



Effectiveness Monitoring for Total Phosphorus Total Maximum Daily Loads in Fenwick and Sawyer Lakes

Abstract

The Washington State Department of Ecology is required, under Section 303(d) of the federal Clean Water Act and the U.S. Environmental Protection Agency's implementing regulations, to develop and implement Total Maximum Daily Loads (TMDLs) for impaired waters and to evaluate the effectiveness of the clean-up plan to achieve the needed improvement in water quality. Total phosphorus (total P) TMDLs were developed for both Fenwick and Sawyer lakes based on the narrative state water quality standard for aesthetics. Maximum in-lake mean summer total P concentration limits of 19 and 16 $\mu\text{g/L}$ were set for Fenwick and Sawyer lakes, respectively, in their TMDLs to deter progression of eutrophication. Preliminary evaluation of available monitoring data indicates non-compliance to the maximum in-lake mean summer target limits set for total P in the TMDLs at both lakes in a short term. Consequently, violation of the narrative state water quality standard for aesthetics and further eutrophication may exist, based on initial individual year survey of the TMDL data. However, Lake Sawyer seems to be meeting the TMDL target limit as a long term average.

Publication Information

This report is available on the Department of Ecology home page on the World Wide Web at <http://www.ecy.wa.gov/biblio/0203054.html>

For additional copies of this report, contact the Department of Ecology Publications Distribution Office and refer to publication number 02-03-054.

E-mail: ecypub@ecy.wa.gov

Phone: (360) 407-7472

Address: PO Box 47600, Olympia WA 98504-7600

Author: George Onwumere, Ph.D.

Washington State Department of Ecology

Environmental Assessment Program

Phone: (360) 407-6730

Address: PO Box 47600, Olympia WA 98504-7600

The Department of Ecology is an equal opportunity agency and does not discriminate on the basis of race, creed, color, disability, age, religion, national origin, sex, marital status, disabled veteran's status, Vietnam era veteran's status, or sexual orientation.

If you have special accommodation needs or require this document in alternative format, please contact Michelle Harper at (360) 407-6677 (voice) or (360) 407-6006 (TDD).

Introduction

This report presents an assessment of the effectiveness of total phosphorus (total P) Total Maximum Daily Load (TMDL) implementation programs at Fenwick and Sawyer lakes. The TMDL is a tool for implementing water quality standards under the Clean Water Act (CWA) and is based on the relationship between pollution sources and in-stream or lake water quality conditions. It is a summation of the individual waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources, including natural background conditions.

The Washington State Department of Ecology (Ecology) is required, under Section 303(d) of the federal CWA and U.S. Environmental Protection Agency's (EPA) implementing regulations, to: periodically assemble the list of water bodies that are out of compliance with the state water quality standards, develop and implement TMDL's for these watersheds, and evaluate the effectiveness of the clean-up plan to achieve the needed improvement in water quality.

Currently, over 40 percent of the nation's and most states' assessed waters still do not meet the water quality standards. While some of the listed water quality parameters of concern are conventional like temperature and pH, other parameters associated with Fenwick and Sawyer lakes are chemical like total P.

Lake Fenwick is a small urban lake located west of the city of Kent in King County. The lake is the smaller of two lakes within the city limits and is considered an important recreational resource. The dominant recreational activities are fishing and boating. In the past, the city had spent money on lake improvement projects that ranged from providing fishing docks and enhanced trail systems to restoration activities such as wet pond construction to reduce sedimentation and aeration to improve water quality (Entranco, 1991). Yet eutrophication due to nutrient input continues to be a problem as in Lake Sawyer.

Lake Sawyer, the fourth largest natural lake in King County, is located in the city of Black Diamond. Although the lake suffers from eutrophication it is used extensively for several recreational activities that include sailing, water skiing, scuba diving, swimming, picnicking, wildlife observation, and aesthetic enjoyment (King County, 2000). In order to improve water quality and maintain the beneficial uses of the lake water, the City of Black Diamond wastewater treatment plant (WWTP) diverted effluent discharges from a wetland on Rock Creek to a Metro sewer line in 1992. The effluent diversion reduced phosphorus loading from the lake inlet, however, the initial overall improvement associated with the WWTP diversion was minimal due to internal phosphorus loading from sediments (King County, 2000).

The purpose of this report is to assess the effectiveness of past TMDL implementation programs set for both lakes in complying with the in-lake mean summer total P concentrations of 19 and 16 $\mu\text{g/L}$ for Fenwick and Sawyer lakes, respectively. These were target limits set through modeling in their TMDLs to deter progression of eutrophication and improve water quality.

This report includes the following:

- Phosphorus background information
- Summary of in-lake mean summer total P concentration limitations
- Discussion of available monitoring results
- Conclusion

Background

Phosphorus in dissolved or bound form is usually found in limited natural supplies compared to the rich supply of other major nutritional and structural components of the biota such as carbon, hydrogen, nitrogen, sulphur, and oxygen, and because of this, it is the most studied element. The interest in phosphorus quantities result from the major role this element plays in ecosystem dynamics. Phosphorus is found in relatively small quantities, hence is the “limiting” nutrient for algal growth and do influence whole-system metabolism that can result in eutrophication. In aquatic environments, phosphorus is commonly measured as total phosphorus (total P), a combination of particulate and dissolved P contents in unfiltered water (Wetzel, 1983).

