CHAPTER 5: LAKE WATER BUDGET

A water budget is a measure of the sources of water discharging to and flowing from a lake over the course of a typical year. A water budget was calculated for Lake Desire using field data and the Hydrologic Simulation Program-FORTRAN (HSPF) computer model. This chapter describes the Lake Desire water budget and the methods and data used to calculate it. It also describes how watershed development and associated changes in land cover affect the water budget.

METHOD OF ANALYSIS

As part of the Lake Desire Phase I Restoration Project, King County SWM personnel and local citizen volunteers conducted a field monitoring program from April 1993 through March 1994. Data obtained through this effort included precipitation, stream flow out of the lake, and lake surface elevation. Computer modeling was used to supplement the collected data to calculate of the lake water budget.

The Cedar River Basin (Peterson Creek subbasin) HSPF model, developed by King County in 1991 and updated in 1994, was obtained to perform the water budget calculations. The Lake Desire watershed, comprised of Peterson Creek subcatchments six and seven (P6 and P7), is located in the upper portion of the Peterson Creek subbasin of the Cedar River Basin or watershed (Figure 5-1). The model was revised so that only subcatchment areas and stream reaches relevant to the lake's water budget were included in the analysis. The model's input data files for current, historical, and future conditions and precipitation and evaporation data are included in Lake Desire Background and Technical Reports (King County, 1994a). Model output included simulated flows of water into and out of the lake and changes in lake water level.

Observed surface flows and lake level data were used to estimate groundwater inflows to the lake as a check on the model's simulation of groundwater inflow. This check was completed for the five months in which sufficient observed data were available (November 1993 through March 1994). Groundwater flow estimates completed during a separate hydrogeologic field study (Hong West, 1994) for the project were also used as a check on HSPF simulated groundwater flows.

Residuals resulting from water budget calculations (the volumes of water left over after all outflows are subtracted from all inflows) represent changes in lake water storage as reflected in fluctuating lake levels. Modeled lake levels were compared to observed lake levels to determine how well the model simulated the lake water budget.

DATA USED IN ANALYSIS

Pan evaporation data were not available for the entire period. Missing data were calculated using a program provided by King County and maximum and minimum daily temperature data for the period, which were available from the National Weather Service station at Monroe, WA. Calculated pan evaporation data were compared with observed data for the period in which both were available. Calculated values were found to be acceptable based on a plot of observed and calculated evaporation. Therefore, calculated values were used to fill in missing data.

Backwatering of the lake inflow due to the adjacent wetland area and the lack of a good hydraulic control location immediately upstream of the lake prevented the estimation of discharge data for the lake inflow.

The excellent record of lake levels was used in conjunction with the seasonal outflow data to evaluate model results. Data used as input for the HSPF model are summarized in Table 5-1.

Table 5-1: Description of Data Used in Water Budget

Location	Type of Data	Units	Data Interval	Period of Record (within analysis period)	Data Use
Lake Desire Outflow	Discharge	cfs	15 minutes	Nov. 6, 1993-Mar 31, 1994	Evaluate simulated vs. observed
Gary Dagan property	Lake Level	inches (datum unknown)	Daily	Apr. 1993-Mar 1994	Evaluate simulated vs. observed
Layton (near Spring Lake on SE 196th)	Precipitation	inches	15 minutes	Apr. 1993-Mar 1994	Model input
Puyallup	Pan Evaporation	inches	Daily	June 1993-Aug. 1993	Model Input
Calculated	Pan Evaporation	inches	Daily	Apr. 1993-May 1993 and Sept. 1993-Mar 1994	Model Input

Groundwater

Groundwater flow is typically the most difficult portion of the water budget to quantify because the entire cross-section of flow cannot be monitored. Therefore, groundwater flows are calculated based on field measurements at specific well or seepage meter locations, or based on water budget calculations used to solve for groundwater flow when all other inflows and outflows are known. All these approaches were used to determine groundwater flow into Lake Desire. Groundwater was assumed to flow into the lake only from Subcatchment P6, which surrounds the lake. The locations of the subcatchments draining to Lake Desire are shown on Figure 5-1. In the HSPF model, all groundwater in subcatchment P7 is assumed to flow into the wetland and enter the lake as surface water. Monthly groundwater flows from subcatchment P6 are listed in Table 5-2, along with surface flow and interflow from that subcatchment.

In Table 5-3, groundwater flows based on observed data are compared to those based on the final HSPF run and on field measurements taken by Hong West. Monthly groundwater flows calculated using the observed data were approximately four times greater on average than the groundwater flows simulated by HSPF; groundwater flows determined using the field data were 60 times lower on average than the groundwater flows simulated by the model.

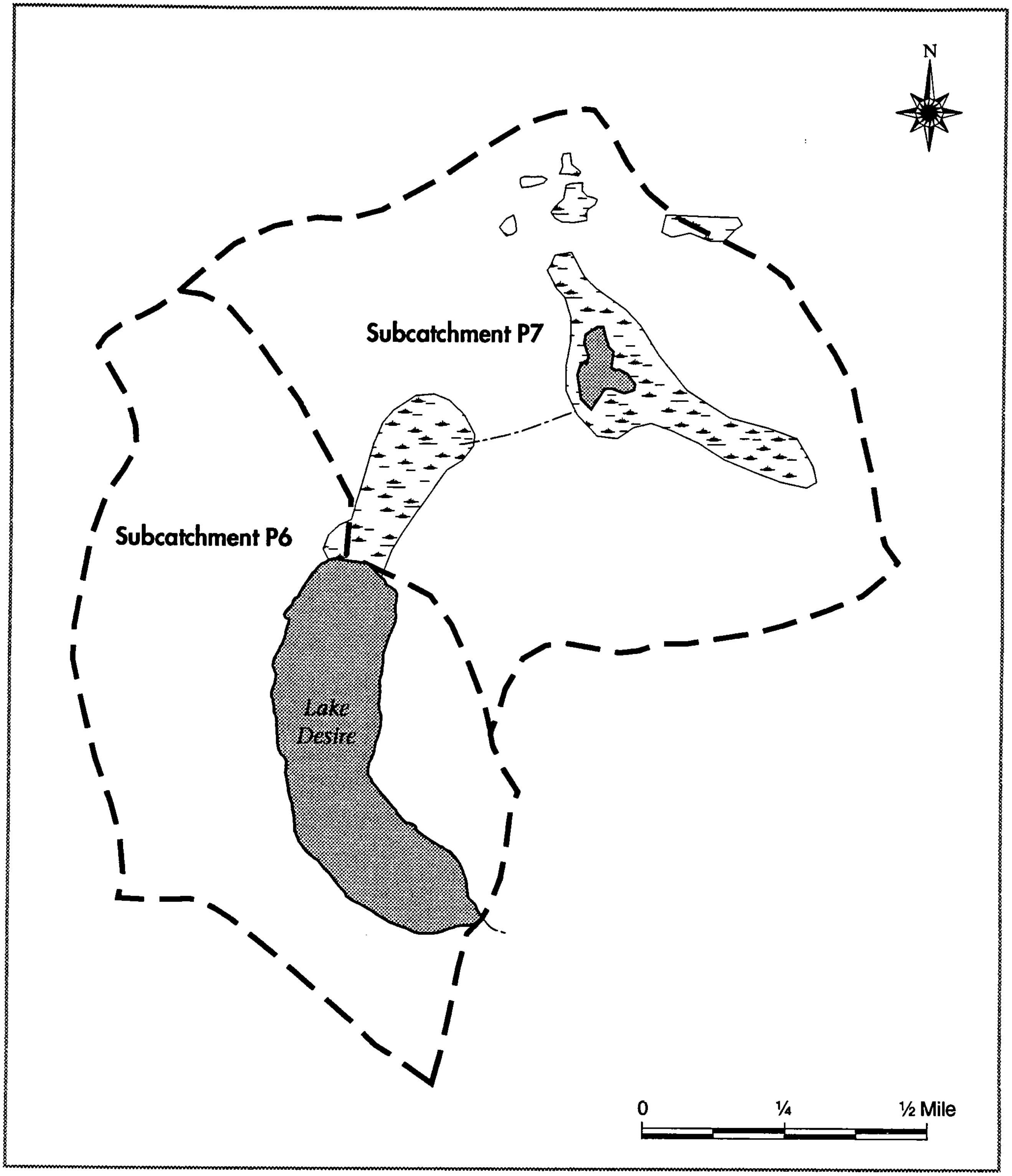


Figure 5-1: Lake Desire Subcatchment Boundaries

Subcatchment Boundary
Stream
Wetland
Lake

King County Surface Water Management
Everyone lives downstream
CARTOGRAPHY & GRAPHICS

Table 5-2: Monthly Flows for Subcatchment P6

Month	Total Surface Outflow (ac-ft)	Total Interflow Outflow (ac-ft)	Total Active Groundwater Outflow (ac-ft)	Total Of P6 Outflows (ac-ft)	Total Surface Outflow (cu. m)	Total Interflow Outflow (cu. m)	Total Active Groundwater Outflow (cu. m)	Total Of P6 Outflows (cu. m)
April	3.1	2.4	1.4	7.0	3836	3015	1788	8640
May	2.8	9.6	6.5	18.9	3431	11884	7966	23281
June	1.3	17.2	11.1	29.6	1550	21216	13696	36463
July	0.6	0.1	9.0	9.7	720	175	11044	11939
August	0.1	0.	7.3	7.4	147	37	9006	9190
September	0.1	0.0	5.7	5.8	168	4	7020	7192
October	1.3	0.0	5.0	6.4	1607	18	6205	7830
November	0.9	0.0	4.4	5.3	1050	53	5412	6515
December	2.7	3.2	7.9	13.8	3341	3947	9759	17047
January	1.9	10.4	14.2	26.5	2344	12773	17555	32672
February	2.4	34.3	16.4	53.1	2994	42249	20257	65501
March	2.8	54.1	28.0	84.9	3499	66695	34529	104722
Total	20.0	131.3	116.9	268.4	24687	162067	144238	330991

Table 5-3: Comparison of Calculated Groundwater Inflows to Lake Desire (values in cubic meters)

Month	Observed Data Water Balance	Final HSPF Calculated "Active" Groundwater	Hong West Field Determined
April	NA	1788	257
May	NA	7966	265
June	NA	13696	115
July	NA	11044	115
August	NA	9006	115
September	NA	7020	259
October	NA	6205	268
November	16410	5412	259
December	85338	9759	287
January	80708	17555	287
February	58625	20257	259
March	62003	34529	265

NA = Data not available
Final HSPF Calculated "Active" Groundwater from final current conditions run (DEEPFR = 0)
Hong West field data described in separate report "King County Lakes Lake Desire Hydrogeologic Evaluation"

Uncertainties in the groundwater flow estimates are due to the following factors:

- Limited field data were available to calculate the mass balance water budget used to solve for groundwater. Gauge lake outflow data were only available from November through March. Lake outflow data during the entire study year are necessary to calculate a mass balance water budget. Subsequently, the water budget could only be calculated for November 1993 through March 1994 and only these months were available for groundwater flow comparison.
- No observed data are available for surface water runoff from Subcatchment P6. Therefore HSPF simulated flows for surface runoff were used in the mass balance water budget calculation. Using a mix of observed and simulated data adds to the uncertainty of the mass balance groundwater flow estimates.
- Calculations of groundwater flows using observed data required use of HSPF simulated data for lake inflow from the wetland because backwatering prevented gauging of the inflow. Data from a gauge at a point further upstream where gauging conditions are more acceptable would reduce the uncertainty in this portion of the water budget.
- The wetland at the lake may act as a storage reservoir, gaining water during wet periods and releasing water during drier periods. This release and storage is difficult to quantify and may not be reflected in the temporal changes predicted by the water budget.
- Use of a limited number of monitoring sites and a limited frequency of observation during the groundwater field study contributes uncertainty to estimates of groundwater flow using field data. While available geologic data indicate that the lake is located on top of a 15- to 100-foot deep till layer (Hong West, 1994), contact of the lake bottom with an underlying aquifer at a point that was not monitored may result in underestimation of groundwater inflows to the lake.

Given these uncertainties and the fact that estimates of groundwater flow to Lake Desire are at best an order of magnitude determination (Hong West, 1994), the final HSPF simulation was used for the current conditions water budget presented in this report.

RESULTS

Model Verification

The acceptability of the model output was evaluated by comparing plots of simulated and observed lake level. The simulated lake levels are within 4 inches of the observed lake levels (see Figure 5-2). Observed and simulated stream inflows, outflows, precipitation, and evaporation were also compared (KCM 1994e).

Study Year Water Budget

Following examination of model output, monthly totals were calculated and plotted for all lake inflows and outflows (Figure 5-3). The percentages of total lake inflow from Subcatchment P6, Subcatchment P7, and precipitation and the percentages of total lake outflow to the outlet stream and evaporation for the study year are shown in Figure 5-4 and Table 5-4.

Figure 5–2 Lake Desire Observed vs Simulated Lake Level

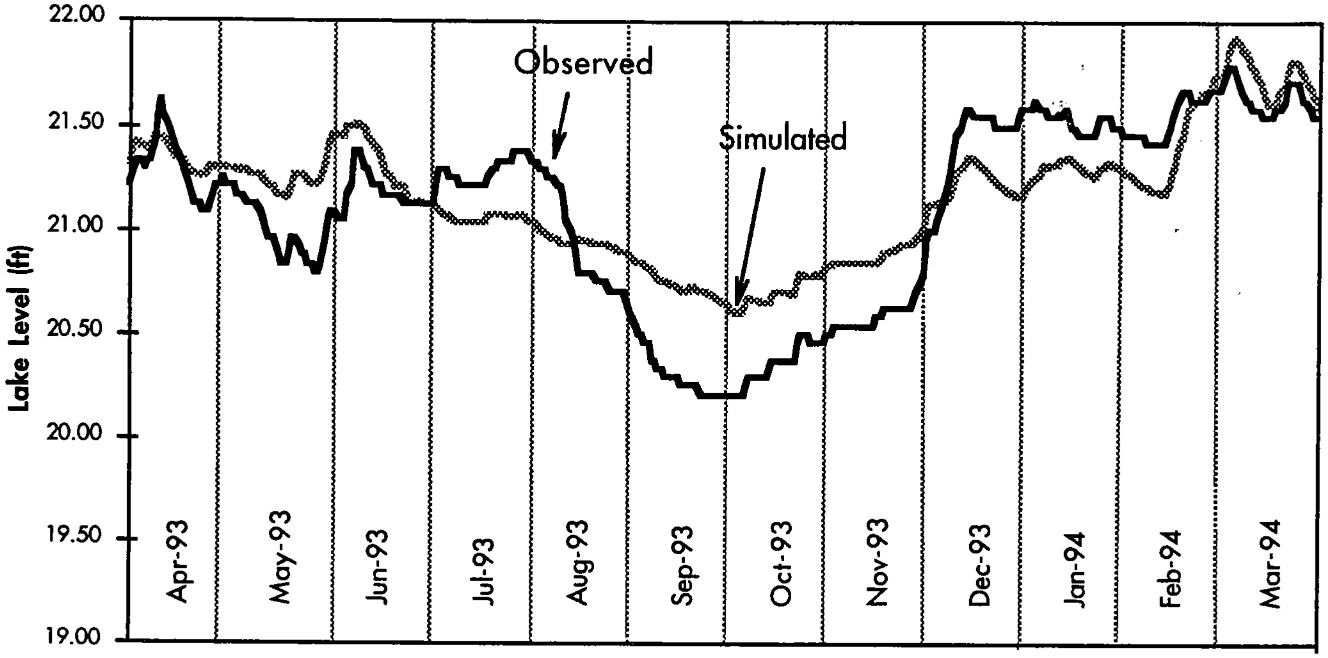


Figure 5–3 Lake Desire Monthly Water Balance Current Conditions

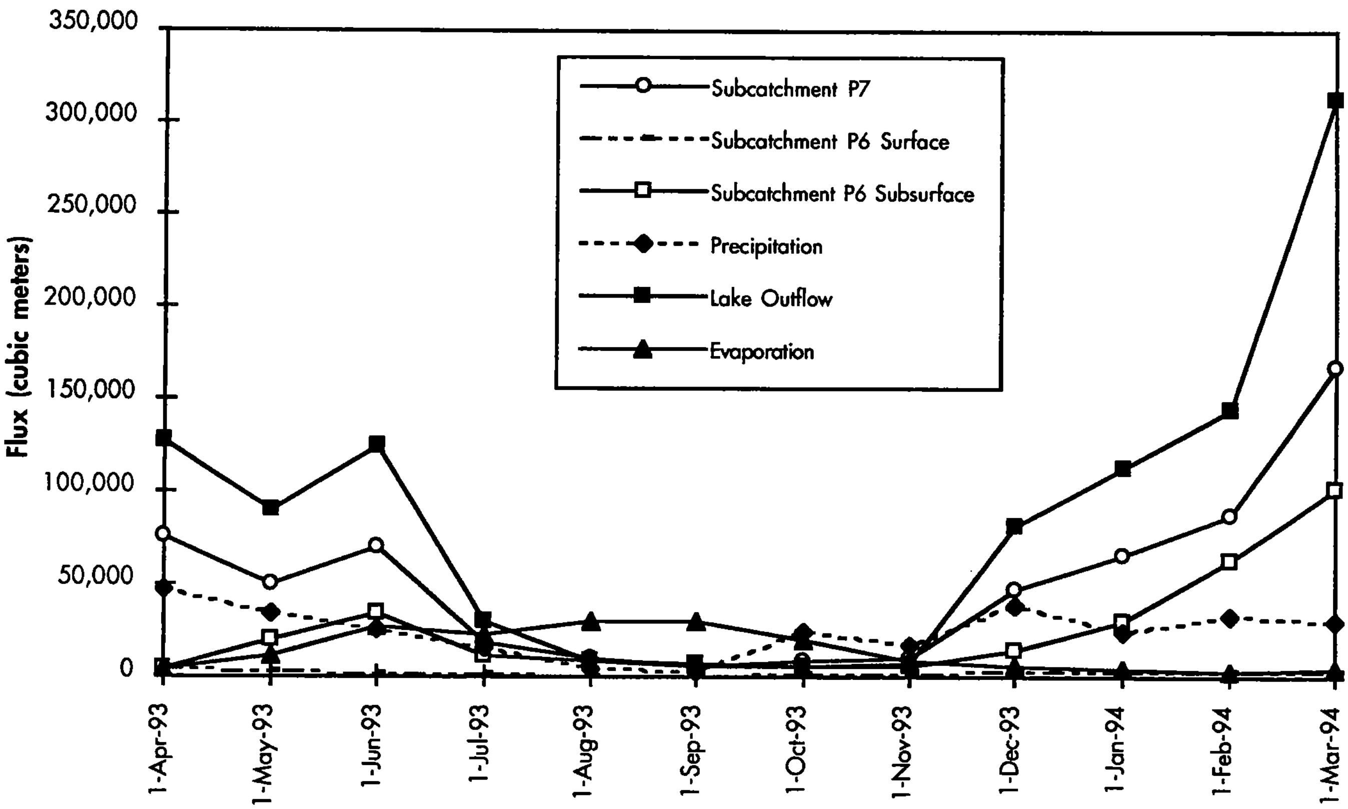
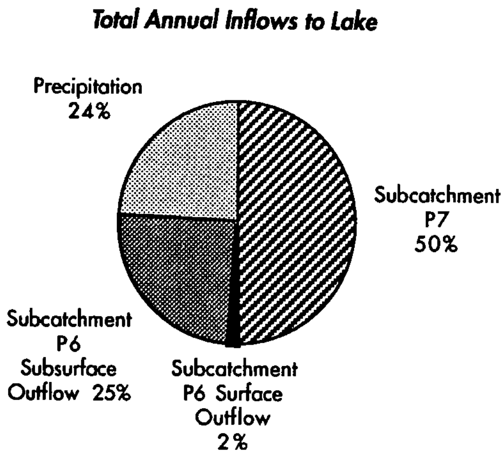


Figure 5–4 Lake Desire Annual Water Balance, Current Conditions



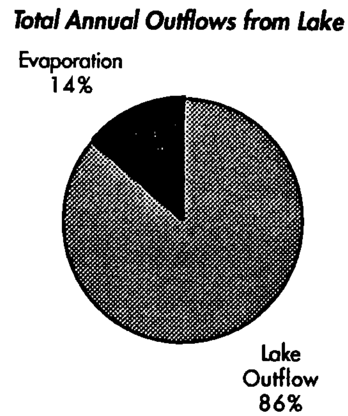


Table 5-4: Lake Desire Water Balance, April 1993 - March 1994

Month / Year	Sub-catchment P7	Sub-catchment P6 Surface	Sub-catchment P6 Subsurface	Precipita-tion	Lake Outflow	Evapora-tion
Apr 1993	75,820	3,830	4,810	46,710	127,320	3,960
May 1993	50,310	3,430	19,850	33,980	90,210	11,060
Jun 1993	70,120	1,550	34,920	25,520	124,200	27,380
Jul 1993	18,930	720	11,220	15,380	29,480	22,750
Aug 1993	10,250	150	9,040	3,610	8,510	29,600
Sep 1993	5,230	170	7,030	2,900	5,460	30,340
Oct 1993	8,310	1,600	6,230	24,200	5,230	19,520
Nov 1993	9,830	1,050	5,460	17,060	6,440	8,380
Dec 1993	47,630	3,340	13,710	38,030	81,510	5,390
Jan 1994	65,180	2,340	30,330	23,590	113,250	4,060
Feb 1994	87,490	3,000	62,500	33,020	143,520	2,330
Mar 1994	167,110	3,500	101,230	30,120	312,200	3,740
Total	616210	24680	306330	294120	1047330	168510

All measurements in cubic meters
Annual Balance:
Wetland Outflow + Basin P6 Surface and Subsurface Outflows + Precipitation - Lake Outflow - Evaporation = Change in Storage = 25,490 cubic meters

The total annual inflow to the lake for the study period was 1,241,340 cubic meters. The total annual outflow from the lake was 1,215,840 cubic meters. This represents a net gain in lake volume of 25,500 cubic meters, which is equivalent to an increase in lake elevation of approximately 4 inches.

