation:

A construction grant from EPA has been awarded to the City of Black Diamond to build the interceptor. The project is scheduled to be completed in the summer of 1992.

Monitoring:

Seattle METRO conducts routine monitoring of nutrients and water clarity of Lake Sawyer.

APPENDIX G
Lake Sawyer Watershed Bioassessment Case Study: 1995

LAKE SAWYER WATERSHED BIOASSESSMENT

1995 CASE STUDY

Submitted To:
United States Environmental Protection Agency
Region 10

Prepared By:
Kenneth Ludwa
Ecologist
Watershed Resource Monitoring Team

KING COUNTY SURFACE WATER MANAGEMENT DIVISION
700 FIFTH AVENUE, SUITE 2200
SEATTLE, WA 98104

April 22, 1996

LAKE SAWYER BIOASSESSMENT REPORT

Overview Of Study

King County Public Works, Surface Water Management Division (SWM) performed a single-season case study of Lake Sawyer and its watershed. The study was intended to demonstrate the role of the watershed and its biological linkages to Lake Sawyer which must be considered when managing and monitoring lake trophic status, water quality, water levels, and biological communities. A particular emphasis was placed on the use of biological monitoring and assessment of riparian habitat. The case study was funded by a grant from The United States Environmental Protection Agency, and was presented at the EPA Clean Lakes Workshop in Seattle, in October 1995.

Case Study Hypotheses

The primary goal of this project was to test the following hypotheses:

- Biological health, as measured by a biological index, will degrade with increased impervious area, degraded water and sediment quality, and degraded riparian habitat.
- Biological communities will reveal differences between the degraded Rock Creek sub-basin and the relatively pristine Ravensdale Creek sub-basin.
- Trends identified in the biological communities of the stream tributaries to Lake Sawyer will parallel trends identified in the lake's biological communities.

Site Description

Lake Sawyer is located in the Big Soos Creek sub-basin of the Green River drainage, in southwestern King County, Washington (Puget Sound Lowlands). The lake and its watershed are detailed in Figure 1; bathymetry and water quality, sediment, and benthos sampling stations are detailed in Figure 2. Lake Sawyer's surface area is 113 hectares (280 acres), draining 3370 hectares (13 miles squared). Its mean depth is 7.6 meters (25 feet), and maximum depth is 18 meters (58 feet); the lake experiences strong thermal stratification throughout most of the year. Lake Sawyer is open to public use, including an adjacent county park.

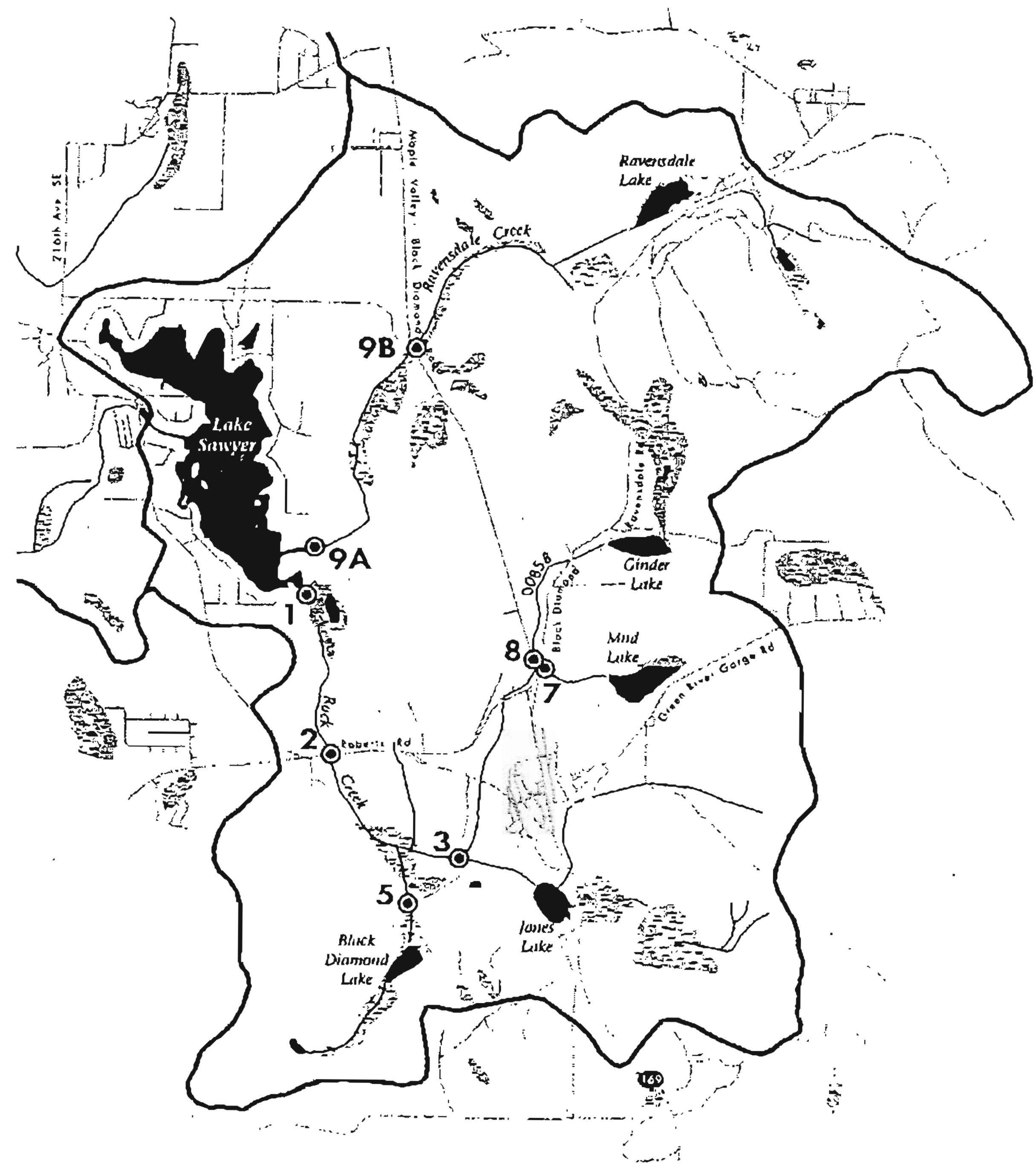
Historical and Current Water Quality

Ravensdale Creek and Rock Creek are Lake Sawyer's primary surface water inflows. Ravensdale Creek is relatively pristine, primarily draining managed forest and low density residential development. Rock Creek drains the City of Black Diamond

Figure 1

Lake Sawyer

Stream Benthic Sampling Locations



◉ 6 Stream Benthic Sampling Sites

Basin Boundary

Stream

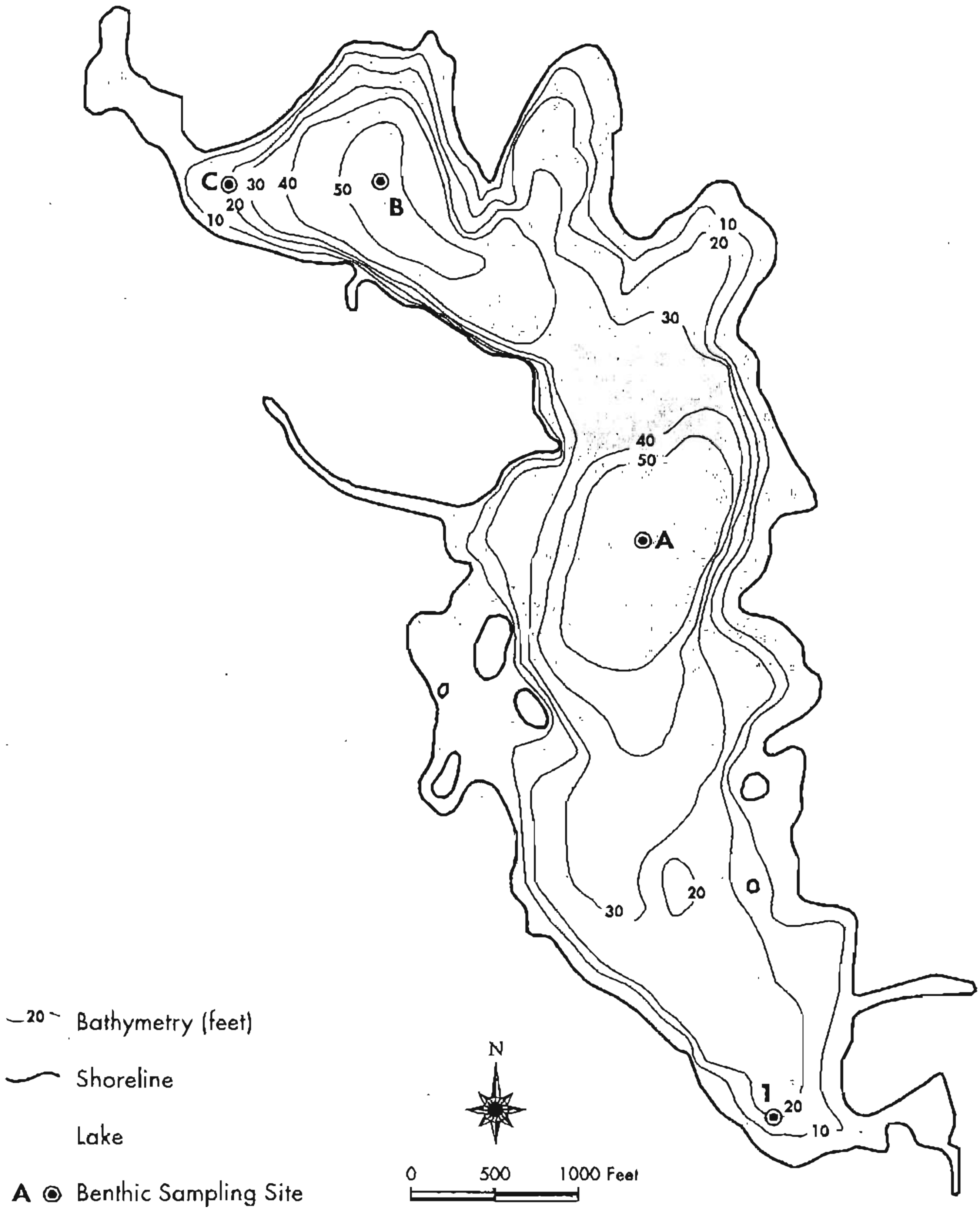
Lake

Wetland

Figure 2

Lake Sawyer

1995 Benthic Sampling Locations



(suburban development and light commercial and industrial land use), managed forest, and a large open-pit coal mining operation. Rock Creek received effluent from Black Diamond's failed wastewater treatment plant (WWTP) for 10 years until wastewater was diverted in 1992.

Limited historical water quality data is available on Rock and Ravensdale Creeks. Tributary water quality was monitored by KCM, Inc. from 1980 to 1982, prior to the City of Black Diamond's startup of the WWTP. Following WWTP startup, water quality was monitored at the Morgansville Bridge (Figure 2) as part of the WWTP's National Pollutant Discharge Elimination System (NPDES) permit. In 1989 and 1990, Washington State Department of Ecology (WSDOE) monitored Rock and Ravensdale Creeks as part of the Diagnostic Study of Lake Sawyer. During this period, mean total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations averaged 150 µg/L and 112 µg/L respectively in Rock Creek and 10.2 µg/L and 7.5 µg/L in Ravensdale Creek. From November 1992 through April 1994, SWM collected water quality samples as part of the Phase I Lake Sawyer Restoration Project. TP concentrations at the mouth of Rock Creek during this period ranged from 34.0 to 163 µg/L and averaged 86 µg/L. From June 1993 through April 1994, SRP monthly concentrations at the mouth of Rock Creek ranged from 20.0 to 124 µg/L and averaged 59 µg/L. Although TP concentrations in Rock Creek have been significantly reduced as a result of the WWTP diversion, the 1993 total maximum daily load is still being exceeded.

In 1989-1990, Lake Sawyer was classified as mesotrophic. Hypolimnetic dissolved oxygen (DO) depletion occurred during stratification due to the oxidation of organic and inorganic matter in the water column and lake sediments. Internal loads of TP and total nitrogen (TN) accounted for less than 20 percent of the total nutrient budgets. The volume-weighted whole-lake TP concentration for the study year March 1989 through February 1990 was 25.7 µg/L. The diagnostic study concluded that, if possible, TP loading should be maintained at a level no higher than the total external and internal TP load following the WWTP diversion (715 kg P/year) or a steady state in-lake mean TP concentration of 16 µg/L (TMDL). The diagnostic study did not meet all the requirements of a Phase I Lake Restoration Diagnostic/Feasibility Study.

Typical of fairly deep, monomictic lakes, Lake Sawyer begins to stratify during the spring (April-May) and remains layered until the fall. During 1994-1995, Lake Sawyer Secchi depth ranged from a low of 2.7 m in April 1994 to a high of 6.1 m in September 1995. The average for the summer (June-September) was 4.7 m and 4.4 m for the entire study year. In 1994-1995, the volume-weighted annual whole-lake TP concentration was 35.0 µg/L and the existing annual TP load was 1342 kg P/year. Modeling results reveal the lakes annual whole-lake TP concentration is expected to increase to 55.0 µg/L under future buildout conditions without mitigation. An annual load of 2414 kg P/year is expected under this scenario.

King County SWM Division expects to complete a restoration alternatives analysis and develop a draft management plan for Lake Sawyer and its watershed in Summer 1996.

Previous Data Collection Activities

In 1989 a diagnostic study of Lake Sawyer was conducted by WSDOE. The primary focus of that study was to determine a waste-load allocation analysis for the WWTP; the study's recommendations led to the 1992 diversion.

To supplement the 1989 WSDOE study and to complete Phase I restoration feasibility requirements, SWM conducted grant project to assess the impact of the WWTP diversion on lake quality, update the nutrient and water budgets, and to evaluate and recommend restoration alternatives that will protect the lake's water quality. This one-year limnological study was completed in May 1995. Mass balance modeling, restoration alternatives, and a draft Final Management Plan will be completed by July 1996.

Watershed Monitoring and Bioassessment Methods

<u>In-Lake Aquatic Macroinvertebrate Samples:</u> Macroinvertebrate samples were taken in June 1995 at stations 1, B, C, and D (Figure 2) using a Ponar grab sampler. Three replicates were taken at each station and sent to a qualified taxonomist for identification to family, species, and genus levels appropriate for use with biotic indices.

<u>Watershed Site Location:</u> The Rock Creek and Ravensdale Creek sub-basins are of approximately the same size, with similar geological features. Ravensdale Creek, which is relatively unimpacted, served as a control for Rock Creek. Because land use in the Ravensdale Creek basin is fairly homogeneous, two monitoring sites were situated on Ravensdale Creek, one near the mouth and one in the headwaters (Stations 9A and 9B, Figure 1). Six sites were selected on Rock Creek, to best isolate different types of land use and impacts in the tributaries (Stations 1, 2, 3A, 5, 7, and 8, Figure 1).

<u>Land Use Analysis:</u> Land use in the Lake Sawyer watershed was analyzed and tabulated for SWM's Phase I study using 1994 satellite GIS imagery and aerial photos. Land use was tabulated by sub-basin for Rock Creek and Ravensdale Creek and their respective tributary catchment areas.

<u>Benthic Macroinvertebrate Collections:</u> Samples were taken at each of the eight monitoring sites on June 28, 1995 (3 replicates per station). Samples were taken using a 500 μm mesh Surber net. Organisms were sent to a professional taxonomist for identification appropriate for use with a biotic index, in most cases genus or species.

Water and Sediment Quality Collections
One grab sample was obtained on June 27, 1995 for the following parameters: soluble reactive phosphorus (SRP), total phosphorus (TP), nitrate + nitrite nitrogen (NO3 + NO2), ammonia nitrogen (NH3N), biochemical oxygen demand (BOD), dissolved oxygen (DO), temperature, total suspended solids (TSS), turbidity, fecal coliform bacteria, calcium hardness, and total copper, lead, and zinc.

Eight sediment samples were taken from on June 26, 1995. Samples were taken from depositional areas in the monitoring reaches. Samples were analyzed for total organic carbon (TOC), percent solids, particle size distribution, TP, total petroleum hydrocarbons, and total copper, lead, nickel, cadmium, arsenic, chromium, iron, mercury, manganese, and zinc.

Habitat Assessment
A semi-quantitative habitat assessment was made at each site on August 18, 1995. Habitat parameters included percent canopy cover, substrate composition, embeddedness, bank stability, and vegetative disturbance in the riparian zone.

Data Analysis

Macroinvertebrate community data were analyzed using Fore and Karr's (1995) Benthic Index of Biotic Integrity (Table 1). Scores were calculated for each replicate sample and analyzed graphically relative to water and sediment quality, land use, and habitat ratings. The level of taxonomic detail performed for the lake organisms did not allow for detailed analysis of the lake benthic data; furthermore, no well-developed index exists for lake benthic communities. The lake benthic data was examined for patterns of taxa richness, dominance, and taxa structure.

Table 1. Metrics used in the Benthic Index of Biotic Integrity (Fore and Karr 1995) and their hypothesized response to watershed and stream degradation.

Metric Name	Response to Degradation
Total Number of Taxa	Decrease
Mayfly Taxa	Decrease
Stonefly Taxa	Decrease
Caddisfly Taxa	Decrease
Pteronarcys Taxa	Decrease
Number Intolerant Taxa	Decrease
% Tolerant	Increase
Sediment Intolerant Taxa	Decrease
% Sediment Tolerant	Increase
% Dominance (3 species)	Increase
Total Abundance	Decrease

Water and sediment data were analyzed relative to land use and localized entities, such as coal mines, highway runoff, the former WWTP, and headwater lakes, wetlands, and other drainages.

Riparian habitat quality was scored using a modified version of EPA's Rapid Bioassessment Protocols (Plafkin et al. 1989). The following habitat parameters were scored as indicated; subscores were summed to produce a total score for each site. Higher scores indicate better habitat quality.

Table 2. Parameters and score ranges for habitat quality.

Parameter	Score Range
Bottom Substrate - Percent Fines	0-20
Instream Cover	0-20
Embeddedness (Riffle)	0-20
Velocity/Depth	0-20
Channel Shape	0-15
Bank Vegetation Protection	0-15
Lower Bank Stability	0-10
Disruptive Pressures within Bankfull	0-10
Width of Least Buffered Side	0-10

Results

Water and Sediment Quality

Water quality data for this study is presented in Table 3. Water quality samples were taken under extremely low flow conditions. Temperatures were relatively warm at all sites; some may be in exceedance of the class AA standard (16.0 C) if the elevated temperatures are "due to human activities" (WAC 173-201-070). Low dissolved oxygen concentrations observed at Stations 1, 3A, and 5 violated class AA standards, and presented some cause for concern. Ammonia nitrogen appeared to be a problem at Station 3A, a reach consisting of a long, stagnant, backwatered pool. Phosphorus concentrations were relatively high, peaking at the two most downstream stations 1 and 2; this observation was consistent with earlier studies. All other water quality values reported were within acceptable ranges.

Table 3. Water quality data. Blanks indicate values less than reporting detection limit.

	TEMP C	DO mg/L	COND µS	pH
LSIN1	15.8	3.5	378	6.9
LSIN2	14.8	8.0	325	7.5
LSIN3A	16.8	3.2	130	6.9
LSIN5	20	5.4	50	6.8
LSIN8	18.2	10.7	550	8.0
LSIN9A	15.5	12.1	90	7.5
LSIN9B	17.1	10.8	102	7.1

	Hardness mg/L	NH3N µg/L	BOD mg/L	NO3 +NO2 µg/L	SRP µg/L	TP µg/L	TSS mg/L	TURB NTU	FC CFU/ 100ml
LSIN1	85.6	30	2		53	76.5	1.6	1.9	69
LSIN2	88.3	27		133	60.9	10.1	3.2	2.8	62
LSIN3A	61.5	101	2		15.9	72.7	4.4	3.9	60
LSIN5	21.6	26	3			59.9	2.1	2.3	56
LSIN8	130	37		427	7.3	23.1	1.8	1.8	80
LSIN9A	45.1	27				12.9	1.6	1.1	14
LSIN9B	45.5	27		746		18.9	4.1	1.5	17

Samples were also analyzed for copper, lead, and zinc. All values were below method detection limits.

Sediment quality data is presented in Table 4. Four metals exceeded various criteria and guidelines at all of the Rock Creek sites except Station 5, a tributary in one of the least impacted locations in the sub-basin. No exceedances for metals were observed at either of the Ravensdale Creek stations. Relatively high total phosphorus values were observed at Station 2 (downstream of former WWTP), Station 3A (highly depositional pool downstream of agricultural areas), and Station 8 (downstream of residential development). Total petroleum hydrocarbon (TPH) values were relatively high at Stations 2, 7, and 8; these three stations were the most proximate to heavily used road crossings.

Currently, there are no freshwater sediment standards for the state of Washington. The Washington State Department of Ecology (WSDOE) is developing biologically-based criteria for evaluating contaminated freshwater sediments. Sediment data collected as part of this study were compared to either: 1) threshold effect levels for *Interim Sediment Quality Assessment Values* Environment Canada 1994); or 2) lowest effect level from *Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario* (Ontario Ministry of Environment and Energy, Persaud et al. 1993). WSDOE references both of these publications in its Summary of Guidelines for Contaminated Freshwater Sediments, Publication Number 95-308 (1995).