Limnological evidence to date has shown a strong relationship between total P concentrations and lake productivity. The sources of phosphorus to streams and lakes are both internal and external. According to Wetzel (1983), the phosphorus content of precipitation and groundwater are highly variable, but are generally low enough not to be considered major sources. Surface runoff, on the other hand, is often a major contributor of phosphorus to streams and lakes. Table 1 shows the major sources of phosphorus to Fenwick and Sawyer lakes with stormwater runoff as a major external contributor to Lake Fenwick (46.5%).

Lake Sawyer runoff was divided into sub-basins with the three sub-basins contributing about 64% of the phosphorus to the lake (12% from Lake Sawyer sub basin, 17% from Ravensdale Creek sub basin and 35% from Rock Creek sub basin). A similar example that can serve as a guide in this situation is that of Gull Lake, one of the largest lakes in southwestern Michigan, where approximately 24% of the total P entering this rapidly eutrophication lake was attributed to lawn fertilization from surrounding residences (Wetzel, 1983).

Once phosphorus enters the lake, it may be absorbed or adsorbed to lake sediments and recycled among the sediment, water, and biotic compartments for many years resulting in an internal phosphorus loading. Table 1 shows net sediment release values of 23.6% and 19% for Lake Fenwick and Lake Sawyer respectively. This exchange of phosphorus between sediments and overlying water is a major component of the phosphorus cycle in natural waters according to Wetzel (1983). Consequently, lakes with a history of sediment phosphorus release or rich in organic matter (bogs and bog lakes) might exhibit high total P concentrations, thereby showing slow response time to a reduction in external phosphorus loading (Wetzel, 1983 and King County, 2000) from mitigation activities. The effectiveness of the phosphorus movement between sediments and water column depends upon a series of physical, chemical, and metabolic factors. Generally, internal loading from sediment release is significant after lake turnovers when nutrient-rich bottom water mixes with the rest of the water column (King County, 2000). The

high net sediment release values of both lakes indicate that they may continue to experience summer algal blooms even though the external sources of phosphorus loading have been substantially reduced or eliminated from this internal recycling. Generally, the amount of total P increases with lake productivity resulting in elevated eutrophication.

Table 1. Sources of Total Phosphorus Loads to Fenwick and Sawyer lakes (Data from Entranco, 1991 and King County, 2000).

Sources	Lake Fenwick (%)	Lake Sawyer (%)
Net sediment release	23.6	19
Aquatic Plants	5.4	5
Birds	6.2	--
Atmosphere	2.6	3
Groundwater	8.5	1
Stormwater	46.5	--
Septic tanks	7.7	8
Lake Sawyer sub-watershed	--	12
Ravensdale Creek sub-watershed	--	17
Rock Creek sub-watershed	--	35

Apart from aesthetics, a more serious consequence of eutrophication or summer algal blooms is oxygen depletion within the water column. The resulting effects are direct and immediate on aerobic organisms and may even lead to fish kills in severe situations. In addition, oxygen depletion in the hypolimnion during summer stratification has a direct impact on the amount of total P released from the sediments. Consequently, low dissolved oxygen concentrations can produce significant internal total P recycling.

In-lake Mean Summer Total P Concentration Limitations

In-lake mean summer total P concentration limitations were established in the TMDLs for Fenwick and Sawyer lakes to ensure compliance with the state’s narrative water quality standard for aesthetics, and to reduce eutrophication in both lakes. Loading capacities set for both lakes are consistent with maintaining in-lake mean summer total P concentration target limits of 19 and 16 µg/L for Fenwick and Sawyer lakes, respectively. These were target limits set through modeling in their TMDLs to deter progression of eutrophication and improve water quality. The loading capacities are intended to accommodate all the total P non-point sources of pollution to the lakes.

Apart from the above load allocation (LA) for Lake Sawyer, a waste load allocation (WLA) of 0 (zero) kg/day for total P was set for the city of Black Diamond’s wastewater treatment plant (WWTP). WLA accounted for all the total P point sources of pollution to the lake. This was accomplished by diverting the city’s effluent discharges from a wetland on Rock Creek to a

Metro sewer line in 1992. No WLA was set for Lake Fenwick since there was no point source pollution to the lake.

The TMDL’s for both lakes also require that adequate ambient monitoring be conducted to assess progress in achieving the TMDL goals. Composite sampling was conducted at Lake Fenwick (see Figure 1). At Sawyer Lake, two routine main stations in the deep part of the lake (A and B) and two auxiliary stations in the shallower part of the lake (C and D) were sampled from October 1994 to April 1995, as illustrated in Figure 2. According to King County (2000), samples were only collected from stations C and D during the growing season from June to September. The rest of the samples were collected between May and October by composite sampling from 1994 to 2001. The results of water quality samples collected through composite sampling at Lake Fenwick are shown in Figure 3. Figures 4, 5, and 6 show Lake Sawyer results at which a composite and discrete water quality sampling was implemented.