There are many more pathways for water flowing into the lake than out of the lake. Almost half the inflow to the lake came from the Subcatchment P7. Annual subsurface flow to the lake (interflow and groundwater flow) from Subcatchment P6 was more than 10 times greater than surface flow from that subcatchment. Precipitation on the 80-acre lake accounted for 24 percent of the total annual inflow. Lake outflow occurred only through evaporation and the lake outlet stream. Outflow to the stream was more than six times greater than the evaporative loss for the year.

Monthly total precipitation during the study period (April 1993-March 1994) was compared to long-term monthly averages at Sea-Tac Airport and monthly pan evaporation totals for the period were compared to long-term monthly averages for Puyallup (KCM 1994e). This comparison showed that the spring and summer of the monitored year were wetter than usual and the autumn and winter were drier than usual. Pan evaporation data for the period closely approximated the long-term averages even though values were consistently higher than the long-term average between August and December 1993. Precipitation from April through July 1993 was consistently greater than the long-term average, while precipitation from August 1993 through March 1994 was generally less than the long-term average. Total annual precipitation at the Layton gauge (SE 196th St.) for the study period was 40.86 inches, compared to a long-term annual average of 38.31 inches at Sea-Tac.

Historical and Future Conditions Simulations

Historical and future conditions were simulated for comparison to current conditions to assess changes to the lake water budget due to changes in land cover. Data relating to land cover changes were developed by King County Surface Water Management as follows (D. Hartley, KCSWM Senior Hydrologist, 3 October 1994, Personal Communication):

- Historical conditions were determined by assuming all current grass and impervious cover to be forested.
- Current conditions were based on GIS analysis of aerial photography from the spring of 1989 and corrections based on field observations.
- Future conditions were determined using a combination of land use zoning as presented in the Soos Creek Community Plan and Community Plan Update, the King County Sensitive Areas Ordinance, and mapping of the urban growth boundary.

A discussion of the development of these land use scenarios is presented in the *Cedar River Current and Future Conditions Report* (King County 1993b). The scenarios referenced in that report were modified slightly by King County SWM to develop land cover data for current and future conditions. The modifications were based on new information on existing development proposals and open space acquisitions.

Changes in land cover are summarized in Table 5-5. As the Lake Desire watershed is developed, forest land cover decreases as it is converted to grassed land cover and impervious areas. The land cover data assumes no net loss of wetland areas to future development. All changes between current and future conditions are of greater magnitude than those between historical and current conditions.

Table 5-5: Distribution of Land Types Based on King County Data (values in acres)

	Historic Conditions	Current Conditions	Future Conditions
Forested	**698**	**556**	**121**
Till Forest Mild	622	489	93
Till Forest Moderate	69	60	23
Till Forest Steep	7	7	5
Grassed	**0**	**124**	**481**
Till Grass Mild	0	116	443
Till Grass Moderate	0	8	38
Till Grass Steep	0	0	0
Wetland	**63**	**63**	**63**
Impervious	**0**	**18**	**95**

Percentages of total annual inflows and outflows for historical and future conditions are shown on Figures 5-5 and 5-6. Monthly breakdowns for each water budget component and scenario (i.e., historical, current and future) are detailed in KCM 1994e.

Figure 5–5 Lake Desire Annual Water Balance, Historic Conditions

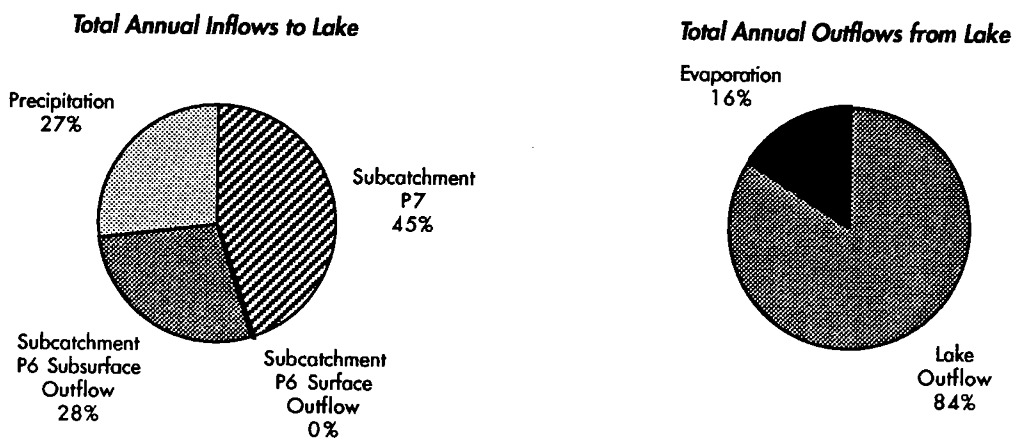
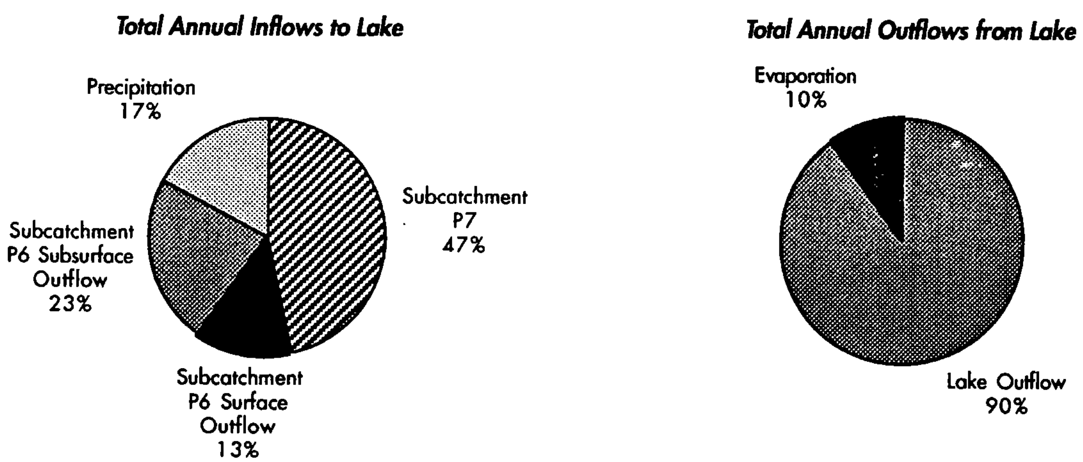


Figure 5–6 Lake Desire Annual Water Balance, Future Conditions



As the area tributary to Lake Desire develops, the following changes are predicted:

- Surface inflow will increase with the change in land cover from current to future conditions. This increase will be greater than the change from historical to current conditions.
- Interflow, which represents shallow subsurface flows generated by storm events that arrive at the lake faster than groundwater inflows, is predicted to increase during the winter as the subcatchment changes from current conditions to future conditions. Summer interflow under all scenarios is negligible. The difference in interflow volumes between historical and current conditions is minimal.
- Groundwater inflows will decrease as the subcatchment develops from current to future conditions. The difference in groundwater inflow between historical and current conditions is minimal.

Subcatchment hydrology will change much more between current and future conditions than it did between historical and current conditions. Maximizing forest retention, implementing stormwater best management practices and enforcing drainage regulations as the subcatchments develop will help to mitigate the changes associated with development.

CHAPTER 6: NUTRIENT BUDGET AND LAKE RESTORATION ANALYSIS

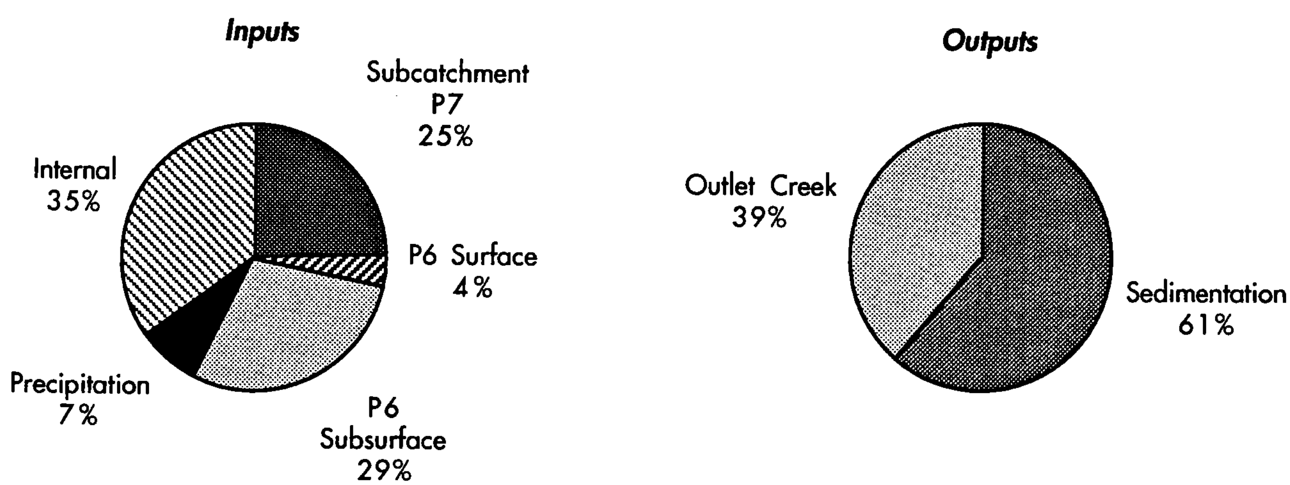
INTRODUCTION

A balanced nutrient supply (nitrogen and phosphorus) and multiple nutrient limitation of phytoplankton productivity in Lake Desire (KCM, 1993b and KCM, 1994b) suggests that reducing the loading of either nitrogen or phosphorus would result in reducing phytoplankton productivity in the lake, increasing water transparency. Because several biogeochemical processes in the lake ameliorate nitrogen deficiency (e.g., feedback from the sediments and nitrogen-fixation), management efforts which focus on reducing phosphorus loading will have the greatest long-term impact on phytoplankton productivity. Therefore, the nutrient budget and subsequent loading analysis was conducted for total phosphorus only.

METHOD OF ANALYSIS

Nutrient loading to Lake Desire was calculated on the basis of the water budget developed for the lake (KCM, 1994e) and nutrient concentrations measured in the lake, lake inlet and outlet, precipitation, and groundwater. Phosphorus sources were divided into five major components (Figure 6-1): internal loading, direct precipitation to the lake surface, overland flow from subcatchment P6 (the area immediately surrounding the lake), subsurface flow through subcatchment P6, and overland flow from subcatchment P7 (the area immediately upstream of the lake which contains Cedar River Wetlands 14 and 15).

Figure 6–1 Lake Desire Total Phosphorus Inputs and Outputs



The model used to define lake phosphorus loading is based on the assumption that phosphorus input to the lake equals phosphorus loss from the lake plus or minus the change in the total amount of phosphorus in the lake:

$$\Delta P = P7 + Int + Pre + P6surf + P6sub - Out - Sed$$

where:

ΔP	=	Change in phosphorus mass (storage) within the lake
P7	=	Lake inflow of phosphorus from upstream wetlands and watershed
Int	=	Internal input of phosphorus from sediments over and above phosphorus loss due to sedimentation
Pre	=	Direct precipitation of phosphorus to the lake surface
P6surf	=	Input of phosphorus from overland flow via subcatchment P6
P6sub	=	Input of phosphorus from subsurface flow via subcatchment P6
Out	=	Outlet loss of phosphorus
Sed	=	Loss of phosphorus to sediments minus phosphorus sediment/water exchange

Groundwater loading was determined by multiplying the subsurface inflow volume from subcatchment P6 by the mean groundwater concentration of total phosphorus (118 μg/L), as measured in the groundwater study (Hong West, 1994). This concentration was calculated using a conservative estimate of the potential phosphorus contribution from on-site waste disposal systems. The mean total phosphorus concentration of 80 μg/L, measured in the groundwater study (Hong West 1994), was considered to be a background level.

For the management plan, on-site waste disposal systems at Lake Desire were evaluated based on variety of sources including: 1) groundwater monitoring data; 2) review of the Seattle-King County Department of Public Health records; 3) the use of Aerial Shoreline Analysis and field surveys; and 4) the preliminary nutrient budget. The potential contribution of phosphorus to Lake Desire from on-site waste disposal systems was also estimated (KCM, 1994d) based on the following assumptions:

- Approximately 101 homes along the shoreline, all using on-site waste disposal systems
- Per capita nutrient loading of 4 grams total phosphorus per day (USEPA, 1988)
- Two persons in each residence
- Nutrient attenuation of 90 percent for the waste disposal systems, based on review of literature.

Surface loading from subcatchment P6 was calculated based on land use in the area as interpreted by King County SWM from existing land use information. Current land use in the subcatchment is approximately 49 percent forest, 25 percent rural 16 percent lake/wetland, 6 percent grass, 3 percent low density residential, and 1 percent impervious surface. Phosphorus loading concentrations for each land use were derived from literature values as summarized in Schueler, 1987. The overall phosphorus concentration estimated for subcatchment P6 overland flow was 196 μg/L (calculated using land use coefficients [Schueler, 1987] and existing land use for Lake Desire). This phosphorus concentration was multiplied by the volume of flow entering the lake via surface flows in the subcatchment as determined by the HSPF model.

Phosphorus loading from precipitation was estimated by multiplying the monthly precipitation volume falling on the lake surface by a mean concentration of 31 µg/L measured in rainfall samples collected by citizen volunteers throughout the study year. Six precipitation samples were analyzed for phosphorus. Two of the six had concentrations that exceeded the normal range for precipitation in this region; these were assumed to have been contaminated and were not used in the calculation of the mean concentration.

Inflow loading from the wetland was estimated by multiplying the inlet flow volume by the monthly mean phosphorus concentration of 52 µg/L. The monthly mean phosphorus concentration was calculated from samples collected by King County SWM at Station LDIN1 during routine monitoring events. Losses of phosphorus from outlet flows were estimated using the same method.

The monthly net gain in phosphorus from sediment phosphorus release and net loss of phosphorus to sedimentation were determined through the development of a transitional phosphorus model for Lake Desire. The model is the Vollenweider (1975) non-steady-state model as modified by Larsen et al. (1979). This model calculates whole-lake total phosphorus concentrations through the development of sediment release rates and sedimentation rates. The model was calibrated to simulate current lake conditions.

The change in lake phosphorus mass was calculated as the residual of the mass balance equation. A gain of phosphorus mass indicates that the weighted mean phosphorus concentration increased from that of the previous month. A decrease in lake phosphorus mass indicates that phosphorus was lost to the sediments, or through the outlet.

Sediment phosphorus release was also estimated from the accumulation of hypolimnetic phosphorus by using the regression of time versus the volume-weighted total phosphorus content in the hypolimnion (Welch et al., 1986). The sediment release rate determined by this method (9.05 µg/L per week) was used to calculate net internal nutrient loading. Release of phosphorus from the sediment was most intense during the 16-week period from mid-May through August. To be conservative, a 16-week period was used to calculate the net internal load.

RESULTS OF THE STUDY YEAR

The Lake Desire monthly phosphorus budget for the study year is presented in Table 6-1. Table 6-2 summarizes the annual nutrient budget based on existing conditions. Nutrient loading is presented graphically as percentages and total weight for each source in Figures 6-1 and 6-2, respectively.

Internal loading originates within the lake, primarily through the release of phosphorus from the sediments. External loading comes from the watershed or atmosphere. Approximately 35 percent of the phosphorus in the lake was from internal sources. The remaining 65 percent was from external sources including subcatchment P7 (the lake inflow), subcatchment P6 surface and subsurface flows, and direct precipitation (Figure 6-1).