Table 4. Sediment quality data. Blanks spaces in table indicate values less than freshwater sediment criteria or guidelines. All values mg/kg dry weight.

	TP	TPH	Arsenic	Cadmium	Copper	Manganese
LSIN1	466	6.5		0.96	17.6	
LSIN2	674	124		1.06	18.7	498
LSIN3A	507	44				1037
LSIN5	420	27				
LSIN7	287	202	6.83	0.73		534
LSIN8	640	80	7.61			1231
LSIN9A	247	5				
LSIN9B	249	24				

Samples also analyzed for chromium, iron, lead, magnesium, and zinc (no exceedances of criteria or guidelines).

No apparent patterns were observed when water and sediment parameters were plotted versus watershed land use parameters such as sub-basin impervious area. Most of the variability in water and sediment chemistry seemed to be explained by qualitative parameters such as road crossings, sampling reach morphology, and impacts close to the sites.

Habitat Quality

Habitat scores are presented in Table 5. All sites, including the two sites on Ravensdale Creek, were located in the vicinity of roads or footpaths. Some human disturbance was therefore directly attributable to this intrusion, but was assumed to be approximately constant between sites unless noted in the Table.

Table 5. Habitat evaluations.

SITE	PROBLEMS	SCORE
1	only sampling site available in pool at outflow from wetland; accumulations of fine sediment; lack of cover	40
2	accumulations of fine sediment; dark oily film on substrate; poor water quality; disturbance on banks and in riparian zone	61
3	accumulations of fine sediment; reach comprised of long stagnant pool; poor water quality; disturbance on banks	37
5	low flow	96
7	extremely low flow; accumulations of fine sediment; extremely disturbed channel and riparian zone; poor water quality; lack of cover	40
8	accumulations of fine sediment; disturbance in riparian zone; poor water quality; direct highway runoff	40
9a	minor disturbance in riparian zone	105
9b	minor disturbance in riparian zone	100

Lake Benthos

The lake benthic communities were highly dominated by five taxonomic groups (Figure 3). Oligochaete worm taxa comprised more than 50 percent of the samples at Stations 1, A, and C. Nematode worms comprised more than 50 percent of Station B's sample; no apparent explanation could be determined for this difference. The *Einfeldia* and *Chironomus* genera belong to tribe Chironomini of family Chironomidae, and are indicated to commonly inhabit littoral areas (Merritt and Cummins 1984). The presence of these genera in deep limnetic sediments may indicate the need for species-level identification of Chironomid larvae to obtain more specific and useful information.

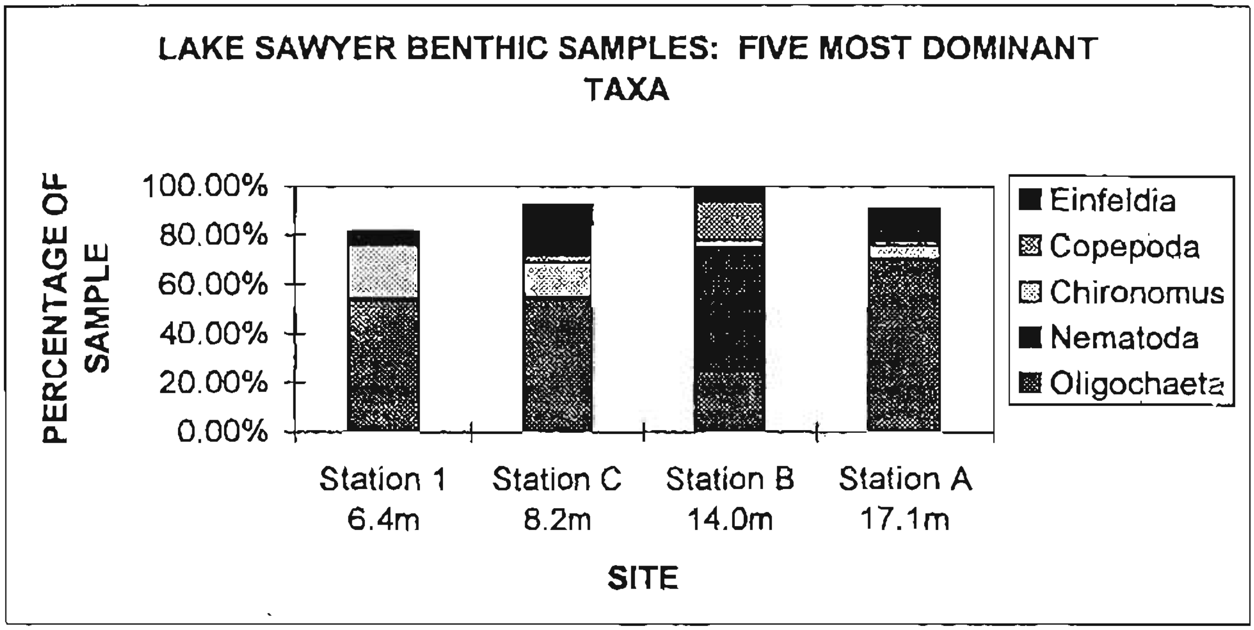


Figure 3. Five most dominant taxa groups in Lake Sawyer benthic samples.

The most striking patterns in the lake samples were for areal density of organisms versus sample depth. Lake Sawyer experiences strong thermal stratification generally between the months of April and November; the thermocline depth ranges between 4.0 m and 7.0 m Stations 1 and C are near that range; Stations B and D are deep in the hypolimnion. The mean density of organisms was notably higher in samples taken at Stations 1 and C (6.4 m and 8.2 m depth) than in samples from deep Stations B and D (14.0 m and 17.1 m) (Figure 4).

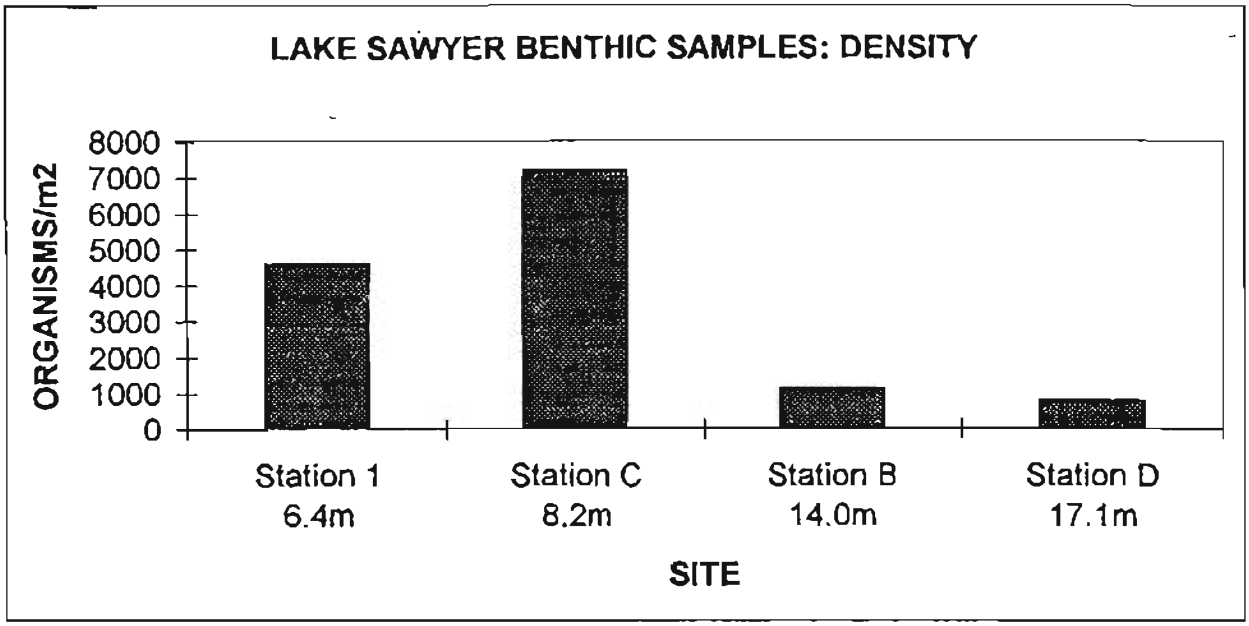


Figure 4. Mean areal density of benthic organisms for Lake Sawyer Benthic Samples.

<u>Stream Benthos</u>

As predicted, biotic index scores revealed differences between the Ravensdale Creek and Rock Creek systems (Figure 5). Mean scores for both Ravensdale sampling sites were higher than all Rock Creek sites. No replicates were obtained at sites 1, 3, and 7; therefore, no statistical analysis was performed on the index scores.

Taxa richness strongly influenced the B-IBI scores. Figure 6 demonstrates the higher overall richness of taxa belonging to orders ephemeroptera (mayflies), plecoptera (stoneflies), and trichoptera (caddisflies) at the two Ravensdale sites. No taxa belonging to these orders were observed at site 3A; this indicates an unusually high level of disturbance.

The particularly sensitive stonefly genus *Pteronarcys* was observed at both of the Ravensdale sites, and none of the Rock Creek sites. This is an encouraging result, and is supporting evidence that high quality habitat and watershed resources in this sub-basin should be protected from the degradation experienced by Rock Creek.

The numbers of stonefly species observed at Rock Creek sites 2, 7, and 8 were comparable to the numbers observed at the Ravensdale sites 9A and 9B. This result was somewhat surprising. Stonefly taxa are considered to be the most sensitive of these three groups, followed by mayflies and then caddisflies. It would normally be expected that the two high quality sites would have a higher proportion of stonefly species. This result demonstrates the value of a multimetric biotic index: the overall pattern reveals differences between sites even when unexpected results are observed for specific properties of the invertebrate community.

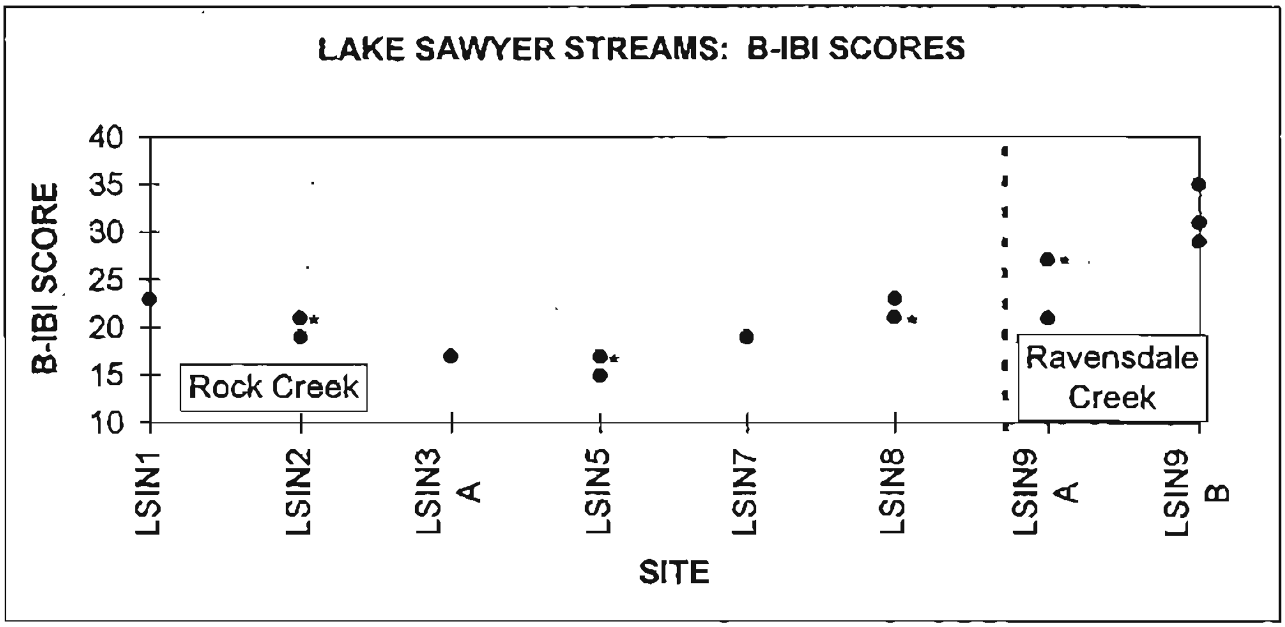


Figure 5. Scatter plot of replicate Benthic Index of Biotic Integrity (B-IBI) scores for Rock Creek and Ravensdale Creek sampling sites. Only one sample was taken at sites 1, 3A, and 7; three replicates were taken at sites 2, 5, 8, 9A, and 9B (replicate scores overlap on this plot). "*" indicates overlapping data points.

B-IBI scores did not respond to impervious area as predicted (Figure 7). It is surmised that impervious area values in these sub-basins are too low to make this correlation; the highest impervious area value was estimated at just above 2 percent. Impervious area may not be a good indicator of urbanization in this case because the intense land use activities in these basins may not substantially contribute to impervious area: coal mining and processing, logging and forest management, heavy truck and equipment traffic on highways and unimproved roads, agriculture, stream channelization, and the failed wastewater treatment facility.

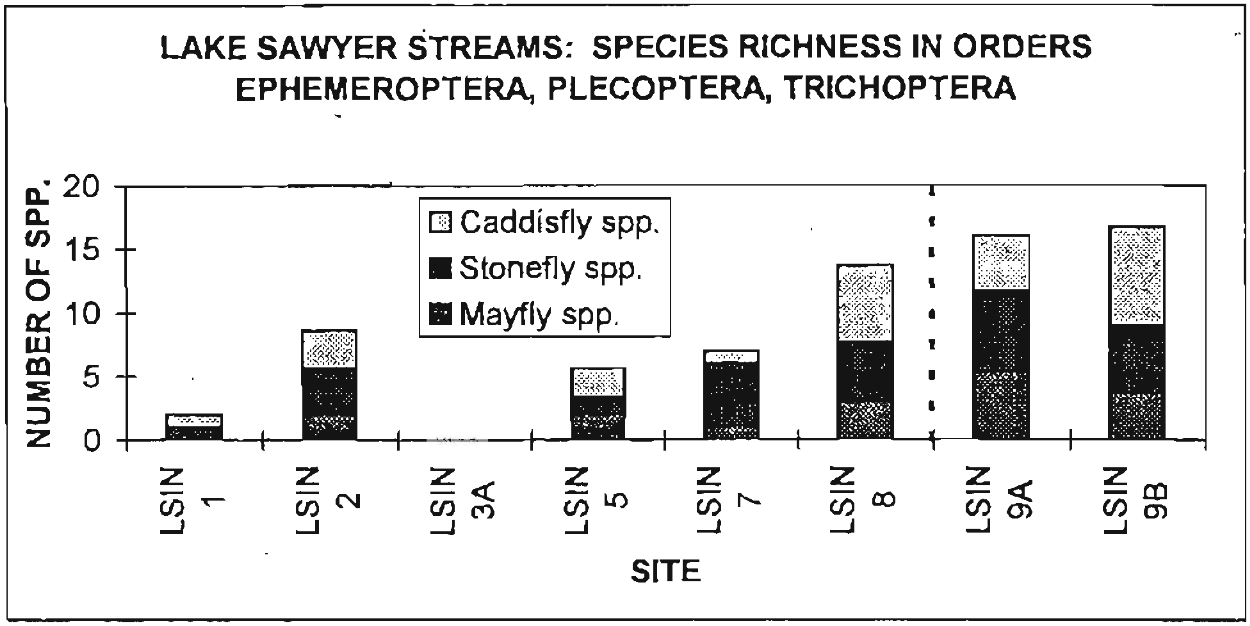


Figure 6. Mean species richness of mayfly, stonefly, and caddisfly orders for Rock Creek and Ravensdale Creek sampling sites.

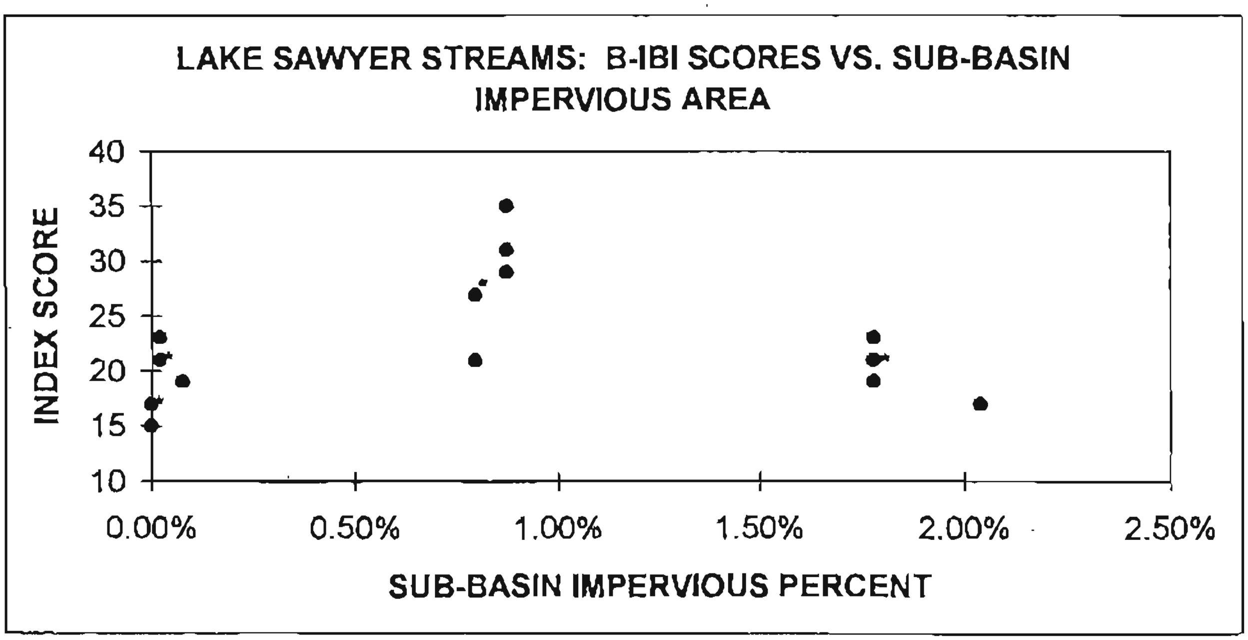


Figure 7. Scatter plot of replicate B-IBI scores versus percent impervious area in sub-basin. "*" indicates overlapping data points.

Localized habitat degradation also exerts an influence on biotic communities in these sub-basins. As shown in Figure 8, B-IBI scores appear to increase with increasing habitat score. This is an important result, demonstrating that successful management of aquatic systems must take a holistic approach, considering both the watershed scale and localized habitat conditions.

Site 5, which had relatively high quality habitat (habitat score 96) and little disturbance in the sub-basin, had a surprisingly low IBI score. This site is approximately 1/3 mile downstream of Black Diamond Lake, a relatively large, very productive, shallow pond; flow at the site was also extremely low when samples were taken. The site's proximity to the lake, combined with low flow, apparently resulted in poor water quality; dissolved oxygen was 5.4 mg/L, and water temperature 20.0 degrees C on the day prior to benthos sampling (Table 3). These conditions are surmised to have impacted the invertebrate community, resulting in a lower B-IBI score.

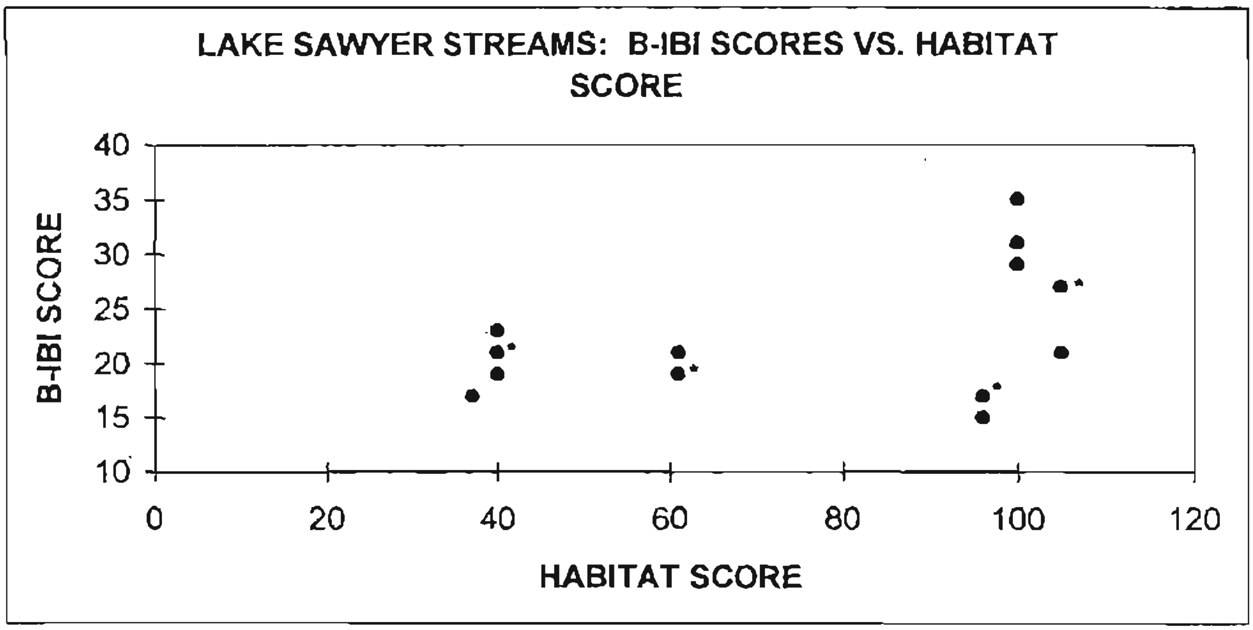


Figure 8. Scatter plot of replicate B-IBI scores versus habitat score. "*" indicates overlapping data points.