Results and Discussion

Lake Fenwick

At Lake Fenwick, total P composite concentrations ranged from 16.6 µg/L in July 1994 to 129 µg/L in August 1995. 2001 data was for 1m deep sampling. Table 2 shows the summary statistics for Lake Fenwick. On the average, the in-lake mean summer total P concentration target limit of 19 µg/L set in the TMDL was not met from 1993-1995 and 2001, as shown in Figures 3 and 4. Lake monitoring data was missing from 1996 to 2000; nevertheless, evaluation of available data and the figure below indicate non-compliance to the in-lake mean summer total P concentration target limit of 19 µg/L set in the TMDL. This target limit was set through modeling in the TMDL to deter progression of eutrophication and improve water quality. Since these observed concentrations are consistently above the total P target limit of 19 µg/L as required in the TMDL, a violation of state’s narrative water quality standard for aesthetics is apparent.

Table 2. Total P Summary Statistics for Lake Fenwick (Data from King County, 2000).

Year	Mean (µg/L)	Sample Number (N)	Coefficient of Variation (%)	TMDL Limitation (µg/L)
1993	33.8	2 (Composites)	7.3	19
1994	29.6	6 (Composites)	31.8	19
1995	45.6	6 (Composites)	56.0	19
2001	35.1	6 (1m deep)	36.0	19
Mean	36.0			19

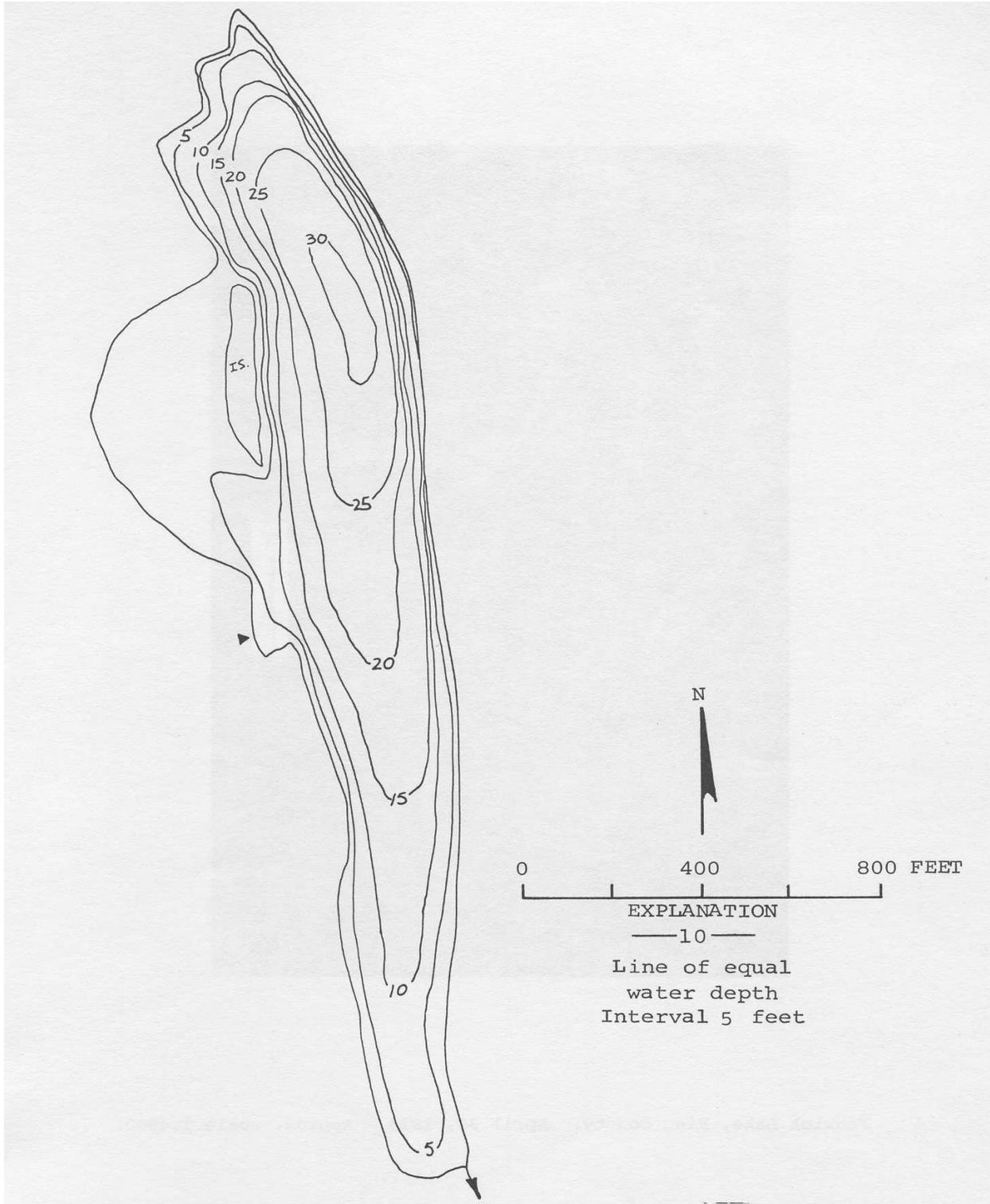


Figure 1. Map of Lake Fenwick (Map from Bortleson et al., 1976).