The transitional phosphorus model developed for the nutrient budget was calibrated to simulate whole-lake, volume-weighted total phosphorus concentrations as observed during the study year. Observed whole lake phosphorus concentrations from July 13 and November 16, 1993 fluctuated for no apparent reason. Phosphorus concentrations in the epilimnion would be expected to decline during stratification due to phytoplankton uptake, while phosphorus concentrations in the hypolimnion would be expected to steadily increase from internal loading. Instead, total phosphorus concentrations in the epilimnion and metalimnion were variable for these two sampling dates. Rather than calibrate the model to mimic the unexplained ups and downs in the lake phosphorus concentrations, the data were smoothed out. This was

Table 6-1: Total Phosphorus Nutrient Budget; April 1993 to March 1994 (values in grams)

	INPUT					OUTPUT		
Month	P7 Lake Inflow	P6 Surface	P6 Subsurface	Precipitation	Internal	Sedimentation	Outlet	ΔLAKE STORAGE
1993								
April	4,018	751	568	1,448	4,775	0	4,711	6,849
May	2,314	672	2,342	1,053	5,186	0	3,067	8,501
June	5,189	304	4,121	791	17,417	0	5,837	21,984
July	0	141	1,324	477	5,764	0	1,445	6,261
August	0	29	1,067	112	1,940	0	221	2,927
September	0	33	830	90	4,636	0	306	5,283
October	0	314	735	750	3,630	0	0	5,429
November	806	206	644	529	0	0	0	2,185
December	2,143	655	1,618	1,179	0	12,613	3,912	-10,931
1994								
January	2,509	459	3,579	731	0	13,559	5,210	-11,490
February	3,500	588	7,375	1,024	0	13,921	6,028	-7,463
March	10,210	686	11,945	934	0	22,087	8,429	-6,741
Total	**30,689**	**4,838**	**36,148**	**9,118**	**43,348**	**62,180**	**39,166**	**22,794**

Table 6-2: Existing Nutrient Budget

Source	Amount (kg)	Percent of Total
Inflow		
P7, Lake Inflow	31	25
P6, Surface	5	4
P6, Subsurface	36	29
Precipitation	9	7
Internal	43	35
Total	**124**	**100**
Outflow		
Outlet	39	39
Sedimentation	62	61
Total	**101**	**100**
Δ Lake Storage	**23**	

done by establishing a linear regression using the total phosphorus concentrations measured on July 13, 1993 and November 16, 1993, and interpolating the values for the sample dates in between. Predicted monthly mean phosphorus concentrations versus observed and interpolated monthly mean values are shown in Figure 6-3.

Figure 6–2 Lake Desire Total Phosphorus Loading Inputs and Losses by Category

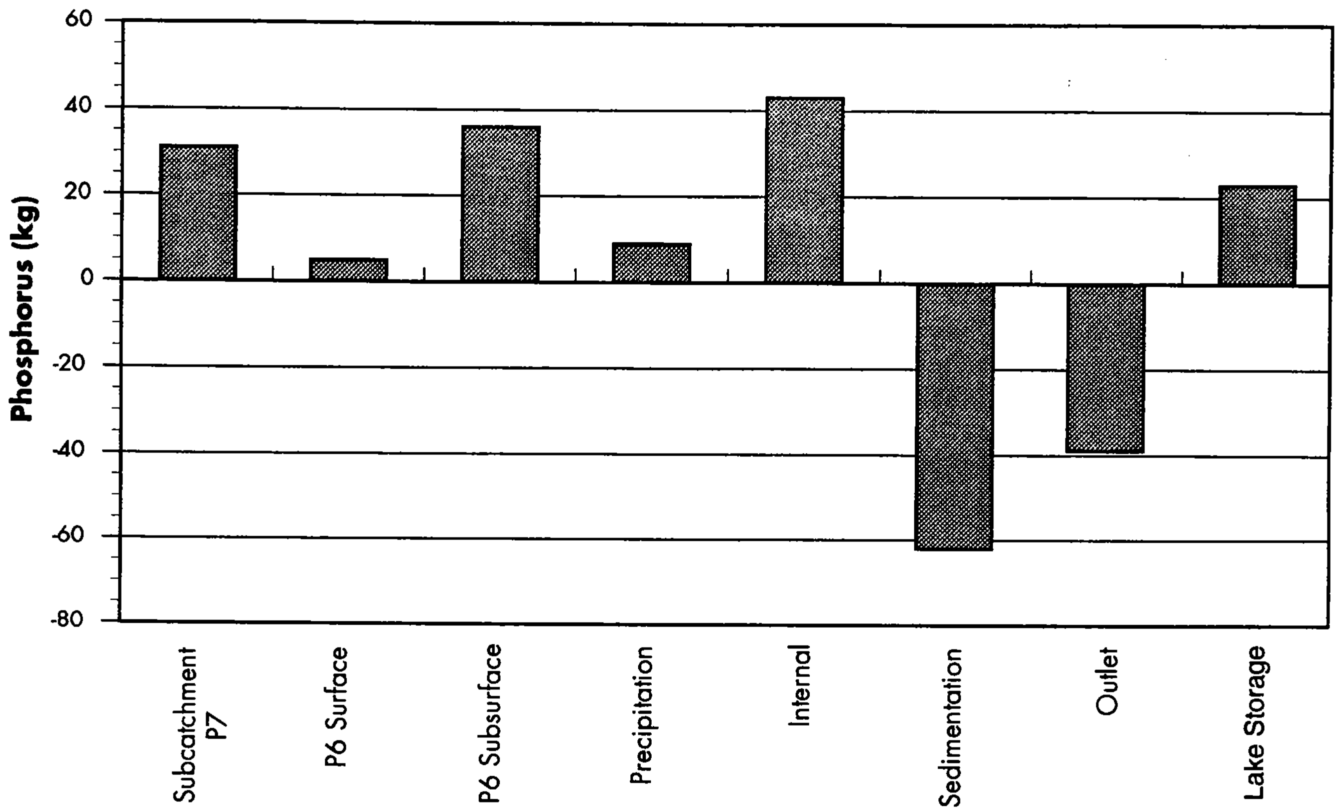
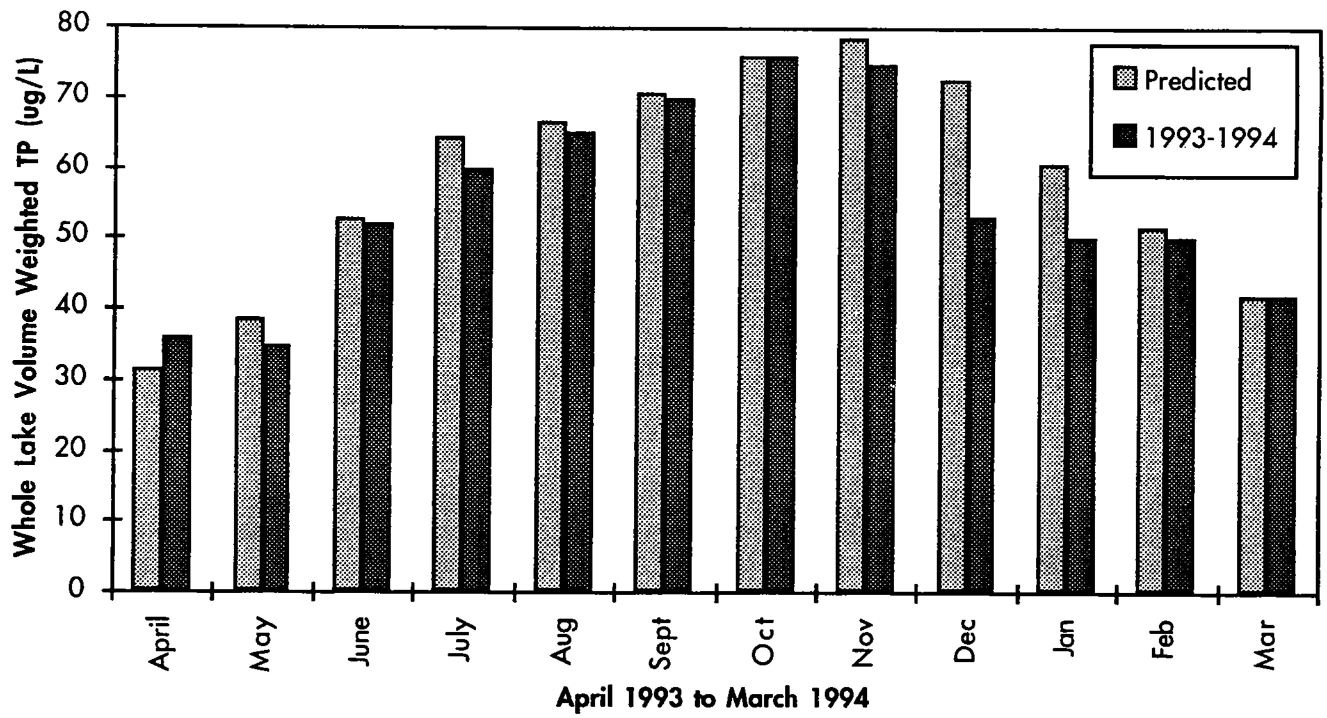


Figure 6–3 Lake Desire Modeled & Measured Volume Weighted, Whole Lake Total Phosphorus, April 1993 to March 1994



External Loading

The 31 kg of phosphorus from subcatchment P7 represents 25 percent of the total phosphorus loading during the study year, the second largest external source of phosphorus (Table 6-2). Phosphorus concentrations in the lake inflow averaged 52 μg/L, ranging from 31 to 119 μg/L throughout the year. The lake inflow provides the largest volume of water to the lake. The large volume of water as well as the moderately high phosphorus concentrations associated with subcatchment P7 results in the large external nutrient load to the lake from subcatchment P7.

The subsurface flows from subcatchment P6 contributed 29 percent of the total phosphorus loading during the study year. The 36 kg of phosphorus from subsurface flows includes both interflow and the flow from the shallow aquifer. The major source of total phosphorus loading from subsurface flows can be attributed to on-site waste disposal system outflows.

From the Lake Desire On-site Septic System Assessment, it was calculated that between 30 and 87 kg per year of total phosphorus could be attributed to on-site septic systems. This *estimate* was based on the average amount of phosphorus discharged in household wastewater (based on literature values) and a series of assumptions regarding the efficiency of the 101 septic systems along the lake shoreline. If a 90 percent efficiency is assumed on average, the loading estimate is as low as 30 kg per year. If a series of less conservative efficiencies are assumed, the loading estimate is as high as 87 kg per year.

Based on the calculated waste disposal loading range, the existing nutrient budget (Table 6-2), groundwater data, and on-site waste disposal system surveys and record reviews, on-site septic systems account for an estimated 30 kg per year of phosphorus. This represents 24 percent of the total nutrient budget, 37 percent of the external loading, and 83 percent of the P6 subsurface loading. The reasoning behind using the 30 kg per year estimate was based on the following information:

- In the groundwater analysis, it was estimated that approximately 15 percent of the total phosphorus entering the lake and 25 percent of the flow was from subsurface flow. This estimate was based on quarterly measured flow and water quality data and the hydrostratigraphy of the area.

- The lake model based on the Vollenweider (1975) non-steady-state model (which predicts whole-lake total phosphorus concentrations), integrates the information from the individual hydraulic phosphorus loading components (subsurface flows, surface, and precipitation sources) and internal phosphorus loading.

- The lake model is based on a mass-balance of total phosphorus using the measured data from the study year, literature values, and professional estimates where data gaps exist or are difficult to accurately measure. As with most modeling applications, certain components are more easily measured and assessed. In lakes, inflow, internal loading, precipitation, and surface runoff are the easiest to measure and predict, while groundwater and subsurface flows remain more difficult.

- As a check on the assumptions used to in the modeling analysis, the nutrient budget must balance on an annual cycle and modeled values should closely match measured values for existing conditions. Figure 6-3 represents the modeled versus the measured values for whole-lake volume weighted total phosphorus concentrations. From month to month, there generally is a good correlation between measured and modeled concentrations.

This model calibration (Figure 6-3) suggests that the assumptions upon which the model is based regarding its individual components (subsurface, internal, surface, and precipitation) are providing a good estimate of the interrelationship between the components. The lack of specific evidence regarding ongoing failure of on-site septic systems confirmed the choice to use the lower end of the loading range or 30 kg per year for on-site septic systems in the model

Surface water flows in subcatchment P6 (directly surrounding the lake) contributed 4 percent of the overall nutrient load to Lake Desire. The majority of the 5 kg of total phosphorus from surface water runoff in the subcatchment most likely originates from the properties adjacent to the lake.

Nine kilograms of phosphorus were attributed to direct precipitation. Generally, precipitation is considered a background component of the nutrient budget. Air quality influences the quality of precipitation and generally air pollution controls recommendations are not made in a lake watershed unless the loading from precipitation is considered significant.

Internal Loading

When oxygen concentrations in the hypolimnion (bottom waters) drop below 2 mg/L, anoxia in the sediments is likely to occur. Under anoxic (oxygen-starved) conditions, phosphorus bound in the sediments as iron phosphate is released to the water column. Conversely, as hypolimnetic oxygen concentrations increase above 2 mg/L, iron and phosphorus combine to form an insoluble precipitate that settles to the lake bottom. Phosphorus in the water column in phosphate form is available for phytoplankton uptake. Uptake occurs at any time of the year for blue-green algae, which can inhabit the nutrient-rich hypolimnion (during the stratified period) and migrate to the surface. Uptake occurs at fall turnover for algae that are restricted to the epilimnion during stratification.

In Lake Desire, the hypolimnetic dissolved oxygen concentration decreases rapidly to almost zero near the water-sediment interface during thermal stratification. Dissolved oxygen concentrations were less than 2 mg/L at the water-sediment interface from May to September. That condition enhances phosphorus release from the sediments and is reflected in the high hypolimnetic phosphorus concentrations. Hypolimnetic dissolved oxygen was depleted from April through October because of strong thermal stratification. Internal loading of phosphorus from lake sediments totaled 43 kg of phosphorus from April through October, providing 35 percent of the overall total phosphorus load to Lake Desire.

A total of 42 kg of phosphorus was estimated to be released from the sediment using the regression of time versus the volume-weighted total phosphorus content in the hypolimnion. This value agrees very well with the internal load estimated from the transitional mass balance model (within 2 percent) described above, lending confidence to the overall estimated values.

ANALYSIS OF HISTORICAL AND FUTURE CONDITIONS

The study year model was modified to simulate lake water quality under historical conditions (i.e., approximately 1960, prior to the most recent development surge and alteration of wetland Cedar River 14) and future conditions (i.e., full build-out per Soos Creek Community Plan [King County, 1991b]). For comparing the various restoration alternatives (mitigated future conditions), a future conditions scenario without mitigation (Scenario 3) and future scenarios using existing watershed regulations only were modeled (Scenario 7 or 8).

Phosphorus loading concentrations for surface waters were estimated based on the historical (1960) land use. The phosphorus concentration of 47 µg/L for water flowing into the lake from subcatchment P7 under historical conditions was taken from literature values for undisturbed wetland outflow (Reinelt et al., 1994). Surface water overland phosphorus concentration used for subcatchment P6 was 150 µg/L. Subsurface flows through subcatchment P6 were assigned a background phosphorus concentration of 51 µg/L as measured in the groundwater study (Hong West, 1994).

The phosphorus concentration of 72 µg/L for water flowing into the lake via subcatchment P7 under future conditions was taken from literature values for urbanized wetland outflow (Reinelt et al., 1994). Based on the future land use, the overall phosphorus concentration used for subcatchment P6 surface waters was 253 µg/L (calculated using land use coefficients [Schueler, 1987] and future land use for Lake Desire). Phosphorus concentrations for subsurface flows through subcatchment P6 remained the same as under current conditions at 118 µg/L. The current conditions value was calculated based on the number of homes along the shoreline (KCM, 1994c). Given the limitation of the soils and that the area is within an urban growth designation which includes sewering, it is not expected that any more homes built along the shoreline would use on-site waste disposal systems.

Table 6-3 summarizes the historical and future nutrient budget. A comparison of the historical, current, and future total phosphorus concentrations is presented graphically in Figure 6-4. The relative changes in loading for the three scenarios are presented in Figure 6-5.

Table 6-3: Historical and Future Nutrient Budget

Source	Historical Amount (kg)	Historical Percent of Total	Future Amount (kg)	Future Percent of Total
Inflow				
P7 Lake Inflow	23	33	58	21
P6, Surface	0	1	58	21
P6, Subsurface	16	22	46	17
Precipitation	9	13	9	3
Internal	21	31	105	38
Total	69	100	277	100
Outflow				
Outlet	32	45	121	51
Sedimentation	39	55	117	49
Total	71	100	238	100
ΔLake Storage	-2		39	

Figure 6–4 Lake Desire Modeled Total Phosphorus Concentrations Under Historical, Current, and Future Conditions

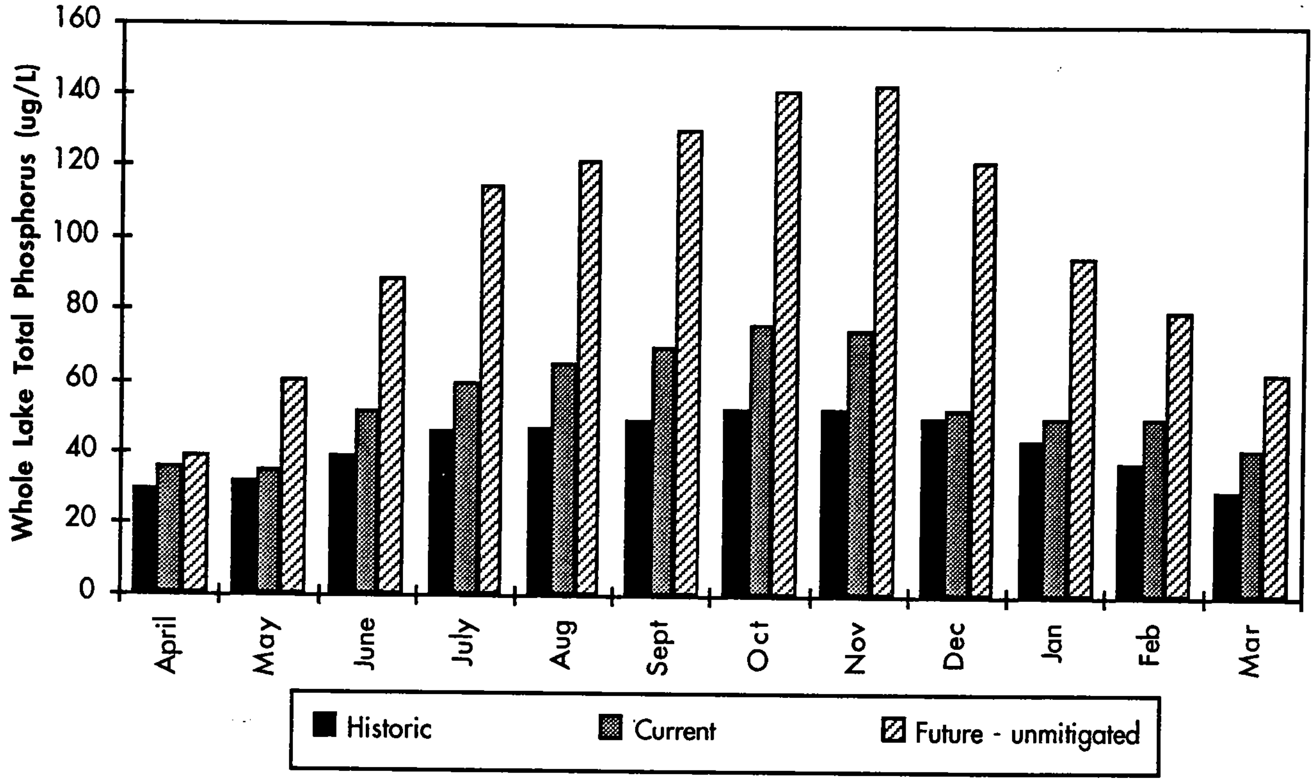
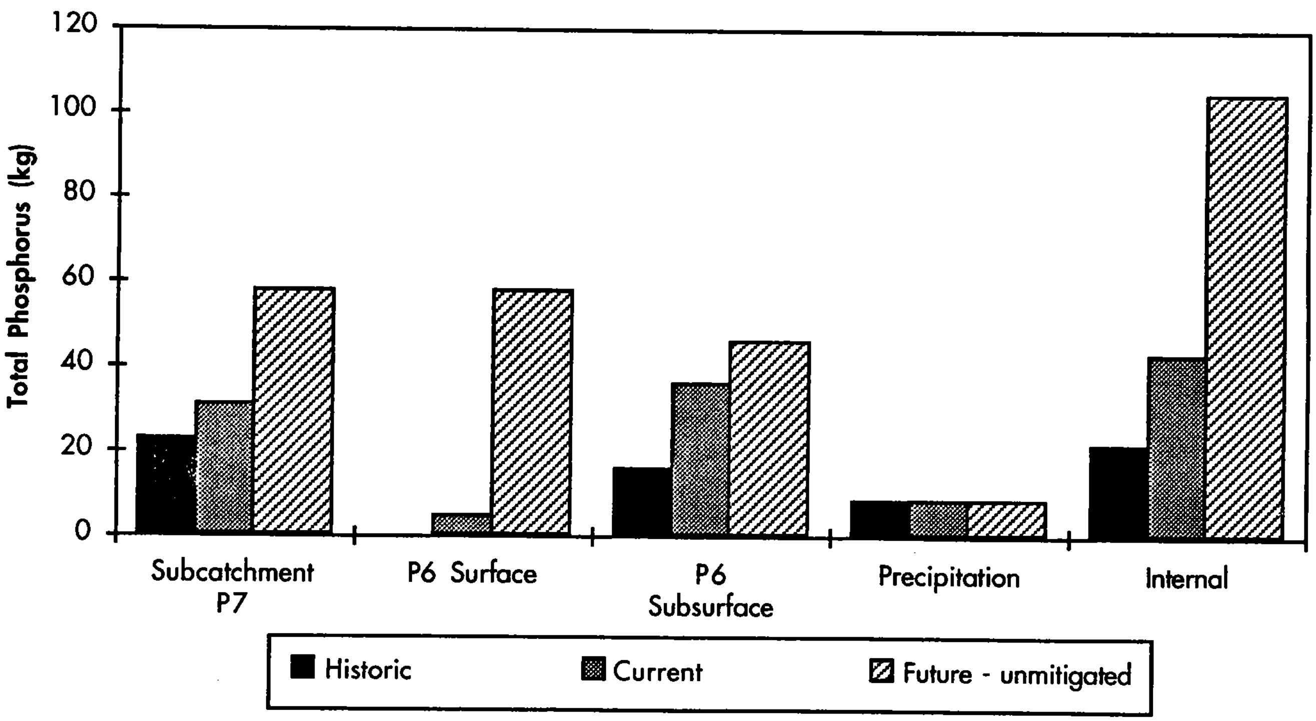


