Modeling the Response of Phosphorus Loading to Lake Villarrica, Chile

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August 2000

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Purpose

The goal of this study is to develop a recommendation for a pollution control strategy to help protect the beneficial uses of Lake Villarrica. The natural lake is an increasingly important body of water in Southern Chile. The lake serves to supply domestic water and is increasingly being used for recreational purposes. As tourism continues to increase in the area, maintaining acceptable water quality in the lake will become increasingly important. It is essential that the lake water quality does not become impaired resulting in driving away tourism and recreation along with the potential economic benefits these activities will bring to the people of the local area.

Pollution from excessive nutrients is the water quality constituent of most interest for protecting the beneficial uses of the reservoir. The loading of excessive nutrients causes accelerated eutrophication of waters. Phosphorus has been shown to be the primary nutrient affecting the eutrophication of freshwaters. This eutrophication impairs the beneficial uses of waters by causing excessive nuisance algal and aquatic weed growth. These growths can impair aesthetic enjoyment by forming scum's on the surface, clog water use intake structures, deplete dissolved oxygen needed for the support of aquatic life, shift to fishery communities with more undesirable coarse fish, and increase noxious aquatic weeds that tangle boat propellers and swimmers. Reversal of eutrophication is difficult since much of the phosphorus entering a lake is stored in the ecosystem and bottom sediments and is available to algae and plants for reuse. This is why it is critical to prevent eutrophication before it starts.

The main objective of the study is to create a water quality model to help assess alternative pollution control solutions for the protection of Lake Villarrica. A second objective is to recommend the application a different management approach to pollution control than has been used previously Chile. Various pollution control alternatives can be assessed using the water quality model. These alternatives can then be posed in community forums for discussion. When local acceptance of an alternative begins to form, implementation of the pollution controls should be easier to achieve than if the controls were mandated from the central government.

Water Quality Criteria and Beneficial Uses of Waters

Water quality criteria specify concentrations of water constituents which, if not exceeded, are expected to result in protection of the beneficial uses of the water. Such criteria are derived from scientific facts obtained studies that measure effects of different concentrations on particular water uses. Often times these criteria are adopted by governments as standards, and therefore are binding to law. However, many criteria are not officially adopted as standards and are used for advisory purposes. Currently, there is no criteria promulgated as standards. For lakes in Chile.

Based on beneficial uses, three criteria for phosphorus may be applied to Lake Villarrica:

Aquatic Life: Excessive phosphorus in lakes can cause nuisance algal growths that affect chemical conditions lakes and shift the community structure of aquatic life in lakes. Levels of phosphorus have been related to different levels of trophic state. The trophic state index developed by the U.S. Environmental Protection Agency Eutrophication Survey is the most widely used. (EPA, 1974). According to this index, with an annual mean total phosphorus concentration below 10 ug/L are considered oligotrophic, between 10 and 20 ug/L are mesotrophic, and above 20 ug/L are eutrophic.

Domestic Water Supply: Phosphate phosphorus concentrations in excess of 0.10 mg/L may interfere with the distribution systems of water supply facilities (EPA, 1986). Treatment processes such as coagulation and filtration may be impacted from phosphate phosphorus concentrations above this level.

Recreation and Aesthetic Enjoyment: To prevent the development of biological nuisances and control accelerated eutrophication, phosphate phosphorus should not exceed 0.050 mg/L at the point where it enters a lake or reservoir (EPA, 1986). Eutrophication can impair aesthetic enjoyment by forming scums on the surface and increase noxious aquatic weeds that tangle boat propellers and swimmers.

Lake Villarrica and Watershed Characteristics

Lake Villarrica is one of a large number of glacial origin lakes in Southern Chile next to the Andes Mountain Range (Figure 1). The total watershed size of Lake Villarrica is 2856 square kilometers, with the majority of land covered in forests (Table 1). The largest tributary to the lake is the Trancura River which accounts for 2580 square kilometers (88%) of that area. The lake outlet drains to the Toltén River which flows to the Pacific Ocean. Lake Villarrica has a volume of 21 cubic kilometers an surface area of 176 square kilometers and a mean depth of 120 meters. It is classified as oligiotrophic, and similar to many of other large lakes that dominate this region of Chile (Campos, 1984). However, the lake shows signs of eutrophication along the banks with an abundance of filamentous algae and contains a high percentage of introduced aquatic flora (Hauenstein, et al. 1996).

Review of Monitoring Data

A literature search found only a few studies where water quality data had been collected in Lake Villarrica. Campos et al. (1983) conducted a classic limnological study which reported information on the morphometric, physical, chemical, and planktonic factors of the lake. Campos (1984) compared the limnological characteristics of Lake Villarrica to similar lakes in the same region. Campos et al. (1991) measured nutrient loads from most tributaries and pollutant sources entering the lake. A lake nutrient balance was conducted to analyze critical loading thresholds. Hauenstein et al. (1996) surveyed the hydrophylous flora and found evidence of human impacts, including an abundance of filamentous algae along the banks of the lake. Comparison of the two data sets collected in Lake Villarrica suggests that total phosphorus levels may be increasing (Table 2).

Based on data collected by Campos et al. (1991), the total nitrogen to total phosphorus ratio (TN:TP) equals 5.3, indicating that nitrogen may be the nutrient most limiting algal growth (Forsberg, 1980). While the actual TN:TP ratio that indicates limitation varies in the literature, a higher ratio indicates more phosphorus limitation. In cases of cultural eutrophication, it is likely that excessive loads of phosphorus will create conditions that are nitrogen limiting. Controlling nitrogen sources may result in some reduction of productivity, but shifts in the algal community to nitrogen fixing species limits this management approach. In most cases, controlling phosphorus loading to any lake will impart the greatest regulation of algal activity (OECD, 1982).

Water Quality Model Construct

As a tool to assess alternative pollution control strategies, a dynamic mass balance model of total phosphorus was constructed for Lake Villarrica (Appendix). The model is based on the classic lake response equations posed by Vollenweider (1969) and modified by Larsen et al. (1979) given as:

$$\frac{d[P]}{V} = \frac{J_{ext}}{V} + \frac{J_{int}}{V} - \rho [P] - \sigma [P]$$

where:

[P] = the concentration of total phosphorus

V = the volume of the lake

Jext = the external phosphorus loading to the lake

Jint = the internal phosphorus loading from anoxic sediments

ρ = the flushing rate coefficient

σ = the sedimentation rate coefficient

The modeling approach treated Lake Villarrica as completely stirred tank reactor with a constant volume. The model mass balance was calculated dynamically with a weekly time step. The total phosphorus concentration calculated for each time step is the volume-weighted mean whole-lake value. The loss of phosphorus to the sediments was based on the a power function of the flushing rate, $\sigma = \rho^{n}$, where n is a positive fraction derived by model calibration. The internal loading of total phosphorus from anoxic sediments was assumed to derived from below 150 meters.