These excessive values do not mean that the TMDL implementation program in the Lake Fenwick watershed is ineffective. Internal phosphorus loading is seen as a major contributor to total P in both lakes (Table 1). In fact, total P contribution from net sediment release at Lake Fenwick is estimated at 23.6% (King County, 2000). However, according to the City of Kent

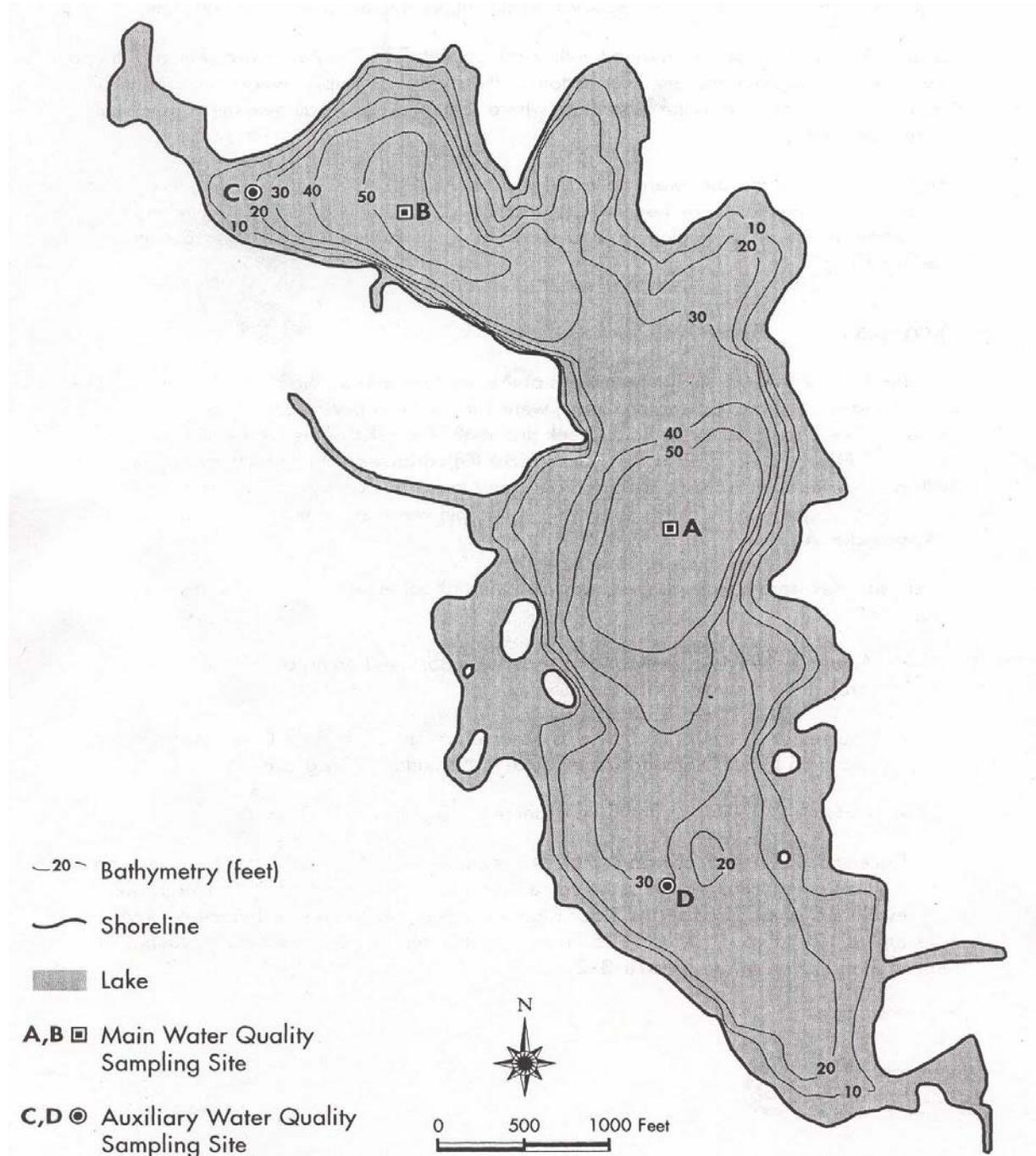


Figure 2. Main and Auxiliary Water Quality Sampling Stations in Lake Sawyer from 1994 to 1995 (Map from Lake Sawyer Management Plan, King County 2000).

monitoring report, there has been a considerable reduction in total P and soluble reactive phosphorus (SRP) concentrations since the introduction of a hypolimnetic aeration system in the lake in 1995. According to the report, the deep station summer mean epilimnetic total P concentrations have been around 20 µg/L since 1990 (City of Kent, 2000) and is contrary to the total P data collected by King County from 1993 to 1995, as shown in Table 2. Although, both data sets have shown progress in water quality recovery over the past several years, more and consistent improvements are required to meet the TMDL target limit of 19 µg/L.