Figure 6–5 Lake Desire Modeled Phosphorus Loading by Source for Historical, Current & Future Conditions



RESTORATION ALTERNATIVES ANALYSIS

Both watershed management and in-lake restoration measures will be needed to improve existing Lake Desire water quality and prevent additional degradation in the future. Watershed management measures improve water quality by reducing pollutant loading to the lake from point and nonpoint sources in the watershed. In-lake restoration techniques typically control nutrients originating within the lake. Watershed and in-lake measures used to control nutrients are presented in Table 6-4.

TABLE 6-4: Lake Desire Management/Restoration Alternatives

Measures	Advantages	Disadvantages	Estimated Cost[a]
Dredging	• Removes nutrient-rich sediments • Reduces internal cycling • Enhances boating and swimming • Long-term solution (>20 yrs.)	• Resuspension of sediments • Disposal concerns • High cost	• Approximately $12/cu. yd.
Aluminum Sulfate Treatment	• Lowers lake phosphorus content • Inhibits release of phosphorus from sediments • Increases water column transparency	• Temporary measure (1-5 yr. effectiveness) • Potential toxic impacts • Increase in aquatic weed growth	• Alum: $92,000 (55 tons alum, 21 tons aluminate)
Hypolimnetic Aeration	• Maintains oxygen in the hypolimnion • Limits release of phosphorus from sediments • Increases habitat and food supply	• Difficulty in supplying adequate oxygen • Potential for premature destratification and subsequent algal blooms • No impacts on aquatic weeds	• Const: $300,000 • O&M: $14,500/yr. • Design & Engineering: $100,000 • SEPA: $50,000
Dilution	• Reduces nutrient concentrations through dilution and increased flushing	• Requires very large quantities of low-nutrient water • High operation cost • No impact on aquatic weeds	• NA[b]

[a] Does not include associated costs such as taxes, engineering, administration, permitting, SEPA review, environmental monitoring, or construction management.
[b] NA - Measure would not meet project goals. Costs not estimated.
[c] EP - Existing programs are expected to cover costs.

TABLE 6-4 (continued): Lake Desire Management/Restoration Alternatives

Measures	Advantages	Disadvantages	Estimated Cost[a]
Hypolimnetic Dilution	• Reduces nutrient concentrations through dilution and increased flushing of bottom waters • Maintains oxygen in the hypolimnion • Limits release of phosphorus from sediments • Increases habitat and food supply • Increases potential for fisheries enhancement in Swifty Creek	• Requires large quantities of low-nutrient water • No impact on aquatic weeds • Potential for premature destratification	• NA[b]
Hypolimnetic Injection and Withdrawal	• Reduces nutrient concentrations through dilution and increased flushing of bottom waters • Maintains oxygen in the hypolimnion • Limits release of phosphorus from sediments • Increases habitat and food supply • Increases potential for fisheries enhancement in Swifty Creek	• No impact on aquatic weeds	• NA[b]
Artificial Circulation	• Disrupts or prevents stratification • Provides aeration and oxygenation • Increases aerobic habitat • May limit sediment phosphorus release	• May or may not decrease algal biomass • May decrease water clarity • No impact on aquatic weeds	• NA[b]

[a] Does not include associated costs such as taxes, engineering, administration, permitting, SEPA review, environmental monitoring, or construction management.
[b] NA - Measure would not meet project goals. Costs not estimated.
[c] EP - Existing programs are expected to cover costs.

TABLE 6-4 (continued): Lake Desire Management/Restoration Alternatives

Measures	Advantages	Disadvantages	Estimated Cost[a]
LD-1 Catchment P7 Forest Retention	• Provides biofiltration potential • Reduces nutrient loading • Reduces amount of toxins entering the lake	• Requires resident participation	EP[c]
LD-2 Wetland Restoration and Enhancement	• Provides biofiltration potential • Reduces nutrient loading • Reduces amount of toxins entering the lake	• May require construction	EP[c]
LD-3 Shoreline Wetland Revegetation	• Provides biofiltration potential • Reduces nutrient loading • Reduces amount of toxins entering the lake • Improves fish and wildlife habitat • Reduces shoreline erosion	• Requires resident participation	$4,000
LD-4 Stormwater Treatment	• Provides biofiltration potential • Reduces nutrient loading • Reduces amount of toxins entering the lake	• May require construction	EP[c]
LD-5 Ditch Maintenance	• Increases Biofiltration • Improves Water Quality	• May require construction	EP[c]
LD-6 Homeowner BMPs	• Reduces nutrient loading • Reduces amount of toxins entering the lake • Reduces the amount of runoff water	• Requires resident participation	$3,000
LD-7 Sewering	• Reduces nutrient loading	• Requires construction	$2,000,000

[a] Does not include associated costs such as taxes, engineering, administration, permitting, SEPA review, environmental monitoring, or construction management.
[b] NA - Measure would not meet project goals. Costs not estimated.
[c] EP - Existing programs are expected to cover costs.

In-lake techniques that can be used to reduce nutrients and control subsequent algal growth include sediment removal (i.e., dredging), phosphorus inactivation and precipitation (e.g., aluminum sulfate treatment), hypolimnetic aeration, dilution, hypolimnetic withdrawal, and artificial circulation. Because of prohibitive cost and expected disposal difficulties, dredging is not recommended for reducing nutrients and controlling algal blooms in Lake Desire. A readily available, low nutrient water source does not exist in the vicinity of Lake Desire (Ron Spear, March 6, 1995, Personal Communication). Therefore, dilution is not considered a viable alternative for improving water quality. Hypolimnetic withdrawal is not a viable technique for Lake Desire because of the impact of low-quality hypolimnetic water on the outlet stream. Artificial circulation has had mixed success in controlling sediment phosphorus release and may actually increase the potential for algal blooms (Cooke et al., 1993b). Artificial circulation was therefore not considered as a technique for improving the water quality in Lake Desire. The two in-lake techniques that are considered viable for Lake Desire are hypolimnetic aeration and a buffered alum treatment.

Several watershed management and in-lake restoration measures were evaluated for their cost and overall impact on lake water quality (Table 6-4). Watershed measures included maintaining subcatchment P7 as open space, providing sewers in the nearshore area, and implementing best management practices (BMPs) throughout the watershed. In-lake restoration measures included a buffered alum treatment, hypolimnetic aeration, and a combination of alum and hypolimnetic aeration.

Watershed Measures

In analyzing the effectiveness of potential watershed management measures, future hydrologic conditions and phosphorus concentrations were assumed, except where specified otherwise.

- **Limited Forest Conversion in Subcatchment P7.** To simulate the impact on water quality of Lake Desire if subcatchment P7 remained primarily forested, the hydrologic conditions and phosphorus loading were modeled as current conditions.
- **Sewering in the Nearshore Area.** It was estimated that sewering in the nearshore area would reduce the phosphorus concentration in subsurface water flowing to the lake to the background level of 51 μg/L (Hong West 1994). The volume of subsurface flow entering the lake was estimated using the full build-out of future conditions in subcatchment P6.
- **Best Management Practices in Subcatchment P6.** It was estimated that implementing best management practices in subcatchment P6 would reduce phosphorus loading from surface flows in that subcatchment by 50 percent over 20 years. The initial (i.e., within five years) reduction in phosphorus loading would be low, and was estimated to be only 5 percent. Future hydrologic conditions were used to estimate the volume of flow entering Lake Desire via surface flows through subcatchment P6.

In-Lake Measures

The two in-lake techniques to control nutrients, and hence algal growth, were evaluated. Planning and regulatory permits are required for both. With any restoration technique, the length of long-term benefits will depend on lake and watershed management programs that continue to address water quality and algal blooms. Cost comparisons between the in-lake alternatives are difficult, due to the large number of variables involved. Whenever possible, recent costs from local projects were used to develop costs for a comparable project in Lake Desire.

Buffered Alum Treatment.

Adding aluminum sulfate (alum) lowers a lake's phosphorus content by precipitating phosphorus and retarding release from the sediments (Cooke et al., 1993a). When alum is added to the water column a polymer forms that binds phosphorus and organic matter. The aluminum phosphate-hydroxide compound (commonly called alum floc) is insoluble and settles to the bottom. Dramatic increases in water clarity typically occur immediately following an alum treatment, as suspended and colloidal particles are removed from the water column by the floc. Once on the sediment surface, alum floc retards phosphate diffusion from the sediment to the water through chemical binding.

Alum is a promising technique for reducing algae through physical removal during the application and through the long-term control of internal nutrient loading. The treatment does not kill the algae instantaneously in the water column but settles them to the lake bottom where they die over a period of up to two weeks. This longer time period and the location at the lake bottom greatly reduce the hazard of any toxins that might be released from the dying algae cells. Alum can also provide long-term reduction in the occurrence of algal toxicity if internal phosphorus loading (often a primary cause of blue-green blooms in eutrophic lakes) is reduced. Alum has also been found to reduce the sediment-to-water migration of blue-greens in Green Lake in Seattle (Welch, E.B., October 13, 1992, Personal Communication). Other nutrient inactivation techniques have been used with less success than alum. Calcium hydroxide or lime has recently been used in hardwater Alberta, Canada lakes to control nutrient supply and algal growth (Murphy et al. 1990; Kenefick et al. 1992). However, lime would not offer the same phosphorus-binding benefit in a softwater lake such as Lake Desire (Cooke et al. 1993b).

Alum has been used extensively in the United States with general success in controlling phosphorus release from lake sediments (Cooke et al., 1993b). Its effectiveness has lasted up to 20 years in some lakes (Garrison and Knauer, 1984; Cooke et al., 1993b) Although most case studies of alum treatments demonstrate multiple-year success, failures also have occurred. These have been attributed to insufficient dose, lake mixing, inadequate reduction in external nutrient inputs, and a high coverage of macrophytes.

Using alum is a stop-gap measure that may control sediment phosphorus release for several years (Cooke et al., 1993a). If external sources are not controlled, alum's effectiveness will decrease with time, as the alum layer on the sediments becomes covered by nutrient-rich silt and organic material. Therefore, the lake may need to be treated again. The duration of effectiveness for a specific lake is difficult to predict. Effectiveness and longevity of treatment increase where external nutrient sources have been controlled. Regular long-term water quality monitoring is required in an alum-treated lake to detect decreases in the treatment's effectiveness.

Alum dose should be based on the lake's pH, alkalinity, and potential aluminum toxicity (Cooke et al., 1993a) The use of sodium aluminate as a buffer would permit a greater alum dose to be used. As alum is added to a lake, pH and alkalinity decrease and dissolved aluminum concentrations increase. Alkaline lakes can tolerate higher alum doses than can softwater lakes. Relationships to determine safe alum doses are presented in Kennedy and Cooke (1982) and Cooke et al. (1993a). Adding alum to a lake with low to moderate alkalinity such as Lake Desire (i.e. average alkalinity = 22 mg $CaCO_3$/L at station 1), requires careful planning to ensure that pH and alkalinity are not lowered to levels that would stress resident aquatic biota. A buffering agent such as sodium aluminate has been applied with alum in several northeastern United States lakes and in Green Lake in Seattle, with high success in maintaining pH and alkalinity levels (Dominie, 1978; Cobbossee Watershed District, 1988; Jacoby et al., 1994). The use of sodium carbonate in the October 1991 alum treatment of Long Lake (Kitsap County, WA) was also highly successful in maintaining safe pH and alkalinity levels, as well as in improving lake water quality (Welch, E.B., October 13, 1992, Personal Communication).

Alum application in Lake Desire would reduce the amount of internal phosphorus loading from the sediments and might also bind some of the phosphorus from inflowing groundwater. Blue-green algal migration from sediments might be reduced by application of alum. Alum might need to be reapplied regularly to control blue-green blooms until surface water phosphorus inputs are reduced through watershed controls.

The use of alum salts may cause toxic conditions, although alum treatments have not resulted in adverse impacts on fish to date (Cooke et al., 1993b) and have not damaged invertebrate populations in well-buffered lakes (Cooke et al., 1993a; Narf, 1990). Invertebrate populations, however, may be more sensitive to alum application in softwater lakes. The alum/sodium aluminate treatment of Vermont's Lake Morey, a softwater lake (alkalinity = 30 to 50 mg/L CaCO3/L), unexpectedly resulted in a short-term decrease in density and species richness of benthic invertebrates (Smelzer, 1990). Benthic invertebrate densities were lower in Green Lake in Seattle following the 1991 alum/sodium aluminate treatment than in 1982 (Jacoby et al., 1994). While alum toxicity is a possible cause, other changes in the lake, such as increased carp predation, or degraded sediment quality due to extensive milfoil decay, may have contributed to the decline in benthic invertebrate densities. The absence of recent pre-treatment data for Green Lake makes identification of the causative factor(s) difficult. In both Green Lake and Lake Morey, water column pH was maintained through the use of a sodium aluminate buffer, a procedure that should have prevented the formation of toxic soluble aluminum forms (e.g., $Al(OH)^{2+}$ and Al^{3+}).

A whole-lake treatment of Lake Desire is recommended because it is likely that nutrient-rich sediments exist throughout the watershed and the entire lake is subject to mixing. Alum would primarily reduce internal phosphorus loading, which contributes approximately 35 percent of the annual phosphorus loading to Lake Desire. Treating the lake with 8 mg Al/L would require approximately 55 tons of alum and 20.4 tons of sodium aluminate. The cost of treating Lake Desire is estimated as $1,660/ton alum (costs include labor and materials, mobilization, demobilization, and taxes). Total costs for an alum treatment of Lake Desire would likely exceed $92,000. Monitoring and sample analysis costs could add additional fees to the overall project. This cost is low relative to dredging, especially if it remains effective for at least five years.

For modeling purposes, a buffered alum treatment was estimated to reduce internal loading 90 percent the first year, with a progressive decline in its effectiveness. The alum treatment was estimated to remain 25 percent effective at reducing internal loading by the fifth year, and be ineffective within 8 years.

Lake Desire currently has few aquatic macrophyte problems. By reducing algal populations and improving water clarity, alum could promote aquatic macrophyte growth at greater depths (Cooke et al. 1993a). An increase in water clarity might allow macrophytes to colonize greater depths at higher densities.

Jar tests and field verification would have to be conducted to establish the proper alum and sodium aluminate dose for Lake Desire. These tests would be part of the preliminary design of the project. However, dose and cost of an alum and sodium aluminate treatment in Lake Desire can be estimated on the basis of information from the October 1991 treatment of Green Lake in Seattle. Green Lake costs are appropriate to use to estimate costs for Lake Desire because they are fairly recent and because an alum/sodium aluminate treatment has not been performed anywhere else in the Northwest. The Green Lake dose was 12 mg Al/L (5.25 mg Al/L from alum and 6.75 mg Al/L from sodium aluminate).

Hypolimnetic Aeration.

Hypolimnetic aeration is a way to oxygenate the bottom waters of a lake without causing destratification. The technique typically uses air to raise cold hypolimnetic water to the surface of deep lakes, where it is aerated through contact with the atmosphere, losing gases such as carbon dioxide and methane, and returned to the hypolimnion (Olem and Flock, 1990). Phosphorus release from the sediments is limited by hypolimnetic aeration if there is sufficient iron in solution. In addition, hypolimnetic aeration increases habitat and food supply for cold-water fish species. The technique has been used with various levels of success (Cooke et al., 1993a). Unsuccessful treatments have been attributed to inadequate oxygen supplies to the system, disruption of stratification, or lack of iron.

Dissolved oxygen concentrations in Lake Desire's hypolimnion are below 2 mg/L during thermal stratification. Aeration of the hypolimnion could control the release of phosphorus from anoxic sediments. It is important, however, that hypolimnetic aeration not destratify the water column. Premature destratification can be toxic to aquatic life when bottom waters with little dissolved oxygen, low pH, and high concentrations of toxic gases mix with surface waters. Destratification can also stimulate algal growth by supplying hypolimnetic nutrients to surface waters and mixing algae throughout the water column. Lake Desire is a relatively shallow but strongly stratified lake. As such, destratification due to wind mixing could occur. However, there have been several lakes with similar geomorphology such as Newman Lake in eastern Washington, that have had successful hypolimnetic aeration systems installed (Ashley, K., April 1994, Personal Communication).

The effectiveness of hypolimnetic aeration depends on the presence of sufficient iron to bind phosphorus in the re-oxygenated waters. Moderate iron concentrations (annual mean = 470 μg/L) measured in Lake Desire indicate that available iron is sufficient to remove phosphorus from the water column at fall turnover. The mean hypolimnetic Fe:P ratio prior to turnover (September 14, 1993) was 17, and following turnover the ratios were approximately 13 throughout the water column. Ratios greater than 3 are optimal to promote iron phosphate precipitation at turnover (Stauffer, 1981). The relatively high Fe:P ratios indicate that there is sufficient iron to remove phosphorus from the water column during lake turnover.