The only significant point source discharge is from the Pucón Wastewater Treatment Plant. Point source loading values from Pucón Wastewater Treatment Plant were derived from population data connected to the system. Daily average sewerage flow from houses was derived from expected water consumption (Salvato, 1960) and sewage yields (Metcalf & Eddy, 1972). Hotel sewerage flow was based on summer occupancy and expected yield (Hubbell, 1962). Overall load to the lake was based on estimated sewerage flows and the median concentration of total phosphorus from similar treatment plants (Metcalf & Eddy, 1972).

Nonpoint source loading was based on the area of land cover in each the subbasin and estimated number of septic systems. The geographical information system land use data supplied by CONAMA were used with the median nonpoint source loading rates (Table 3) that were derived from numerous published studies (Reckhow et al. 1980). To determine if the estimates of loading rates based on land use are accurate for the Lake Villarrica watershed, the estimates were compared to loads measured by Campos et al. (1991). The Lake Villarrica watershed was delineated into 20 subbasins for analysis of relative loads (Figure 2). These subbasins were the same as monitored by Campos et al. (1991) and named for the purposes of this report according to the major local stream or city within that area (Table 4). The land use data information was intersected with the subbasin delineation's to access the relative phosphorus loads within each subbasin area based on land use. Phosphorus loads predicted based on land use compare favorably with loads measured by Campos (1991), with the estimated loads totaling 113% of the measured loads overall.

Loads from septic systems along the shoreline were derived from typical household loads expected (Mattson and Isaac, 1999) and an estimate of the number of shoreline homes on septic systems from CONAMA. Atmospheric loading was derived from measured phosphorus levels in rainfall from a study in an area with similar climate and surrounding land uses (Butkus, et al. 1987).

The model was calibrated using the data collected in 1991 and validated with the 1979 data. Calibration was conducted by adjusting the retention factor for each weekly time step to maximize predictive performance based on data collected in 1991. The retention factor describes the exponent term in the power function of the lake flushing rate. Validation was conducted by using the same parameter value determined through calibration with the estimated flows for 1979. The internal loading from sediment release was sent to zero for both calibration and validation, since there were no anoxic conditions measured in either 1991 or 1979. The initial condition of 9.0 ug/L was used to correspond to the total phosphorus concentration on January 1. The initial condition was used in both runs and derived from the mean of values taken in the 3rd week of 1991 and the 52nd week of 1979.

Flow data were collected from the outlet of the lake on the Toltén River since 1989. The flow data for 1991 ranked 4th out of 10 annual flows, with a recurrence interval of 3 years. To estimate flow for 1979, a regression equation was developed between annual Toltén River flows and annual rainfall at Villarrica. The regression was significant with 88 percent of variance explained. Using this relationship, 1979 Toltén River flows were estimated to be 93% of 1991 flows. Model validation was conducted using 1991 flows adjusted lower to estimated 1979 flows and the calibrated retention factors.

Model output was compared to volume-weighted means of total phosphorus data collected from the lake at various water column depths. Model performance was fair for both calibration and validation. Model calibration resulted in a relative error of 134% and a median absolute deviation of 4.0 ug/L. Model validation showed a relative error of 98% and a median absolute deviation of 6.3 ug/L. Given that no systematic lake sampling design was used resulting in highly variable observed data, the model performance is considered adequate for evaluating relative changes in lake phosphorus concentrations. Precise predictions of lake phosphorus concentrations should be reviewed carefully.

Phosphorus Loading Analyses

The calibrated lake response model was used to determine the relative phosphorus loads entering Lake Villarrica. Loads were determined for various pollution source categories. Most of the phosphorus load to the reservoir comes from nonpoint sources within the watershed (Table 5). Of the nonpoint source load contribution to the reservoir, nearly half comes from scrublands, with forested lands accounting for nearly a third of loading (Table 6). Urban areas and agricultural areas contribute only about 2% of the phosphorus loads.

The calibrated lake response model was also used to estimate the effect of various pollution controls on phosphorus concentrations entering Lake Villarrica. Treatment efficiencies for point sources (EPA, 1995) and nonpoint sources (EPA 1993) were taken form literature sources (Table 7). It was assumed that treatment alternatives assessed for nonpoint pollution applied broadly to all relevant sources since many of these controls have yet been implemented in the Lake Villarrica watershed.

One of the sources of phosphorus loading to Lake Villarrica is domestic wastewater. The lake response model was run to test the predicted effect on the lake with two different wastewater treatment scenarios. The first is the recent upgrade to the Pucón WWTP to secondary treatment. Secondary treatment is the level of treatment required by all dischargers in the United States. Secondary treatment involves unit operations beyond simple screening or settling of solids. Secondary treatment for domestic waste uses the activated sludge process which includes the unit operations of aeration and clarification. The model was also run to test the effect on Lake Villarrica total phosphorus concentration, if the Pucón wastewater received tertiary treatment (Table 8). Tertiary treatment if often used in the United States for wastewater that impact lakes and reservoirs. Tertiary treatment typically involves the unit operation of biological phosphorus removal and had a median removal efficiency of 80% (Metcalf and Eddy, 1991).

The model predicts that the May 2000 upgrading of the Pucón WWTP to secondary treatment will result in a 16% reduction in the annual whole-lake total phosphorus concentration in Lake Villarrica. Without any further pollution controls, increases in population will increase total phosphorus concentration in the lake by 7%. If the Pucón WWTP was upgraded to tertiary treatment, the lake would receive a reduction of 4% in total phosphorus concentration (Table 9).

The lake response model was also used to predict the effect of agricultural best management practices on phosphorus loads to the reservoir (Table 8).Three separate best management practices were tested with the model: (1) reduced tillage systems which include practices such as conservation tillage, no-till, and crop residue use, (2) terrace systems, and (3) filter strips, which add vegetative buffer areas between crop areas and streams (EPA, 1993). The model predicted that in each of these cases, the lake total phosphorus concentration would not change (Table 9). This result is due to the small loading contributed by agriculture in the watershed (Table 6).

The lake response model was also used to predict the effect of various urban stormwater treatment systems on the phosphorus entering the reservoir (Table 8). Four different stormwater treatment systems were tested with the model: (1) use of catch basins, (2) dry ponds for flooding control modified to increase nutrient removal, (3) use of wet ponds, and (4) vegetative filter strips. The model predicted that in each of these cases the lake total phosphorus concentration would not change (Table 9). This result is due to the small loading contributed by urban areas in the watershed (Table 6).