Apart from the sediments, contribution from stormwater runoff is also estimated at 46.5%, as shown in Table 1. Therefore, cumulative loadings from both internal phosphorus loading following turnover of the lake and the increased fall and winter stormwater runoff activities could keep total P concentrations in the lake elevated for many years. Consequently, the lake may continue to experience elevated total P concentrations and subsequent eutrophication even though some of the external sources of phosphorus may have been eliminated or considerably reduced. According to Wetzel (1983), the likelihood of this sediment-water exchange of phosphorus occurring depends on the following:

- capacity of the sediments to retain phosphorus,
- biota within the sediment environment, and
- overlying water conditions.

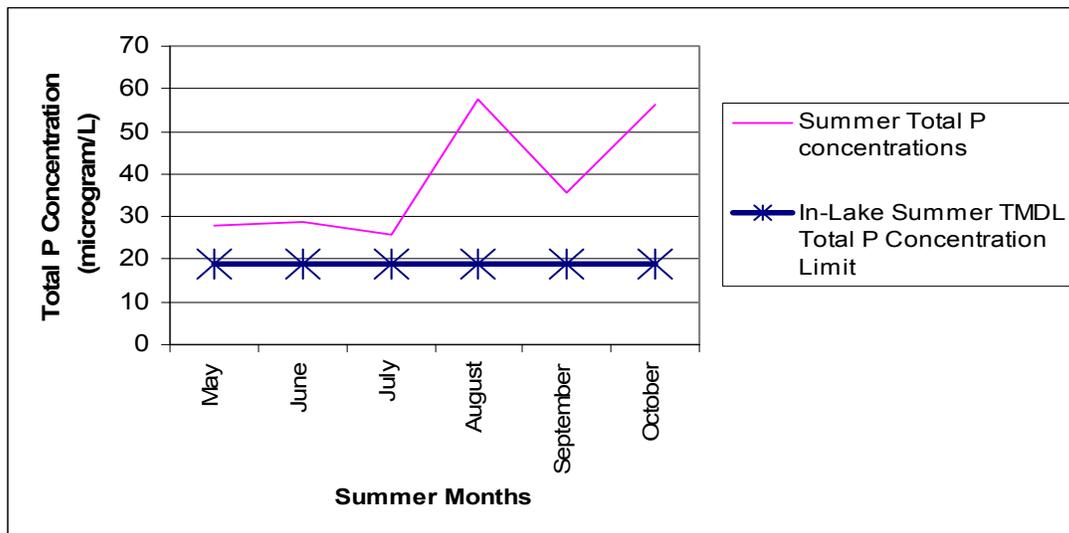


Figure 3. Summer Average Total Phosphorus Composite Concentrations at Fenwick Lake from 1993-1995 (Data from King County Water and Land Resources Division).

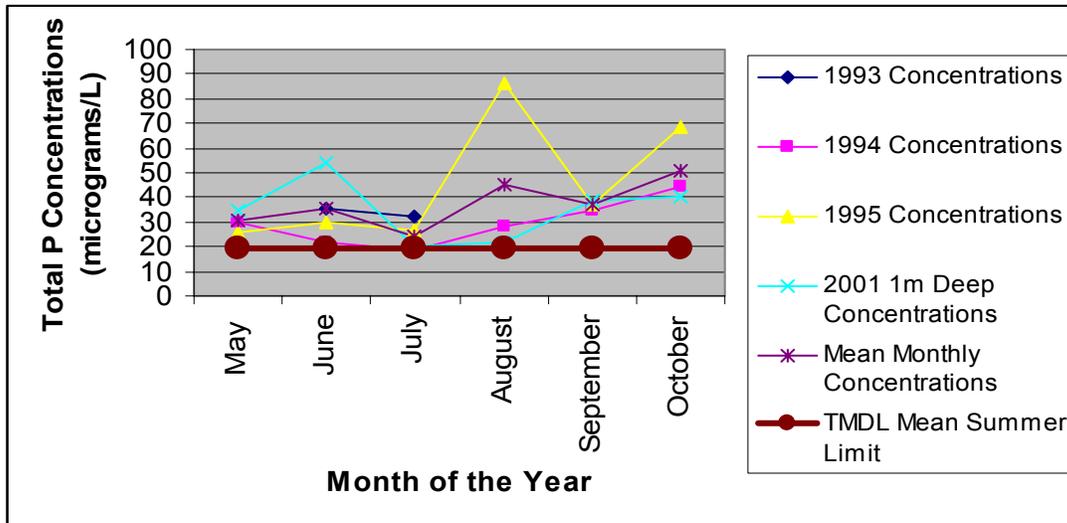


Figure 4. Comparison of Summer Months' Composite and 1m Deep Phosphorus Results to Mean Monthly and TMDL Summer Limit Concentrations from 1993-1995 and 2001 at Lake Fenwick (Data from King County Water and Land Resources Division)

Lake Sawyer

Figure 5 shows the one year total P study at Lake Sawyer with the highest total P concentrations recorded at both stations A and B for the month of December 1994. Part of the fall and all of the winter months' data show total P concentrations well above the in-lake mean summer total P concentration target limit of 16 $\mu\text{g/L}$ set in the TMDL. According to King County (2000), this could be due to cumulative loadings from both internal phosphorus loading following turnover of the lake and the increased fall and winter stormwater runoff activities. Actually, total P contribution from net sediment release and total P contributions from the three sub basins at Lake Sawyer are estimated at 19% and 64% (12% from Lake Sawyer sub basin, 17% from Ravensdale Creek sub basin and 35% from Rock Creek sub basin), respectively, as indicated in Table 1.