There are two types of aeration systems designed for lake restoration; these are full-lift or partial-lift systems. A full-lift system is recommended for Lake Desire because the hydraulic characteristics of a partial-lift system are not as favorable in shallow applications. The circulation of hypolimnetic waters using an aerator is a function of the air lift length. In a shallow system the quantity of water that can move through the aerator is limited. Therefore, full-lift systems are more efficient in their ability to aerate shallow lakes. Based on costs developed for aerators in Lake Fenwick (Kent, Wash.) and Lake Stevens (Snohomish County, Wash.), the costs of hypolimnetic aeration in Lake Desire were estimated to be approximately $300,000 for construction and $14,500 per year for operation and maintenance (KCM, 1993a).

Hypolimnetic aeration was estimated to reduce internal loading by 75 percent. To model this, sediment phosphorus release within the model was reduced by 75 percent.

Modeling Scenarios

Eleven scenarios were simulated to determine whole-lake total phosphorus concentrations using the transitional non-steady state model developed for Lake Desire. They included the historical, current, and future conditions scenarios already described. The scenarios were as follows:

1. Historical Conditions
2. Current Conditions
3. Future Conditions - Unmitigated
4. Buffered Alum Treatment
5. Hypolimnetic Aeration
6. Combined Alum and Aeration
7. Watershed Package (All-Forest Retention, Watershed BMPs, and Sewer)
8. Watershed Package (Without Sewer)
9. Watershed Package plus Alum
10. Watershed Package plus Aeration
11. Watershed Package plus Alum and Aeration.

Using the lake model, the benefits of each restoration measure were assessed by estimating monthly whole-lake total phosphorus concentrations, from which summer mean concentrations were calculated. The relative effectiveness of each alternative was then compared using summer means (Table 6-5). Restoration measures were also evaluated based on their external or internal loading reduction effectiveness (Figure 6-6).

Results

A comparison of the summer total phosphorus concentrations estimated for all modeled scenarios is shown in Table 6-5. For all modeled scenarios, full watershed build-out was assumed so that the long-term effectiveness of each restoration alternative could be evaluated. For contrast, summer in-lake total phosphorus concentrations were included for existing conditions for select in-lake and watershed treatments. Concentrations in Table 6-5 are modeled values and represent the relative effectiveness of the various watershed and/or in-lake loading reduction measures on in-lake water quality.

Benefits of Watershed Measures

A mass balance for each watershed scenario was developed to estimate the mass of total phosphorus which would be prevented from entering Lake Desire in the future as the result of each measure or combination of measures (Figure 6-6). The specific loading benefits for implementation of each watershed measure are as follows:

- **Limited Forest Conversion in Subcatchment P7.** Restoring the wetlands and maximizing open space in subcatchment P7 could reduce the <u>future</u> phosphorus load from that subcatchment by 30 kg TP per year or 51 percent.
- **Sewering in the Nearshore Area.** Sewering the nearshore areas could result in a 26 kg TP per year or 56 percent reduction in future subsurface loading.
- **Best Management Practices in Subcatchment P6.** BMPs in subcatchment P6 would reduce future phosphorus loading by 26 kg per year or 45 percent.

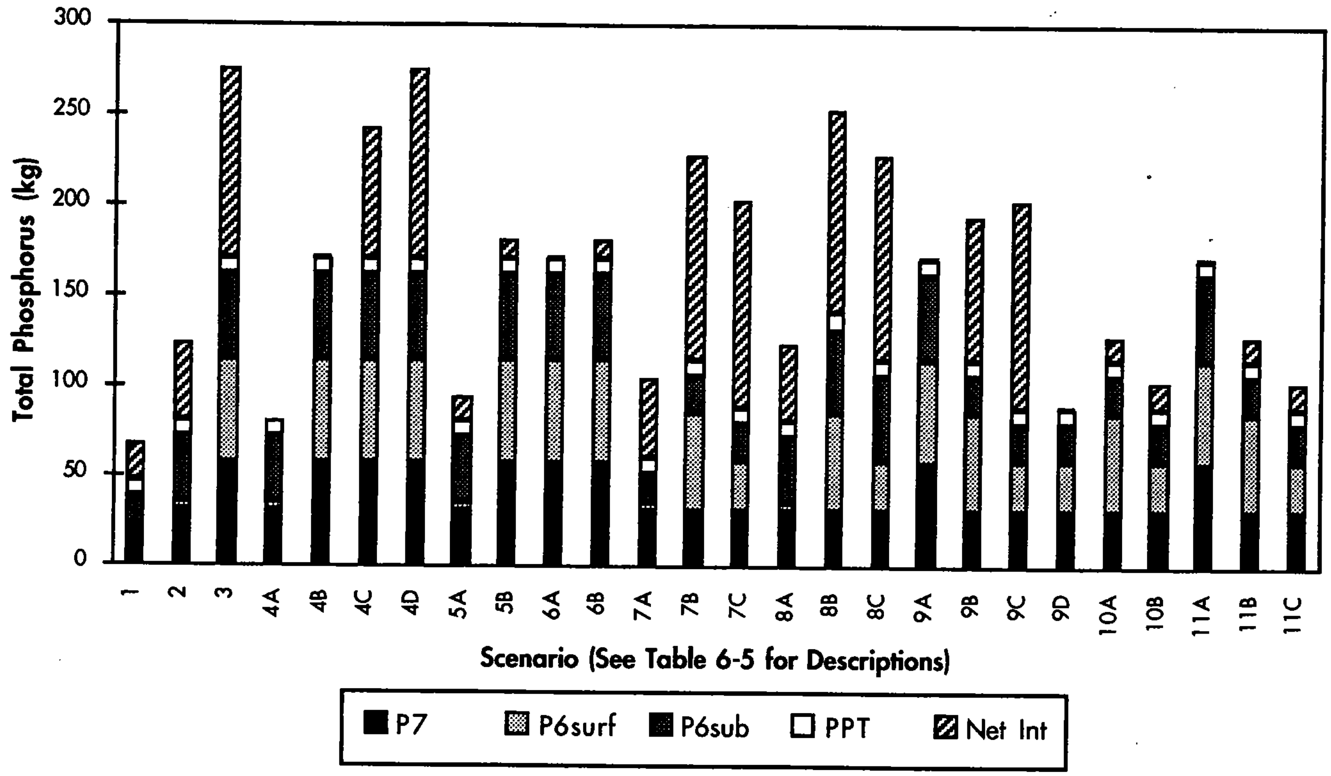
Under future conditions, the three watershed measures (Scenario 7, Table 6-5) would result in a summer total phosphorus value of 110 μg/L in the first five years and a value of 106 μg/L after 20 years (This assumes that the effectiveness of watershed best management practices increase from five percent to 50 percent during the 20 year evaluation period). To evaluate the effectiveness of sewering alone, watershed measures were also evaluated without sewers (Scenario 8, Table 6-5). Although sewering results in a 30 kg TP reduction annually under future land use conditions, summer whole-lake total phosphorus concentration is reduced by only 5 μg/L.

Table 6-5: Summer TP Concentration Under Modeled Scenarios

Scenario	Summer TP [a] (µg/L)
1. Historic	46
2. Current	59
3. Future	114
4. Buffered Alum Treatment	
A. 1st year–90 percent internal load reduction	35[b]
B. 1st year–90 percent internal load reduction	46
C. 5 years–25 percent internal load reduction	95
D. 8 years–0 percent internal load reduction	114
5. Hypolimnetic Aeration	
A. 75 percent internal load reduction	46[b]
B. 75 percent internal load reduction	58
6. Combined Alum plus Aeration	
A. 1st year–90 percent internal load reduction	46
B. 5 years–65 percent internal load reduction	58
7. Watershed Package–All[c]	
A. Approximately 5 years	60[b]
B. Approximately 5 years	110
C. Approximately 20 years	106
8. Watershed Package–Without Sewers	
A. Approximately 5 years	64[b]
B. Approximately 5 years	115
C. Approximately 20 years	110
9. Watershed Package–All plus Alum	
A. Year 1	46
B. Approximately 5 years after alum	91
C. Approximately 20 years without alum	106
D. Approximately 20 years with alum @ 20 years	36
10. Watershed Package–All plus Aeration	
A. Approximately 5 years	52
B. Approximately 20 years	48
11. Watershed Package–All plus Alum and Aeration	
A. 1st year	46
B. 5th year	52
C. 20 years (without additional alum added)	48

[a]*Using modeled whole-lake June–September concentrations.*
[b]*In-lake concentration based on existing conditions and specified mitigation.*
[c]*Watershed Package includes forest retention in P7, BMPs in P6 and P7, and sewering along Lake Desire.*

Figure 6–6 Lake Desire Annual Total Phosphorus Loading for Modeled Scenarios



Benefits of In-lake Measures

The overall benefits for each in-lake restoration measure were also evaluated by the overall mass of total phosphorus which would be reduced in Lake Desire. The specific benefits to lake internal loading and summer whole-lake total phosphorus concentration are the following:

- **Buffered Alum Treatment.** Application of alum to Lake Desire is expected to reduce internal loading by 90 percent. Existing loading would be reduced from 43 kg TP per year to 4.3 kg TP per year. Summer whole-lake concentration is predicted to average 33 µg TP/L for existing conditions. Based on future land use, loading would be reduced from 104 kg TP per year to 10 kg per year (Figure 6-6) with a summer whole-lake average of 46 µg/L (Table 6-5) after the first year of alum application. Alum would over time become less effective at reducing internal loading and reapplication would be needed every 5-8 years to maintain improved water quality.

- **Hypolimnetic Aeration.** Construction of an in-lake hypolimnetic aeration system is expected to reduce internal loading by 75 percent. Existing total phosphorus loading would be reduced to 11 kg TP per year while future internal loading would be reduced to 26 kg per year (Figure 6-6). Summer whole-lake total phosphorus concentration would average 44 µg/L for existing conditions and 58 µg/L for future conditions (Table 6-5).

Recommendation

The whole lake summer mean total phosphorus concentrations predicted by the lake model indicate that watershed measures alone (including sewering of the shoreline) are not enough to improve existing water quality or prevent the future decline in water quality. This is due to the high rate of sediment phosphorus release occurring in the summer months and the subsequent internal loading to the lake.

The in-lake restoration activities examined for this analysis would reduce the internal loading to Lake Desire by as much as 94 kg TP per year with alum treatment and 76 kg TP per year if hypolimnetic aeration is used. Alum would achieve the maximum phosphorus load removal and subsequent reduction in summer whole-lake total phosphorus concentration and appears at first glance to be the preferred choice for addressing internal loading. However, it is unlikely that alum could be pursued successfully as a long-term treatment option for Lake Desire. This is in part due to the permitting issues involved with alum use (single or repeated applications), the questionable long-term toxicity effects to benthic organisms and other lake plant and animals, and the long-term costs associated with repeated applications.

Aeration, although a less proven technique than repeated alum treatments in shallow lakes, increasingly has been successfully used with in other shallow lake systems (Ashley, K., April 1994, Personal Communication). Aeration, like alum, also provides a significant improvement to lake water quality in the short-term. Over time as external loading increases, watershed controls would become increasingly important in maintaining the benefits of in-lake aeration on water quality.

Based on the alternatives analysis, the preferred plan for the restoration of Lake Desire would be the implementation of the full watershed package, plus aeration for long-term oxygenation of the hypolimnion, and an initial alum treatment to break the internal cycling sequence. Installing a hypolimnetic aerator and implementing all the watershed management measures are recommended to maintain the improved water quality long-term. An alum treatment is recommended after the start-up of the aeration system to ensure an improvement in water quality initially and to increase the probability that the aeration will be effective long-term. Engineering analysis for construction of the in-lake hypolimnetic aeration can be found in Appendix F.

Watershed management measures typically take time to implement and may not result in immediate, measurable improvements in lake water quality. However, the long-term protection of Lake Desire will depend on reducing external nutrient sources. Under future conditions, aeration alone will not significantly improve water quality from that of current, unmitigated conditions. The duration of the benefits and overall long-term costs associated with in-lake restoration activities will be impacted by how effective the watershed management measures are at reducing the overall loading to Lake Desire. The more effective watershed control measures are in the future, the greater likelihood that internal loading will remain significantly reduced by in-lake aeration, granting continued improvement in water quality.

CHAPTER 7: LAKE AND WATERSHED MANAGEMENT

MANAGEMENT APPROACH

Lake Desire is a very productive lake characterized by frequent and intense algal blooms in the spring and fall which degrade the lake for a variety of recreational activities including swimming, boating, and fishing. The aesthetic appeal normally associated with the lake also dramatically decreases during the bloom periods. Existing water quality (and associated lake productivity) is unacceptable to the majority of residents who live on the lake and many people from surrounding urban areas who utilize the lake for recreational purposes.

Based on the "historical" water quality data, the lake system has been characterized as a productive system since the early 1970s. Examination of the sediment phosphorus profiles (Chapter 4) suggests that productivity in Lake Desire has increased recently (within the past 60 years). Two major watershed scale changes have occurred during this time period which may account for this shift in lake productivity. These watershed changes include: 1) the logging of the watershed and the beginning of shoreline development in the 1930's; and 2) the beginning of peat excavation in Cedar River Wetland 14 in the 1960s.

It is unlikely that watershed loading levels can be restored to pre-logged conditions or prior to the peat excavation of Cedar River Wetland 14. However, a reasonable long-term management goal is to maintain lake productivity at a level between historical and existing trophic conditions. By focusing on maximizing external loading reductions in the watershed and minimizing existing internal loading and subsequent future increases in internal loading, the long-term management goal of improved trophic conditions can be achieved.

The management approach for the restoration of Lake Desire, then, is designed to address both watershed and in-lake sources of nutrients which contribute to the existing water quality problems. Restoration of Lake Desire will require a long-term commitment to reducing future watershed nutrient loading through source control best management practices, restoration of watershed wetlands, restoration of the existing wetland shoreline, retrofitting of existing stormwater facilities for pollutant removal, and the removal and management of non-native aquatic plants. In the near-term, in-lake water quality is proposed to be addressed using a combination of a buffered alum treatment and an in-lake aeration system to reduce internal nutrient cycling in the lake which contributes to eutrophic lake water quality. Watershed measures, which in the short-term, are not likely to result in an immediate improvement of lake water quality are nonetheless essential to reduce future watershed loading which would otherwise exacerbate current lake water quality conditions and reduce the effectiveness of in-lake measures under future conditions.

LAKE AND WATERSHED MANAGEMENT GOALS

Lake and watershed management goals were established by the Lake Desire community and were used in the restoration alternatives analysis and in the development of the subsequent management plan recommendations. The eight management plan goals are as follows:

- Improve Water Quality and Lake Trophic Status;
- Restore Watershed Wetlands;
- Protect Human Health;
- Protect Property Values;

- Maintain a Healthy Lake Fishery Habitat;
- Control Invasive, Nonnative Aquatic Plants;
- Educate and Involve Watershed Residents in Lake Restoration and Protection; and
- Work More Effectively with Government to Improve and Protect Lake Water Quality.

Improving lake water quality is the primary management goal for the lake. If lake water quality is improved, many of the remaining management goals, including protection of human health, lake property values, and the lake fisheries will also be met. Through in-lake aeration of the lake hypolimnion (LD-9) and the implementation of watershed measures, internal lake phosphorus loading should be reduced resulting in less frequent and severe algal blooms and improved lake water quality. Improving lake water quality will also reduce water quality related dermatitis and the risk of blue-green toxic algal bloom occurrence, thereby improving human health protection. Improved lake water quality resulting in swimmable, fishable, and boatable waters will also protect existing and future property values. In-lake aeration will also benefit the lake fisheries and general aquatic habitat by expanding the oxygenated area of the lake to include the currently oxygen depleted lake hypolimnion.

The remaining management goals of restoring watershed wetlands, controlling invasive nonnative aquatic plants, and education and involvement of the watershed residents are designed to be accomplished through the remaining management plan recommendations. To achieve these lake management plan goals, an effective working relationship with government and watershed residents will be needed. Without a combined long-term commitment and investment by watershed residents and government, the goal of improving lake water quality will likely remain unmet for Lake Desire.

RECOMMENDATIONS

The 14 recommendations for the lake management plan (Table 7-1) are divided into four groups: (1) watershed measures; (2) in-lake measures; (3) aquatic plant management; and (4) monitoring. Watershed recommendations address forest retention, wetland restoration, shoreline revegetation, stormwater treatment, ditch maintenance, homeowner source control best management practices, and sewers. These measures are designed to reduce existing and future external pollutant loading to the lake from watershed sources. Implementation of watershed measures is essential to the long-term restoration of Lake Desire water quality.

In-lake restoration measures including buffered alum treatment and in-lake aeration will result short-term in lake water quality improvement. It is important to note that long-term gains made through in-lake measures, however, will not be maintained unless watershed measures are successfully implemented.

Details of the watershed and in-lake measures, the aquatic plant management, and monitoring recommendations are described in the following sections. This chapter also includes a brief discussion of implementation of the management plan. The State Environmental Policy Act (SEPA) checklist and determination of non-significance (DNS) for the plan has been included in Appendix D. Public comment and responses on the draft management plan are included in Appendix G.

Watershed Measures

LD-1 Subcatchment P-7 Forest Retention-*Forest retention should be maximized in the Peterson-7 subcatchment in the Cedar River basin in areas zoned AR-2.5-P following the recommendations of the Cedar River Draft Basin and Nonpoint Action Plan (King County, 1995) for mandatory open space retention and areal clearing limits for individual lots as minimum guidelines.*

Table 7-1: Lake and Watershed Recommendations

No.	Recommendations	Lead Implementor(s)[a]	Cost
	Watershed Measures		
LD-1	Subcatchment P-7 Forest Retention	King County	EP[b]
LD-2	Wetland Restoration	KCSWM	EP[b]
LD-3	Shoreline Wetland Revegetation	KCSWM/LDCC	$4,000
LD-4	Stormwater Treatment	King County	EP[b]
LD-5	Ditch Maintenance	Roads/KCSWM	EP[b]
LD-6	Homeowner BMPs	LDCC/KCSWM/SKCDPH	$3,000
LD-7	Sewering	SCWSD/LDCC	EC[c]
	In-Lake Measures		
LD-8	Buffered Alum Treatment	LDCC/KCSWM	$92,000
LD-9	Aeration (design and engineering)	LDCC/KCSWM	$100,000
	Aeration (SEPA)		$50,000
	Aeration (construction)		$340,000
	ongoing O/M $17,500/year[d]		
	Aquatic Plant Management		
LD-10	Milfoil Removal	LDCC/KCSWM	$20,000
LD-11	Purple Loosestrife Removal	LDCC/KCSWM	$5,000
LD-12	Lake Access through Hand Pulling	LDCC/KCSWM	EP[b]
	Monitoring		
LD-13	Lake, Fishery, and Watershed Monitoring	LDCC/KCSWM/WSDFW/ MIT	$70,000[d]
LD-14	Wetland Monitoring	KCSWM	$5,000
		Total	$689,000
		Total with 5-year O/M	$796,000[d]

[a] *KCSWM-King County Surface Water Management; LDCC-Lake Desire Community Club; MIT-Muckleshoot Indian Tribe; Roads-King County Roads Division; SKCDPH-Seattle King County Department of Public Health; SCWSD-Soos Creek Water and Sewer District; and WSDFW-Washington State Department of Fish and Wildlife.*

[b] *EP-existing programs are expected to cover costs.*

[c] *EC-the estimated cost for sewering lake properties is two million dollars but has not been included here.*

[d] *Four percent inflation factor assumed for O/M and monitoring costs.*

Watershed phosphorus loading from the Peterson-7 subcatchment is already a major contributor to eutrophic conditions in Lake Desire. Twenty-five percent or 31 kg TP per year of the total phosphorus budget originates from the lake inflow (Peterson-7 subcatchment). All efforts including maximizing forest retention and establishment of clearing limits should be implemented to minimize future phosphorus loading to Lake Desire. The current zoning for most of this catchment is one unit per 2.5 acres. Under this zoning, much of the forested land could be converted into 2.5 acre homesteads. At modeled build-out, this level of development, although rural in character, will contribute an estimated 58 kg TP per year, an increase of 47 percent over existing phosphorus loading from this subcatchment.