The lake response model was also used to predict the effect of a combination of these pollution controls (Table 8). The lake response model was used to predict the total phosphorus concentration of the lake using each of the all of the most efficient pollution controls for domestic wastewater, agricultural best management practices, and urban storm water treatment (Table 9). If each of these approaches is applied throughout the watershed, the total phosphorus concentration of the lake is reduced by 10% in the summer.

An option sometimes used in the United States is the complete removal of wastewater discharges from rivers, with the wastewater applied to land for irrigation of agriculture. It is questionable whether this option is feasible, since there is not likely sufficient agricultural land areas available to receive such large volumes of wastewater if applied at agronomic rates. If the land application of domestic wastewater was not conducted correctly, the phosphorus would still find its way to the reservoir through surface runoff or groundwater loading.

The lake response model was used to test the effect of removal of the Pucón WWTP along with the other most efficient pollution controls. Complete removal of the discharge, coupled with application of the most efficient pollution controls for the other sources, the total phosphorus concentration of the lake is reduced by 17% in the summer (Table 9).

The recommended pollution reduction strategy is based on what controls are economically and politically achievable in the near future that would produce the greatest results in reducing the phosphorus loading to Lake Villarrica. The water quality model predicts that connecting shoreline home to a wastewater treatment plant is the best pollution control strategy to reduce existing total phosphorus concentrations in Lake Villarrica. This strategy is predicted to give a total phosphorus concentration slightly less than current conditions, even with an expanding population growth.

Recommended Implementation Approach

There are many different approaches used in managing water quality. Many of these are based on laws and regulations where governments enforce the same pollution controls across all polluters. This type of approach is often called "technology-based" since the controls are applied broadly. This type of approach is often found to be inadequate since it not takes into account the individual sensitivities of specific waters to pollution. Many times, the level of technology-based pollution control is not sufficient to protect the beneficial uses of sensitive waters. This approach also uses a top-down strategy for decisions on which pollution controls are put in place. There is little local public involvement in applying a technology-based pollution control strategy.

In the United States, the federal Clean Water Act (Section 303(d)) describes a "water quality-based" approach to pollution control. These "water quality-based" controls are often derived through a process defined as Total Maximum Daily Loads (TMDLs). The U.S. Environmental Protection Agency (EPA) has promulgated regulations (40 CFR 130) and developed guidance (EPA, 1991; EPA, 1992) for establishing TMDLs

The water quality-based controls derived in a TMDL process are based on a site-specific technical analysis. This analysis looks at the relative sensitivities of waters to specific pollutants. The scope of the analysis is based on one or more watershed areas so that the cumulative effects of multiple pollutant sources can be assessed together. The technical analysis offers several different alternative strategies to pollution control. The TMDL process then uses a locally driven public process to craft solutions. This grass-roots involvement in the decision making process improves

The U.S. federal Clean Water Act allows for the establishment of TMDLs on waters that are either have impaired water quality, or are threatened, good quality waters. By establishing TMDLs on good quality waters is a more proactive, "pollution prevention" approach to water quality management. It is generally easier and less costly in the long term to prevent impairments rather than retrofit controls to clean up pollution problems. In these cases, the TMDL process can plan protection of waters for pollution expected in the future from economic or development growth.

What is a TMDL Designed to Accomplish?

TMDLs for control of pollution sources are designed to address water quality problems by systematically identifying sources of pollution and carrying out mutually agreeable solutions that correct the problem. They are used as one method for addressing waterbody pollution problems.

Most larger watersheds contain a combination of point sources and nonpoint sources. The fundamental approach to addressing each situation will vary depending on the size and complexity of the problems. A combination of nonpoint source and point source control mechanisms should be integrated to meet overall goals as needed for the watershed.

It is instructive to begin with an examination of the differences between establishing controls for point source problems and those for nonpoint. Many factors used to develop controls for point sources are different from those used to develop controls for nonpoint sources. Analysis of pollutant loading from point sources involve input parameters that are generally better known, quantified and controllable to some degree than nonpoint sources. The assimilation capacity of the waterbody for one or more pollutants from point sources is generally modeled and the water quality improvement is reasonably predicted. Finally the levels of pollutants in the effluent are easier to regulate with treatment processes than the diffuse pollution coming from nonpoint sources.

Sources of nonpoint source pollution are rarely well defined. A TMDL with many nonpoint sources involves evaluation, source identification, planning, public involvement, and monitoring which may include a wide array of participants. TMDLs with many nonpoint sources are based on the assumption that designed management approaches will produce the desired water quality goals.

Progress is regularly checked against interim targets identified in a planning effort. Often the true effectiveness of management approaches is not known until programs are implemented. Thus, new programs are developed, tested and refined as workable solutions are identified. Through time, new science and adaptive management will result in better understanding of the interactions in the aquatic environment.

A recognition of the technical limitations is inherent in developing TMDLs with many nonpoint sources. In doing so, the process of TMDL development allows for progressively more stringent requirements to be "phased in" over time as needed to meet the water quality goals. This allows locally driven non-regulatory programs a chance to be successful before more restrictive measures are applied. The adequacy of nonpoint source management activities is monitored over time to determine if implementation is effective in meeting the targets.

Determining the amount of pollutant loads contributed from wide areas within a watershed is often not an effective measure of need. The concept of loading capacity is rarely used because of limited research and the need to use broad assumptions. Instead, the process relies heavily on the development of targets or identifying a desired future condition for the waterbody. TMDLs can be expressed in terms other than loads. For instance, pollutant concentrations may be used as a target condition.

Best management practices (BMPs) are specifically mentioned as a method for addressing nonpoint sources defined in TMDLs. There are several factors to consider when evaluating whether BMPs are stringent enough to implement applicable water quality standards. They include:

- Data analysis of the controls relative to the problem;
- Mechanisms requiring implementation and maintenance of the pollution controls;
- Reasonable time frame for attaining water quality standards (waterbody responsive); and
- Monitoring to track implementation and effectiveness of controls.

A locally managed watershed plan is one of the best approaches to implementing the nonpoint source components of a TMDL. The plan should represent the needs and views of a variety of affected parties. A basic objective of the plan should be to meet or exceed water quality standards. Where applicable, other in-stream targets may be established in the plan. Management plans should address specific resource protection and restoration issues which are outlined later in this guidance.

The plan may call for short-term fixes and/or long-term rehabilitation. It may rely on activities specifically controlled by human activities or may be a combination of natural and specific restoration or management activities . Examples of short-term TMDL implementation approaches are farm plans for a situation where a single farm or small number of farms can be shown to be the primary source of water quality impairment.