All the Lake Sawyer sites have total P concentrations near or slightly above the in-lake mean summer total P concentration target limit of 16 $\mu\text{g/L}$ set in the TMDL during the growing season (June to September). This probably indicates utilization of total P by zooplankton during the growing season. The only exceptions are stations B and C with elevated total P concentrations for the month of August 1994, as indicated in Figure 5. Although the growing season (June to September) total P concentrations are lower than the November to February levels, concentrations still remain above the in-lake mean summer total P concentration limit. This supports King County's overall assessment that states Lake Sawyer is predominantly phosphorus limited and that management activities should be tailored to controlling total P inputs.

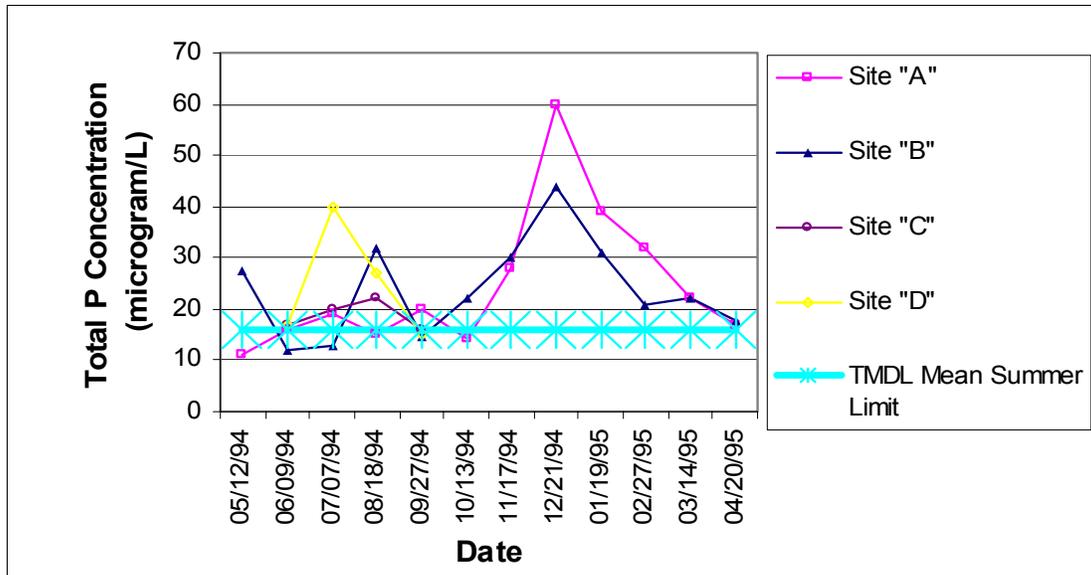


Figure 5. Total Phosphorus Concentrations from different Locations at Lake Sawyer from 1994 to 1995 (Data from King County Water and Land Resources Division)

Table 3 shows the composite and 1m deep sampling summary statistics for Lake Sawyer from 1994 to 2001. Composite sampling results, available only for 1994, show the highest total P concentrations occurring in June of that year than at any other time, as indicated in Figure 5. The 1m deep sampling results show the highest total P concentrations occurring on different months in 1995, 1997, and 2001 as indicated in Figures 7 and 8. They also have concentrations that are considerably higher than the in-lake mean summer total P concentration target limit of 16 µg/L set in the TMDL, as illustrated in these figures.

Table 3. Total P Composite Sampling Summary Statistics for Lake Sawyer (Data from King County, 2000).

Year	Mean (µg/L)	Sample Number (N)	Coefficient of Variation (%)	TMDL Limitation (µg/L)
1994	25.4	5 Composites	38.2	16
1995	18.2	5	34.0	16
1996	15.9	6	19.9	16
1997	21.6	6	26.6	16
1998	9.4	6	29.0	16
1999	9.2	6	7.4	16
2000	9.6	6	25.0	16
2001	14.2	6	24.8	16
Mean	15.4			16