The B-IBI scores for Rock and Ravensdale Creeks were composited and compared to scores for samples taken in 1994 in the Soos Creek basin, of which the Lake Sawyer system is a part (Figure 9). Ravensdale Creek's scores are near the expected position in the plot, relative to the amount of impervious area in the basin. Rock Creek's scores are alarmingly low for the impervious area value of its sub-basin; this seems to indicate disproportionate localized disturbances in the watershed or the stream corridor.

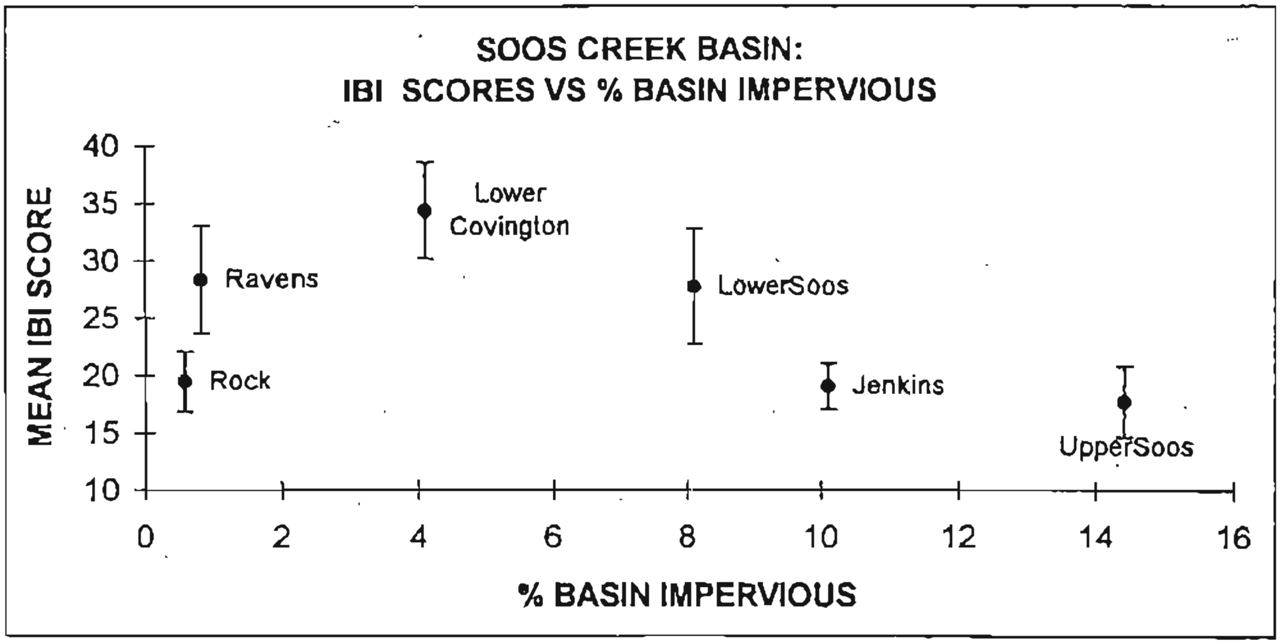


Figure 9. B-IBI scores versus percent impervious area in sub-basin for Rock Creek and Ravensdale Creek composite scores relative to other tributaries to Soos Creek.

B-IBI scores showed some response to water and sediment quality, most notably water column dissolved oxygen, and sediment TP and TPH (Figures 10, 11, and 12). It is surmised that phosphorus does not directly impact the invertebrate community. Rather, TP may act as a surrogate for other parameters which are also degraded by impacts in the watershed, in turn impacting stream biota.

Graphical examination of IBI scores versus other water and sediment quality parameters (Tables 3 and 4) did not reveal any apparent relationships.

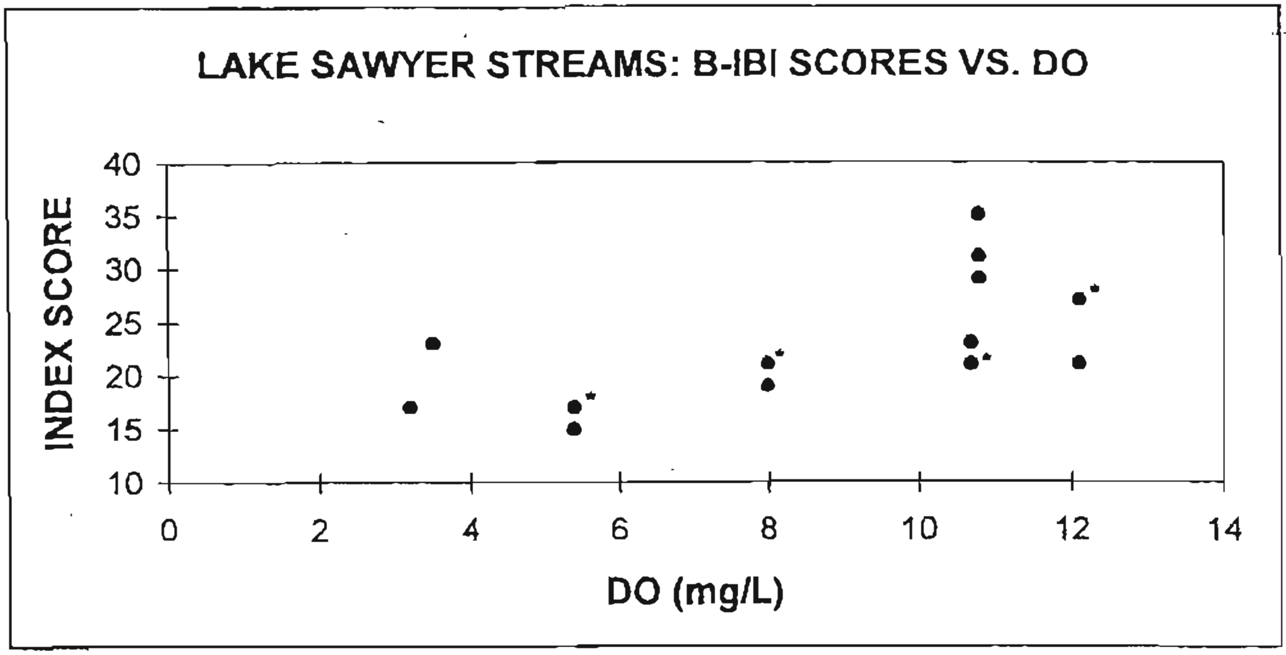


Figure 10. Scatter plot of replicate B-IBI scores versus water column dissolved oxygen concentration. "*" indicates overlapping data points.

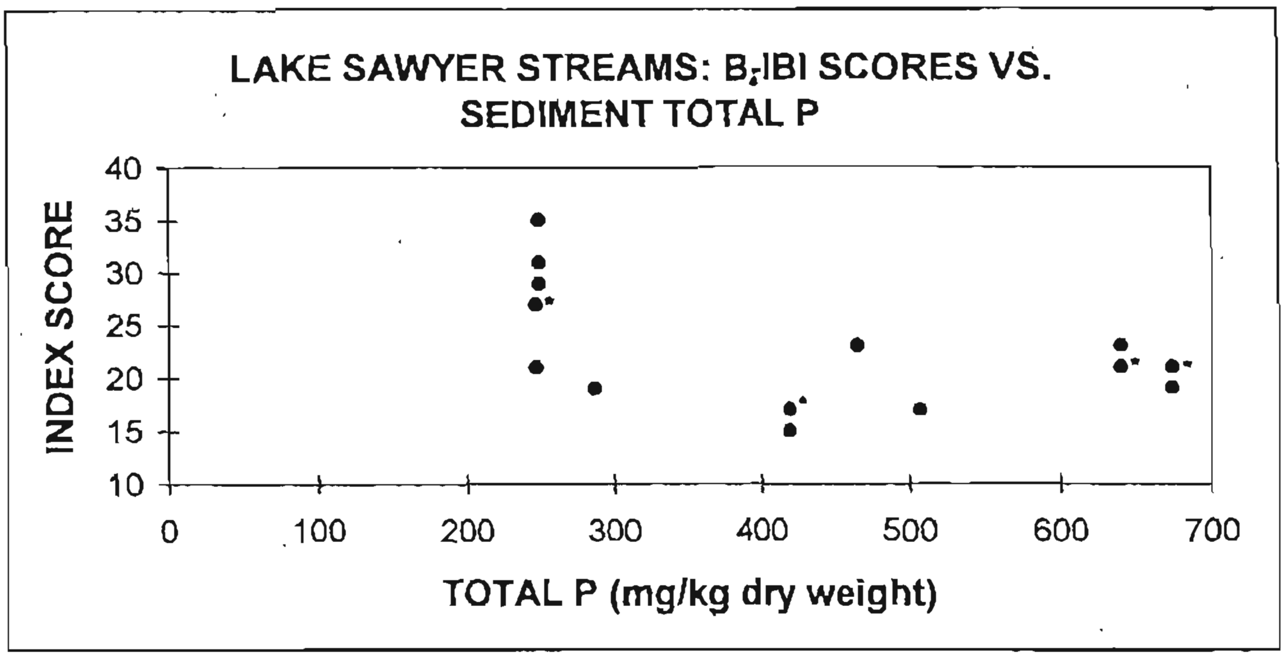


Figure 11. Scatter plot of replicate B-IBI scores versus sediment total phosphorus concentration. "*" indicates overlapping data points.

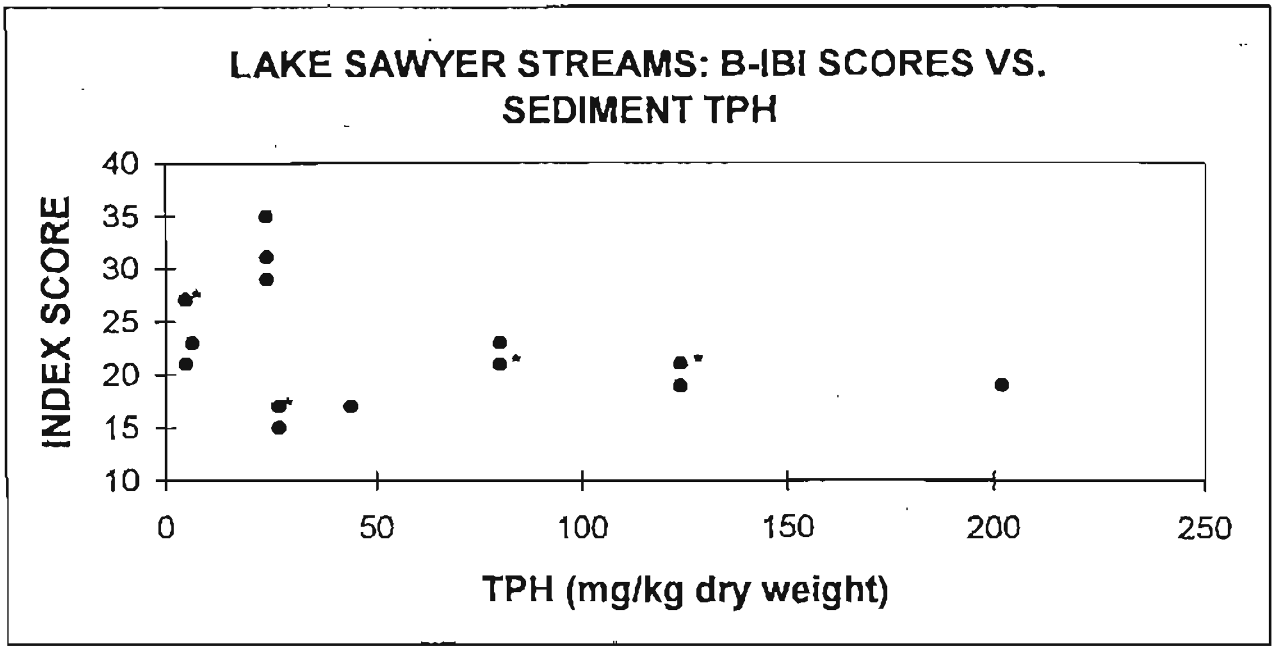


Figure 12. Scatter plot of replicate B-IBI scores versus sediment total petroleum hydrocarbons concentration. "*" indicates overlapping data points.

Conclusions and Recommendations

Although no statistical analyses were performed on the data in this case study, graphical observations suggest the following conclusions to the study hypotheses:

- Biological health, as measured by a biological index, did not show a response to increased impervious area in the sub-basins. It is surmised that the range of impervious area values was too low to produce a direct effect. Localized riparian conditions appeared to have a stronger effect on stream biota.

- Stream biota responded to degraded water and sediment quality. B-IBI scores decreased with decreased dissolved oxygen in the water column and increased phosphorus and petroleum hydrocarbons in the sediment.

- Stream biota responded to riparian habitat conditions, quantified with a modified version of an EPA scoring protocol. B-IBI scores increased with increased habitat scores.

- Biological communities revealed differences between the degraded Rock Creek sub-basin and the relatively pristine Ravensdale Creek sub-basin. Mean B-IBI scores for both Ravensdale sampling sites were higher than all Rock Creek sites.

- Trends in stream biota could not be linked to trends in the Lake Sawyer biota with only one season's data. The Lake will respond to the influences of both Rock and Ravensdale Creeks; the mouths of both of these streams are relatively close to each other. Therefore, no spatial comparisons of the lake samples could be made relative to proximity to the respective stream inlets.

This case study identifies some unique management challenges for Lake Sawyer and its watershed. While the Rock Creek and Lake Sawyer system slowly recover from the effects of the failed WWTP, the basin continues to develop, creating new sources of nonpoint pollution, including nutrients, and a less stable hydrologic system. The Ravensdale Creek system, among the highest quality aquatic habitat in western King County, also faces development in the near future. This study, past studies of Lake Sawyer, and numerous results reported in literature demonstrate that effective watershed management must take a holistic approach, protecting riparian corridors and lake habitats, as well as limiting changes to surrounding sensitive landscapes.

This case study should be used as a baseline for continued biological monitoring of the Lake Sawyer system. Stream biota, sampled in conjunction with conventional parameters, will help to determine whether the Rock Creek system is improving or degrading. As development occurs in the Ravensdale Creek system, stream biota may serve an early warning of changes in overall stream health and integrity. Biological monitoring, in conjunction with water and sediment quality, hydrology, and land use monitoring, will help to identify areas requiring extra protection (such as the Ravensdale Creek system and its riparian corridor), watershed scale impacts (such as the developing headwaters of Rock Creek), localized impacts (such as the failed wastewater treatment facility).

REFERENCES

Environment Canada. 1994. *Interim Sediment Quality Assessment Values (Draft).* Environment Canada, Soil and Sediment Quality Section, Guidelines Division, Ottawa.

Fore, L.S., J.R. Karr, and R.W. Wisseman. 1996. Assessing Invertebrate Responses to Human Activities: Evaluating Alternative Approaches. *Journal of the North American Benthological Society.* 15: 212-231.

Merritt, R.W., and K.W. Cummins (editors). 1984. *An Introduction to the Aquatic Insects of North America.* Second edition. Kendall/Hunt Publishing, Dubuque, Iowa.

Persuad D., R. Jaagumagi, and A. Hayton. 1993. *Guidelines for the Protection and Management of Aquatic Sediment in Ontario.* Ontario Ministry of Environment and Education, Ottawa.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish.* Assessment and Water Protection Division, United States Environmental Protection Agency. EPA/440/4-89-001. EPA, Washington, D.C.

State of Washington. 1990. *Washington Administrative Code*, Chapter 173-201A: Water Quality Standards for Surface Waters of the State of Washington. Statute Law Committee, Olympia.

Washington State Department of Ecology. 1992. *Summary of Criteria and Guidelines for Contaminated Freshwater Sediment.* Department of Ecology, Olympia.

APPENDIX H
Timing of Juvenile Coho Salmon Emigration from the Lake Sawyer Drainage Basin

TIMING OF JUVENILE COHO SALMON EMIGRATION FROM THE LAKE SAWYER DRAINAGE BASIN

Report Prepared For

KING COUNTY SURFACE WATER MANAGEMENT DIVISION

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June 25, 1996

ADDENDUM

At the time of this study, the bottom of the notched weir at the upper end of the fishway measured approximately 1.8 inches below the crest of the concrete spillway. After completion of this report, it was discovered that the normal position of the notch is 6 inches below the top of the dam. The configuration of the notch at the time of this study was temporarily set at 1.8 inches below the spillway during repairs to the dam on November 18, 1995, following vandalism to the fishway on November 15, 1995. The notch will be readjusted to its normal position of 6 inches below the spillway during Summer, 1996.

Adjustment of the notch will affect two items of note: 1) it will lengthen the number of additional days of outflow (and thus, potentially, migration) from the fishway after flows over the spillway cease, and 2) it will increase the potential volume of lakewater lost from the notch. The significance of these two changes is unknown at this time.

A survey of the notch and an estimation of flow from it will take place in Autumn, 1996, hopefully when water is flowing from the notch only. An additional note will be added to this report at that time, weighing the significance of the effect of the changed notch height on fish migration relative to the potential volume of water lost through the notch.

KAL
June 26, 1996

TIMING OF JUVENILE COHO SALMON EMIGRATION FROM THE LAKE SAWYER DRAINAGE BASIN

In the spring of 1996, the King County Surface Water Division (SWM) monitored coho salmon outmigration from the outlet of Lake Sawyer. The goal of this study was to determine whether cessation of flow from the outlet, which normally occurs shortly after the fishway is blocked on 15 April, could interfere with smolt or juvenile outmigration from the system.

THE STUDY AREA

Lake Sawyer (279 surface acres; elevation 512 ft) is located east of the City of Kent in an area of King County that is urbanizing rapidly. Lake Sawyer itself is surrounded by private property, about three-quarters of which is already comprised of lake front homes, but a maintained public boat ramp provides access for boaters and recreational anglers. The lake is fed by two inlet streams: **Ravensdale Creek** (also known as Upper Covington Creek, Beaver Creek, and for awhile into the mid-1950s, Frenchman's Creek) and **Rock Creek**. Sub-surface exchange of water with local aquifers also occurs; net annual groundwater flow occurs as discharge from the lake to the aquifers. Seepage from the lake is an especially important component of the water balance in summer and fall, when the level of Lake Sawyer declines markedly. A water balance for Lake Sawyer has been published by the Washington Department of Ecology (Carroll and Pelletier 1991), and an update by King County SWM is due out in summer 1996 as part of a major limnological study of the lake.

Lake Sawyer supports a diverse fish fauna. Of perhaps greatest importance is a late-winter run of coho salmon which migrates through Lake Sawyer, peak migration usually after Christmas,[1] bound for spawning areas in upper Ravensdale Creek. Some coho spawning may also occur in Rock Creek, although Ravensdale Creek appears clearly to be the most important spawning tributary in the drainage at present (Trotter 1995). The Washington Department of Fish and Wildlife (WDFW) also releases hatchery-produced juvenile coho salmon into Rock Creek. Native resident fishes of Lake Sawyer include coastal cutthroat trout, northern squawfish, sculpins, and three-spined stickleback. Introduced

[1] Winter 1995-1996 and spring 1996 were marked by unusually high water, with the major events being severe floods that occurred in November, 1995 and January, 1996 (the media called the latter event "The Floods of 96"). Probably because of the unusually high water, adult coho salmon began passing through the Lake Sawyer fishway in late November, 1995, about Thanksgiving week, about a full month earlier than had been observed previously. As in years past, however, spawners were observed to continue migrating and spawning in Ravensdale Creek until late January, 1996.

warmwater gamefishes such as largemouth and smallmouth bass, crappie, bluegill and pumpkinseed sunfish, yellow perch, and bullheads have also established thriving populations. Kokanee were also introduced some years ago and persisted for awhile, but are rare now. The most recent kokanee reported in the system was a single carcass found just upstream from the lake in Ravensdale Creek in September, 1992 by a stream monitoring team from the Alpine Flyfishers Club (Fishback 1994). Hatchery-reared rainbow trout are released in Lake Sawyer from time to time by WDFW for harvest by recreational anglers. The lake is open for angling on a year-around basis.

Covington Creek is the surface outlet of Lake Sawyer. It flows into Soos Creek and thence to the Green River, which discharges into Elliott Bay. Lake Sawyer has a low dam and fishway located at the Covington Creek outlet. Adult salmon must pass through this fishway or over the dam (indeed, they have been observed leaping the dam itself) in order to reach spawning sites above the lake. Likewise, any juvenile salmon or smolts exiting the system must also pass the dam and fishway on their migration to downstream rearing areas or on their journey to the sea. The present dam and fishway was built in 1954 to restore Lake Sawyer to its original level after a land developer, seeking to expose additional land for housing development, had breached a natural barrier at the Covington Creek outlet and was sued by local property owners. This dam controls the maximum height of the lake during the winter high flow period, but not during the summer and fall low flow period, due to a high rate of percolation of water from Lake Sawyer into local aquifers through the porous glacial soils. This high percolation rate severely reduces storage in the lake during the low flow period (Carroll and Pelletier 1991). As a result, sometime in early- to mid-summer of each year the lake level drops, first below the spillway of the dam and then below the notch in the fishway, so that flow over the dam and through the fishway ceases. Some leakage does occur at the dam, maintaining a minimal flow in Covington Creek, but during this period—which lasts until the rather abrupt onset of high flows in late December—the dam and fishway is a total barrier to fish passage.