Plans developed and used as partial elements of TMDLs can address watersheds of various scales. They can be as small as a reach or as large as a whole drainage. The key is the ability to identify relationships between sources of pollution and resources that are impaired. Specific practices need to be designed to address the sources and show likely improvement in the resource.

TMDLs can be used to address existing problems or may be used to prevent problems in the future. Those TMDLs designed to prevent future problems in pristine or high quality waters are often called “preventive” TMDLs. They are established on waters not currently not impaired by water quality. Preventive TMDLs should attempt to identify all characteristic uses in the watershed, and establish targets and practices to ensure that the uses are protected.

Finally, TMDLs must include a provision for enforcement to back up voluntary plans. Noncompliance with plan provisions (i.e. no implementation of BMPs) may be grounds for enforcement action on specific individual polluters if the problem is clearly identifiable and persists in spite of local action to comprehensively address these problems. Other provisions for enforcement that may be used include inter-local agreements, local ordinances, court ordered decrees, and conditioned grant funding from government.

The Five Components of a TMDL

When a TMDL is developed specific documentation should be compiled to help affected parties understand the pollution control strategy. This documentation helps form the basis of technical recommendations and any actions that will come out of the public process. The reason for developing the documentation is to assure that institutional agreements become memorialized so that changes in affected parties do not affect implementation of the TMDL.

1. Problem formulation

Information is presented to show that a problem exists and there is a need for special management approaches. The TMDL documentation should describe the water quality problem using available information. If the TMDL is a preventive (e.g., water quality standards are currently being met), a description on why a TMDL is being done and what problem is being addressed (e.g. protection from future development, protection of a pristine water, etc.).

In describing the problem, the documentation should identify applicable water quality standards, applicable regulations or agreements, pollutants of concern, source of these pollutants, and control actions taken to date. The documentation should reference the technical reports, memorandum, and other information documenting the water quality problem(s) that the TMDL addresses.

2. TMDL data and supporting studies

Data and information that is collected as part of the planning process is presented to support assumptions needed to make resource management decisions. This includes the method and results used to establish TMDL interim targets and final goals.

The TMDL needs to include technical reports with calculations used to derive the allocations of loads among pollutant sources. A TMDL study determines the loading capacity based on a water quality standard (or other quantifiable goals). Loads are allocated among pollution sources so as to not exceed the loading capacity. The loading capacity should equal the sum of the loads from point source waste load allocations plus loads from nonpoint source load allocations, and a margin of safety (MOS) to account for uncertainty (EPA, 1991). The MOS can be a specific allocation or be included into the other allocation by using conservative assumptions in the analysis (e.g. using an extreme low flow event with maximum loading during modeling). An allocation can also be set aside as a reserve for future growth.

TMDLs can also be established for water quality problems that are difficult to quantify as loads. TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure. The ability to express TMDLs using other appropriate measure is a key concept in nonpoint source controls. For example, TMDLs have been established for fecal coliform using the goal of meeting a concentration goal instead of attempting to estimate billions of organisms per day.

3. Anticipated control action and implementation schedule

Control measures are designed to address the problem and a schedule for implementation is created. Several alternative pollution control strategies may be proposed for public review. After a strategy has been selected, projected dates to reach target conditions and final goals are identified.

The TMDL documentation needs to include copies of plans for the implementation of control actions. This includes permits, nutrient management plans, applicable ordinances, and intergovernmental agreements that outline roles and responsibilities for implementing the actions. The plans should also include a schedule of when such actions will be implemented.

Where nonpoint source controls are involved, it is recommended that a phased TMDL be established. A phased TMDL can be developed where uncertainty is a factor, where estimates involve best professional judgment, or where non-chemical stressors are involved. A TMDL developed under a phased approach should include a monitoring plan and a schedule of when it will be determined whether TMDL revisions are needed.

4. Public participation

This component of a TMDL includes specific interactions with the public designed to ensure adequate consultation and public involvement in decision making. This is the most important aspect of TMDL development. Without public support of the TMDL, experience has shown that the pollution control strategy derived will not be sufficiently implemented.

The TMDL documentation should include copies of materials showing that a public process has been conducted. This insures that the public commitment to agreements formed are not questioned or discounted in the future. The TMDL public participation program should consist of the 4 elements described below:

1) Information and Assistance - All information used in the development of a TMDL process must be available to the public. In addition, a list of interested and affected parties needs to be compiled and maintained.

2) Public Notification - All interested and affected parties must be notified in advance of when major decisions will be made. The notices should include a timetable in which the decision will be made, issues under consideration, alternative courses of action, and how relevant documents may be reviewed, and the name of an individual to contact for more information.

3) Public Consultation - Interested and affected parties should be consulted before any decisions on alternatives are made. Consultation may take many forms including public forums, public meetings, advisory groups, ad hoc committees, task forces, or workshops.

4) Responsiveness Summary - After an open public comment period all comments and a response should be compiled into a summary document. This document must summarize the public's views, significant comments, criticisms and suggestions. Specific responses must be set forth by modification of the proposed alternative or an explanation for the rejection of any proposals made by the public.

5. Follow-up monitoring

Monitoring is needed to assess progress toward meeting TMDL goals and targets. From the results of the monitoring, affected parties decide whether the TMDL is on track toward meeting water quality goals.

As part of the TMDL documentation, the monitoring plan must be included and the entities committing to the monitoring must be identified. All monitoring data should be evaluated periodically to assure that the TMDL implementation is effective. If future monitoring shows that the TMDL is not adequately effective, the TMDL should be modified and the control actions altered as appropriate.

Goals and Targets

Most TMDLs will use a combination of water quality standards, goals, and targets to make management decisions. Goals are related primarily to support of a characteristic use defined in the water quality standards. Targets are generally indicators of ecosystem improvement and habitat quality, but need not be a measure of characteristic use. Targets are interim steps that lead to the final goal. In some cases, final goals and targets will be the same.

All TMDLs should have specific goals for support of characteristic uses. A goal could be related to fish health, lake aesthetics, or public health. In lakes, the goal is typically represented by a numeric water quality standard (e.g. phosphorus). The water quality standard is designed to protect beneficial uses.