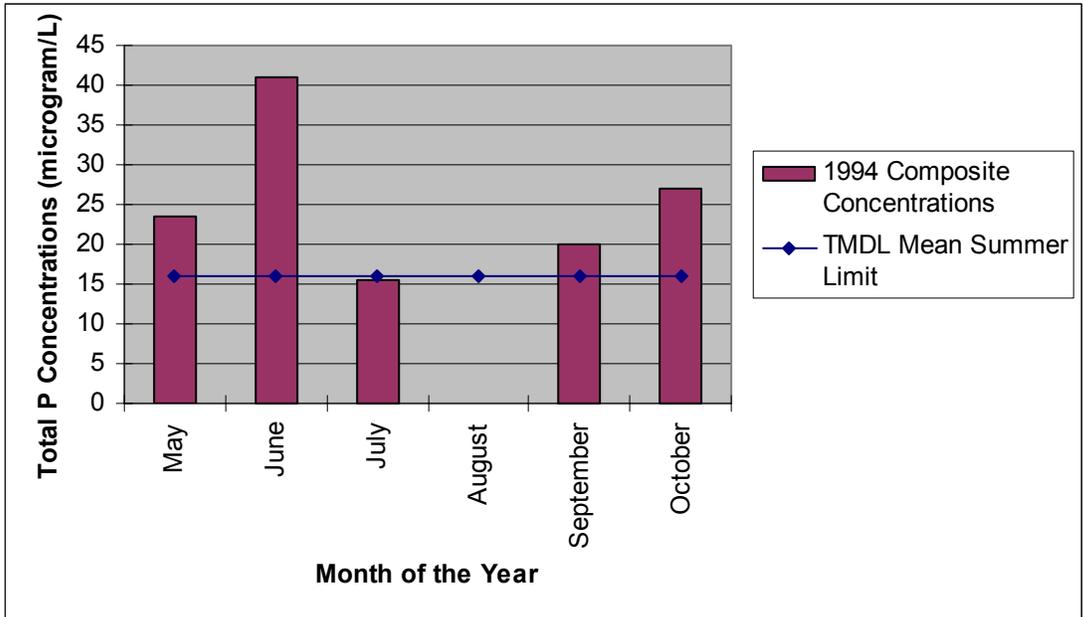


Figure 6. Comparison of Summer Months' Composite Phosphorus Concentrations to the TMDL Summer Target Limit for 1994 at Lake Sawyer (Data from King County Water and Land Resources Division)

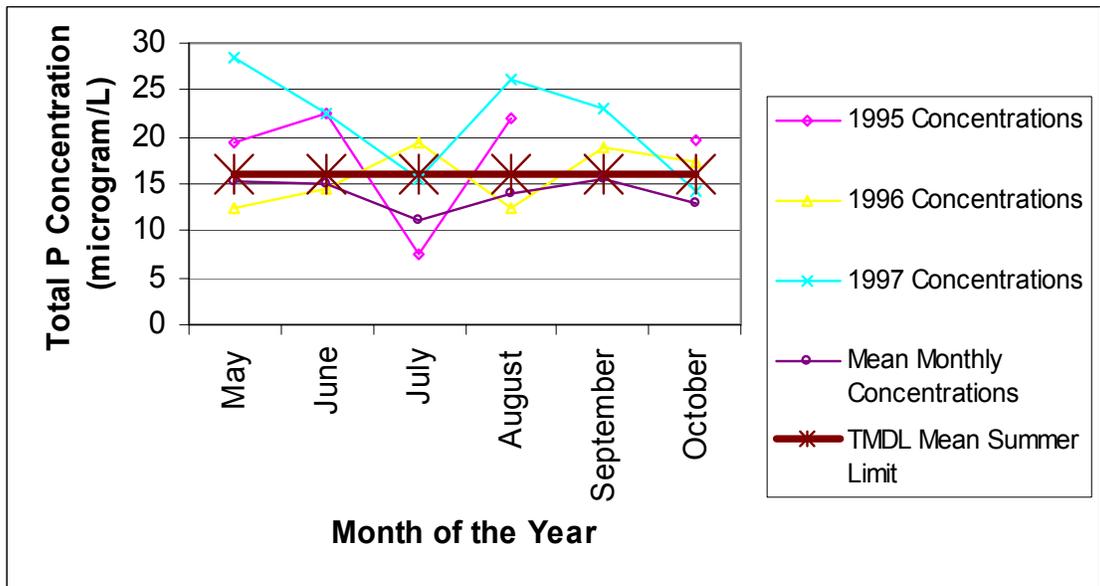


Figure 7. Comparison of Summer Months' 1m Deep Phosphorus Results to Mean Monthly and TMDL Summer Limit Concentrations from 1995 to 1997 at Lake Sawyer (Data from King County Water and Land Resources Division)

However, the results from 1998 to 2000 show there are periods where in-lake mean summer total P concentration limits are met, as depicted in Table 3 and Figure 8. This may indicate a progressive improvement in total P reduction efforts over the years; but more data is required over the next several years to verify that this is a trend toward lake improvement. Similarly, the mean concentrations from all years in which data was collected seem to be below or around the in-lake mean summer total P concentration target limit, as shown in Figures 7 and 8.