A notched weir at the upstream end of the fishway is positioned approximately 1.8 inches below the top of the concrete spillway. Under normal conditions, this weir would allow flow to continue through the fishway up to 30 days after flow over the top of the concrete spillway ceases each spring (flow over the spillway normally ceases between mid-May and mid-June). By agreement with SWM and WDFW, the Lake Sawyer Property Owners' Association blocks passage in the fishway on 15 April each year, in an attempt to maintain the lake level longer into the summer. Analysis of lake level records and hydrological modeling indicate that placement of the "summer board" in the fishway has no appreciable net effect on summer water levels. In essence, after flow over the concrete spillway ceases, the small amount of flow from the fishway weir is negligiblee compared to groundwater discharge and evaporation. Unfortunately, the "summer board" cuts off the only exit from the lake after flow over the spillway ceases. This effectively reduces the potential outmigration period by 30 days, at a time when fish would likely still be leaving the lake. The "summer board" must be removed on 15 October. However, it is only later, after the heavy rains of late fall and early winter have saturated the soils and recharged local aquifers (about Christmas-time in a normal water year) that the lake level comes up enough to again provide flow through the fishway and over the dam.

Although increasing withdrawal of water from local aquifers for municipal use may have exacerbated the water storage problem of Lake Sawyer as development of the surrounding area has increased in recent years, the high percolation rate and resultant low-flow storage deficit of Lake Sawyer appears to be a natural phenomenon which surely pre-dates the present dam and fishway. If this belief is correct, then the late-running coho salmon which spawn in Ravensdale Creek have adapted to this unique flow regime, and migrate in and out of the system only when flows ensure passage. Upstream passage of adult salmon does not appear to be a problem, but the early blockage of the fishway on 15 April could inadvertently trap downstream-migrating juveniles or smolts that are counting on finding water flowing through the fishway for several more weeks each spring.

METHODS AND MATERIALS

Originally, we had hoped to monitor fish emigration from the system by installing a fyke net and live box in Covington Creek just below the Lake Sawyer dam and fishway, where the outlet exits from culverts under Lake Sawyer Road SE (224th Ave. SE). The live box was to be monitored daily beginning 1 February and ending about 1 June, earlier or later depending on when flow over the dam and through the fishway actually ceased. This approach was abandoned when a promise of personnel to monitor the live box had to be withdrawn by an erstwhile project participant due to other priorities.

As an alternative approach, we used a Smith–Root SR-1600 electronic fish counter equipped with two 2-inch i.d. counting tubes, which we mounted inside the fishway. The counter was installed on 19 March, 1996, and was removed on 16 May, 1996 when the project terminated. We thank the Lake Sawyer Property Owners Association for leaving the fishway open for the extra month to allow us to complete our work.

The SR-1600 fish counter works on the principle of a balanced resistance bridge, using water within the tubes as two elements of a four-element bridge. Passage through one of the tubes of a fish or any other object large enough relative to the inside diameter of the tube to cause a change in the conductance within that tube, is registered by the counter as a "count." The unit registers counts for each tube separately, but does so simultaneously. Each time we checked the counter, we recorded the total counts accumulated since the last visit then set the counter back to zero for the next interval. We generally monitored the counter on Tuesday and Friday of each week, but we always checked the counter the next day, after an overnight interval of about 16 hours, if we had installed a bag net or live box to sample migrating fish.

Because of the unusually high water this spring, which overspilled the dam throughout our study and was sufficiently high in depth and volume to enable fish to pass directly over the dam, and also because the SR-1600 counter is insensitive to what kind of objects pass through the counting tubes (as explained, it counts anything large enough to change the conductance in a tube, whether fish or not), we never expected to get an accurate count of the total number of fish exiting the system using this approach. Also, we had tested the ability of the counter to detect juvenile coho salmon of different sizes by passing groups of pre-smolts (median fork length 131 mm as of 4 April) and young-of-the-year (y-o-y) or fingerling-size fish (median fork length 38 mm as of 4 April) through the tubes. Although the counter successfully counted 100 percent of the pre-smolt fish, it counted only a fraction of the y-o-y fish[2] and this fraction varied. Therefore, we expected only to be able to determine <u>when</u> fish were migrating, not how many were migrating, and even there we had to assume that the counter would register significantly higher counts when fish were migrating than when they were not. We verified the presence or absence of migrating fish by installing a bag net or live box at frequent intervals to actually capture and inspect these fish.

For capturing fish, we at first used a fine-mesh cylindrical bag net approximately 10 inches in diameter and about 30 inches long. This net was sewn so that it could be installed and drawn tight over the exit of one of the counting tubes (for consistency, we always attached the net to the same tube). The net then billowed open in the water below the tube to allow anything passing through the tube to be retained in the net. This worked satisfactorily at first, but as numbers of migrating fish increased, we began experiencing almost total mortality of the captured fish. At that point a rectangular box-net with a zippered top opening, intended for use as a live box, was made available to us. This box-net measured 2 feet x 2 feet x 4 feet and was fixed to an external frame made of PVC pipe. This was attached to the fishway board immediately upstream of the counting tubes with the zippered top open to accept all the water spilling through the notch in the fishway board and most of the water overspilling

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[2] These test fish were obtained from the WDFW Green River Hatchery at Soos Creek on April 4, 1996. The counter successfully registered 100 percent of the pre-smolt fish passed through the tubes in two tests, but only 72 and 34 percent in two tests of the young-of-the-year fish.

the board as well. This proved highly satisfactory for capturing fish and no further mortalities occurred.

All fish captured were counted, identified by species, and measured for fork length to the nearest millimeter (when coho numbers were large, only a subsample, minimum of 12 fish, was measured for fork length). All migrating coho salmon were released into Covington Creek below the dam.

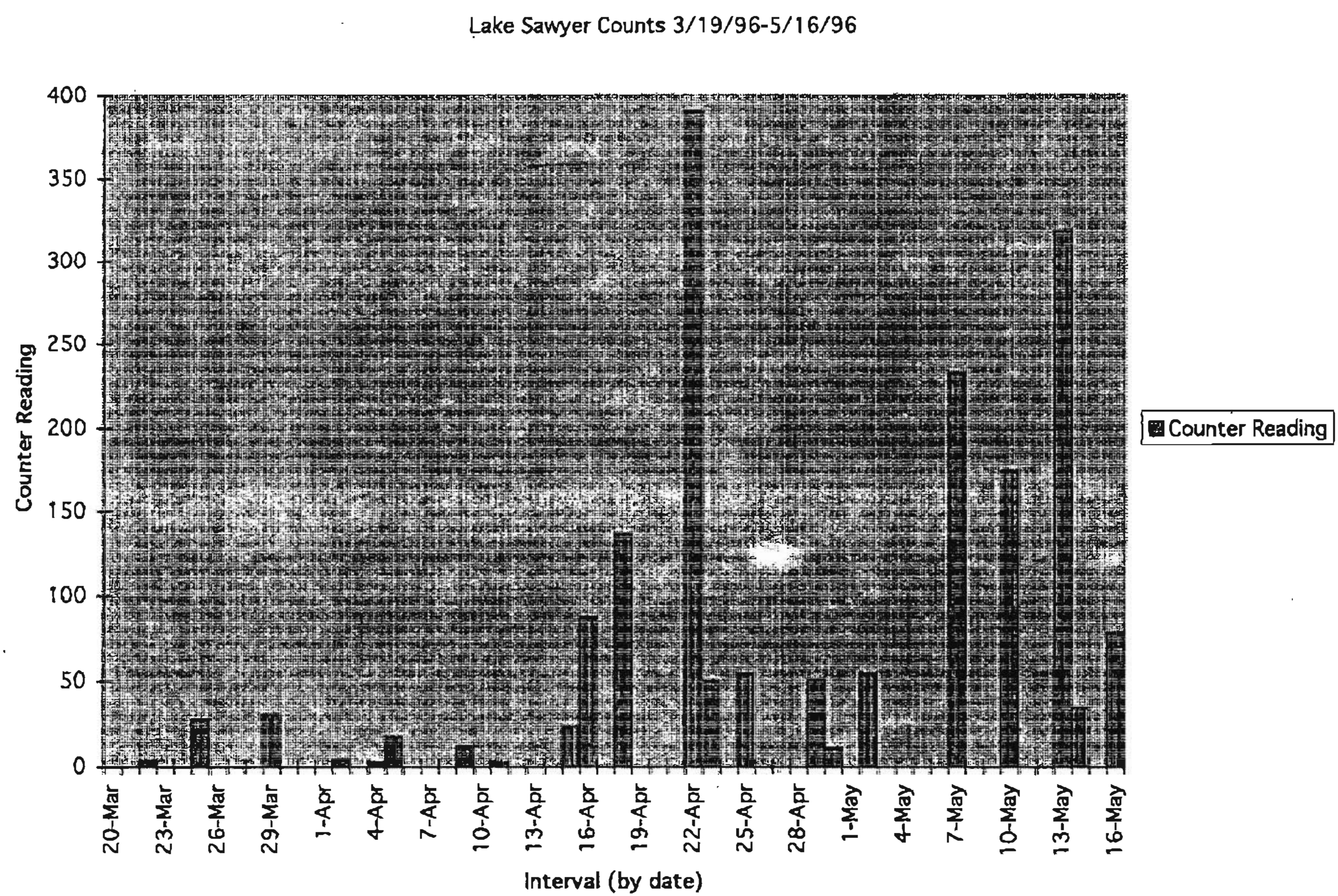
RESULTS

The overall results of the electronic counter operation are displayed in the accompanying bar chart and are tabulated in Appendix I. Each bar on the chart represents the total accumulated count since the previous counter reading. From our bag net monitoring, we ascertained that fish movement out of the system did not commence until 16 April, so readings prior to that date are background "noise" due to clumps of grass, reeds, and other debris passing through the counting tubes.

On 16 April we found three y-o-y coho in an overnight set of the bag net, marking the beginning of juvenile outmigration from the system. From that date on, all of our bag net and live box sets captured juvenile salmon. Both the counter readings and our bag net and live box captures suggested that this outmigration occurred in two peaks, the first in the five-day period 18 April through 22 April and the second in the seven-day period 7 May through 13 May. All of these fish were y-o-y, and outmigration of y-o-y fish was still occurring, albeit in decreasing numbers, when we terminated the study on 16 May.

No smolts or smolt-size coho were ever observed.

As mentioned, all of the juvenile coho salmon that we observed in this study were y-o-y. Fork lengths of these fish, tabulated below, showed a slow but steady increase as residence time in the system increased. These values are similar to fork lengths and rates of growth reported by Mason (1974) for y-o-y coho rearing for the same length of time in Great Central Lake, B.C.


Lake Sawyer Counts 3/19/96-5/16/96
Counter Reading
400
350
300
250
200
150
100
50
0
20-Mar
23-Mar
26-Mar
29-Mar
1-Apr
4-Apr
7-Apr
10-Apr
13-Apr
16-Apr
19-Apr
22-Apr
25-Apr
28-Apr
1-May
4-May
7-May
10-May
13-May
16-May
Interval (by date)
Counter Reading

FORK LENGTHS OF Y-O-Y COHO
CAPTURED IN BAG NET AND LIVE BOX SETS

Date	No. captured	Median FL, mm	FL Range, mm
4/16/96	3	46	45–47
4/18/96	44	46	44–51
4/23/96	5	49	48–50
5/07/96	129	58	49–67
5/14/96	21	64	49–74

Other fishes captured in bag net and live box sets included yellow perch (three total, released back into the lake), three-spined stickleback (two total, released back into the lake), sculpins (six total, released back into the lake), and coastal cutthroat trout (one only, 134 mm FL, released below the dam).

DISCUSSION

As indicated above in the Study Area description, a late-winter run of coho salmon passes through Lake Sawyer, peak migration usually after Christmas, bound for spawning areas in upper Ravensdale Creek. Some coho spawning may also occur in Rock Creek, although Ravensdale Creek appears clearly to be the most important spawning tributary in the drainage at present (Trotter 1995). Juvenile coho salmon normally rear in streams for a year, and exit the system as smolts averaging 110-130 mm in FL the following spring (Sandercock 1991).[3] However, that may not be the case in the Lake Sawyer basin. Even though potential rearing habitat does exist in Lake Sawyer's tributary streams, rearing conditions especially in the summer may not be suitable. The Alpine Flyfishers stream-monitoring team has reported that emergent coho vanished completely from their monitoring sites in Ravensdale Creek in late March to early April in three successive seasons (Fishback 1994), thus raising a question as to whether juvenile coho actually remain in the system for rearing.

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[3] The median FL of the hatchery pre-smolts used in our tests of the fish counter was 131 mm, which is larger than the sizes given for naturally spawned and reared 1-year old smolts in Sandercock (1991).

Our results suggest that y-o-y coho may not rear in Lake Sawyer tributaries or in the lake itself, but may exit the system within weeks after emergence to seek more satisfactory rearing habitat elsewhere—in Covington Creek, in Soos Creek, or perhaps even in the Green River.

An alternative explanation is that the fish do rear in the system, at least to pre-smolt size, but exit much earlier than normal—in the late winter or very early spring, say—so that they had already migrated before our counting project started. Later migration of smolts, after our counts had terminated, is ruled out because the fishway was closed off following our study, an action that normally occurs even earlier, on 15 April.

We cannot really reject this alternative explanation, but we do think it is unlikely for at least two reasons. First, it is a marked departure from the normal timing of smolt outmigration from Puget Sound streams, which usually occurs between 15 April and 1 June with the peak in May (Salo and Bayliff 1958). Second, even though some exodus of y-o-y coho is common and occurs throughout the summer in most streams as excess y-o-y fish are forced to migrate downstream in a density-dependent adjustment to the carrying capacity of summer rearing habitat (Chapman 1962), the outmigration of y-o-y fish that we observed appeared to be unusually large—much larger than could be accounted for by a density-dependent adjustment to carrying capacity. Indeed, the number of fish that we counted suggests an outmigration large enough to account for the entire juvenile production of the upper basin, thus precluding any smolt migration.

We base this assertion on a "back of the envelope" estimate of the number of y-o-y coho produced in the upper basin compared with a similar estimate of the total number of fish that might have passed over the dam and fishway during the period we were counting. For the estimate of y-o-y coho produced in the upper basin, we used counts of redds and adult spawners collected in January and February, 1992 by the Alpine Flyfishers stream team[4] and survival estimates to different life-history stages given in Salo and Bayliff (1958) and Sandercock (1991). Our estimate was a potential 35,900 y-o-y coho produced in the upper basin.[5] For the estimate of total y-o-y fish passing the dam and fishway, we took our live box catches and the proportion of water intercepted by the live box and simply projected these values over the entire span of the dam and fishway. We felt this was justified

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[4] Fishback (1994) reported on the overall results of the Alpine Flyfishers stream monitoring project, but did not include this information. We obtained it by consulting the original field notebooks kept by members of the stream team.

[5] This value includes 5410 y-o-y hatchery coho planted in Rock Creek by WDFW on 12 April, 1996. WDFW also stocked 5350 y-o-y hatchery coho into Rock Creek on 17 April, 1995, on the expectation that they would rear to smolt size in Rock Creek and emigrate as smolts this spring (C. Baranski, WDFW, personal communication, 1996).

because the water this spring was unusually high and overspilled the dam throughout our study, enabling fish to pass directly over the dam as well as through the fishway. Our estimate for total y-o-y coho exiting the system was 36,400. Further details of these calculations are given in Appendix II.

This large a number of exiting y-o-y coho—a number that turns out to be well within the ballpark of estimated total y-o-y production of the upper basin—coupled with the fact that we did not see a single coho smolt or smolt-size fish, suggests that neither naturally spawned nor hatchery outplanted y-o-y coho utilize Lake Sawyer tributaries or the lake itself for rearing. The potential for good rearing habitat does exist in Lake Sawyer tributaries. Ravensdale Creek is presently the least degraded of the potential rearing tributaries, and is certainly of greatest importance for the adult coho that presently migrate to the upper basin for spawning (Trotter 1995).

Turning back to the original question, could interruption of flow through the fishway, which normally occurs shortly after the "summer board" is inserted on 15 April, interfere with juvenile coho outmigration from the system? The answer to that question appears to be yes. Had the fishway been blocked on 15 April this year, the greater than usual volume of water spilling over the dam would probably have enabled most of the coho year class to escape from the lake. But this year's high, cool water conditions also seem to have delayed fish life-cycle schedules about a month, meaning that in a normal water year outmigration would probably occur somewhat earlier, in a flow regime with much less water spilling over the dam and more reliance on flow through the fishway. That being so, while a portion of the y-o-y outmigrants might safely exit the lake in a normal year by passing through the fishway prior to 15 April, a substantial number of fish would still be trapped by a closure of the fishway on that date.

MANAGEMENT IMPLICATIONS

Our findings about the timing of juvenile coho outmigration from Lake Sawyer suggest that the fishway should be left open for as long each spring as water continues to flow through the fishway, to ensure that all fish have an opportunity to exit the system. In fact, we have to question whether the "summer board" needs to be placed in the fishway at all. Water balances (Carroll and Pelletier 1991; King county SWM, in prep.) show that it is not the dam, but rather the high rate of percolation into local aquafers that controls the summer level of the lake. Therefore, blocking the fishway serves no useful purpose for the Lake Sawyer property owners and could, indeed, cause harm to the coho run.

We make one additional point regarding release of hatchery fingerlings into Rock Creek. On 12 April, just one week before our first observation of outmigrating fish at the Lake Sawyer fishway, WDFW released 5410 hatchery-produced y-o-y coho into Rock Creek (C. Baranski, WDFW, personal communication, 1996). This was done on the expectation that these fish would rear in Rock Creek for a year, and migrate to sea as smolts next spring. WDFW also stocked 5350 y-o-y hatchery coho into Rock Creek in April of 1995, on the expectation that they would leave the system as smolts this spring. As we have explained, our observations suggest that juvenile rearing is not occurring in the upper basin, but instead the fish abandon that portion of the drainage within weeks after emergence to seek more suitable rearing habitat somewhere further downstream, either in Covington Creek or elsewhere. Therefore, WDFW would accomplish just as much with these hatchery fingerlings, and perhaps more, by releasing them directly into Covington Creek or some other point downstream of Lake Sawyer, and leaving the upper basin to the naturally spawning fish.

ACKNOWLEDGMENTS

We thank the Lake Sawyer Property Owners Association for allowing the fishway to remain open for an additional month this spring to allow us to complete our counting study, and the Alpine Flyfishers of Federal Way, Washington for the use of their stream monitoring data for Ravensdale Creek. We are also grateful to Lake Sawyer residents Joey Perkins for providing boat transportation, and Mike Birtsch for helpful historical comments and observations about fish migration at the fishway. We also thank the heirs of the late Harold Sovie, unofficial custodian of the fishway, for allowing access to the facility across their property.

REFERENCES CITED

Carroll, J. V. and G. J. Pelletier. 1991. Diagnostic study of Lake Sawyer, King County Washington. Olympia, Washington State Department of Ecology, Surface Water Investigations Section.

Chapman, D. W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. Journal of the Fisheries Research Board of Canada 19: 1047-1080.

Fishback, F. 1994. Report on Ravensdale Creek stream monitoring project, 1992-1994. Alpine Flyfishers, Federal Way, WA, Stream Team report to King County Parks Department and Adopt-A-Stream Foundation.

Mason, J. C. 1974. Aspects of the ecology of juvenile coho salmon (*Oncorhynchus kisutch*) in Great Central Lake, B.C. Nanaimo, B.C., Fisheries Research Board of Canada, Technical Report 438.

Salo, E. O. and W. H. Bayliff. 1958. Artificial and natural production of silver salmon (*Oncorhynchus kisutch*) at Minter Creek, Washington. Olympia, Washington Department of Fisheries, Research Bulletin 4.

Sandercock, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 395-445 in C. Groot and L. Margolis, editors. Pacific salmon life histories. Vancouver, UBC Press.

Trotter, P. C. 1995. Stream and fisheries analysis and recommendations for the Ravensdale Lake/Creek and Rock Creek greenspace corridors. Consultant's report to W & H Pacific, Bellevue, WA, for Plum Creek Timber Company and City of Black Diamond. August 7, 1995.

APPENDIX 1

LAKE SAWYER COUNTER READINGS

Date	Counter Reading	Date	Counter Reading
19 Mar	0	18 Apr	137
22 Mar	3	22 Apr	390
25 Mar	27	23 Apr	50
29 Mar	30	25 Apr	54
2 Apr	4	29 Apr	51
4 Apr	2	30 Apr	10
5 Apr	17	2 May	54
9 Apr	11	7 May	232
10 Apr	0	10 May	174
11 Apr	2	13 May	318
15 Apr	23	14 May	34
16 Apr	87	16 May	78

APPENDIX 2

I. Estimate of Total Y-O-Y Coho Passing Dam and Fishway

Total span of dam and fishway = 78 ft.

Assume we captured a column of water equivalent to 4 ft. of this span in our live box, or 4/78 = 5% of the water column passing the dam.