To establish a goal or target, a public process is needed. Participants should identify the characteristic uses in the watershed and evaluate the factors influencing those uses. All available information from existing standards, literature, government goals, and other watershed specific data should be considered. Once this information has been evaluated, the participants should identify their goals and targets to be measured

Developing Technical Information and Making Decisions

Developing a TMDL requires a common sense approach to watershed level protection involving evaluation, decision making and follow-up. The questions outlined below are designed to assist affected parties with determining what types of information and decisions are needed for a successful TMDL. The information is presented in the form of questions:

- **What are the beneficial uses of the waters in the watershed?**
- **Are the characteristic uses of the waters currently supported?**
- **What is the nature of the impairment?**
- **What are the likely causes of the impairment of these uses?**
- **To what degree is the impairment natural and man-caused?**
- **What alternative pollution control strategies will achieve standards?**
- **Which alternative pollution control strategy is acceptable to the public?**
- **What resources have been identified to implement these pollution controls?**

These questions should be addressed and discussed in a public forum. All interested and affected parties in the watershed should be represented in these discussions. Particular attention should be paid to participation and input from landowners and users of the water resources.

It is vital that the public understands the nature of the impacts to characteristic uses and the sources of impairment. Public involvement is also important in the determination of the desired future condition for the watershed (targets and goals). Public support for the plan and its implementation will largely determine the success of the TMDL.

Where established water quality standards are exceeded in a watershed, meeting the standard must become a final goal. The public should be informed of the need to meet water quality standards and the necessity to establish this goal based on the standards. Where habitat problems are resulting in non-attainment of characteristic uses, goals based on characteristic uses and targets based on narrative criteria are needed. The public must be involved in the determination of both final goals and interim targets. All available technical information pertinent to the situation should be used to make this determination. Education of some interested parties may be necessary.

Once targets are established, a very important step is to identify the activities that need to be implemented on the site to reach the goal. This may be straight forward, or it may be very complex. A best estimate of the needs should be identified and implemented as broadly as appropriate in the drainage of concern. The practices most likely to address the problem directly are the best course of action initially.

The desired future condition or target water quality condition for the watershed should be established in a public forum. Along with identifying the target condition, an approximate timetable established for reaching the target. For long-term TMDLs interim targets and monitoring should be identified to test the effectiveness of control activities.

It is important that the time frame and expectations for water quality improvement be realistic and based on good science. Some improvements can be realized in a relatively short amount of time. On the other hand, projects relying on natural processes may take a long time to reach targets and should propose interim targets for the TMDL.

The Importance of Monitoring

Monitoring to test the effectiveness of pollution controls is an important component of a TMDL. As a key part of the plan, participating parties should agree to a monitoring and feedback approach that allows for the determination of TMDL effectiveness. Timelines for achieving goals should be established and all parties involved in the planning process need to agree with the commitments.

A unique aspect of TMDLs is the recognition that many variables affect the ultimate outcome of water quality. Therefore, the process calls for long-term monitoring of the affects of management changes and an agreement by all parties to evaluate the progress through time. Monitoring provides the basis for "phasing in" management decisions as part of the TMDL process. All parties agree to long-term solutions through an iterative process. This usually means a refinement of the implementation plan for the TMDL and changes to implementation if goals are not being attained.

The primary focus of evaluations should be to determine if sufficient progress is being made toward the targets. The TMDL process does not assume that problems in a drainage will be solved with the first estimate of what is needed. Thus the phased concept kicks in and allows for interim alterations to the implementation plan. Issues likely to impact the effectiveness of the TMDL at meeting its targets include the following: Some landowners may not be cooperating (BMPs not applied); the BMPs chosen may not be adequate; an unusual climatic change or other natural event; or the watershed dynamics may not be well understood.

The key is in the monitoring and feedback loop. Once implementation begins, progress should be monitored against the desired future condition and interim targets. Data should be evaluated by the interested and affected parties, and modifications to the management plan should be implemented as needed to get the process back on target. Feedback discussions and review of data should occur at regular intervals. As in the temperature or sediment examples, the interested and affected parties should review the results and commitments in the TMDL on a regular basis. Some projects may need annual reviews. The actual review periods will depend on the time frame established for monitoring the interim targets.

Changes needed at the review time may involve any of the following: alteration of time-frames, additional education and outreach, updating BMPs, focused restoration, improved compliance inspections, and enforcement actions where necessary. In some cases, the participants may find that the target is unreasonable or unreachable. Modifications to the TMDL target will need to be discussed with affected parties.

Monitoring should be carried out throughout the life of the TMDL. Monitoring activities can be the responsibility of the local government, a local entity, or an individual or group of landowners. The responsible party should be identified in the TMDL.

An adequate monitoring program has three components:
- track implementation of BMPs or other controls;
- track water quality improvements; and
- track progress toward meeting water quality standards (targets).

Regular reports should be prepared presented to affected parties on a routine basis. Reporting dates should correspond to planned interim monitoring points in the schedule. Data for these reports should be collected and analyzed in such a manner that routine reviews of progress can be carried out by the affected parties. Responsible parties should be encouraged to present monitoring results with local participants, and a review of program adequacy and targets should be discussed.

The failure to consistently implement the agreed upon management practices is the primary cause for lack of progress in achieving goals or targets in a TMDL. This may be due to a lack of education, political support, enforcement, funding, or any combination of these factors. A second likely case is related to inadequate management measures identified in the plan. If the management measures don't work, targets will not likely be reached. Improved knowledge of the area may be cause to reassess targets. However, justification for a change to the targets should be well documented and all involved parties should be involved in the decision.

Advantages of Establishing a TMDL

TMDLs have numerous advantages from a process, water quality and public acceptance standpoint. TMDLs provide a common sense process for evaluating watershed needs and designing activities to specifically address water quality problems. These activities have a reasonable likelihood of achieving water quality goals.

TMDLs may also address regulatory needs. For some they represent a threat; for others protection. The TMDL processes provide a handle to convince landowners and government to achieve real water quality and habitat improvement. Completion of a TMDL should provide to some a certain level of protection from additional unexpected regulatory burdens from government. Any TMDLs completed should be viewed as a major success if for no other reason than a local effort is underway to address local needs.

Efforts should be made to incorporate TMDL principles into many water quality improvement activities. Although each planning effort will be unique, a standard sequence of actions will allow government officials to work more effectively with local interest.

Local efforts are the key to a successful TMDL process. They should be fostered on a variety of scales wherever there are willing parties around the watershed. In all the planning and implementation efforts, advocates should be encouraged to adopt this approach so that their efforts will have a higher likelihood of success. Only a systematic approach such as this will provide the kind of water quality results needed to achieve broader water quality goals across the watershed.

What the public should know about TMDLs

The concept of TMDLs is difficult to explain to the public. Maximum daily loading for a different sources of pollutants is very difficult to visualize. In light of these difficulties, a different term should be for communicating these concepts to the public: **Water Quality Management Strategy**.