Forest retention is the most effective mechanism by which future loading can be significantly decreased in this portion of the watershed. Because the current development density for much of the catchment area is below the threshold for standard stormwater treatment requirements, structural controls for reducing phosphorus loading have limited application. Forest retention and open space dedication of the upper lake watershed area is essential to the long-term restoration and protection of lake water quality.

Currently, a large portion of the Peterson-7 subcatchment is proposed for inclusion in King County's 4 to 1 program as a pilot project. The 4:1 program allows for rural property owners with properties contiguous to the Urban Growth Boundary Line to have the opportunity to obtain urban designation in exchange for dedicated open space. The program allows for the redesignation of one acre of property as urban for every four acres of property designated as permanent open space. This designation would allow for a major portion of the subcatchment to remain forested and meet the intent of the forest retention recommendation.

Little opportunity exists for similar application of forest retention in the remaining portions of the lake watershed due to the zoning of most of the Peterson-6 subcatchment area within the Urban Growth Boundary line. Voluntary retention of forest should be encouraged within the Peterson-6 subcatchment where possible.

LD-2 Wetland Restoration and Enhancement- *Restoration and enhancement of Cedar River Wetlands 14 and 15 should be pursued through open space acquisition; restoration of the natural habitat, water quality, and detention functions; and the establishment of wetland management areas. Implementation of all actions should be coordinated with the recommendations in the proposed Cedar River Draft Basin and Nonpoint Action Plan (King County, 1995).*

Cedar River wetland 14 forms the headwaters of the Lake Desire watershed and plays an important role in nutrient cycling and subsequent loading to the lake. Commercial peat extraction between 1960 and 1990 has resulted in significant wetland alteration and functional value loss. The long-term reduction of watershed nutrient loading is linked to the restoration of the wetland's hydrologic and water quality functional values. Restoration activities should at a minimum include increased ponding and soil saturation, establishment of a 100 to 200 foot wide vegetative buffer, noxious weed removal, and native vegetation planting.

Cedar River Wetland 15 abuts the northern edge of Lake Desire and surrounds the main inlet to the lake. The wetland has been bisected by road construction of E. Lake Desire Drive and is abutted to the west by a small horse pasture. Restoration of the wetland buffer and pretreatment of road runoff should be included in proposed future road modifications to reduce existing roadway flooding.

LD-3 Shoreline Wetland Revegetation-*A native vegetation buffer should be reestablished along the Lake Desire shoreline to filter surface water runoff to the lake and stabilize the lake shoreline.*

Currently, there is little vegetation between many lakefront homes and Lake Desire. In places where shoreline vegetation is absent, surface water runoff and septic system inputs from poorly operating systems enter the lake directly, degrading lake water quality.

Surface water from the residential properties adjacent to the lake currently contribute 5 kg TP per year or four percent to the total phosphorus lake loading. The majority of this surface loading originates from the properties most closely associated with the lake. Under modeled future land build-out, this surface loading is expected to increase to 58 kg TP per year or 21 percent of the future total phosphorus lake loading. Shoreline vegetation should be restored on a volunteer basis to maximize the shoreline buffer between private residences and the lake which will, in turn, reduce the current and future total phosphorus loading; reduce shoreline erosion; and improve wildlife habitat.

The King County Sensitive Areas Ordinance (King County, 1990b) requires a 100, 50, or 25 foot setback for wetlands depending upon classification for all new development and establishes guidelines for activities which are allowable adjacent to a wetland area. The shoreline of Lake Desire has not been classified by the King County wetlands inventory (King County, 1991a). However, by definition the shoreline meets the criteria for wetland delineation and could require setback for new development or for some shoreline activities. Prior to any shoreline alterations, the King County Department of Development and Environmental Services, shorelines review section should be consulted.

LD-4 Stormwater Treatment-*For land parcels in the Urban Phase I area around Lake Desire "all known, available, and reasonable methods of prevention, control, and treatment" (AKART) for total phosphorus control should be utilized to meet the intent of the updated Soos Creek Community Plan P-suffix conditions. For areas outside of the Urban Phase I area, AKART equivalent phosphorus control should be applied where new development will create 5,000 square feet of new impervious surface subject to vehicular use. For areas which drain to watershed bogs or fens, the management objectives of the King County Surface Water Design Manual 1995 update for bog/fen protection should be applied.*

In the restoration analysis, external nutrient loading from surface water runoff has been identified as a significant source of phosphorus to Lake Desire under future land use conditions. Given that the lake already experiences degraded water quality and that any in-lake restoration technique's benefits will be offset by unmitigated future phosphorus loading, stormwater treatment should be utilized to maximize total phosphorus removal from new stormwater runoff sources in the watershed.

The extent of the future threat of phosphorus loading to lake water quality was also recognized in the Soos Creek Community Plan Update (King County, 1991b). The water quality analysis performed in the development of the Lake Desire Management Plan supplies additional support for the implementation of the existing P-suffix condition which was placed on the Urban Phase 1 area around Lake Desire. The P-suffix condition states:

> "Properties in the Lake Desire Drainage Basin shall meet all water quality and quantity requirements as outlined by the King County Surface Water Management Division. These requirements must be in compliance with the State Growth Management Act. Special attention should be given to increased retention/detention requirements and clearing restrictions on undeveloped parcels *and stormwater treatments which will ensure that the quality of discharge waters shall be equal to or better then current Lake Desire Water Quality* [emphasis added]."

To meet the intent of this condition, AKART should be applied in the watershed area or area draining to Lake Desire. Currently the AKART standard or interim best management practices for phosphorus sensitive lakes is as follows:

- A wet pond or combined detention/wet pond with a permanent pool volume equal to 4.5 times the volume of runoff from the mean annual storm (VB/VR=4.5).
- Roof downspout infiltration is required unless shown to be unfeasible, and forest or native vegetation retention should be maximized.
- To encourage maximum forest retention, pond volume can be reduced by the following schedule:

Forest (%)	VB/VR ratio
25	4.25
30	4.00
40	3.50
50	3.25
60	3.00

- Forest retention areas should be in tracts dedicated to the County. Buffers without trails can be counted in the percent forest figure.

The VB/VR ratio is the volume of the wet pond basin divided by the volume of the runoff from the mean annual storm. The mean annual storm is equal to 0.46 inches at Sea-Tac. Runoff can be estimated using a runoff coefficient of 0.9 for impervious area and 0.25 for all other pervious area. Forested areas in tracts dedicated to the County need not be included in the calculation of pond sizing (i.e. zero new runoff volume assumed). If this method is used in other areas, and Sea-Tac precipitation statistics under estimate the rainfall as judged by the isopluvial distribution of the 2-year 24-hour precipitation, the mean annual rainfall should be adjusted upward.

Although current King County SWM designs are not complete for a sand filtration treatment system, incorporation of sand filters into stormwater treatment facility designs can be voluntarily pursued by new development to achieve additional total phosphorus removal and the AKART standard. However, upon completion of the sand filtration design by the SWM Division, the AKART standard for Lake Desire will be revised to include a combined wet pond/sand filter treatment system which will maximize total phosphorus removal.

Moreover, where soil are suitable, on-site infiltration of stormwater runoff can be pursued as alternative, if equivalent or better total phosphorus removal can be achieved. Soils are considered suitable for infiltration if at least two feet of soil exist where one of the four following soil conditions are met:

- The cation exchange capacity of the soil equals or is greater than five milliequivalents;
- The organic content of the soil is equal to or greater than five percent;
- The grain size distribution of site soils is equivalent to not more than 25 percent gravel by weight (75 percent passing the #4 sieve) and of that passing the #4 sieve, either (1) 50 percent minimum passes the #40 sieve and two percent minimum passes the #100 sieve, or (2) 25 percent minimum passes the #40 sieve and five percent minimum passes the #200 sieve; and
- The infiltration rate is 2.4 inches/hour or less.

LD-5 Ditch Maintenance-*Ditch maintenance protocols for roads within the watershed will be reviewed by SWM with the Roads Division to identify areas where enhanced maintenance activities could increase lake water quality protection.*

The existing land development pattern combined with the future watershed zoning will provide few opportunities for implementation of *King County Surface Water Design Manual*-based water quality treatment facilities (see LD-1). Thus, surface water quality protection will rely more heavily on source control strategies and BMPs including the management of the roadside drainage system. Ditch maintenance activities may include the retention of ditch vegetation, minimization of soil disturbance during maintenance, maximization of open-ditch system use (versus closed, culvert systems), and involvement of the Lake Desire Community Club in trash removal and other appropriate citizen-based maintenance activities. These additional maintenance activities will reduce the erosion of soil, increase pollutant removal of stormwater runoff in vegetated ditch areas, and reduce the transport of trash to the lake.

LD-6 Homeowner BMPs-*Residential best management practices (BMPs) should be promoted to the watershed residents and facilitated by the Lake Desire Community Club and the SWM Division.*

Sub-surface loading from on-site septic systems was estimated as 30 kg TP per year. Although, the soil type present in the majority of the shoreline area is not optimal for wastewater treatment, the on-site septic system evaluation (see Chapter 4) conducted during the study did not identify any significant pollution problems. However, due to the age of many septic systems and the surrounding soil types present, on-site wastewater disposal may represent a more significant nutrient source to the lake in the future.

In all likelihood, the area around Lake Desire will probably have sewers in the future. In the interim, phosphorus loading from on-site septic systems should be minimized through residential best management practices. Voluntary dye-testing by individual homeowners is a relatively unobtrusive means for residents to evaluate the significance of their contribution to lake nutrient loading. Systems which are not operating properly can be identified through dye testing and professionally repaired. If a significant number of failures are identified that cannot be repaired, sewering of the lake shoreline should be given a higher priority by the community and the Soos Creek Water and Sewer District.

Surface water runoff from residential properties adjacent to the lake currently contributes 5 kg TP per year or four percent of the total phosphorus lake loading. The majority of this load originates from properties directly adjacent to the lake. Under modeled future build-out conditions, surface loading is expected to increase to 58 kg TP per year. Again, much of this future load will be contributed by the adjacent lake properties.

Source control BMPs are the most effective means for preventing pollutants from entering surface waters from nonpoint sources. For example, revegetation of shoreline properties (LD-3) provides a buffer between yard activities and the lake and will help reduce pollutant loading as surface waters runoff. Additional residential BMPs including lawn fertilization, yard maintenance, proper household hazardous waste disposal, animal waste control, and the use of low phosphate household and garden products will also need to be implemented to reduce impacts from current and future total phosphorus loading to the lake. The details for each residential BMP are described below and should be the target of an educational outreach focus by the Lake Desire Community Club (LDCC).

- **Septic tank and drainfield maintenance**. A workshop should be conducted with the LDCC in conjunction with King County SWM and the Seattle-King County Department of Public Health to assist lake-side watershed residents in: (1) conducting dye testing of their septic systems to ensure the proper system functioning; (2) establishing an annual inspection schedule for their septic tanks and drainfields; and (3) performing routine maintenance as necessary. The Lake Desire Community Club should pursue discounted fees from private septage companies for community sponsored multiple site pump-out days.

- **Lawn fertilization and yard maintenance.** Alternatives to standard lawn and yard maintenance practices should be implemented by residents including minimal use of organic fertilizers, reduction in lawn size, regular thatching and aeration if lawns are retained, incorporation of native plants in new landscaping, soil enhancement through mulching and composting rather than chemical fertilization, and integrated pest management techniques for pest control.

- **Proper household hazardous waste disposal.** Alternatives for common household cleaning products are available from the Seattle-King County Department of Public Health and should be pursued by residents. Household hazardous waste should be properly disposed of at King County household hazardous waste collection sites.

- **Animal waste control.** Waterfowl feeding should be discouraged by lakeside residents and at the public fishing dock. Pet and domestic animal waste should be properly disposed of away from the lake and surface water pathways which reach the lake.

- **Low phosphate garden and household products.** Voluntary use of low phosphate garden and household products should be promoted by the Lake Desire Community Club.

The King County SWM Lake Stewardship Program offers an annual BMP workshop which addresses lawn fertilization and yard maintenance activities, proper household hazardous waste disposal, animal waste control, and the use of alternative lawn and household products. The LDCC should offer to host the workshop in 1996.

LD-7 Sewering-*The eventual sewering of Lake Desire shoreline properties is recommended to reduce sub-surface phosphorus loading to the lake and protect human health.*

A variety of watershed restoration measures was evaluated for the lake restoration alternatives analysis including sewering. Although loading from on-site septic systems was estimated to be 30 kg TP per year, the effect of sewering alone is not expected to result in a significant decrease in summer total phosphorus concentrations in Lake Desire under modeled existing or future land use conditions. It is expected over the short-term due to sewering alone, a 4 µg/L decrease in whole-lake phosphorus concentration will occur and long-term, a 5 µg/L decrease. On the other hand, with aeration, modeled whole-lake summer total phosphorus concentration would in the short-term be decreased by 18 µg/L and in the long-term by 56 µg/L. Additionally the cost of sewering versus the relative benefit produced in terms of improved lake water quality is small compared with the implementation of other watershed and in-lake measures. Nonetheless, some incremental benefit to lake water quality could be achieved through sewering shoreline properties if independent funding can be procured.

If sewering does occur, the short-term gains of phosphorus reduction from existing properties may be offset by increased shoreline density and associated nonpoint pollutant loading increases. Therefore, the implementation of sewering is a low priority and is recommended only in the event that human health or lake trophic status is threatened.

In-lake Measures

LD-8 Alum Treatment-*A whole-lake buffered alum treatment is recommended for reducing the in-lake phosphorus concentration and associated lake trophic status as a short-term solution for improving in-lake water quality.*

To most effectively reduce summer whole-lake total phosphorus concentration short-term, a single alum application is recommended at the onset of in-lake aeration. A buffered alum treatment is predicted to reduce internal loading by approximately 90 percent during the first year to 4.3 kg/yr. As a result of the initial alum treatment, whole-lake concentrations would be substantially lower for the first few years, averaging 35 µg/L from June to September based on current modeled whole-lake phosphorus concentration estimates (Table 6-5).

In the future, modeled internal loading in Lake Desire is expected to increase to 105 kg TP per year (Table 6-3). Although repeated alum treatments could reduce future internal loading to 10.5 kg TP per year and result in a modeled summer total phosphorus concentration of 46 µg/L (Table 6-5), within 5-8 years after application, the effectiveness of an alum treatment will have declined and a repeat treatment will be needed to maintain in-lake water quality goals. Because of the short-term benefits to internal loading reduction, the potential concerns regarding aquatic toxicity associated with alum, and the permitting issues and costs associated with repeat treatments, in-lake aeration is the recommended in-lake activity for the long-term internal loading control.

LD-9 Aeration -*Hypolimnetic aeration is recommended as a long-term solution to reduce summer whole-lake phosphorus concentration and improved lake trophic status.*

Aeration is recommended as the preferred long-term in-lake restoration measure for four reasons: (1) its cost effectiveness for reducing internal loading; (2) the benefit to aquatic habitat through hypolimnetic oxygenation; (3) minimal permitting problems associated with its implementation compared with other in-lake measures; and (4) in combination with watershed controls, lake trophic status goals can be met.

Modeled current in-lake summer total phosphorus concentration averages 60 µg/L (Table 6-5). Internal loading currently contributes 35 percent of the annual phosphorus load (Table 6-2) to Lake Desire and aeration is predicted to reduce this load by 75 percent. Based on existing total phosphorus loading, hypolimnetic aeration would result in a an average summer mean whole-lake phosphorus concentration of 44 µg/L.

Under the future land use scenario, modeled internal loading will increase to 105 kg TP per year (Table 6-3) and corresponding whole-lake summer concentrations are predicted to increase to 114 µg/L (Table 6-5). Hypolimnetic aeration only would reduce the modeled summer average whole-lake total phosphorus concentration to 58 µg/L (Table 6-5). Without watershed controls, hypolimnetic aeration would not result in significant lake water quality improvement under the future land use scenario. However, the preferred alternative of hypolimnetic aeration combined with watershed controls would maintain a modeled average in-lake total phosphorus concentration of 48 µg/L (Table 6-5), which meets the long-term goal of improved lake trophic status.

Two full lift aerators are proposed for meeting the internal phosphorus reduction goal of 75 percent. The complete engineering analysis and detailed cost estimate for in-lake hypolimnetic aeration is included in Appendix F.

Aquatic Plant Management

LD-10 Milfoil Removal-*A milfoil management plan should be developed by the Lake Desire Community Club, the SWM Division and other affected parties which targets eradication of the species.*

During the 1993 aquatic plant survey, *Myriophyllum spicatum* or Eurasian watermilfoil was observed in several areas of the lake. The level of milfoil observed, however, did not appear to present nuisance conditions at the time. Milfoil, however, can quickly become a problematic plant and timely efforts should be made to eradicate the plant from the lake in the near-term. Diver dredging, selective herbicide use, and public education should be the primary mechanisms explored for milfoil management. Targeted removal of milfoil will be especially important if increased lake clarity occurs as a result of in-lake restoration measures and growing conditions are optimized for its spread.

LD-11 Purple Loosestrife Removal-*Purple loosestrife should be removed annually by shoreline residents until the plant is eradicated. If biocontrols become available for use in King County, application for their use at Lake Desire should be explored.*

Purple loosestrife (*Lythrum salicaria*) is a state noxious weed which invades wet pastures, wetlands, stream and river banks, lake shores, irrigation and roadside ditches, and stormwater detention/treatment facilities. Purple loosestrife harms these aquatic areas by crowding out native wetland plants including cattail, bulrushes, sedges, and hardhack. When purple loosestrife overruns an area, a monoculture of vegetation is established and waterfowl, wildlife, amphibian, and aquatic insect diversity are reduced. Purple loosestrife is a prolific reproducer via seed production and root propagation. Just a few plants can quickly spread to an entire lake shoreline in a year or two.

Purple loosestrife is already widespread throughout the state and full eradication is unlikely. In smaller areas, including lake shorelines, eradication can be achieved through the diligent, annual efforts of shoreline residents. Removal methods include hand pulling of plant stems and roots, clipping flower heads prior to seeding to prevent further spread, mowing, mulching with plastic, and restoration of cleared areas with native vegetation. Biocontrols (e.g. insects) may be available in the near future for purple loosestrife control. If available, they may present an alternative to hand removal methods. Prior to any removal of purple loosestrife, the King County Department of Development and Environmental Services, shorelines review section should be consulted.