Peak outmigration periods totaled 12 days; the 7 May live box capture of 129 fish was taken as representative of this period. We used a value of 120 fish per day to estimate total outmigrants during peaks:

$$= (120(12)/0.05 = 28,800$$

Non-peak outmigration periods totaled 19 days; the live box capture of 21 fish on 14 May was taken as representative of these periods. We used a value of 20 fish per day to estimate total outmigrants during non-peaks:

$$= (20)(19)/0.05 = 7,600$$

<u>Total y-o-y coho outmigration</u>: <u>36,400</u>

II. Estimate of Y-O-Y Coho Production in the Upper Basin

Based on Alpine Flyfishers data for redds and spawning adults in upper Ravensdale Creek, January and February, 1992. Fecundity and survival values for Washington coho were taken from Sandercock (1991).

Estimated number of spawning females in upper Ravensdale Creek: 70.

Fecundity of 2500 eggs per female is listed as typical forWashington coho.
Then number of eggs deposited in upper Ravensdale Creek: (70)(2500) = 175,000

Survival, eggs to emergence, under average conditions is listed as 27%.
Then number of emergent fry in upper Ravensdale Creek: (0.27)(175,000) = 47,250

Overall survival, eggs to smolts, is listed as about 2% with the highest mortality occurring early and tailing off as the fish grow older. If survival during the first few weeks from emergence to the start of the exodus period may be taken as 50%,

Then total y-o-y fry produced in Ravensdale Creek: (0.50)(47,250) = 23,625

Ravensdale Creek is the more important of the Lake Sawyer tribs for spawning.
Assume for Rock Creek that y-o-y production is only 1/3 that of Ravensdale.
Then total y-o-y fry produced in Rock Creek: (0.33)(23,625) = 7,875

Fingerlings stocked in Rock Creek by WDFW on 12 April, 1996: 5,410

<u>Total y-o-y coho production</u> <u>35,900</u>

APPENDIX I
Contingency In-Lake Measures for Phosphorus Control in Lake Sawyer

IN-LAKE MEASURES FOR PHOSPHORUS CONTROL

Whole-lake Alum Treatment, Hypolimnetic Aeration, and Circulation are in-lake methods used for controlling eutrophication. The following sections provide information about each method of treatment, reliability, longevity of treatment, potential adverse impacts, and mitigation for each of these techniques.

Whole Lake Alum Treatment

Treatment Mechanism Aluminum sulfate (or a combination of aluminum sulfate and sodium aluminate) is considered one of the more effective and long lasting in-lake control techniques. Aluminum sulfate chemically binds with phosphorus and other particulates in the water column as a "floc" (the floc forms somewhat like snowflakes in the water column) and settles to the lake bottom. Once on the lake bottom, the aluminum sulfate floc also binds phosphorus at the sediment surface, thus preventing release of sediment phosphorus from contributing to algal bloom formation (**Cooke et al. 1993**). In addition to reducing the total amount of algae in lakes, there is evidence that alum treatments also result in shifts in the relative abundance of algal species, reducing the presence of one or two dominant blue-green species (like *Aphanizomenon flos-aquae*), and favoring a more balanced and diversified mix of blue-greens, greens and diatoms (**Welch and Cooke 1995**).

Reliability Welch and Cooke (1995) report that six out of nine shallow (average depth of 12 feet or less), non-stratified lakes and three, deep stratified lakes (similar to Lake Sawyer) have been successfully treated with aluminum sulfate. Treatments were successful in lakes where external loading was either not a problem, or was also controlled. In the successfully treated shallow lakes, lake phosphorus concentrations declined by 29 to 75 percent. Because the majority of alum treatments have been successful, alum treatment is considered more reliable than hypolimnetic aeration.

Alum treatments can fail in lakes with excessive, uncontrolled external loading, or extensive aquatic plant beds. Aquatic plants take up nutrients from sediment depths below the effective depth of the alum floc and use the nutrients to build new plant tissue. Later in the season, when the plants decay, these nutrients are recycled back into the water column. Similarly, large inputs of P from the watershed can quickly "re-load" the lake with P greatly shortening the duration of treatment affects. Either of these conditions could limit the effectiveness of alum treatment in Lake Sawyer, and measures to control external loading and aquatic plant growth would have to be implemented prior to, or concurrently with aluminum sulfate.

Estimated Load Reduction Potential Total load reduction potential for (alum treatment) Lake Sawyer under present conditions would be 200 kg P/year (80 percent of the 249 kg P/year estimated existing internal loading). This load reduction would represent about 15 percent of the total (external plus internal) existing phosphorus load of 1,318 kg P/year. If an alum treatment was performed under existing conditions, there would be a substantial lowering of lake phosphorus and chlorophyll a levels during winter and spring months, but there would probably be no measurable benefit during summer months.

Longevity of Treatment Treatment benefits are both immediate and long term, with benefits from a single application lasting at least 8 years in shallow, non-stratified lakes, and as long as 13 to 19 years in deeper, stratified lakes like Lake Sawyer (Welch and Cooke 1993). The longevity of treatment is likely to be shortened in cases where (1) high external loads are not controlled, (2) high aquatic plant growth exists, (3) external loads increase following treatment, or (3) aquatic plant growth increases following treatment. As indicated above, these problems could limit the longevity of treatment in Lake Sawyer, and should be addressed prior to, or concurrent with, any future alum treatment.

Engineering Feasibility Aluminum sulfate has been applied on 10 or more lakes in the State of Washington, and engineering feasibility has been clearly proven (Funk et al. 1975; Entranco Engineers, Inc. 1980, 1986, 1987a and 1987b; Jacoby et al. 1994, Welch and Cooke 1995).

Use Restrictions and Permits Use of aluminum sulfate for whole lake treatments requires a Short-term Water Quality Modification permit and compliance with dosage determinations, monitoring programs and other elements of the State of Washington Department of Ecology Aluminum Sulfate Treatment Policy (March 11, 1991), including prior implementation of watershed controls for nonpoint nutrient sources. Application would also require a Shoreline Master Program permit through King County, and a Hydraulic Project Approval permit from the Washington Department of Fish and Wildlife.

Potential Adverse Impacts - Potential short-term adverse impacts include: (1) short-term reduction (about 2 months) in zooplankton numbers and diversity, (2) possible temporary adverse impacts on benthic fish food insects, (3) possible reduction in carrying capacity for fish following reduction in primary productivity (algal growth) and possible related food chain effects, (4) possible anoxia if the treatment causes too much algae to settle to the lake bottom at one time, and (5) possible adverse impacts to public health (Cooke et al. 1993, Entranco Engineers, Inc. 1987a and 1987b, and Skagit County Planning Department 1984).

Regarding effects on public health, aluminum is one of a number of suspected causative agents associated with Alzheimer's disease, a disease that causes loss of memory. However, aluminum sulfate has been widely used to treat drinking water supplies and there are no criteria for aluminum concentrations in drinking water. Also, aluminum is found in quite high concentrations in the normal diet, since it is the third most abundant element in the earth's crust and is also an ingredient in certain foods and antacids. Therefore, the risk of ingesting large quantities of aluminum from lake or groundwater supplies seems very small compared to the amounts of aluminum that are ingested through normal diet and over-the-counter medications (Thurston County Planning Department 1984).

Mitigating Measures Jar tests are needed to determine proper dosage rates prior to application, and use of computerized dosing control systems can be used to accurately match the amount of aluminum sulfate with the volume of lake water at the point of application. Buffered alum (sodium aluminate) is used to reduce the risk of formation of toxic free aluminum and avoid potential toxicity to fish. The timing of application would be restricted to avoid periods of excessive algal production and to thus avoid oxygen depletion during or following treatment. Field monitoring of dissolved oxygen, pH and other parameters as required by Ecology policy would be performed during application and be used as the basis for temporarily interrupting treatment if adverse water quality conditions occurred. Lime or soda ash would be applied to restore pH balance and aeration could be used to restore oxygen supplies in localized areas, if needed.

Impacts to benthic aquatic insects could be partially mitigated by establishing proper dosing rates using laboratory jar tests to ensure that dissolved aluminum remains below the EPA criteria of 87 µg/l for sensitive aquatic species (US EPA 1988). Monitoring of aquatic insect populations before and after treatment could also be performed to assess impacts. If temporary impacts are clearly established by the monitoring program, they could be mitigated with artificial fish feeding programs and/or re-colonization of benthic insect populations from other lakes. In addition, the treatment could be phased, over several weeks so as to limit impacts to given lake sectors at one time. However, depending on the timing of phasing, this could increase treatment cost.

Although there is no conclusive evidence that aluminum sulfate treatment is, or is not, a cause of Alzheimer's disease, and the potential affect from a lake treatment would be minimal compared to impacts from drinking water and general ingestion; public health concerns would still be addressed. Jar tests would be performed to determine proper dosage and buffered alum would also be used to limit the levels of dissolved aluminum in the water column following treatment. Monitoring of down-gradient domestic wells for total and dissolved aluminum before and after treatment could also be performed. Finally, a public health risk assessment could be performed by public health specialists. Implementation of such monitoring and/or other mitigation measures could add significantly to the cost of treatment and is not covered in the planning-level cost data.

Hypolimnetic Aeration & Circulation

Hypolimnetic aeration and whole lake circulation are both aimed at controlling internal release of P from lake sediments by maintaining a well oxygenated hypolimnetic zone. Although they achieve this goal by different mechanisms, they are similar in terms of reliability, feasibility, and etc. In order to simplify this discussion both techniques are covered in the following paragraphs.

Treatment Mechanism Hypolimnetic aeration (often referred to simply as aeration) systems are employed in stratified lakes using pumps, compressors or other means, to increase the oxygen level in the hypolimnion while maintaining stratification. Typically, a compressor is installed on shore with air lines extending from the compressor to an aeration structure located in the deepest portion of the lake. The strategy with hypolimnetic aeration is to increase oxygen levels in the hypolimnion without disrupting lake density layers caused by thermal stratification . Since anoxic conditions in the hypolimnion of stratified lakes are often associated with dramatic increases in phosphorus release from lake sediments (this is the case at Lake Sawyer), aeration is applied as a means of controlling internal loading (Cooke et al. 1993). (An indirect benefit associated with maintaining an oxygenated hypolimnion is that it also makes it possible for fish to reside in the cooler, oxygenated waters of the hypolimnion during summer months.) However, hypolimnetic aeration does not always provide effective phosphorus control, as discussed below.

Circulation involves the use of compressed air or water pumps to break down stratification and promote increased oxygenation of the entire water column by atmospheric mixing. This approach eliminates the cold water hypolimnion that is preferred by rainbow trout, and may also result in increased phosphorus loading from lake bottom sediments as a result of (1) resuspension of highly flocculent sediments, and/or (2) higher temperatures and corresponding increases in bacterial decomposition of organic matter at the sediment surface.

Whole lake circulation is likely to be more effective in deeper, stratified lakes because mixing forces algal populations to spend a greater percentage of time in the dark (outside the photic zone). With increasing residence time in the dark, net production (new algal growth produced by photosynthesis in the light, minus the amount consumed in the dark) decreases, with corresponding decreases in chlorophyll a levels (Cooke et al. 1993). This approach is most likely to be effective in lakes where the epilimnetic volume is small compared to the hypolimnetic volume. Therefore, it would not be likely to work in Lake Sawyer where the hypolimnion represents only 30 to 40 percent of total lake volume.

Another potential eutrophication control mechanism associated with whole lake circulation, which also is primarily associated with deeper stratified lakes, is reduced pH (increased acidification) in the photic zone. Some limnologists argue that reduced pH favors green and diatom algal populations rather than the blue-green species that are commonly associated with floating, smelly algal blooms. It is generally believed that non-blue green algal populations are able to out-compete blue green species for carbon supplies at lower pH levels. In addition, there is evidence that blue-green algae are more susceptible to viral attack at lower pH levels. These combined factors suggest that whole lake circulation should result in a shift in algal dominance from blue-green to the more desirable green and diatom species (Cook et al. 1993).

Estimated Load Reduction Potential The load reduction potential, under best-case assumptions, could be as great as those estimated for aluminum sulfate treatment - approximately 80 percent of internal load or 253 kg P/year. However, the case study literature indicates that under worst case conditions, hypolimnetic aeration may not provide any reduction in phosphorus loading to the photic zone. Or, in the event that stratification is disrupted, phosphorus loading could actually increase.

Reliability The application of both techniques for eutrophication control has resulted in mixed success. While aeration and circulation have commonly resulted in increased oxygen levels (where systems were properly designed to provide adequate oxygen supply or adequate mixing), there has not always been a corresponding reduction in algae growth or shift in algal dominance (Cooke et al. 1993). This may be due to the fact that, even in the absence of aeration/circulation, high levels of phosphorus in the hypolimnion are not available to algae in the photic zone during the growing season, a period which typically coincides with stratification. Or, as is the case in Lake Sawyer, hypolimnetic phosphorus does have an effect, but only during the winter months when recreational impairment is not an issue. Thus the stratification that causes higher levels of phosphorus in the hypolimnion also prevents these nutrients from entering the epilimnion and photic zone during the growing season, where they might otherwise stimulate undesirable algal growth and interfere with recreational uses.

It has also been observed that in some stratified lakes, phosphorus concentrations do not increase following lake turnover in the fall when high-phosphorus hypolimnetic waters naturally mix with lower nutrient epilimnetic waters. One possible explanation for this is that at turnover much of the phosphorus that had been released during the anaerobic period is suddenly precipitated back out of the water column as iron- or aluminum-phosphorus complexes. In such lakes, aeration or circulation would offer little advantage to the natural mechanisms controlling internal phosphorus cycling.

Another potential problem with hypolimnetic aeration is that the mixing energy introduced by aeration may be sufficient to breakdown stratification, causing the problem of whole-lake warming and potentially resulting in increased internal loading, as sometimes occurs with whole-lake circulation. This is more likely to occur in relatively shallow lakes, that may be weakly stratified, or where the hypolimnetic volume is too small to absorb the mixing energy and still remain stratified. Cooke et al. (1993) indicate that lakes should be at least 12-15 meters deep for successful application of hypolimnetic aeration. Since Lake Sawyer has a mean depth of 7.6 meters and a maximum depth of 18 meters, it may meet the depth requirements for hypolimnetic aeration. However, because the hypolimnetic volume of Lake Sawyer is relatively small, this potential problem would need to be addressed if hypolimnetic aeration is attempted.

Other problems that may arise with aeration/circulation systems include (1) inefficient air/oxygen transfer into the water column due to poorly designed diffusers, (2) high damage potential to the in-lake structure due to wind/wave action, settling, freezing/thawing, etc., (3) high repair costs because divers are often required to inspect and repair underwater facilities, and (4) high annual operational costs associated with routine inspection, maintenance, repair and electric power requirements.

Longevity of Treatment Aeration/circulation systems require sustained operation through at least six months during the year for as many years as the benefits are desired. Because mechanical systems wear out, complete replacement of the system should be assumed to be necessary about every ten years. This means that the life cycle cost of hypolimnetic aeration offers no advantages over alum treatment.

Engineering Feasibility Engineering feasibility has been proven. Engineering design should take advantage of recent improvements in efficiency of oxygen exchange with improved diffuser heads. Another possible design improvement may be the Speece cone system (installed about a year ago on Newman Lake near Spokane, Washington) that uses pure oxygen. However, despite the best engineering, hypolimnetic aerators seem to have unexpected damage and repair costs.

If this technique is to be given serious consideration for use on Lake Sawyer in the future, project-specific design calculations would have to be performed to ensure that the rate of oxygen supply would exceed the sediment oxygen depletion rate. Often times this rate is greater than the oxygen depletion rate measured in the hypolimnion following the onset of stratification, because the mixing energy of the aeration system can suspend flocculent sediments into the water column, thus increasing biochemical oxygen demand. Proper design may involve sizing calculations to provide 50 to 100 percent more oxygen than indicated by the hypolimnetic oxygen depletion rate alone.

Use Restriction and Permits Installation of aeration/circulation systems would require a Shoreline Master Program permit from King County and an Hydraulic Project Approval permit from the Washington Department of Fish and Wildlife.

Potential Adverse Impacts Potential adverse impacts would be possible increases in phosphorus and algae levels in the lake and increased cost to homeowners assessed by the lake management district (LMD) in the event of system failure.

The only other potential problem is related to the possibility of nitrogen supersaturation, a condition that could be lethal to fish. This problem is likely to be more significant in deeper lakes where greater air pressures are required to bring the oxygen to the depth of the hypolimnion. However, according to Cooke et al. (1993) this has not been a problem with applications to date.

Mitigating Measures None.

Evaluation Of Treatment Effects And Recommendations

The predicted water quality benefits from implementing watershed control measures and in-lake treatment are shown in **Table 6-3**. To estimate potential future conditions, full build-out of the watershed, as defined by the City of Black Diamond, was used to recalculate the water budget and the lake response model. Under predicted future development conditions, if no controls or treatments are implemented, total phosphorus load is expected to reach 2,414 kg P/yr, an 83 percent increase over existing conditions. This will cause significant increases in lake P concentrations. The increase in summer period epilimnetic P concentrations would likely lead to blooms of algae during this high recreational use period.

The effectiveness of watershed control measures for removing P can vary widely, depending upon design, maintenance, and other issues. For the purposes of medeling the predicted impacts from implementation of watershed controls, it was assumed that the combination of source control measures and regional treatments would reduce the phosphorus concentration in impervious area runoff by a minimum of 40 percent, from 235ug/L to 142 ug/L. To predict the impact from in-lake treatment systems, it was assumed that either an alum treatment or hypolimnetic aeration would reduce internal release of P by 80 percent.

As shown in Table 6-3, watershed controls would lead to the greatest decrease in P loading to the lake, although loading would be higher than existing conditions. Addditionally, there would be higher P concentrations in the lake. The predicted epilimnetic concentration of 31 μg/L would increase the frequency and magnitude of summer algal blooms. Implementation of in-lake control measures would slightly reduce phosphorus loading. Although it would cause the greatest reduction on whole-lake summer and annual phosphorus concentrations, it is not predicted to have a significant impact on epilimnetic P concentrations.

Based on the modeling results, that the lake management plan should focus on reducing phosphorus sources in the watershed. In-lake controls, would not sufficiently reduce phosphorous loading under current or future conditions. If initial external load control programs prove insufficient, then in-lake techniques can be considered on a contingency basis as a means of temporarily suppressing eutrophication, while new initiatives are taken to control external loading. Prior to implementation, the City of Black Diamond, King County and Ecology will want to confirm that some combination of in-lake and watershed controls will be able to achieve water quality goals.

The recommended management plan is to fully implement watershed control measures (as listed in Table) to attain a P reduction goal of 40% or greater. A whole-lake alum treatment is recommended as the contingency plan for further reducing lake P concentrations. Alum treatment is preferred over aeration due to its greater reliability, especially in a lake such as Lake Sawyer with a low hypolimnion volume and moderate depth.

1. Table 6-3
Comparison of Phosphorus Loading and In-lake Concentration (µg/L) Results under different control scenarios.

	Phosphorus Loading		*In-Lake Concentrations*				
	Annual Load (kg P/yr)	Percent Increase	Epilimnion (Summer)	Whole Lake (summer)	Whole Lake (Annual)	Chl a (summer)	Secchi (m)
Current Conditions	1,318	0	23	43	38	6.6	2.1
Future Conditions/ No Controls	2,414	83	38	57	55	13.8	1.3
Future Conditions/ Watershed Controls	1,895	44	31	50	47	10.2	1.6
Future Conditions/ Internal Load Control	2,315	76	37	39	46	13.2	1.1

REFERENCES

Cooke, D.G., E.B. Welch, S.A. Spencer, and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. Second Edition. Lewis Publishers. Ann Arbor, Michigan.

Entranco Engineers. 1978. Water Quality and Restoration Analysis: Thurston County Lakes. Prepared for Thurston County, the City of Lacey and the State of Washington Department of Ecology.

Entranco Engineers, Inc. 1980. Long Lake Restoration Project - Final Report. Prepared for Kitsap County and the State of Washington Department of Ecology.

Entranco Engineers. 1982a. Volume I. Water Quality Analysis and Restoration Plan for Patterson and Long Lakes. Prepared for Thurston County and the State of Washington Department of Ecology.

Entranco Engineers. 1982b. Volume II. Technical Appendices. Water Quality Analysis and Restoration Plan for Patterson and Long Lakes. Prepared for Thurston County and the State of Washington Department of Ecology.

Entranco Engineers, Inc. 1986. Wapato Lake Restoration - A Discussion of Design Considerations, Construction Techniques and Performance Monitoring.

Entranco Engineers, Inc. 1987a. Final Report for the Pattison and Lake Sawyers Restoration Project. Prepared for Thurston County and the State of Washington Department of Ecology.

Entranco Engineers, Inc. 1987b. Final Report: Restoration Implementation and Evaluation - Erie and Campbell Lakes. Prepared for Skagit County and the State of Washington Department of Ecology.

Entranco Engineers, Inc. 1996. Draft Lake Sammamish...........

Funk, W.H. et al. 1975. Determination, Extent, and Nature of Nonpoint Source Enrichment of Liberty Lake and Possible Treatment. Wash. Water Res. Center Rep. No. 23. Washington State University, Pullman, Washington.

Horner, R. 1992. Constructed Wetlands for Storm Runoff Water Quality Control. Course Materials. November 1992.

Jacoby, J.M., H.L. Gibbons, K.B. Stoops, and D.D. Bouchard. 1994. Response of a Shallow Polymictic Lake to Buffered Alum Treatment. Lake and Reservoir Management. 10(2) 103-112.

Schueler, T.R. 1992. Design of Stormwater Wetland Systems. Metropolitan Washington Council of Governments, Washington, D.C.