Since the objective is to move people to take action locally, some simple terminology should be used to explain what needs to happen for acceptable water quality improvements to occur. The TMDL concepts combined with water quality standards provide an excellent framework to increase the likelihood of success. The term "Water Quality Management Strategy" is a clearer term for describing what is going to happen.

In outreach efforts, it may be of benefit to not referring to the process as a TMDL. The focus should be on the end result (improved water quality) and making sure the TMDL steps are followed to help ensure success.

Since it is not likely feasible to achieve the phosphorus criteria at critical conditions without extreme management efforts, the reasonable approach would be to devise a Water Quality Management Strategy which uses a phased approach. The best way to establish this strategy is through an iterative process between technical analysis and public consultation. The process is started by proposing a series of pollution reduction measures that would when applied in combination likely produce the best results for the level of effort and cost involved. The likely results of this strategy would be predicted from the water quality model. The information could then be presented in various public forums, community meetings, or special workshops for affected parties. Suggested modifications to the strategy could be tested with the model. Through this iterative process a consensus may be formed on what is achievable politically and economically. Then, as the strategy is implemented, new information can be collected that would improve the model predictions. Water quality monitoring should also be conducted to verify that the expected results are being achieved.

The Water Quality Management Strategy proposed here should be used as only the beginning. Implementation of the proposed pollution controls will likely only occur through public empowerment. Controls that are mandated from higher authorities will likely never be actually put in place correctly. As public discussion occurs on the strategy it should be modified and improved upon. Only through environmental education and participation of affected parties and the public using the water resources can progress toward the goal of cleaner water be achieved.

Recommendations for Further Study

This report should be considered as the first step in the cleanup of pollution. As with all modeling exercises, the analysis presented here used many assumptions to provide results. It is simply not practical to measure every parameter needed for the model. As such, there are many improvements that could be made in the model and predictions with more monitoring data and more sophisticated techniques. Below is listed some recommendations that could be pursued:

Enhanced monitoring of the lake and streams within the watershed. Only two studies have monitored a limited number of stations in the lake and watershed. At a minimum, the water quality from those subbasins where pollution reduction activities are implemented should be monitored to assess effectiveness of the controls.

Obtain local land use export loading values. All of the phosphorus loading estimates for nonpoint sources was obtained from data published in the literature. Even though efforts were made to select values based on similarities in other factors (e.g. weather, crop types, etc), actual export loading values are likely to be somewhat different. Some monitoring of specific land covers may be used to obtaining better values.

Additional monitoring data from point sources. The data obtained for the point sources was limited. Many of the effluent concentrations and treatment levels were assumed based on the information obtained. Only mean values were used for the modeling. Knowledge of daily maximum values for each of the input parameters would greatly improve the modeling estimate. A distribution of effluent concentrations and flows over time would allow assessment of risks.

Lake response modeling and monitoring should be conducted. Trophic state measures such as chlorophyll *a*, secchi depth, and total phosphorus should be routinely collected in Lake Villarrica. Impairments to beneficial uses should be compiled for assessing the data against observed impacts such as excessive algal blooms.

Trophic state needs of fisheries should be evaluated. Often use of standardized criteria in management decisions on pollution control does not match the needs of particular waters. Balancing the trophic state to support a healthy fishery and maintaining other beneficial uses can be difficult. Certain fishery stocks may improve with increased amount of phosphorus loading, while other stock decline. Reducing phosphorus to protect against filtration problems for water supply or aesthetic enjoyment may decrease certain fishery stocks that are of economic importance. Evaluating the correct phosphorus loading specific to Lake Villarrica for the correct balance of beneficial uses is both a technical and social challenge. These issues should be discussed in a public forum.

Stochastic modeling should be conducted to provide risk assessment of viable approaches. The results presented are given in deterministic answers. These are simple to understand, but do not reflect the variability associated with various constituents used in the model. The model used was calibrated using the worst case situation measured of the data obtained. There was other periods of time for which water quality pollutant levels were lower. Knowledge of the distribution of these variables could be used in a Monte Carlo modeling approach to give answers described in risk-based terms. This type of analysis would provide results related to the frequency that a particular criterion would be exceeded, instead of the absolute result provided by modeling steady state at critical conditions.

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Figure 1. Study Area of Lake Villarrica

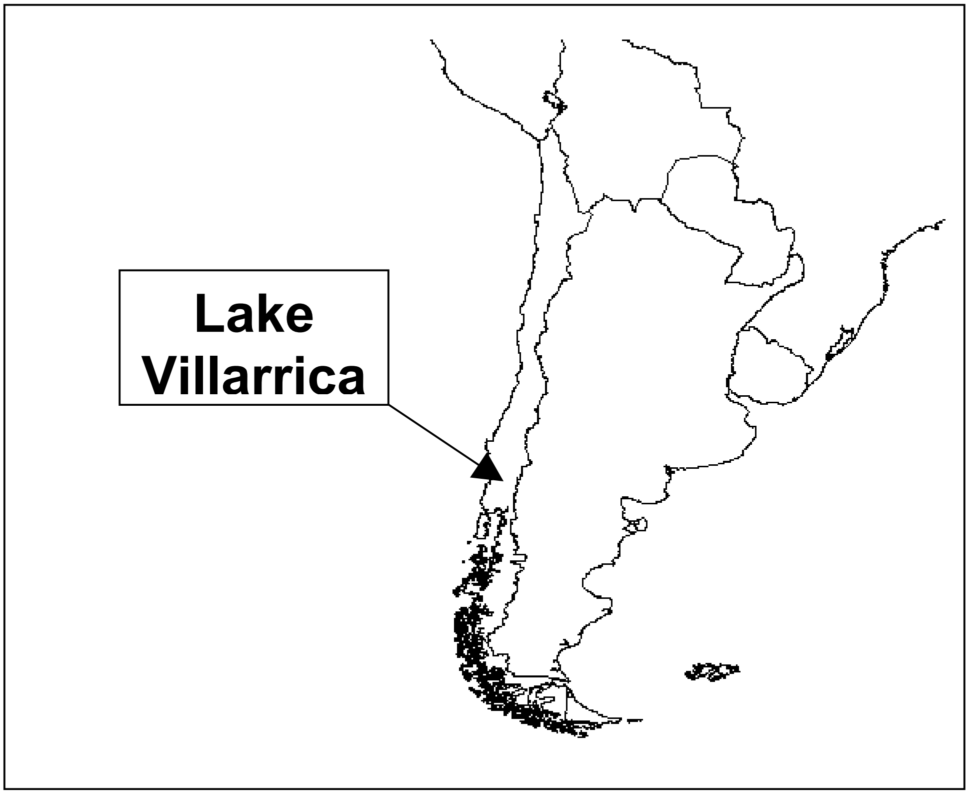

Table 1. Land Uses of the Lake Villarrica Watershed

Land Use	**Area**	
	Square km	**Percent of Watershed**
Forest Lands	1,616	57
Scrublands	751	26
Wetlands	251	9
Barren Areas	154	5
Glaciers	72	3
Urban Areas	8	<1
Agricultural Lands	2	<1
Total	2,856	100