LD-12 Lake Access through Hand Pulling -*Where desired, residential lake access restricted by aquatic plant growth should be achieved by selective hand removal of plants to clear an open area no greater than 10 feet in width. Where practical, adjacent neighbors should establish shared access so that <u>maximum retention</u> of shoreline aquatic plants is achieved.*

Aquatic plants were not identified as a significant lake problem by lake residents during the project study. However, some residents have pointed out a minor problem of lake access where thick growths of aquatic lilies are present. The white water lily, *Nymphaea ordorata*, is a non-native plant which was introduced into many lakes throughout the state as an ornamental plant. The lily plants tend to reproduce well and form dense surface coverage that is difficult to navigate through. Hand pulling plants should provide sufficient access to the lake where entry is restricted. Total plant removal should be minimized in order to maintain the natural benefits of shoreline stability, nutrient removal, and aquatic habitat afforded by aquatic plants. Prior to any aquatic plant removal, the King County Department of Development and Environmental Services, shorelines review section should be consulted.

Monitoring

LD-13 Lake, Fishery, and Watershed Monitoring-*A long-term in-lake and watershed monitoring program should be developed by the Lake Desire Community Club, King County SWM, Muckleshoot Indian Tribe (MIT), and the Washington State Department of Fish and Wildlife (WDFW) to evaluate the effectiveness of in-lake and watershed restoration and protection measures.*

The lake, fishery, and watershed monitoring program should focus on evaluating the effectiveness of watershed phosphorus control measures on the maintenance and improvement of in-lake trophic status. The MIT and WDFW shall be invited to participate in the development of the final monitoring program. To the extent possible, lakeside residents, the MIT, and the WDFW, in conjunction with a local high school environmental class or other volunteer group should be trained to perform individual components of the lake and watershed monitoring program. A proposed 5-year monitoring program for the lake is summarized in Table 7-2.

Table 7-2: Lake Desire Water Quality Monitoring Program

Component	Sampling Frequency	Stations	Parameters[a]
In-lake	Monthly	1 station, 0,1,2,3,4,5 meters	Temp., pH, DO, Cond., TP, Ortho-P, TN
	Same	1 station	Secchi depth
	Same	1 station, water column composite (@0.5m, 1.5m, 2.5m, and 3.5m)	Chl a, Phaeo a, Phytoplankton species, biovolume, and identification
	Same	1 station, vertical tow	Zooplankton species, enumeration, and identification
	6 times/year	1 station, surface only	FC, Turb., Alk., color
	Quarterly	2 stations, deep spots, each meter	Al, Fe
Inlets/Outlets	Monthly	2 stations	Temp., pH, DO, Cond., TP, Ortho-P, TN, FC (inflow)
Sediment characterization	Every five years	three depth strata (0-2m, 2-4m, and >4m) four cores from each stratum, analyzed top 0-2 and 2-10 cm increments	TP, TN, % solids, Total Organic Carbon, AL, and Fe
Benthic Invertebrates	Once prior to alum application, twice post-alum application	littoral and deep stations	Density, identification to genus except for chironomid and oligochaete families
Fisheries Analysis	Twice during the monitoring period	To be determined	To be determined

[a]Parameters are abbreviated as follows: Temp.-temperature, DO-dissolved oxygen, Cond.-conductivity, TP-total phosphorus, Ortho-P-orthophosphate, , TN-total nitrogen, Turb.-turbidity, Alk.-alkalinity, Chl a - chlorophyll a , Phaeo a-pheophytin a, FC-fecal coliform, Al-aluminum, and Fe-iron.

LD-14 Wetland Monitoring- *Vegetation monitoring should be performed for restored wetland areas three years post restoration to ensure successful vegetation establishment.*

Restoration of Cedar River Wetlands 14 and 15 should include monitoring of revegetated areas for plant survival. In areas where significant plant mortality has occurred, replanting should be performed in cooperation with the wetland property owners and the SWM Division.

Cost/Benefit Analysis for Management Plan Implementation

One of the principal concerns in implementing lake management plan actions is whether the benefits derived from the preferred alternative actions equal or exceed the cost of their implementation. Granted, there are multiple benefits to good water quality that go beyond property value including fish and wildlife habitat, water supply, and aesthetics. However, for the purpose of this analysis, the "benefits" of good water quality through the implementation of the Lake Desire Management Plan were correlated only to the direct effect on shoreline property values.

The complete cost/benefit methods and analysis has been included in Appendix E. The analysis focused on the 126 shoreline properties located on Lake Desire. It was assumed that the greatest economic benefit (or potential loss) related to lake water quality was garnished by shoreline properties and that the majority of implementation costs (two-thirds for this cost/benefit analysis) would be borne by those properties which received the greatest benefit.

In order to evaluate the relative benefits of management plan implementation on lake water quality, the proportion of shoreline property values which would increase due to the successful implementation of the lake and watershed management plan (the benefit) was estimated (Appendix E). This estimated property value increase was then compared with the draft plan implementation costs of the preferred alternative's lake and watershed actions (Table 7-1).

Based on 1993 assessed property values, shoreline properties currently account for 26 percent of the total assessed watershed value or about $17.5 million. Shoreline property values at Lake Desire have increased at the rate of 4 percent between 1989 and 1993, which corresponds well with King County-wide averages of 4 to 5 percent for the same period.

For this analysis, three 10-year property value forecasts were completed for the shoreline properties: (1) no action alternative with an assumed annual increase in property value of four percent; (2) preferred alternative with a one percent annual impact on shoreline assessments above the no action alternative (total increase is five percent); and (3) preferred alternative with a three percent annual impact on shoreline assessments above the no action alternative (total increase seven percent). The property values for individual shoreline parcels are shown in Appendix E, Table 1. Based on the forecast assumptions, the total shoreline property value increase by the year 2006 ranges from $46.6 million for the no action alternative to between $60.1 and $89.6 million for the preferred alternative, which yields a net property value benefit of $13.5 to $43.0 million with implementation of the management plan over 10 years.

Annual differences between the no action and preferred alternative scenarios were also calculated. Table 7-3 shows the annual change in shoreline property value for the two alternatives for each of the forecast scenarios. The difference between the preferred and no action alternatives equals the benefit to shoreline property values that can be attributed to the management plan. The financial benefits range from $187,000 after one year to as much as $9,000,000 in the year 2006 (Table 7-3).

Table 7-3: Lake Desire Shoreline Property Assessment Comparison

Year	No Action Alt.: Annual Change in Property Assessment 4%/Yr. (1994 $)	2006 Preferred Alt.: Annual Change in Property Assessment 5%/Yr. (1994 $)	Annual Difference Between No Action & 5%	2006 Preferred Alt.: Annual Change in Property Assessment 7%/Yr. (1994 $)	Annual Difference Between No Action & 7%
1996[a]	$18,729,366	$18,729,366		$18,729,366	
1997[b]	$749,174	$936,467	$187,294	$1,311,056	$561,882
1998[b]	$1,528,314	$1,919,758	$391,444	$2,713,885	$1,185.571
1999[b]	$2,338,620	$2,952,213	$613,593	$4,214,913	$1,876,292
2000[b]	$3,181,339	$4,036,291	$854,952	$5,821,012	$2,639,673
2001[b]	$4,057,766	$5,174,573	$1,116,807	$7,539,539	$3,481,773
2002[b]	$4,969,250	$6,369,769	$1,400,519	$9,378,362	$4,409,112
2003[b]	$5,917,194	$7,624,725	$1,707,531	$11,345,903	$5,428,709
2004[b]	$6,903,055	$8,942,428	$2,039,373	$13,451,172	$6,548,116
2005[b]	$7,928,351	$10,326,017	$2,397,666	$15,703,809	$7,775,458
2006[b]	$8,994,659	$11,778,785	$2,784,126	$18,114,131	$9,119,473
Cumulative Increase	$46,567,722	$60,061,026	$13,493,305	$89,593,782	$43,026,059

[a]*Beginning Assessed Value*
[b]*Annual Assessed Value Change*

To complete the cost/benefit analysis, property values associated with the management plan must be compared to costs associated with the plan. The plan implementation costs exclusive of operation and maintenance costs or financial expenses are $649,000. Assuming that shoreline properties receive the most benefit from management plan (in terms of property value) and in turn bear two-thirds of the implementation costs, a total of $432,700 in implementation costs would be paid by shoreline residents. In this simplified cost/ benefit analysis, the 10-year benefit in shoreline property value—$13 to $43 million (see Table 7-3)— exceeds the implementation cost.

Funding of the management plan implementation was assumed to come from a single financial instrument payable through annual revenue from a lake management district (LMD; see description below). Assumptions regarding borrowing rates and the payment schedule are detailed in Appendix E. Table 7-4 shows the total bond cost with interest and the payment schedule for shoreline properties, as well as an example of the LMD assessment each year for a $250,000 property. The cost on a $250,000 property ranges from $581 to $592 at the beginning of the 10-year period and from $316 to $381 in 2006.

The analysis indicates that the property tax benefit derived from implementation of the management plan exceeds the costs of the implementation activities. A variety of factors could affect the analysis presented and the potential revenue which could be generated from property owners, including higher shoreline property values attributed to the preferred alternative, amortization period, and implementation impact on remaining watershed properties. More definitive results regarding the cost/benefit of management plan implementation could be gained using comparative analysis with another lake which has previously undergone restoration. However, the analysis performed for Lake Desire does indicate the potential benefit to shoreline property value from management plan implementation.

Table 7-4: Preferred Alternative Cost And Property Tax Comparisons (1994 $)

Year	Total Annual Bond Payment	Shoreline Portion of Bond Payment (2/3 of Total)	Tax Per $1,000 Assessed Value–5% Preferred Alt.	Example: 5% Preferred Alt. Property Tax: Assessed Value = $250,000	Tax Per $1,000 AV: 7% Preferred Alt.	Example: 7% Preferred Alt. Property Tax: Assessed Value = $250,000
1997	$69,806	$46,537	$2.37	$591.60	$2.32	$580.54
1998	$69,806	$46,537	$2.25	$563.43	$2.17	$542.56
1999	$69,806	$46,537	$2.15	$536.60	$2.03	$507.07
2000	$69,806	$46,537	$2.04	$511.05	$1.90	$473.90
2001	$69,806	$46,537	$1.95	$486.71	$1.77	$442.89
2002	$69,806	$46,537	$1.85	$463.54	$1.66	$413.92
2003	$69,806	$46,537	$1.77	$441.46	$1.55	$386.84
2004	$69,806	$46,537	$1.68	$420.44	$1.45	$361.53
2005	$69,806	$46,537	$1.60	$400.42	$1.35	$337.88
2006	$69,806	$46,537	$1.53	$381.35	$1.26	$315.78
10 Year Total	$698,060	$465,373		$4,796.60		$4,362.92

MANAGEMENT PLAN IMPLEMENTATION

A combination of grant funding, local revenue from lake management district (LMD) formation, and private sector funding is proposed in order to fund implementation of the Lake Desire Management Plan over an initial 10-year period. Operation and maintenance costs for the lake aeration system will need to be continued indefinitely and a mechanism for funding such activity will need to be identified.

Grants

Implementation funding for the management plan could be obtained potentially from three grants sources: 1) Washington State Department of Ecology Centennial Clean Water Fund (CCWF) grants; 2) Ecology Aquatic Weed Management Fund (AWMF) grants; and 3) U.S. Environmental Protection Agency (EPA) Clean Lakes or Nonpoint grant funds. All grants are either statewide or regional programs and are awarded annually on a competitive basis. Both CCWF and EPA Clean Lakes grants could be used to fund 50 percent of in-lake restoration measures and potentially 75 percent of watershed and monitoring measures. USEPA Nonpoint grants could also be used to fund up to 75 percent of watershed measures. Up to 75 percent of the project costs for Lake Desire aquatic plant management activities could be met through AWMF funding.

Lake Management Districts

An LMD uses a community-defined assessment to raise revenue for lake protection or improvement activities. Property owners on or near a lake pay a special charge on their property, either annually or on a one-time basis. LMDs can be formed for up to a 10-year period. LMDs have been formed and operated successfully in Snohomish and Thurston counties. Grant matching funds could be generated and/or specific management plan recommendations could be implemented through LMD formation.

Section 36.61 of the Revised Code of Washington (RCW) describes the process for LMD formation. According to the law, an LMD can be initiated through a petition to the County Council by property owners of at least 15 percent of the acreage within the proposed LMD boundary or by the Council who can adopt a resolution of intention. The petition or resolution of intention needs to include the following information: (1) proposed lake protection or improvement activities; (2) total amount of money to be raised; (3) whether money will be collected annually or one-time only; (4) amount of assessment (one-time or annual); (5) duration of LMD; and (6) proposed LMD boundaries.

After the petition is adopted or the resolution of intention is passed, a public notice is sent and a public hearing is held. This is followed by a special election in which each property owner has one vote for every dollar of proposed assessment. The proposed LMD must be approved by a simple majority of the votes cast. If there is a positive vote, the County Council adopts an ordinance to create the LMD. If there are no appeals, the King County Assessor prepares a special assessment roll which lists each property and the proposed special assessment. There is a second public hearing at which individuals can raise objections to the amount of the special assessment. The County Council may revise the special assessment roll in response. Then the special assessment roll is confirmed and billing can proceed. The money is administered by the County but a community-based advisory board can be appointed by the Council to oversee the project expenditures.

Preliminary Schedule

Management plan implementation is contingent on a variety of items including: (1) the availability of both public and private funding; (2) the successful award of public funding; and (3) the successful formation of an LMD. A Washington State Department of Ecology Centennial Clean Water Fund grant application was submitted in February, 1995, for Phase II implementation of the *Lake Desire Management Plan*. Listed below is a preliminary schedule for management plan implementation which assumes that successful grant award will occur in 1995 and private-sector funding/LMD formation will be pursued for matching the CCWF grant revenues.

• Apply for CCWF Grant Funding	February 1995
• Final Management Plan	April 1995
• Transmittal of Management Plan to Metropolitan King County Council	May 1995
• Initiate Lake Management District (LMD)	July 1995
• Initiate Implementation	January 1996
• Complete LMD Formation	September 1996

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APPENDICES

A. Glossary and Conversion Units

APPENDIX A.
GLOSSARY OF TERMS

Aerobic - Condition characterized by the presence of oxygen.

Algae - Single or multi-celled, non-vascular plants containing chlorophyll. Algae form the base of the food chain in aquatic environments.

Algal bloom - Heavy growth of algae in and on a body of water as a result of high nutrient concentrations.

Alkalinity - The acid combining capacity of a (carbonate) solution, its buffering capacity.

Allochthonous - Arising in another biotope, from outside of the lake basin (Gr. *allos* other, *chthon* land).

Anaerobic - Absence of oxygen (Gr. *an* without, *aer* air).

Anoxic - Lack of oxygen.

Aphotic zone - That part of a body of water to which light does not penetrate with sufficient intensity to maintain photosynthesis.

Autochthonous - Arising in the biotope under consideration, from within the lake basin (Gr. *autos* self, same, *chthon* land).

Autotrophic - The nutrition of those plants that are able to construct organic matter from inorganic (Gr. *autos* self, *trophein* to nourish).

Benthic - Bottom area of the lake (Gr. *benthos* depth).

Biochemical Oxygen Demand (BOD) - The decrease in oxygen content in milligrams per liter of a sample of water in the dark at a certain temperature over a certain period of time due to microbial respiration.

Biogenic - Arising as a result of life processes of organisms (Gr. *bios* life, *genos* origin).

Biomass - The total organic matter present (Gr. *bios* life).

Buffer - A mixture of weak acids and their salts which (in solution) is able to greatly minimize changes in the hydrogen-ion concentration.

Chlorophyll - The green pigments of plants (Gr. *chloros* green, *phyllon* leaf).

Colloids - substances that are distributed in a liquid as large aggregates of molecules; they are intermediate between true solutions and suspensions.

Colluvium-a loose deposit of rock debris accumulated at the base of a cliff or slope.

Consumers - Organisms that nourish themselves on particulate organic matter (Lat. *consumere* to take wholly).

Core - Sample of soil or sediment taken in such a way as to keep the vertical characteristic of the sediment undisturbed.

Decomposers - Organisms, mostly bacteria or fungi, that break down complex organic material into its inorganic constituents.

Detritus - Settleable material suspended in the water: organic detritus, from the decomposition of the broken down remains of organisms; inorganic detritus, settleable mineral materials.

Dimictic lake - A lake which circulates twice a year.

Drainage Basin - The area drained by, or contributing to, a stream, lake, or other water body.

Drumlin-a streamlined hill or ridge of glacial drift.

Ecosystems - Any complex of living organisms together with all the other biotic and abiotic (non-living) factors which affect them.

Electrolytic conductivity - The unit is the electrical conductivity, expressed in "reciprocal ohms," of a column of liquid 1 cm^2 in cross section and 1 cm high possessing a resistance of 1 ohm. In dilute solutions the conductivity is approximately proportional to the concentration.

Epilimnion - The turbulent superficial layer of a lake lying above the metalimnion (Gr. *epi* on, *limne* lake).

Euphotic zone - That part of a water body where light penetration is sufficient to maintain photosynthesis.

Eutrophic - Waters with a good supply of nutrients and hence a rich organic production (Gr. *eu* well, *trophein* to nourish).

Fall turnover - A natural mixing of thermally stratified waters that commonly occurs during early autumn. The sequence of events leading to a fall turnover includes 1) cooling of surface waters, 2) density change in surface water that produces convection currents from top to bottom, and 3) circulation of the total water volume by wind action. The turnover generally results in a uniformity of the physical and chemical properties of the water.

Fecal Coliform bacteria - A group of organisms common to the intestinal tract of vertebrates.

Glacial drift-a general term for unconsolidated sediment transported by glaciers and deposited directly on land or in the sea.

Glacial till-predominately unsorted and unstratified glacial drift, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consiting of heterogenneeous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

Hardpan-a cemented or compacted and often clay-like layer of soil that is impenetrable by roots.

Holomictic - Lakes that are completely circulated to the bottom at the time of winter cooling (Gr. *holos* entire, *miktos* mixed).

Humus substances - Organic substances only partially broken down, which occur in water mainly in a colloidal state (humus colloids). Humic acids are large-molecule organic acids that dissolve in water (Lat. *humus* soil).

Hydrogen sulfide gas - A gas resulting from the reduction of sulfate containing organic matter under anaerobic conditions which is frequently found in the hypolimnion of eutrophic lakes.

Hypolimnion - The deep layer of a lake lying below the metalimnion and removed from surface influences (Gr. *hypo* under, *limne* lake).

Isohyetals-a series of lines representing a constant depth of total precipitation for a given return frequency.

Isopleth - A line for the same numerical value of a given quantity (Gr. *isos* equal, plethos quantity).

Lenitic - slowly flowing (Lat. *lenis* mild, soft).

Limiting nutrient - Essential nutrient which is the most scarce in the environment relative to the needs of the organism.

Limnology - The study of inland waters (Gr. *limne* lake).

Littoral - The shoreward region of a body of water.

Metalimnion - The layer of water in a lake between the epilimnion and hypolimnion in which the temperature exhibits the greatest difference in a vertical direction (Gr. *meta* between, *limne* lake).

Moraine-debris, as boulders or stones, deposited by a glacier.

Morphology - Study of configuration or form (Gr. *morphe* form, *logos* discourse).

Nannoplankton - Those organisms suspended in open water which because of their small size cannot be collected by nets. They can be recovered by sedimentation or centrifugation (Gr. *nannos* dwarf).

Net production - The assimilation surplus in a given period of time after subtracting the amount of dissimilation in the same time inerval.

Niche - The position or role of an organism within it community and ecosystem.