Skagit County Planning Department. 1984. Final Environmental Impact Statement, Lake Restoration Project, Lake Erie and Lake Campbell, Skagit County.

U.S. EPA. 1988. Ambient Water Quality Criteria for Aluminum. EPA 440/5-86-008.

U.S. EPA. 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. 840-B-92-002

Welch, E.B. and G.D. Cooke. 1995. Effectiveness and Longevity of Alum Treatments in Lakes.

APPENDIX J
QA/QC Plan

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
P.O. Box 47600 • Olympia, Washington 98504-7600 • (206) 407-6000 • TDD Only (Hearing Impaired) (206) 407-6006

RECEIVED
MAY 5 1994
KING COUNTY
SURFACE WATER MANAGEMENT DIVISION

May 2, 1994

Mr. Bob Storer
Metropolitan King County
Surface Water Management Division
700 Fifth Avenue, Suite 2200
Seattle, Washington 98104

Dear ~~Mr. Storer~~ Bob:

The enclosed, revision of the "Quality Assurance/Quality Control Plan for Lake Sawyer Phase I Restoration Analysis, Grant Number No. G9400262" dated April 27, 1994 is hereby approved.

If you have any questions, please call me at (206) 407-6563 or SCAN 407-6563.

Sincerely,

Allen

Allen W. Moore
Project Officer
Water Quality Financial Assistance

AWM:pko
Enclosure

cc: Kathleen Kilian, EPA
Grant file

QUALITY ASSURANCE/QUALITY CONTROL PLAN

FOR

LAKE SAWYER PHASE I RESTORATION ANALYSIS

GRANT NUMBER: G9400262

Prepared by:

Bob Storer

King County Surface Water Management Division

Prepared for:

Washington State Department of Ecology

April 27, 1994

Prepared by: Bob Storer
Title: Senior Water Quality Specialist
Date: 4-27-94

Approved by: Allen W. Moore
Title: WQFA, Nonpoint Project Officer
Date: May 2, 1994

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1.0 PROJECT DESCRIPTION

1.1 Historical Information

Lake Sawyer, a 280-acre lake is located two miles northwest of Black Diamond, and lies within the Big Soos Creek subbasin of the Green River drainage (Figure 1). The lake is an extremely significant resource and is the only lake in southeast King County that is open for fishing year-round. Lake Sawyer was sampled during 1971-1972 as part of a preliminary phase of the pollution abatement program developed by the River Basin Coordinating Committee (RIBCO). In addition, the Lake was sampled by the Municipality of Metropolitan Seattle (METRO) during 1973-1974 as part of an intensive survey of 16 lakes in the Lake Washington and Green River drainage basins. During this period, the Lake was classified as highly eutrophic, based on maximum phytoplankton density and mesotrophic according to mean summer chlorophyll a concentrations. The U. S. Geological Survey performed lake profile sampling of the Lake in 1973 prior to the Black Diamond wastewater treatment plant (WWTP) installation. METRO also collected lake samples from May 1979 to March 1980, and has been routinely monitoring the lake during the past decade in their Small Lake Monitoring Program. The most recent sampling shows Lake Sawyer is still classified as eutrophic as indicated by Total Phosphorus (winter average) values.

Historical water quality data indicates the Lake has relatively high nutrient concentrations that have resulted in increased algal and aquatic plant problems. From 1982 to 1992, the City of Black Diamond operated a WWTP which discharged to a natural wetland. This system was designed to utilize the wetland's natural processes to remove nutrients. The wetland component was considered innovative prior to its construction in the early 1980's. After several years of operation, the treatment system was determined through monitoring to have failed. A 1989 diagnostic study of Lake Sawyer was conducted by the Washington State Department of Ecology (WSDOE). This resulted in a wasteload allocation analysis that determined the amount of phosphorus the WWTP must remove in order to protect Lake Sawyer. Subsequently, the WWTP effluent was diverted to a METRO sewer line in November 1992.

The 1989 WSDOE wasteload allocation diagnostic study concluded that the lake was expected to respond fairly rapidly to reductions in nutrient loading following WWTP diversion because of the rapid flushing and low sedimentation rates. The lake is predicted to attain about 99 percent of the new steady state concentration within the first year after a change in the loading rate. Furthermore, 1989 study predicts future loading conditions and lake trophic status following WWTP diversion.

Lake Sawyer has been historically characterized as mesotrophic to eutrophic. The proposed project will update the water quality assessment of Lake Sawyer to see if its status has changed and to determine a current trophic state. The current water quality will be compared to predicted water quality made following WWTP diversion in the 1989 WSDOE diagnostic study.

The steady-state mass balance model from the 1989 study will be recalibrated using current water quality data and used to evaluate potential restoration alternatives. The results of the updated trophic modeling, combined with the knowledge of current and future land use in the drainage basin will be used to develop recommendations which will improve existing conditions, prevent further degradation, and protect beneficial uses.

The 1989 diagnostic study performed by the WSDOE does not meet all the requirements of a Phase I Lake Restoration study. This timely feasibility project would supplement the diagnostic study and complete the Phase I requirements. The primary purpose of the Phase I restoration analysis is to assess the impact of the WWTP diversion, assess present and future nonpoint impacts on lake quality, and evaluate and recommend (within a public participation process) restoration alternatives to improve and protect lake water quality. Additionally, this proposed project will examine whether or not current loading conditions and the average in-lake TP concentration of 16 ug /L goal are being met as established by the EPA/DOE Total Daily Maximum Load (TMDL) for Lake Sawyer.

1.2 Project Objectives

The purpose of this project is to develop a lake management plan for Lake Sawyer based on the Phase I lake restoration study process. As part of this process education and involvement of the public is essential to a successful project. Meeting the major goals of improving current water quality and reducing future watershed impacts is very much dependent upon the participation and commitment of the surrounding community. In order to successfully complete this project, the following five objectives must be accomplished:

1. Provide education and involvement opportunities for the public throughout the project to foster public ownership and commitment to the development and implementation of the lake management plan.

2. Re-examine the physical, chemical, and biological components of the lake and its surrounding watershed.

3. Re-calibrate the steady-state mass balance model from the 1989 study and develop updated nutrient and water budgets which can be used as analytical tools for the development of a lake management plan and as a benchmark for evaluating post-plan implementation effectiveness.

4. Identify current and future sources of point and nonpoint pollution to the lake.

5. Develop a comprehensive management plan for the protection and enhancement of Lake Sawyer water quality.

1.3 Data Use

Inflow, outflow, and in-lake water quality samples will be obtained throughout a one-year monitoring program. To evaluate inflow water quality, State Class AA water quality standards (Chapter 173-201A WAC), United States Environmental Protection Agency (EPA) phosphorus guidelines (USEPA, 1986) for the prevention of biological nuisances and to control cultural eutrophication, and the EPA/DOE TMDL for Lake Sawyer will be used. All inflow sources which exceed current standards or recommendations will be targeted for source control treatment as part of the Phase II lake restoration. In-lake water quality will be evaluated using appropriate indices including the *Carlson Trophic Status Index*.

The proposed project will update the water quality assessment of Lake Sawyer and determine a current trophic state. The current water quality will be compared to predicted water quality made following WWTP diversion in the 1989 WSDOE diagnostic study and to the recently approved TMDL.

> The TMDL states, " the goal of maintaining an average in-lake total phosphorus concentration of 16 ug P/l has been identified in a technical study prepared by Ecology. The loading capacity of total phosphorus to Lake Sawyer necessary to achieve this goal is estimated to be 1.9 kg P per day (715 kg P/yr). This estimated loading capacity is likely to be achieved from a loading allocation to the tributaries of 1.4 kg P per day (which includes a 0.08 kg P per day allocation for uncertainty) and a loading allocation from internal loading of 0.54 kg P per day (which includes a 0.34 kg P day allocation for uncertainty).

The development of a trophic model based on hydrologic and nutrient monitoring will be used to evaluate restoration alternatives. The results of the trophic modeling, combined with the knowledge of current and future land use, will be used to develop recommendations that will prevent further water quality degradation and restore water quality.

1.4 Sites

Lake Sawyer is a natural lake of moderate depth. The lake basin is elongated on a north/south axis and contains two distinct basins. The bathymetric map (Figure 2) shows the southern quarter of the lake to be shallower than the middle and northern areas. Given the limited funds for this project, a targeted sampling scheme is proposed using the two deep stations (Number 3 or SAWYERA, and Number 4 or SAWYER B) as a subset of the original five which were used to assess within lake distributions and variability in 1989. Additionally, two other shallow stations (Number 5 or SAWYERC and Number 2 or SAWYERD) will be used as auxillary and sampled monthly only during the growing season to assess in-lake variablity.

Proposed locations for these in-lake sites and the proposed 10 watershed inlet and outlet sampling sites are shown in Figures 2 and 3. Additional sampling sites for various in-lake special studies will be determined prior to the initiation of those monitoring components. An addendum to this plan will be provided which detail these additional studies.

1.5 Design

The sampling program is designed with the primary purpose of providing quantitative estimates of
1) sources of water to the lake and the volume of water which is lost from the lake annually, and
2) nutrient concentration associated with these water volumes.

The information derived from the sampling program will then be used to develop a current water and nutrient budget for the lake from which a re-calibrated lake model will be developed. Groundwater inputs for the water and nutrient budgets will be treated as a residual and representative of typical loads from inflow and septic systems respectively,, similar to the way in which the groundwater hydrological influence on and nutrient loading to Lake Sawyer was calculated during the 1989 study. The lake model will be used as an assessment tool to evaluate the current and future land use effects, as well as the expected effectiveness of the proposed restoration alternative(s) on lake water quality.

Additionally, the sampling program is designed to provide an overall characterization of the physical, chemical, and biological components of the lake ecosystem. This information will be used to determine the current trophic state of the lake and aid in the evaluation and prediction of current and future lake quality.

1.6 Schedule

Table 1 details the overall project schedule while Table 2 details the monitoring and data collection schedule for Lake Sawyer. The project and monitoring schedule assume a April, 1994, start-up date. Actual sample dates for routine lake monitoring and baseflow sampling are included in Appendix A.

Table 1: Project Schedule

TASK	DESCRIPTION	COMPLETION DATE
1. Public Involvement	-Committee start-up -Public meetings and workshops	December, 1995
2. Background/Monitoring	-Background data collection -Wetland analysis -Monitoring -Data reduction	May, 1995
3. Restoration/Management Plan	-Water and nutrient budgets -Restoration analysis -Plan production	July, 1995
4. Public Access/SEPA/Final Report	-Public Access Plan- -SEPA -Final Plan	December, 1995
5. Project Management	-Grant reporting/management -Landuse review -Consultant management	December, 1995

Table 2: Lake Sawyer Monitoring and Data Collection Schedule

January 1994	February	March	April
-Locate in-lake, tributary and outflow sampling locations	-Locate in-lake sampling locations	Perform Test-run and d.o/temp profiles	-One routine sampling trip, -Storm sampling

May	June	July	August
-Two routine sampling trips, one baseflow sampling	-Two routine sampling trips, benthics, one baseflow sampling	-Two routine sampling trips, one baseflow sampling -Sediment	-Two routine sampling trips, benthics, one baseflow sampling -Macrophyte sampling

September	October	November	December
-Two routine sampling trips, one baseflow sampling	-One routine sampling trip, benthics, one baseflow sampling	-One routine sampling trip, -Storm sampling	-One routine sampling trip, -Storm sampling

January 1995	February	March	April
-One routine sampling trip, one baseflow sampling	-One routine sampling trip, one baseflow sampling	-One routine sampling trip	-One routine sampling trip, one baseflow sampling

Adverse weather conditions which threaten human health and safety may affect the monitoring and data collection schedule by one or more days. Storm event sampling is weather dependent and sample collection schedule for this component may slide by a month or more.

Holding times, preservation, and containers for specific test variables will be followed as described in Appendix A. All samples will be delivered to analytical laboratories within their specified holding times. Analytical results will be reported to the project manager within 30 days of sample delivery to the analytical laboratory.

2.0 PROJECT ORGANIZATION

The key personnel who will be involved in the development and completion of this project are summarized in Table 3. Additional information regarding the personnel associated with the project consultant will be provided after completion of the consultant selection and hiring process.

Table 3: Project Personnel

PERSONNEL	RESPONSIBILITY	ADDRESS	PHONE NUMBER
Jim Kramer, Manager, SWM	Review/Policy	King County SWM	(206) 296-6585
Bill Eckel, Manger, Water Quality Unit	Review/Policy	King County SWM	(206) 296-8384
Bob Storer, Senior Water Quality Specialist	Project Manager, Technical Support	King County SWM	(206) 296-8383
Sharon Walton, Senior Limnologist	Technical Support, Review	King County SWM	(206) 296-8382
Luke Bloedel, Engineer Technician	Technical Support	King County SWM	(206) 296-8057
Environmental Laboratory Division (Department of Metropolitan Services (DMS))	Conventional, metals, and microbiological analyses	322 W. Ewing St. Seattle, WA 98119	(206) 684-2300
Steve Lazoff, Aquatic Research	Additional laboratory services	3927 Aurora Avenue, N. Seattle, WA 98103	(206) 632-2715
Consultant	Technical Support Plan Production	To be determined	

3.0 DATA QUALITY OBJECTIVES

3.1 Precision

Precision will be assessed using laboratory duplicates, which will be analyzed with every sample batch. Two levels of precision for duplicate analyses will be evaluated. The relative percent difference (RPD) of laboratory duplicates will be less than or equal to 25 percent for values which are greater than 5 times the detection limit and $\pm$ 2 times the detection limit for values less than or equal to 5 times the detection limit. Laboratory replicates will be analyzed at a frequency of a least 5 percent of the total number of samples submitted.

3.2 Bias
Accuracy will be assessed with analyses of laboratory preparation blanks, matrix spikes and control standards. Where applicable, these quality control analyses will be performed for every sample batch. The values for blanks will not exceed 2 times the detection limit. The percent recovery of matrix spikes will be within 75 and 125 percent. The percent recovery of control standards will be between 90 and 110 percent. The laboratories will analyze a preparation blank with each batch. The laboratories will analyze matrix spikes and standard solutions at a frequency of at least 5 percent of the total number of samples submitted.

3.3 Representativeness
Sample representativeness will be ensured by employing consistent and standard sampling procedures. Documentation of sample collection will occur in the field. Particular attention will be paid to the physical environment (temperature, wind, precipitation, and cloud cover) which will be used in assessing the representativeness of the data collected. The sampling program will adhere to a regular schedule for all routine sample collection (Appendix A). The exceptions to this schedule will be 1) during stormwater sampling which is weather dependent and 2) when weather conditions make routine sample collection unsafe.

3.4 Completeness
A minimum of 95 percent of the samples submitted to the laboratory will be judged valid. Field conditions may hinder the collection of some samples but every effort will be taken to assure critical samples can be collected even during adverse conditions. Additionally, samples will not be collected when flow in inflow or outlet channels is stagnant or absent.

3.5 Comparability
Data comparability will be ensured through the application of standard sampling procedures, analytical methods, units of measurement and detection limits. The results will be tabulated in standard spread sheets for comparison with criteria and historical data.

The field and laboratory procedures used for this project will be similar to those used for other stream and lake monitoring projects sponsored by King County. The data generated by this project will also be compared to stream and lake data collected by the Environmental Laboratory Division (DMS).

4.0 SAMPLING PROCEDURES

The limnological, biological, and hydrologic monitoring program for Lake Sawyer is summarized in Table 4. Where applicable, the *Recommended Protocols for Measuring Conventional Water Quality Variables and Metals in Fresh Waters of the Puget Sound Region* (USEPA, 1988, and herein referred to as the recommended protocols) are used and referenced below. Additional sampling procedures for the various components of the monitoring program shown in Table 4 but not contained in the recommended protocols are listed below.

All sample bottles will be prewashed and obtained from the laboratory. Requirements for preservation will either be performed in the field or back in the laboratory in accordance with standard operating procedures and holding times (Appendix A). When appropriate (i.e. when the sample bottle contains no preservative), the sample container will be rinsed three times with sample water before filling the sample bottle. All sampling devices will be prepared according to the recommended protocols. Water samples collected in the sampling devices will be transferred to pre-labeled sample containers which have been prepared according to the recommended protocols. Finally, sample containers will be immediately placed on ice in a cooler.

TABLE 4: LIMNOLOGICAL, BIOLOGICAL AND HYDROLOGIC MONITORING

COMPONENT	SAMPLING FREQUENCY	STATIONS	PARAMETERS
In-lake	Monthly: Oct-April Bimonthly: MaySept	2 stations, both deep, (SAWYER A and SAWYER B) every 3 meters,	Temperature, pH, Dissolved Oxygen, Conductivity, Total Phosphorus, Soluble Reactive Phosphorus, Nitrite + Nitrate-Nitrogen, Ammonia, Total Nitrogen, Turbidity, Alkalinity, TOC
	Monthly: Only during growing season	2 stations, both shallow, (SAWYERC AND SAWYERD) every 3 meters .	Total Phoshorus, Total Nitrogen, Chlorophyll a
	Monthly/Bimonthly	2 stations (A and B)	Secchi depth, Color, Chloride
	Monthly/Bimonthly	2 stations, (A and B) surface and (0.5, 1.5, 2.5, and 3.5 M composites), water column (photic zone)	Chlorophyll a, Phaeophytin a, Phytoplankton species, biovolume, and identification
	Monthly/Bimonthly	2 stations, (A and B) vertical tow	Zooplankton species, enumeration, and identification
	Quarterly	2 stations, deep spots, (A and B) every 3 meters	Iron, Aluminum
Inlets/Outlets	Monthly (9 Baseflow)	Nine stations	Temperature, pH, Dissolved Oxygen, Conductivity, Turbidity, Total Suspended Solids,Total Phosphorus, Soluble Reactive Phosphorus Nitrite + Nitrate-Nitrogen, Ammonia, Total Nitrogen, Chloride, Fecal Coliform (inflow)
	Three storm events	7 stations -grab, and 2 main inflow sites composited over storm	Baseflow parameters plus Hardness, Copper**, Lead**, and Zinc**
Sediment, In lake	Once	12 stations, 0.5 M core, analyzed only at top few cm	Total Phosphorus, Percent Water, Total Organic Carbon, Aluminum, Manganese, and Iron
Sediment release	Once	2 stations, 1 cores/station, 3 samples/core, aerobic, anaerobic	Total Phosphorus, Soluble Reactive Phosphorus, Dissolved Oxygen, Temperature, pH
Precipitation	Monthly	2 stations, composited	Total Phosphorus, Total Nitrogen
Macrophytes	Once	20 transects, 5 samples/transect	Species, Biomass, Total Phosphorus, Areal Mapping
Benthic Invertebrates	Bimonthly, growing season	Three sites, bottom grab	Density, identification to genus except for chironomids and oligochaetes

Hydrology	Biweekly: Oct-Mar Monthly:April-Sept	Lake level Inflow and Outflow Rain Gauge	Volume Fluctuations Total Discharge Total Precipitation

Duplicate samples of in-lake TP at surface, and bottom depths; inflow TP; and chlorophyll a will used to assess the variation in the sample media with respect to site, depth, and/or season. Holding times for specific test variables will be followed as outlined in Appendix A and samples will be delivered to analytical laboratories within those specified times. Analytical results will be reported to the project manager within 30 days of sample delivery to the analytical laboratory.

4.1 In-Lake

Water samples will be collected from various depths using a Van Dorn water collection device. Prior to sample collection, the sampling device will be prepared according to the recommended protocols. Water samples collected in the sampling devices will be transferred to prelabled sample containers which have been prepared according to the recommended protocols. Station descriptions can be found in Appendix A.

All *in situ* measurements (dissolved oxygen, conductivity, pH, temperature, and secchi depth) will be made with calibrated equipment according to the recommended protocols or manufacturers suggested calibration. For those variables where direct measurement can be made via a probe and/or line, a vertical profile will be developed on site. For some *in situ* measurements, it may first be necessary to collect a water sample using a water sampling device before proceeding with variable measurement.

4.2 Inlet and Outflow

Manual grab sampling methods based upon the recommended protocols will be used to collect both baseflow and storm flow inlet and outflow samples. During stormwater sampling events, the Rock Creek inflow will be sampled several times (3-5) over the storm event and composited for analysis. A storm event will be defined as 0.5 inches of rainfall in a 6-hour period or 1.0 inches of rain in a 24-hour period preceded by 60 to 72-hours of dry conditions (less than 0.25 inches per day). Inlet and outlet station descriptions can be found in Appendix A.

4.3 Groundwater

The groundwater inflow and nutrient contributions from on-site septic systems will be estimated from values derived from the 1989 WSDOE Wasteload Diagnostic Study of Lake Sawyer.

4.4 Precipitation

Precipitation depths will be recorded and volumes collected by trained volunteers living adjacent to the lake. Volunteers will be responsible for recording precipitation levels on a daily basis and collecting daily rainfall in a sample bottle, and then storing it in their freezer until sample pick-up occurs. The protocols used by the volunteers are outlined in Appendix B.

4.5 Flow

Automated flow monitoring equipment will not be used to monitor the main inflows and outflow to the lake. Manual methods (staff gauge reading and velocity measurements) outlined in the recommended protocols have been used during 1993 and will continue throughout 1994. SWM staff will make periodic streamflow measurements and develop rating curves for the inflows and outflow. Additionally, volunteers will be identified to record lake level or read staff gauges on a weekly or daily basis according to the protocols outlined in Appendix B.