Table 2. Levels of Total Phosphorus in Lake Villarrica
(From Campos et al. 1991 and Campos, 1983)

Mean Water Column Statistic	**Total Phosphorus (ug/L)**	
	1979	**1991**
Maximum	47.8	66.6
Median	14.0	17.6
Minimum	5.0	11.7

Table 3. Non-Point Source Total Phosphorus Loading Rates
(from Reckhow et al. 1980)

Land Use	**Phosphorus Loading Rate (kg/km^2/year)**
Water	0
Ice and Glaciers	0
Wetlands	0
Forest	20.6
Prairies and Scrublands	81
Agriculture	91
Urban and Industrial	110
Lacking Vegetation	110.
Unknown Landuse	110

Table 4. Land Use Areas of Subbasins Assessed in the Lake Villarrica Watershed.

Subbasin	**Area (hectares)**	**Percentage of Subbasin Area**				
		Forest	**Urban**	**Agriculture**	**Scrublands**	**Glacier**
City of Villarrica (several creeks & ditches)	865	7	38	-	55	-
Parque del lago Creek	747	-	-	-	100	-
Lorena Creek	1,183	4	-	-	96	-
Huichatío River	3,696	59	-	3	38	-
Molco River	3,552	50	2	-	47	1
Loncotraro Ditch	1,109	16	2	-	82	-
Los Chilcos River	545	28	1	-	71	-
Correntoso River	3,640	50	-	-	45	5
Candelaria Ditch #1	327	-	-	-	100	-
Candelaria Ditch #2	826	15	-	-	85	-
Pucón River	1,810	37	12	-	50	-
Claro River	4,003	49	-	-	51	-
Trancura River	230,653	63	-	-	32	6
Quilque River	3135	83	-	-	17	-
Aserradero Creek	595	37	-	-	63	-
El Suizo River	1,870	91	-	-	9	-
Montana Suizo Creek	189	37	-	-	63	-
Fundo Pesca Creek	269	44	-	-	56	-
El Castillo River	707	45	-	-	55	-
Los Boldos River	534	45	-	-	54	-

Table 5. Overall Relative Total Phosphorus Loads to Lake Villarrica

Source	Total Phosphorus Load	
	kg/year	Percent of Total
Pucón WWTP	13,936	11%
Land Use Nonpoint Sources	112,357	86%
Septic Systems	1,500	1%
Atmospheric Deposition	2,000	2%

Table 6. Nonpoint Source Relative Total Phosphorus Load to Lake Villarrica based on Land Use

Land Use	**Total Phosphorus Load**	
	kg/year	**Percent**
Forest Lands	33,296	30
Scrublands	60,839	54
Wetlands	0	0
Barren Areas	16,940	15
Glaciers	0	0
Urban Areas	814	1
Agricultural Lands	127	<1
Total	112,357	100

Table 7. Total Phosphorus Removal Efficiencies Modeled for Different Pollution Controls (adapted from EPA,1993 and EPA,1995).

Pollution Control Measure	**Total Phosphorus** Removal Efficiency
Secondary Treatment for Domestic Wastewater	84%
Tertiary Treatment for Domestic Wastewater	90%
Reduced Tillage for Agricultural Lands	45%
Terrace Systems for Agricultural Lands	70%
Filter Strips for Agricultural Lands	75%
Catch Basins for Urban Stormwater	10%
Modified Dry Ponds for Urban Stormwater	60%
Vegetative Filter Strips for Urban Stormwater	80%
Wet Ponds for Urban Stormwater	90%

Table 8. Predicted Whole-lake Total Phosphorus Concentration in Lake Villarrica using Different Pollution Controls

Pollution Controls	**Total Phosphorus** (ug/L)		
	Annual Mean	Spring Mean	Summer Mean
Current Conditions	10.3	11.1	11.8
No Further Pollution Controls – Year 2020	11.0	11.7	13.0
Tertiary Treatment for Pucón WWTP	10.6	11.4	12.4
Sewer Shoreline Homes	10.0	10.9	11.3
Reduced Tillage for Agricultural Lands	11.0	11.7	13.0
Terrace Systems for Agricultural Lands	11.0	11.7	13.0
Filter Strips for Agricultural Lands	11.0	11.7	13.0
Catch Basins for Urban Stormwater	11.0	11.7	13.0
Modified Dry Ponds for Urban Stormwater	11.0	11.7	13.0
Wet Ponds for Urban Stormwater	11.0	11.7	13.0
Vegetative Filter Strips for Urban Stormwater	11.0	11.7	13.0
Combined Pollution Controls: 1. Filter Strips for Agricultural Lands 2. Wet Ponds for Urban Stormwater	11.0	11.7	13.0
Combined Pollution Controls: 1. Teritary Treatment for Pucón WWTP 2. Filter Strips for Agricultural Lands 3. Wet Ponds for Urban Stormwater	10.6	11.4	12.4
Combined Pollution Controls: 1. Teritary Treatment for Pucón WWTP 2. Sewer Shoreline Homes 3. Filter Strips for Agricultural Lands 4. Wet Ponds for Urban Stormwater	10.4	11.2	11.9
Combined Pollution Controls: 1. Pucón WWTP Discharge Removal 2. Sewer Shoreline Homes 3. Filter Strips for Agricultural Lands 4. Wet Ponds for Urban Stormwater	9.7	10.7	10.8

Table 9. Relative Reductions in Whole-lake Total Phosphorus Concentrations in Lake Villarrica from Predicted Year 2020 Conditions using Different Pollution Controls

Pollution Controls	Percent Reduction		
	Annual Mean	Spring Mean	Summer Mean
Tertiary Treatment for Pucón WWTP	4	3	5
Sewer Shoreline Homes	9	7	13
Reduced Tillage for Agricultural Lands	0	0	0
Terrace Systems for Agricultural Lands	0	0	0
Filter Strips for Agricultural Lands	0	0	0
Catch Basins for Urban Stormwater	0	0	0
Modified Dry Ponds for Urban Stormwater	0	0	0
Wet Ponds for Urban Stormwater	0	0	0
Vegetative Filter Strips for Urban Stormwater	0	0	0
Combined Pollution Controls: 3. Filter Strips for Agricultural Lands 4. Wet Ponds for Urban Stormwater	0	0	0
Combined Pollution Controls: 4. Teritary Treatment for Pucón WWTP 5. Filter Strips for Agricultural Lands 6. Wet Ponds for Urban Stormwater	4	3	5
Combined Pollution Controls: 5. Teritary Treatment for Pucón WWTP 6. Sewer Shoreline Homes 7. Filter Strips for Agricultural Lands 8. Wet Ponds for Urban Stormwater	5	4	10
Combined Pollution Controls: 5. Pucón WWTP Discharge Removal 6. Sewer Shoreline Homes 7. Filter Strips for Agricultural Lands 8. Wet Ponds for Urban Stormwater	12	9	17