Nutrient - Any chemical element, ion, or compound required by an organism for the continuation of growth, reproduction, and other life processes.

Oligotrophic - Waters that are nutrient poor and have little organic production (Gr. *oligos* small, *trophein* to nourish).

Outwash- glacial drift deposited by meltwater streams beyond an active glacier.

Oxidation - A chemical process that can occur in the uptake of oxygen.

Periphyton - The biological community attached to substrate (such as rocks, sediments, aquatic plants) that is primarily composed of algae.

pH - The negative logarithm of the hydrogen ion activity.

Pheophytin - A pigment resulting from chlorophyll degradation found in dead algae or suspended organic matter.

Photosynthesis - Production of organic matter (carbohydrate) from inorganic carbon and water in the presence of light (Gr. *phos, photos* light, *synthesis* placing together).

Phytoplankton - Free floating microscopic plants (algae) (Gr. *phyton* plant).

Primary production - The production of organic matter from inorganic materials within a certain period of time by autotrophic organisms with the help of radiant energy (Lat. *primus* first, *producere* to bring forward).

Producers - Organisms that are able to build up their body substance from inorganic materials (Lat. *producere* to bring forward).

Profundal - The deep region of a body of water below the light-controlled limit of plant growth (Lat. profundus deep).

Residence time - The average length of time that water or a chemical constituent remains in a lake.

Respiration - An energy-yielding oxidation which can occur in aerobic or anaerobic conditions.

Secchi disc - A 20-cm (8-inch) diameter disc painted white and black in alternating quadrants. It is used to measure light transparency in lakes.

Sediment - Solid material deposited in the bottom of a basin.

Sorb - The process of a compound adhering to a particle.

Stability of stratification - The work that must be done to destroy or equalize the density stratification existing in a lake.

Stagnation period - The period of time in which through warming (or cooling) from above a density stratification is formed that prevents a mixing of the water mass (Lat. *stagnum* a piece of standing water).

Standing crop - The biomass present in a body of water at a particular time.

Suspension - Very finely divided particles of an insoluble solid material dispersed in a liquid (Lat. *suspendere* to suspend below).

Thermocline - (Gr. *therme* heat, *klinein* to slope.) Zone of temperature decrease. See metalimnion.

Trophic state - Term used to describe the productivity of the lake ecosystem and classify it as oligotrophic, mesotrophic, or eutrophic.

Watershed - See drainage basin.

Watershed management - The management of the natural resources of a drainage basin for the production and protection of water supplies and water-based resources.

Zooplankton - The animal portion of the plankton (Gr. *zoion* animal).

Conversion of SI or Metric Units to English Units			
SI or Metric		**English**	
1	kilometer (km)	0.62	miles
1	meter (m)	3.28	feet
1	centimeter (cm)	0.39	inches
1	millimeter (mm)	0.04	inches
1	micrometer (μm)	0.00004	inches
1	hectacre (ha)	2.477	acres
1	square meter (m^2)	10.764	square feet
1	cubic meter (m^3)	35.32	cubic feet
1	cubic centimeter (cm^3)	0.061	cubic inches
1	liter (L)	0.26	gallons
1	milliliter (mL)	0.20	teaspoons
1	kilogram (kg)	2.205	pounds
1	gram (g)	0.035	ounces
1	milligram (mg)	0.015	grains
1	milligram/liter (mg/l)	1	part per million .
1	microgram/liter (μg/L)	1	part per billion
1	degree Celsius (°C)	x 9/5 + 32	degree Fahreheit

Abbreviation	Definition
AKART	All known, available, and reasonable methods of prevention, control, and treatment.
AWMF	Aquatic Weed Management Fund
BMPs	Best Management Practices
CCWF	Centennial Clean Water Fund
cfs	cubic feet per second
DMS	Department of Metropolitan Services
HSP-F	Hydrologic Simulation Program-FORTRAN
LD	Lake Desire
LMD	Lake Management District
Metro	Municipality of Metropolitan Seattle
P6	Peterson 6 subcatchment of the Peterson Creek Subbasin of the Cedar River Watershed
P7	Peterson 7 subcatchment of the Peterson Creek Subbasin of the Cedar River Watershed
SAO	Sensitive Area Ordinance
SEPA	State Environmental Policy Act
SWM or KCSWM	King County Surface Water Management
TAC	Technical Advisory Committee
UGB	Urban Growth Boundary
USDA	United States Department of Agriculture
USEPA or EPA	United States Environmental Protection Association
USFW	United States Department of Fish and Wildlife
USGS	United States Geologic Survey
VB/VR	Wetpond basin volume divided by volume of the runoff from the mean annual storm
WAC	Washington Administrative Code
WSDFW	Washington State Department of Fish and Wildlife
WSDOE or DOE	Washington State Department of Ecology

B. Public Access

Lake Desire Public Access Inventory
December 27, 1994

The lake's primary beneficial uses of Lake Desire include fishing, boating, aquatic habitat, and aesthetics. Access to these lake uses is provided via: (1) a Washington Department of Fish and Wildlife (WDFW) public boat launch on the northern shore and (2) a 382-acre King County open-space park located on the eastern shoreline (Figure 1).

The WDFW launch has been historically operated for seasonal access but was recently upgrade (physically) and opened for year-round access beginning last year. The lake is stocked every spring by the WDFW with trout and has one boat launch, a newly constructed fishing pier, paved parking for thirty vehicles, handicapped access, pit toilets, and trash collection.

The forested open-space park occupies an extensive area to the east of the lake including a hill which affords views of both Lake Desire and Spring Lake. The open-space park reaches the Lake Desire shoreline near the outlet at the southern end of the lake (Figure 1). Future plans for this forested park include the formal development of year-round public access through two-miles of existing pedestrian/equestrian trails, formalized shoreline access via the pedestrian trails, park signage, picnic tables, and parking for 10 vehicles. Currently, the park trails can be entered from W. Lake Desire Drive or W. Spring Lake Drive.

Less than a quarter of a mile from the lake is Petrovitsky Park (Figure 1), a 108 acre King County park facility operated year-round for passive and active recreational use. The park currently has a baseball/softball field, a lighted soccer field, a children's play area, pedestrian trails, and parking for 100 vehicles. The park's Phase II development will include additional baseball and soccer fields. The master plan for the park (attachment 1) shows a final designs with 6 lighted tennis courts, four baseball fields, two soccer fields, parking for 200 vehicles, picnic shelter, and foot trail access to W. Lake Desire Drive.

A public access inventory by element per the Washington State Department of Ecology's Centennial Clean Water Fund public access requirements is included below. The public access inventory includes both elements from facilities adjacent to the lake and nearby Petrovitsky Park.

1) Park Identification Signs:

- The WDFW Boat Launch is currently signed at its W. Lake Desire Drive entrance.
- Interpretive and location signage for the King County Open-Space Park is currently being developed.
- Petrovitsky Park is signed at its entrance from Petrovitsky Road.

2) Boat Launch:

- There is an existing boat launch on Lake Desire located on the northern edge of the lake with access via W. Lake Desire Drive. The launch is operated by WDFW for non-motorized boats. The facility is open year-around.

3) Parking Area:

- Paved parking is provided at the boat launch for thirty vehicles.
- Parking for 10 vehicles will be provide at the open-space park trail head located via W. Spring Lake Drive.
- Parking for 100 vehicles is currently provided at Petrovitsky park.

4) Garbage Receptacles:

- A garbage receptacle is located at the boat launch.
- Garbage receptacles are located at Petrovitsky Park.

5) Picnic Area:

- The fishing pier serves as an informal picnic area at the launch. From the pier, Mount Rainier can be viewed.
- Petrovitsky Park currently has __ picnic tables.

6) Sani-Kans or Portable Toilets:

- A permanent handicapped accessible pit toilet has been installed at the boat launch.
- Sani-Kans are installed at Petrovitsky Park but will be replaced with permanent facilities once the sewer extension to the park is complete.

7) Play Area:

- An active recreational area including a children's play area, soccer field, baseball field, and an open meadow is located at Petrovitsky Park.

8) Swimming Area:

- The lake has no formal swimming beach, however, access to the lake for swimming activities occurs informally from the boat launch and at the open-space shoreline access areas.

9) Fire Pits:

- No fire pits are located in any of the park facilities.

10) Permanent Restroom Facilities:

- The boat launch has a permanent pit toilet installed, but no running water is available on-site.
- Permanent facilities, including running water, will eventually be located in Petrovitsky Park.

11) Portable Water Supply:

- A portable water supply will eventually be available in Petrovitsky Park

12) Fishing Pier/Floats:

- The WDFW constructed a fishing pier in 1993 as part of the upgrading of the boat launch area. The pier provides fishing access to the lake for 10-20 individuals and is heavily used year-round. From the pier, Mount Rainier as well as much of the lake can be viewed.

13) Nature Trails:

- Two miles of pedestrian/equestrian trails are located in the open-space park. The trails provide access to both Lake Desire and Spring Lake shorelines as well as hilltop view of both lakes. The park area trail system is linked to the nearby Cedar River and Lake Youngs Trails.
- Petrovitsky Park, upon completion of the park master plan will have additional pedestrian trails through the forested portion of the park located in the eastern and northern portions of the park. These trails will be connected with the existing park trails located in the active recreation area.

Per DOE requirements, phase II projects which total less than $400,000 must provide items 1 through 6 as the minimum requirement for public access. For projects between $400,000 and $800,000, items 1-9 must be provided. For projects greater than $800,000, public access elements 1-13 must be present.

At present, items 1-6, 12, and 13 are met with adjacent water access. If the definition of public access is expanded to included the recreational facilities of Petrovitsky Park, item 7 is also met at present. Upon completion of the Petrovitsky Park master plan and the open-space park future development, items 9, 10, and 11 will be met. Currently, there are no future plans by the County to develop a swimming area at Lake Desire. The lake has not been used historically for swimming except by a few residents. The dark tannic water color probably is related to is low use for swimming and its high use for fishing, boating, fish and wildlife habitat, and aesthetics

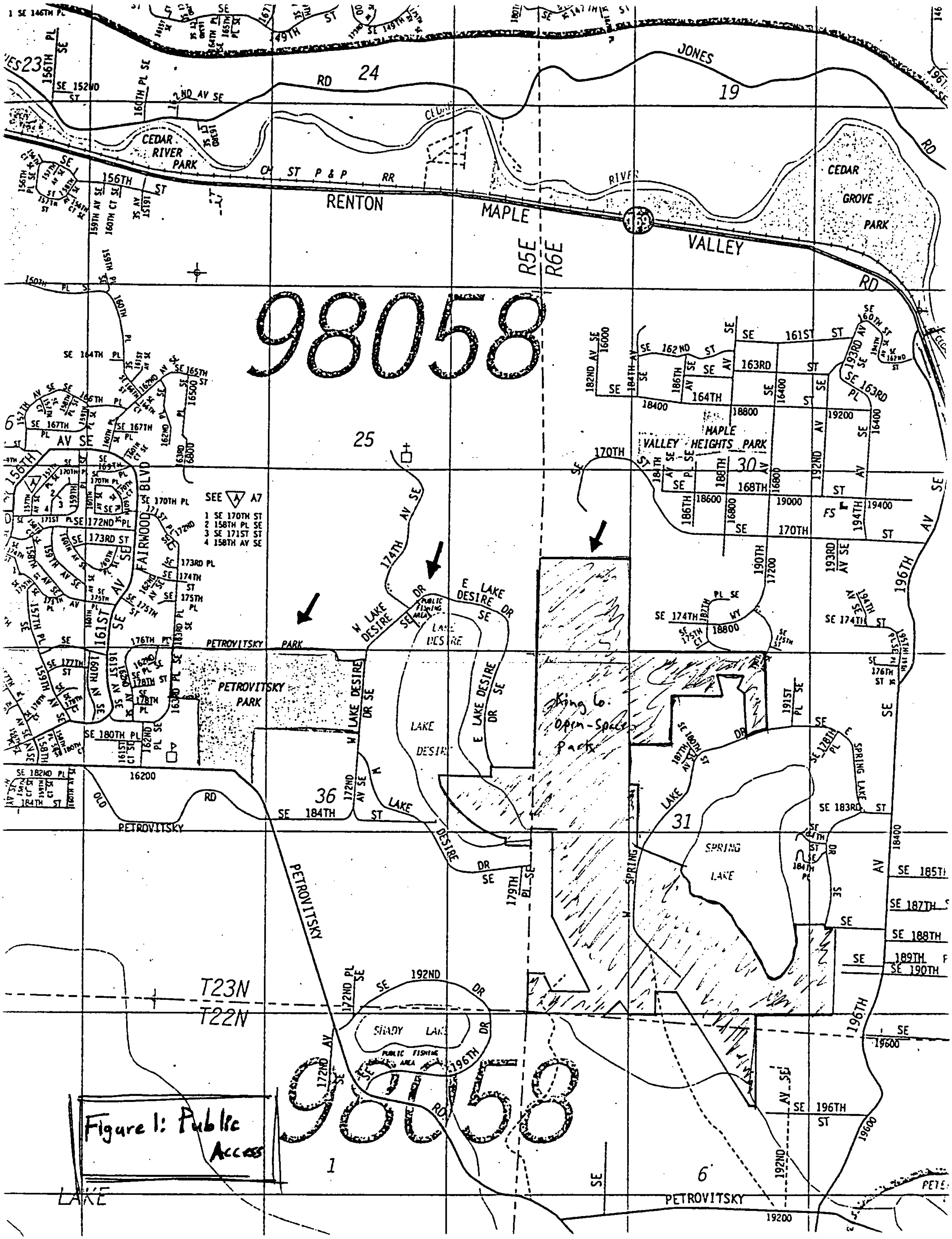
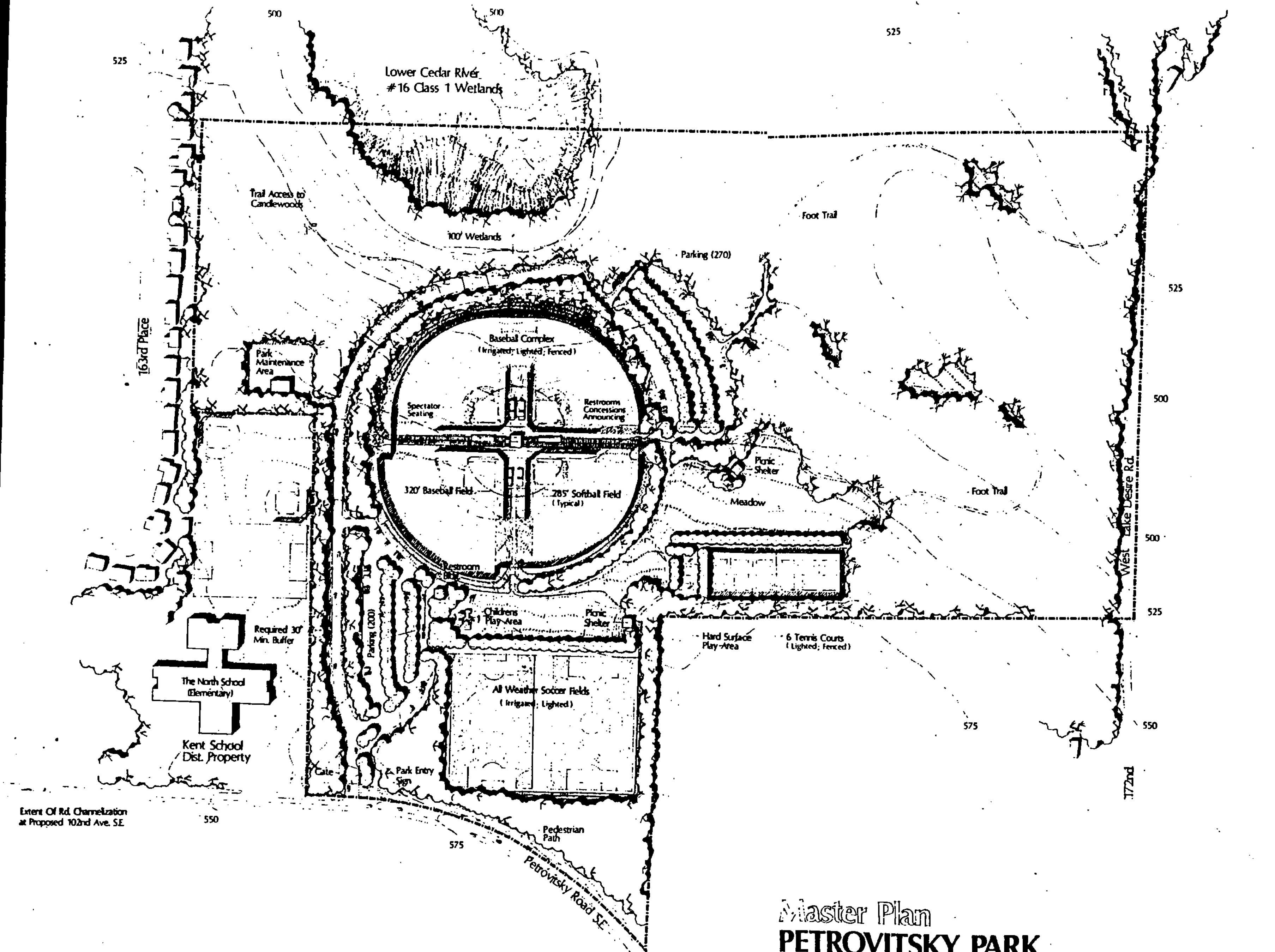


Figure 1: Public Access

Attachment 1



Master Plan
PETROVITSKY PARK
KING COUNTY PARKS & RECREATION
JONGEJAN · GERRARD · McNEAL

C. Sampling Locations Descriptions

Lake Desire Station Descriptions

Station	Description	Depth (meters)
DESIRE1	North lake basin in-lake sampling station, located at maximum lake depth	0,1,2,3, 4,5,&6
DESIRE2	South lake basin in-lake sampling station, located at maximum lake depth	0,1,2,3, 4,&5
LDIN1	Tributary 0328B at inlet to Lake Desire	0
LDOUT1	Tributary 0328B at outlet from Lake Desire	0
LDW1	The combined outflow channel from Cedar River Wetland 14 and southeastern drainage area. The site is located downstream of the confluence of LDW2 and LDW3.	0
LDW2	A channel has been created which flows east to west along the south-side of Cedar River Wetland 14. The sample site is located 10-20' upstream of the intersection of this channel with the main wetland outflow channel.	0
LDW3	The outflow channel from Cedar River Wetland 14 upstream of the confluence with LDW1 into LDW2. No samples were taken at this location during Jan-Mar. 94.	0
LDW4	Inflow to Cedar River Wetland 14. Sample site is approximately 40-50' north of wetland edge but downstream of the confluence of two small tributaries which drain to the wetland.	0
LDSRP1	Shadow Ridge Detention Pond outflow located adjacent to 190th Ave SE. Sample was take 10-15' downstream of pond outflow.	0
LDSRP2	Shadow Ridge Detention Pond outflow located along SE 174th Way. Sample was taken 10-15' downstream and within the biofiltration swale.	0
LD1 and LD2	Tony Sieger residence, west-side of Lake Desire, 126 Lake Desire Rd.	0
LD3 and LD4	Tony Sieger undeveloped lot on the north end of Lake Desire	0
LD5 and LD6	Steve Crowley residence on the southeast side of Lake Desire, 360 Lake Desire Dr.	0