4.6 Sediment

Sediment quality will be characterized using sediment core characterization and sediment phosphorus release analysis. A supplemental sediment sampling program will be developed prior to sample collection in July 1994. The sampling program will be submitted as an addendum to this quality assurance plan.

4.7 Fisheries

Due to funding constraints, fisheries will not be sampled.

4.8 Macrophytes

Aquatic plant community composition, areal distribution, and phosphorus content will be determined during peak abundance (typically during August). Plant community composition and distribution will be mapped using 1) a visual survey by boat to map and identify floating and emergent plants and 2) a recording fathometer and a rake sampler to collect, identify, and map submerged macrophytes. A field press will be used to preserve collected specimen for positive identification back at the laboratory.

Plant biomass and phosphorus content will be sampled using a "half barrel" or other sampling device of known area with attached netting for macrophyte capture. Once the sampler is place on the lake bottom, a diver (snorkeling or scuba) will uproot and push the macrophytes into the net. The net will be twisted, closed, and samples brought to the surface. The plant samples will be rinsed in lake water and stored on ice before sorting and processing back at the laboratory.

4.9 Field Notes

At each station, the following information will be recorded on waterproof field notes: date and time of sample collection, station location, name of samplers, weather and flow conditions, unusual conditions (e.g. algal scum, oily sheen, turbidity, odors etc), calibration of field instruments, field measurements, number and type of samples collected, and alterations of routine sampling procedures. The field notes will be used to evaluate the quality of the data upon receipt from the commercial laboratory. Sample field data forms are in Appendix C.

4.10 Sample transport and custody

Samples will be transported on ice in a cooler to the laboratories within the recommended holding times (Appendix A). Chain-of-custody or work order documents and a field sheet will be completed for each sampling event. A chain of custody record or work order form will accompany all samples (Appendix D). Upon return to the office, a signed copy of the chain of custody record or work order form and field forms will be placed in the project file.

4.11 Sample identification

Each sample will be identified by a site identification name and sample date. Upon return to the laboratory a unique laboratory number will be assigned to each sample to track it through its analysis.

5.0 ANALYTICAL PROCEDURES

Laboratory analytical procedures will follow United States Environmental Protection Agency (EPA) approved methods (EPA 1983, 1984, 1986, American Public Health Association et al., 1992). The laboratories identified for this project are certified by Ecology and participate in audits and inter-laboratory studies by the Department and EPA. These performance and system audits have verified the adequacy of the laboratory standard operating procedures which include preventative maintenance and data reduction procedures. The analytical procedure proposed for this project are summarized below in Table 5.

Table 5: Environmental Laboratory Division's methods for sample analysis.

PARAMETER	REFERENCE
A. Conventionals	
Total Phosphorus	SM 4500-P-B,-E
Orthophosphorus	SM 4500-P-F
Nitrate + nitrite-N	SM 4500-NO3-F
Ammonia	SM 5500-NH3-H
Total Nitrogen	BACHMAN & CANFEILD
Total Suspended Solids	SM 2540-D
Turbidity	SM 2130-B
Alkalinity	SM 2320-B
Hardness	SM 2340-C
Dissolved Oxygen	SM 421
pH	EPA 150.1
Conductivity	EPA 120.1
Temperature	SM 212
Chlorophyll a	SM 10200-H
Phaeophytin	SM 10200-H
Color	SM 2120-C
Sulfate	SM 4500-S04-F
Total Organic Carbon	SM 5310-B
Chloride	SM 4500-CN-C,E
B. Metals	
Aluminum	ICP EPA 200.7/3050/6010
Calcium	ICP EPA 200.7/3050/6010
Copper	ICP EPA 200.7/3050/6010 GF EPA 220.2

Iron	ICP EPA 200.7/3050/6010
Lead	ICP EPA 200.7/3050/6010 GF EPA 220.2
Magnesium	ICP EPA 200.7/3050/6010
Potassium	ICP EPA 200.7/3050/6010
Sodium	ICP EPA 200.7/3050/6010
Zinc	ICP EPA 200.7/3050/6010
C. Bacteria	
Fecal Coliform	SM 9222D

6.0 DATA REDUCTION, REVIEW, AND REPORTING

Data reduction, review and reporting will be performed under the Environmental Laboratory Division's standard operating procedures. Reporting by any additional laboratories used in this study will reduce, review, and report data in accordance with pre-established criteria set forth by the County and contingent upon the approval of the Department.

7.0 QUALITY CONTROL PROCEDURES

7.1 Field Quality Control Procedures

Field meters (pH, DO, and conductivity) will be calibrated in the field using standard solutions that are within the approximate range of the expected temperature of the water to be sampled or in accordance with the instruments operating instructions. Field meters will be recalibrated every two hours or as recommended for each meter's standard operating procedures.

Five percent of all samples will be obtained with field replicates. Field replicates will be chosen randomly and will provide an estimate of the total precision of the sampling methodology.

7.2 Laboratory Quality Control Procedures

Aquatic Research, Inc. (a WSDOE accredited lab), and the Environmental Laboratory Division's (DMS Lab) routinely performs quality control procedures for other King County Surface Water Management Division's projects. These procedures include but are not limited to: duplicates (relative percent difference); spikes (percent recovery); quality control checks (percent recovery); and blanks. These routine laboratory quality control procedures will be conducted throughout this project.

8.0 PERFORMANCE AND SYSTEMS AUDITS

The Environmental Laboratory Division (DMS) and Aquatic Research, Inc., participate in performance and systems audits for all of their routine procedures. The Environmental Laboratory Division (DMS) laboratory operates in accordance with its standard operation procedure manual. Additionally, the SWM Division has a standing invitation with the Environmental Laboratory Division to observe all operating procedures which can be used to evaluate the quality of the work performed by the laboratory.

9.0 PREVENTIVE MAINTENANCE

To minimize equipment failure in the field or in the laboratory, preventative maintenance will be performed routinely on all equipment. This will include periodic cleaning of equipment, use of fresh standards, and repair of damaged or malfunctioning equipment.

10.0 DATA ASSESSMENT PROCEDURES

Data assessment will be conducted by reviewing quality assurance/quality control data supplied from the laboratory. Holding times will be compared to the data received versus when the analysis was performed along with a review of the methods used and the detection limits obtained. Lab and field duplicate samples will be evaluated for their relative percent differences. Spiked samples will be reviewed for their percent recoveries and quality assurance/quality control checks for the difference between the true value and the found value for individual parameters. Blank samples will also be compared to individual detection limits.

Statistical calculations highlighted in Appendix G of Washington State Department of Ecology's (1991) quality assurance project plan guidelines will be followed to assess whether the data quality objectives were met. Professional judgment will also be used in consultation between the Project Manager and Laboratory personnel.

10.1 Precision

If the results are beyond the established control limits, the analyses should be terminated. Once the problem has been identified and corrected, the analyses affected by the problem will be repeated.

10.2 Bias

Field blanks will be analyzed as routine samples. Criteria will be established with the analytical laboratory regarding the rejection of sample results if the results of a field blank is positive and exceeds the laboratory blank by some factor. These criteria will vary depending on the parameter analyzed.

10.3 Completeness

Completeness will be assured by comparing valid sample data with this quality assurance project plan and the chain-of-custody records. Completeness will be calculated by dividing the number of valid values by the total number of values. Samples will be re-analyzed or re-collected if completeness is less than 95 percent.

11.0 CORRECTIVE ACTION

If quality control procedures indicate problems with data quality, the project managers will initiate corrective actions to ensure the quality of the data collected. Corrective action may include modification of field and laboratory procedures where problems of contamination or technique have been identified.

12.0 QUALITY ASSURANCE REPORTS

Laboratory reports and quality assurance worksheets will be included in the quarterly project progress report. Any problems and associated corrective actions taken will be reported. Specific quality assurance information that may be noted in the report includes the following:

- changes in the monitoring quality assurance project plan
- results of performance and/or system audits
- significant quality assurance problems and recommended solutions
- data quality assessment in terms of precision, accuracy, representativeness, completeness, comparability and detection limits.
- discussion of whether the quality assurance objectives were met and the resulting impact on decision making and limitations on use of the data.

13.0 REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1992. Standard Methods for the Examination of Water and Wastewater. 18th Edition.

United States Environmental Protection Agency (USEPA), 1988. Recommended Protocols for Measuring Conventional Water Quality Variables and Metals in Freshwaters of the Puget Sound Region.

USEPA, 1986. Quality Criteria for Water.

Washington State Department of Ecology (WSDOE), 1991. Diagnostic Study of Lake Sawyer, King County, Washington. February 1989 through March 1990.

Washington State Department of Ecology (WSDOE), 1991. Guidelines and Specifications for Preparing Quality Assurance Project Plans.

WSDOE, 1993. Chapter 173-201A WAC: Water Quality Standards for Surface Waters of the State of Washington.

PRECISION AND ACCURACY INFORMATION FOR CONVENTIONAL PARAMETERS

PARAMETER	DESCRIPTION	PRECISION	ACCURACY	REFERENCE
Alkalinity	Titration	120+/-5mg/L	9mg/L low bias on 120mg/L	SM2320-B
Acid Volatile Sulfides	subcontractor	none available	none available	SM4500-S
Bioavailable Ortho Phosphorous	Auto analyzer	same as orthoposphorus	same as orthophosphorus	METRO
Biochemical Oxygen Demand	Titration	300+/-30.5	none available	SM5210
Cation Exchange Capacity	subcontractor	none available	none available	SW 846 9080 / 9081
Chloride	Ion Chromatography	26+/-2.5	-11% bias	SM4500-CL-F
Chlorophyll	Spectrophotometric	none available	none available	SM10200-H
Cyanide	Colorimetric,manual	0.900+/-0.051	7%bias	SM4500-CN-C,E
Cyanide, Weak and dissociable	Colorimetric,manual	same as cyanide	same as cyanide	SM4500-CN-I,E
Chemical Oxygen Demand	Closed reflux	208+/-10mg/L	none available	SM5220-D
Color	Visual Comparison	none available	none available	SM2120-B
Conductivity	Conductivity meter	0.1 to 1.0%	none available	SM2510-B
Dissolved Organic Carbon	Combustion, IR	within 10%	none available	SM5310-B
Fluoride	Ion Chromatography	8.49+/-0.36	-2.6% bias	SM4500F-F
Hardness	EDTA Titration	610+/-17mg/L	0.8% relative error	SM2340-C
Methylene Blue Act. Substance	subcontractor	none available	none available	SM5540-C
Ammonia	Phenate,automated	0.2mg/L+/-39%	2.4% relative error	SM5500-NH3-H
Nitrite	Colorimetric,automated	0.2mg/L +/-.04	<5% relative error	SM4500-NO2-B
Nitrite/Nitrate	Colorimetric, Cd reduction, automated	same as nitrite	same as nitrite	SM4500-NO3-F
Nitrate	Colorimetic, Cd reduction,automated	same as nitrite	same as nitrite	SM4500-NO3-F
Total Oil and Grease	Gravimetric and IR	12.6 +/-1	-7% bias	SM5520-B (5520-D.B for soxhlet)
Oil Petro (non polar)	Gravimetric and IR	same as total oil	same as total oil	SM5520-F
Oil Polar (non-petro)	Gravimetric and IR	same as total oil	same as total oil	SM5520-F
Organic Nitrogen	subcontractor	same as total oil	same as total oil	SM4500-N ORG
Orthophosphorous	Ascorbic acid,automated	0.340mg/L +/-0.015	-10%bias	SM4500-P-F
pH	pH meter	7.3+/-0.13	+/-0.1ph units	SM4500-H,B
Phenol	photometric,manual	none available	none available	SM5530-D
Pheophytin	Spectrophotometric	none available	none available	SM10200-H
Particle Size Distribution	subcontractor	none available	none available	PSEP,1986
Oxidation Reduction Potential	pH meters	+/-15mv	within 10mV	SM2580-B
Salinity	Salinometer	none available	none available	SM2520-B
Settleable Solids (grav)	by difference	none available	none available	SM2540-F
Settleable Solids (vol)	Imhoff cones	same as grav	same as grav	SM2540-F
Silica	subcontractor	none available	none available	SM4500-Si-D
Sulfate	Ion Chromatography	95.0+/-6.8	-5% bias	SM4500-SO4-F
Sulfide	subcontractor, varies	none available	none available	SM4500-S
Total Dissolved Phosphorous	ascorbic acid,manual	same as total phosphorus	same as total phosphorus	SM4500-P-B,C

PARAMETER	DESCRIPTION	PRECISION	ACCURACY	REFERENCE
Total Dissolved Solids	Dried at 180C	293+/-21	none available	SM2540-C
Total Kjeldahl Nitrogen	subcontractor	none available	none available	SM4500-N-B
Total Organic Carbon	Combustion, IR	within 10%	none available	SM5310-B
Total Nitrogen	Colorimetric, manual	none available	none available	BACHMAN & CANFIELD
Total Petroleum Hydrocarbons	IR	none available	-3%bias	SM5520-F
Total Phosphorous	ascorbic acid,manual	0.228mg/L +/-1.75%	2.38% relative error	SM4500-P-B,E
Total Solids	Dried at 103C	6%	none available	SM2540-B
Total Sulfur	subcontractor	none available	one available	SUBCONTRACTOR
Total Suspended Solids	Dried at 103C	33% at 15mg/L, 10% at 242mg/L	none available	SM2540-D
Total Suspended Solids 0.45	Dried at 103C	same as TSS	same as TSS	SM2540-D
Turbidity	Nephelometric	none available	none available	SM2130-B
Total Volatile Solids	Dried at 500C	170+/-11	none available	SM2540-E
Volatile Suspended Solids	Dried at 500C	same as TVS	same as TVS	SM2540-E
Dissolved Oxygen (Winkler)	Titration	+/- 0.1mg/L	none available	SM4500-O-B

note: none available is used in cases where the official reference method does not list any information. This is because in some cases it's difficult to determine the accuracy on real samples (eg BOD). In addition, none available is used in the cases of subcontracted parameters. This is because we do not currently have information from the subcontracted laboratory.

DESPINA\PROD4A.DOC

PRECISION AND ACCURACY INFORMATION FOR TRACE METALS

Parameter	Reference	Precision	Bias
Ag	EPA 200.7	Not available at this time.	
Al	EPA 200.7	RSD = 5.6% a @ 700 ug/L	-0.6%
		33%a @ 60 ug/L	3%
As	EPA 200.7	RSD = 7.5% a @ 200 ug/L	4%
		23%a @ 22 ug/L	-14%
	EPA 206.2	s = ± 0.7b @ 20 ug/L	5%
		± 1.6b @ 100 ug/L	1%
Ba	EPA 200.7	Not available at this time.	
Be	EPA 200.7	RSD = 6.2% a @ 750 ug/L	-2%
		9.8%a @ 20 ug/L	0%
Ca	EPA 200.7	Not available at this time.	
Cd	EPA 200.7	RSD = 12% a @ 200 ug/L	-4%
		16%a @ 22 ug/L	16%
	EPA 213.2	s = ± 0.10b @ 20 ug/L	4%
		± 0.33b @ 100 ug/L	2%
Cr	EPA 200.7	RSD = 3.8% a @ 700 ug/L	-1%
		18%a @ 60 ug/L	0%
	EPA 218.2	s = ± 0.1b @ 19 ug/L	-3%
		± 0.8b @ 77 ug/L	2%
Cu	EPA 200.7	RSD = 5.1% a @ 700 ug/L	-6%
		40%a @ 60 ug/L	0%
	EPA 220.2	Not available at this time.	
Fe	EPA 200.7	RSD = 3.0% a @ 700 ug/L	-1%
		15%a @ 60 ug/L	-5%
K	EPA 200.7	RSD = 2.7% a @ 700 ug/L	3%
		6.7%a @ 60 ug/L	2%
Mg	EPA 200.7	Not available at this time.	

PRECISION AND ACCURACY INFORMATION FOR TRACE METALS (continued)

Parameter	Reference	Precision	Bias
Mn	EPA 200.7	RSD = 2.7% a @ 700 ug/L	-1.4%
		6.7%a @ 60 ug/L	0.000
Ni	EPA 200.7	RSD = 5.8% a @ 700 ug/L	-2%
		11%a @ 60 ug/L	-7%
Pb	EPA 200.7	RSD = 16% a @ 700 ug/L	-6%
		32%a @ 60 ug/L	25%
	EPA 239.2	s = ± 1.3b @ 25 ug/L	-12%
		± 3.7b @ 100 ug/L	-5%
Se	EPA 200.7	RSD = 22% a @ 40 ug/L	-20%
		42%a @ 6 ug/L	142%
	EPA 270.2	s = ± 0.6b @ 5 ug/L	-8%
		± 0.5b @ 20 ug/L	0
Zn	EPA 200.7	RSD = 5.6% a @ 200 ug/L+0.5%	
		45%a @ 16 ug/L	19%

References: EPA Methods for Chemical Analysis of Water and Wastes,
EPA Methods for Chemical Analysis of Water and Wastes,

Notes: a = Interlaboratory precision
b = Intralaboratory or single analyst precision

APPENDIX A

circled days for
○ = pickup days for precip. samples

Routine = Lake -
Baseflow = Stream

Routine Sampling Dates for Lake Sawyer and Baseflow Sampling Dates

DATE	MAJOR COMPONENT(S)
~~March 9, 10 1994~~	~~inlets/outlet, in-lake~~ missed
~~April (6) 7 1994~~	~~inlets/outlets, in-lake~~ missed
May (11) 12	inlets/outlets, in-lake
May 26 Quarterly	in-lake
June (8) [9] A,B,C,D	inlets/outlet, in-lake
June 23	in-lake, benthics
July ~~(6)~~ [7] A,B,C,D	inlets/outlet, in-lake,
July 20, 21	sediments, in-lake
August (3) [4] Quarterly	inlets/outlet, in-lake, benthics
August 16th 17, [18] A,B,C,D	macrophytes, in-lake
September (7) 8	inlets/outlet, in-lake
September [2~~2~~1] A,B,C,D	in-lake
October (12) 13	inlets/outlet, in-lake, benthics
November (16) [17] Quarterly	inlets/outlets, in-lake
December (14) 15 1994	inlets/outlet, in-lake
January (18) 19, 1995	inlets/outlets, in-lake
February (15) [16] 1995 Quarterly	inlets/outlet, in-lake
March (16) 1995	in-lake
April (19) 20 1995	inlets/outlet, in-lake
May —, — 1995	inlets/outlet, in-lake
Note: Three storm samples will be sampled during sping and winter.	

CONTAINERS, PRESERVATION AND HOLDING TIMES

Parameter	Container	Sample Size(mL)	Preservation	Holding Time
Acidity	Poly or Glass	100	Cool, 4°C	14 Days
Alkalinity	Poly or Glass	100	Cool, 4°C	14 Days
BOD_5	Poly or Glass	2000	Cool, 4°C	48 Hours
COD	Poly or Glass	100	Cool, 4°C, H_2SO_4 to pH < 2	28 Days
Chloride	Poly or Glass	100	None	28 Days
Color	1-L Cubetainer	100	Cool, 4°C	48 Hours
Conductivity	Poly	1000	Cool, 4°C	28 Days
Cyanide	Poly or Glass	500	Cool, 4°C, 0.6 g ascorbic acid	14 Days
Fluoride	Polyethylene	100	None	28 Days
Hardness	Poly or Glass	100	HNO_3 or H_2SO_4 to pH < 2	6 Months
Ammonia N	Poly	125	Cool, 4°C, H_2SO_4 to pH < 2	28 Days
Kjeldahl N	Poly	125	Cool, 4°C, H_2SO_4 to pH < 2	28 Days
NO_3^--NO_2^- N	Brown Poly	125	Cool, 4°C, H_2SO_4 to pH < 2	28 Days
Metals	Poly	250	HNO_3 to pH < 2(1)	6 Months
Cr^{+6}	Poly or Glass	250	Cool, 4°C	24 Hours
Hg	Poly	250	HNO_3 to pH < 2	28 Days
Oil & Grease	Glass	500	Cool, 4°C, H_2SO_4 to pH < 2(2)	28 Days
TOC	Amber Glass	50	Cool, 4°C, Store in dark, HCl or H_2SO_4 to pH < 2	28 Days
PO_4^{-3} P	Brown Poly	125	Filter immediately, Cool, 4°C	48 Hours

CONTAINERS, PRESERVATION AND HOLDING TIMES (Continued)

Parameter	Container	Sample Size(mL)	Preservation	Holding Time
Total P	Poly	125	Cool, 4°C, H_2SO_4 to pH < 2	28 Days
Solids	Poly or Glass	500	Cool, 4°C	7 Days
Sulfate	Poly or Glass	100	Cool, 4°C	28 Days
Turbidity	Poly or Glass	100	Cool, 4°C	48 Hours
Coliform	Sterile Glass	250	Cool, 4°C, 0.008% $Na_2S_2O_3$	6 Hours[3]
Volatile Organics	Glass, Teflon lined septum	40	Cool, 4°C, 0.008% $Na_2S_2O_3$, HCl to pH 2	14 Days
Phenolics	Glass, Teflon lined lid	500	Cool, 4°C, H_2SO_4 to pH < 2	28 Days
BNAs	Glass, Teflon lined lid	2000	Cool, 4°C, 0.008% $Na_2S_2O_3$	7 Days to extraction, then 40 Days
Pesticides & PCBs	Glass, Teflon lined lid	200	Cool, 4°C	7 Days to extraction, then 40 Days
Chlorophyll	Brown Poly	1000	Cool, 4°C	
TOX	Amber Glass, Teflon lined lid	500	Cool, 4°C, HNO_3 to pH 2, 5 mg Na_2SO_3/L	14 Days

(1) Samples for total metals analysis can be acidified at the lab if they arrive within 24 hours of collection and have been maintained at 4°C from the time of collection. Be sure not to acidify samples for <u>dissolved metals</u> analysis prior to filtration.