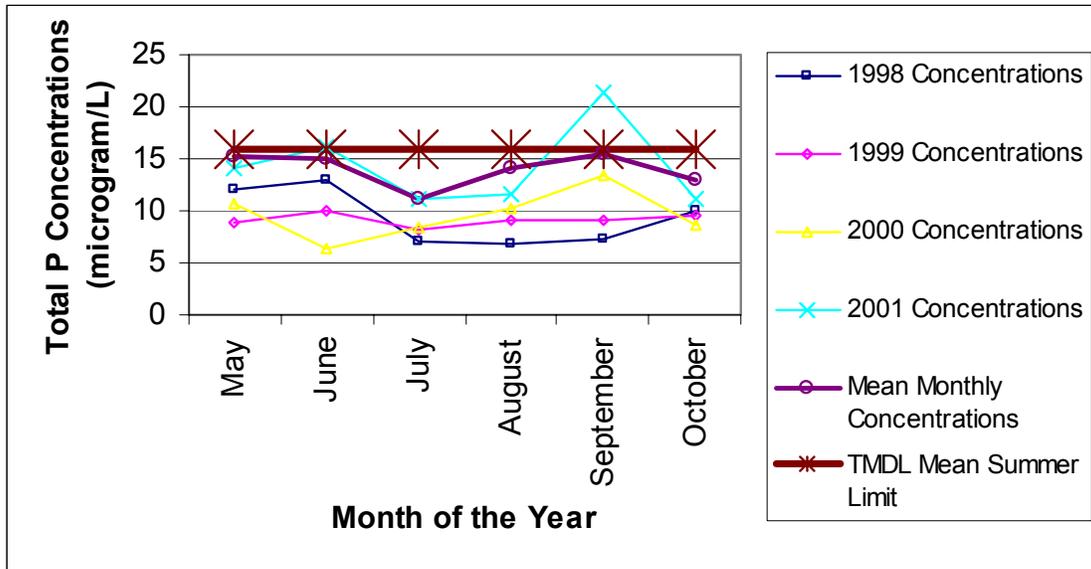


Figure 8. Comparison of Summer Months' 1m Deep Phosphorus Results to Mean Monthly and TMDL Summer Limit Concentrations from 1998 to 2001 at Lake Sawyer (Data from King County Water and Land Resources Division)

Evaluation of available data in these figures indicate incidences of non-compliance with the in-lake mean summer total P concentration target limits set for these lakes in their respective TMDLs in a short term, as shown in these figures. There were occasions that total P concentrations were below TMDL limits, especially at Lake Sawyer; however those occasions are not a verifiable trend yet. The intent of the total P reduction is that samples collected meet design conditions of the TMDL target limit. As a result, the fundamental supposition is that, in the short term, the state's narrative water quality standard for aesthetics is not being met based on the current TMDL implementation strategies, especially at Lake Fenwick. Lake Sawyer has shown improvement in the last several years based on the figures but more water quality monitoring data is required to verify the observed trends at both lakes.

Conclusion

Evaluation of available effectiveness monitoring data indicates that both lakes have periods when total P concentrations are above their in-lake mean summer total P concentration target limits as set by their respective TMDL goals, especially at Lake Fenwick. For several years at Lake Sawyer, total P concentrations at individual stations or years are below the TMDL target limits, but they appear not to be a typical trend. In the short term, the state's narrative water quality standard for aesthetics cannot be met and sustained for Fenwick and Sawyer lakes without strategically targeting further reduction of total P contributions from internal and stormwater loadings.

Although, Lake Sawyer seems to be meeting the TMDL target limit as a long term average, more data is required to validate this improvement. Progress in reducing total P levels in these lakes should be tailored to: 1) reducing cumulative loadings from internal phosphorus sources following turnover of the lakes, 2) reducing the increased fall and winter stormwater runoff activities, 3) continuing aeration at Lake Fenwick and considering its appropriateness at Lake Sawyer, and 4) considering alum addition to take phosphorus out of the water column, which may improve adsorption to the sediments. Without strategically targeting the sources of total P, both lakes may likely continue to experience elevated total P concentrations and subsequent eutrophication.

Acknowledgements

The author would like to thank the following people and organizations for their contributions to this report.

- Sally Abella, King County, for providing the lake data sets and reviewing the draft report.
- Robert W. Plotnikoff, Maggie Bell-Mckinnon, and Steve Butkus, Department of Ecology, for providing the Unit-level review and providing comments on the report. Special thanks to Robert W. Plotnikoff for editing the final draft report.
- Greg Pelletier, Department of Ecology, for providing timely Program-level review.
- Drs. Ken Hall and Stephen Smith, University of British Columbia, Vancouver, Canada, and Simon Fraser University, Burnaby, Canada, respectively for providing timely external-level review of the draft report.
- Michelle Harper for formatting the report.

References

- Bortleson, G.C., Dion, N.P., McConnell, J.B., and Nelson, L. M. 1976. Reconnaissance Data on Lakes in Washington. King and Snohomish Counties. Water-Supply Bulletin 43, Vol. 2. 424p.
- City of Kent. 2000. Lake Fenwick Aeration. 2000 Monitoring Report. City of Kent Public Works Department, Environmental Engineering Section, Kent, Washington. 7p.
- Entranco. 1991. Lake Fenwick Restoration Study. Prepared for the City of Kent by Entranco, 10900 NE 8th Street, Bellevue, Washington. 121p.
- King County. 2000. Lake Sawyer Management Plan. Surface Water Management Division, Department of Public Works, King County, Washington. Pp. ES1-G4.
- King County. 2002. Lake Data from King County Water and Land Resources Division, King County, Washington.
- Wetzel, R.G. 1983. Limnology. Saunders College Publishing – Harcourt Brace College Publishers, New York. 2nd Edition. Pp. 255-297.