(2) Samples for oil and grease analysis can be acidified at the lab if they arrive "within a few hours" of collection and have been maintained at 4°C from the time of collection.

(3) The Manchester Lab Users Manual lists a holding time of 30 hours. EPA is allowing 30 hours as a practical matter.

Soil and sediment samples should be collected in 8 Oz. wide-mouth glass jars with Teflon lid liners. The jar should be nearly full and samples should be cooled to 4°C during transportation and storage.

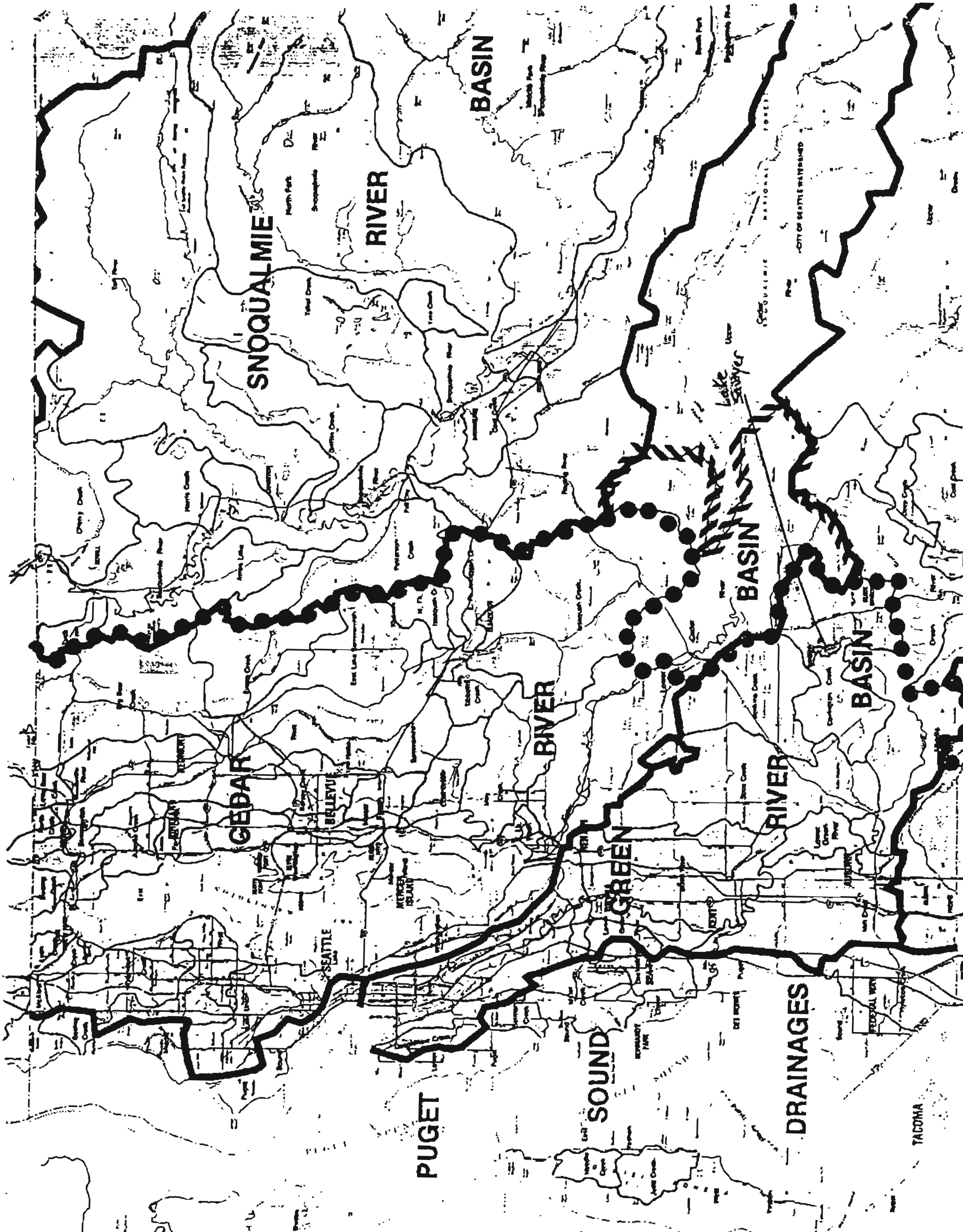

Figure 1: Location of Lake Sawyer, Metropolitan King County, Washington

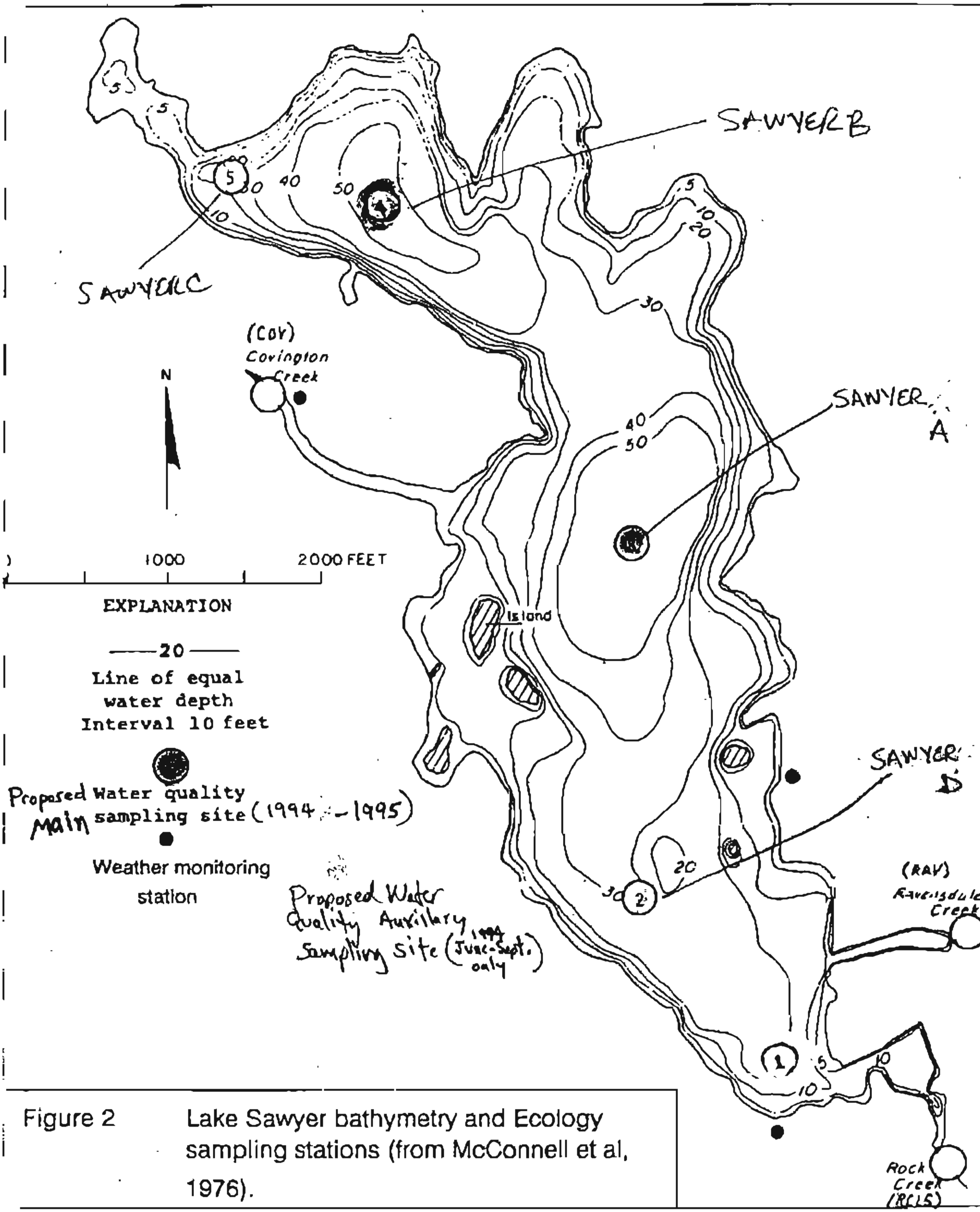

Figure 2 Lake Sawyer bathymetry and Ecology sampling stations (from McConnell et al, 1976).

Lake Sawyer Station Descriptions

Station	Description	Depth
SAWYERA	Central lake basin in-lake sampling station (deep).	0,3,6,9,12,15,17.5
SAWYERB	North lake basin in-lake sampling station (deep).	0,3,6,9,12,15
SAWYERC	(Auxillary) North lake basin in-lake sampling station (shallow).	0,3,6
SAWYERD	(Auxillary) South lake basin in-lake sampling station (shallow).	0,3,6
LSIN1	Rock Creek Inflow at Mouth	
LSIN2	Rock Creek at Morganville Bridge	
LSIN3	Rock Creek at Abrahms Ave.	
LSIN4	Rock Creek at Morgan Street	
LSIN5	Black Diamond Lake Outflow	
LSIN6	Jones Lake Inflow at HWY. 167	
LSIN7	Tributary to Ginder Creek (Mud Creek @ PCCC)	
LSIN8	Ginder Creek at Hwy 169	
LSIN9	Ravensdale Creek Inflow at Mouth	
LSOUT10	Lake Sawyer Outflow	
LSPRECIP1	PRECIP @ Mr. & Mrs. McPherson	
LSPRECIP2	PRECIP @ John Davies	
LSBACK007	Mine Runoff samples (background) } to	
LSMUD002	" " (outfall location)	

APPENDIX B

KING COUNTY SURFACE WATER MANAGEMENT DIVISION

INSTRUCTIONS FOR PRECIPITATION SAMPLE COLLECTION FOR LAKE SAWYER WATER QUALITY STUDY

1. Write your name, home location, and the time of day you plan to read your rain gauge on the enclosed data sheet (Morning is preferred).

2. Each day, record how much rain has fallen and empty your rain gauge into the labeled sample collection bottle. Once the sample bottle contains some rainfall, store it in the freezer and remove it only to add more sample or to have the sample picked up.

3. Bob Storer (296-8383) will pick up your sample on a regularly scheduled basis (see attached pickup date schedule). He will call you beforehand to arrange for the sample pick-up.

4. If you are home during especially wet periods, try to record the rainfall in both the morning and evening.

5. During periods of freezing weather, be sure your gauge is kept empty so that it will not break.

6. If you are unable to read your gauge for several days, please draw a vertical arrow through the days you were gone and enter the accumulated rainfall into your dample container and return it to the freezer. If at all possible, ask a neighbor to take over your sample monitoring and collection responsibilities for the time that you will be gone. If you are gone for several days during freezing weather with no one to monitor for you, please take the gauge inside to prevent freezing.

7. For the Lake Sawyer study, we will be collecting samples through March, 1995. We would like to have you continue participation in the precipitation monitoring and complete the data form which goes through September, 1995.

8. If you have questions at any time, please feel free to call Bob Storer, 296-8383 (W) or 488-9327 (H).

This project is funded in part through a Washington State Department of Ecology Centennial Clean Water Fund Grant.

KING COUNTY SURFACE WATER MANAGEMENT DIVISION

LAKE SAWYER WATER QUALITY STUDY
WEEKLY LAKE LEVEL RECORDING

WEEK #	DATE	LAKE LEVEL	WEEK #	DATE	LAKE LEVEL
1			27		
2			28		
3			29		
4			30		
5			31		
6			32		
7			33		
8			34		
9			35		
10			36		
11			37		
12			38		
13			39		
14			40		
15			41		
16			42		
17			43		
18			44		
19			45		
20			46		
21			47		
22			48		
23			49		
24			50		
25			51		
26			52		

OBSERVER____________________ WATER YEAR____________________

OBSERVATION TIME________________ LOCATION____________________

APPENDIX C

Lake Sawyer Field Sheet

Date: ______________ Samplers: ______________

eather:

Current ______________

Past 48hrs ______________

Station: Lake SawyerA (SAWYERA)

Depth (m)	Time	Temp (C)	DO (mg/L)	Cond (µS)	pH	Light
0						
3						
6						
9						
12						
15						
17.5						
Field Rep						

Secchi Depth (M): ______________

Surface Light: ______________ at ______________

Euphotic Zone Depth (M): ______________

Zooplankton Haul Depth (M): ______________

Phytoplankton Sample: ______________

Duplicate TP at Surface, and Bottom: ______________

Duplicate Chlorophyll a: ______________

Comments:

Date: ____________ Samplers: ____________

Weather:

Current ____________

Past 48hrs ____________

Station: Lake SawyerB (SAWYERB)

Depth (m)	Time	Temp (C)	DO (mg/L)	Cond (μS)	pH	Light
0						
3						
6						
9						
12						
15						
Field Rep						

Secchi Depth (M): ____________

Surface Light: ____________ at ____________

Euphotic Zone Depth (M): ____________

Zooplankton Haul Depth (M): ____________

Phytoplankton Sample: ____________

Duplicate TP at Surface, and Bottom: ____________

Duplicate Chlorophyll a: ____________

Comments:

Lake Sawyer Field Sheet

Date: ______________

Weather:

Current: ____________________

Past 48hrs: ____________________

Samplers: ________________

____

Stations: Inlets/Outlet
Lake Sawyer Inflows 1-9
Lake Sawyer Outflow 10

Station	Time	Temp (C)	DO (mg/L)	Cond (uS)	pH
LSIN1 (Rock Cr Mouth)					
LSIN2 (Rock Cr Morganville Br)					
LSIN3 (Rock Cr Abrahms Ave.)					
LSIN4 (Rock Cr Morgan St.)					
LSIN5 (Black Diamond Lake Outfl)					
LSIN6 (Jones Lake Inf at Hwy 169)					
LSIN7 (Trib to Ginder Cr (PCCC)					
LSIN8 (Ginder Cr. at Hwy 169)					
LSIN9 (Ravensdale Cr Mouth)					
LSOUT10 (Lake Sawyer Outflow)					
Field Rep					

Rock Creek at Morganville Bridge
Upstream Staff Gage (LSIN2) = ______

Comments:

Rock Cr Inflow
South Staff Gage (LSIN1) = ______

Rock Cr Inflow
North Staff Gage = ______

Ravensdale Cr Inflow
Staff Gage (LSIN9) = ______

Lake Sawyer Outflow
Staff Gage (LSOUT10) = ______

Project: ______________________

struments

Extra Batteries
Benthos Sieve/Forceps
Compositors
Conductivity Meter
DO Meter
DI Water
Flow Meter
Flow Meter Rod
Measuring Tape
Messengers
pH Meter
pH Buffers
Ponar Sampler
Secchi Disk
Sediment Pail/Spoon
Thermometer
Van Dorn (1)
Zooplankton Net & Weight
____
____

Miscellaneous

Buckets/Extra Bottles
Calculator
Clip Board
Compass
Equipment Manuals
Field Notebook
Flashlight
Ice Chest
Knife
Maps/Charts
Pens/Sharpies
Rope
Tape
Tools
____
____
____
____
____

Bottles

Zooplankton (Glass)
Phytoplankton (Nalgene)
Nutrients
Chlorophyll a
Turbidity/Alkalinity
Fecals
Anions
Cations
Metals

Boat/Clothes

Rubber Boots
Raingear
Gloves
Rubber Gloves
Anchor/Rope
Weight
Life Vests
Paddles

Lake Sawyer Field Sheet

Date: ______________ Samplers: ______________

Weather:
Current ______________
Past 48hrs ______________

Station: Lake Sawyer 5 (SAWYER5) Auxillary (Sampled only on June 9, July 7, Aug. 18, & Sept. 21)

Depth (m)	Time	Temp (C)	DO (mg/L)	Cond (µS)	pH	Light
0						
3						
6						
Field Rep						

Secchi Depth (M): ______________

Surface Light: ______________ at ______________

Euphotic Zone Depth (M): ______________

Zooplankton Haul Depth (M): ______________

Phytoplankton Sample: ______________

Duplicate TP at Surface, and Bottom: ______________

Duplicate Chlorophyll a: ______________

Comments:

Lake Sawyer Field Sheet

Date: ____________ Samplers: ____________

Weather:
Current ____________
Past 48hrs ____________

Station: Lake Sawyer D (SAWYER D) Auxillary (sampled only on June 9, July 7, Aug. 18, & Sept. 21)

Depth (m)	Time	Temp (C)	DO (mg/L)	Cond (µS)	pH	Light
0						
3						
6						
Field Rep						

Secchi Depth (M): ____________

Surface Light: ____________ at ____________

Euphotic Zone Depth (M): ____________

Zooplankton Haul Depth (M): ____________

Phytoplankton Sample: ____________

Duplicate TP at Surface, and Bottom: ____________

Duplicate Chlorophyll a: ____________

Comments:

APPENDIX D

METRO ENVIRONMENTAL LABORATORY *322 West Ewing Street* *Seattle, WA 98119*

LABORATORY WORK ORDER

page 1 of

Project Name: KC-Lake Sawyer IN-LAKE ROUTINE

Project Number: 840179BT (KC.BTIL)

Laboratory Project Manager: Mary
684-235

Sampler(s): ____________________

Sample #	Locator	Sample Depth	Collect Date	ALK	TURB	TOTP	TOTN	NH3	NO23	ORTHOP	FE-ICP	AL-ICP	COLOR	CLOA/PHAEO	CL	TOC	# of Containers	Comments
	SAWYERA	0		X	X	X	X	X	X	X			X	X	X			
	SAWYERA	3		X	X	X	X	X	X	X				C				
	SAWYERA	6		X		X	X	X	X	X								
	SAWYERA	9		X		X	X	X	X	X								
	SAWYERA	12		X		X	X	X	X	X								
	SAWYERA	15		X		X	X	X	X	X						X		
	SAWYERB	0		X	X	X	X	X	X	X			X	X	X			
	SAWYERB	3		X	X	X	X	X	X	X				C				
	SAWYERB	6		X		X	X	X	X	X								
	SAWYERB	9		X		X	X	X	X	X								
	SAWYERB	12		X		X	X	X	X	X								
	SAWYERB	15		X		X	X	X	X	X						X		
	SAWYERADUP	X		X		X	X	X	X	X				X				Field Duplicat
	SAWYERBDUP	X		X		X	X	X	X	X				X				Field Duplicat
	SAWYERA	17.5		X		X	X	X	X	X								

Additional comments:

Total Number of Containers:

C = COMPOSITED IN FIELD (0.5, 1.5, 2.5, 3.5M)

RELINQUISHED BY	Date	RECEIVED BY	Date
Signature		Signature	
Printed Name	Time	Printed Name	Time
Organization		Organization	

METRO ENVIRONMENTAL LABORATORY 322 West Ewing Street Seattle, WA 98119

ORATORY WORK ORDER

ect Name: KC-Lake Sawyer INLETS/OUTLET STORM

ject Number: B40179BT (KC.BTINST)

Laboratory Project Manager: Mary Silva 684-2359

Sampler(s): ____________________

Sample #	Locator	Sample Depth	Collect Date	TSS	TURB	TOTP	TOTN	NH3	NO23	ORTHOP	CL	HARDNESS	CU, PB, ZN-ICP	CU, PB, ZN-ICP, DISS	FC-MF	# of Containers	Comments
	LSIN1			X	X	X	X	X	X	X	X	X	X	X	X		
	LSIN2			X	X	X	X	X	X	X	X	X	X	X			
	LSIN3			X	X	X	X	X	X	X	X	X	X	X			
	LSIN4			X	X	X	X	X	X	X	X	X	X	X			
	LSIN5			X	X	X	X	X	X	X	X	X	X	X			
	LSIN6			X	X	X	X	X	X	X	X	X	X	X			
	LSIN7			X	X	X	X	X	X	X	X	X	X	X			
	LSIN8			X	X	X	X	X	X	X	X	X	X	X			
	LSIN9			X	X	X	X	X	X	X	X	X	X	X			
	LSOUT10			X	X	X	X	X	X	X	X						
	LSINOUTDUP			X	X	X	X	X	X	X	X	X	X	X	X		Field Duplicate
	LSIN1			X	X	X	X	X	X	X	X	X	X	X			Composite
	LSIN9			X	X	X	X	X	X	X	X	X	X	X			Composite
	LSIN9																

Additional comments:

Total Number of Containers:

RELINQUISHED BY	Date	RECEIVED BY	Date
Signature		Signature	
Printed Name	Time	Printed Name	Time
Organization		Organization	

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CHAIN-OF-CUSTODY RECORD

SHEET ______ OF ______

CLIENT: ____________________ PROJECT ID: ____________________
SAMPLING DATE: ____________________ CASE FILE NO.: ____________________
SAMPLERS: ____________________
DATA RECORDED BY: ____________________

SAMPLE INFORMATION

PARAMETERS

SAMPLE ID	DATE/TIME COLLECTED																						BOTT #	NOTES

	Relinquished By	Date/Time	Received By	Date/Time
Printed Name				
Signature				
Affiliation				
Printed Name				
Signature				
Affiliation				

Miscellaneous Notes (Hazardous Materials, Quick turn-around time, etc.): ____________________