Appendix:

Calibrated Lake Response Model Source Code Written in DBASE

```
************************************************************************
*
* PROGRAM : VILLRICA.PRG
*
* CONTACT : STEVE BUTKUS
*          LIVING EARTH INSTITUTE
*          1930 WOODLAND CREEK STREET NE
*          OLYMPIA, WA  98516
*
*          EMAIL => LIVINGEARTH@HOME.COM
*
* DBASE PROGRAM TO DYNAMICALLY EVALUATE THE RESPONSE OF
* LAKE VILLARRICA, CHILE, TO PHOSPHORUS LOADING.
*
* THE MODEL IS BASED ON THE MASS BALANCE EQUATION PROPOSED BY
* VOLLENWEIDER (1969) AND MODIFIED BY LARSEN ET AL. (1979)
*
*  d[TP]/dt = Jint/V + Jext/V - sig[TP]/V - ro[TP]/V
*
* WHERE:
*
*  [TP] = WHOLE LAKE TOTAL PHOSPHORUS CONCENTRATION (mg/m^3)
*  Jext = EXTERNAL LOADING (mg/week)
*  V = LAKE VOLUME (m^3)
*  ro = FLUSHING RATE (1/week)
*  sig = SEDIMENTATION RATE (1/week)
*  Jint = INTERNAL SEDIMENT LOADING FROM ANOXIC SEDIMENTS
*
* THE PROGRAM NEEDS THESE DBASE FILES IN SAME SUBDIRECTORY TO RUN:
*
*  FLOW.DBF        ---> WEEKLY MEAN FLOWS MEASURED IN TOLTÉN RIVER
*  SEDIMENT.DBF ---> WEEKLY SEDIMENT TP RELEASE RATE AND RETENTION FACTOR
*
*  LAKECONC.DBF ---> WEEKLY PREDICTED WHOLE LAKE TP CONCENTRATIONS
*  LAKEMEAN.DBF ---> ANNUAL, SPRING AND SUMMER WHOLE LAKE TP CONCENTRATIONS
*
*
*************************************************************************

  SET PROCEDURE TO VILLRICA.PRG
  DO SET_ENVIR
  DO SET_VARS
  DO OPEN_DBFS

* MAIN ROUTINE
CLEAR
 @ 5,5 SAY 'PROCESSING WEEK ------> '


* READ WEEKLY MEAN FLOWS FOR TOLTÉN RIVER (VILLARRICA OUTFLOW)

SELECT FLOW
GO TOP

DO WHILE .NOT.EOF()

TWEEK = WEEK
@5,31 SAY TWEEK

TFLOW = FLOW*604800      && CONVERT M^3/SEC TO M^3/WEEK
TFLOWFRAC = FRAC
```

```
* CALCULATE INTERNAL LOADING = RELEASE RATE*AREA OF ANAEROBIC HYPOLIMNION
SELECT SEDIMENT
GO TOP
LOCATE FOR WEEK = TWEEK
TSEDREL = SEDREL
TINTERNAL = (TSEDREL*HYPOAREA)/VOLUME

* CALCULATE LAKE RETENTION TIME
RO=TFLOW/VOLUME

* CALCULATE LOSS FROM SEDIMENTATION
TRF=RF
SIG=RO^TRF
SEDLOSSTP=SIG*TLAKETP

* CALCULATE LOSS FROM OUTFLOW TO TOLTÉN RIVER
OUTFLOWTP = RO*TLAKETP

* CALCULATE PRECIPITATION LOAD FOR WEEK TIME STEP
TRAINFRAC = TFLOWFRAC
TRAINTP = (TRAINFRAC*TPRAINYEAR*1000000)/VOLUME

* CALCULATE NONPOINT SOURCE LOAD
* BASED ON MEDIAN LOADS AT MEDIAN FLOWS(RECKHOW ET AL. 1980)
TNPS = 0.0000142*TFLOW
*TNPS = NPS*TFLOWFRAC

TNPSTP = TNPS*1000000/VOLUME


* CALCULATE PUCÓN WWTP LOAD
TPSTP = TPS*1000000/VOLUME

* CALCULATE SHORELINE SEPTIC SYSTEM LOAD
* EVEN LOAD PROPORTIONED OVER THE YEAR
TSEPTICTP = (SEPTIC*1000000*SHOREHOMES)/52/VOLUME

* CALCULATE CONCENTRATION FROM EXTERNAL LOADING
TEXTERNAL = TRAINTP+TSEPTICTP+TNPSTP+TPSTP

* CALCULATE LAKE CONCENTRATION FOR WEEK
TWEEKTP = TINTERNAL + TEXTERNAL - SEDLOSSTP - OUTFLOWTP
TLAKETP = TLAKETP + TWEEKTP

* CALCULATE SEASONAL SUMS

IF TWEEK > 0
        ANNUALSUM = TLAKETP + ANNUALSUM
ENDIF

IF TWEEK > 39
        SPRINGSUM = TLAKETP + SPRINGSUM
ENDIF

IF TWEEK < 13
        SUMMERSUM = TLAKETP + SUMMERSUM
ENDIF

* RECORD WEEKLY TP CONCENTRATION
SELECT LAKECONC
APPEND BLANK
REPLACE WEEK WITH TWEEK
REPLACE TPCONC WITH TLAKETP
REPLACE RAINTP WITH TRAINTP
REPLACE SEPTICTP WITH TSEPTICTP
REPLACE NPSTP WITH TNPSTP
REPLACE INTERNAL WITH TINTERNAL
REPLACE SEDLOSS WITH SEDLOSSTP
REPLACE OUTFLOW WITH OUTFLOWTP
```

```
REPLACE RF WITH TRF
REPLACE RO_TEST WITH RO


SELECT FLOW
SKIP

ENDDO  && END OF FLOW FILE

* CALCULATE SEASONAL MEAN CONCENTRATIONS

TANNUALTP = ANNUALSUM/52
TSPRINGTP = SPRINGSUM/12
TSUMMERTP = SUMMERSUM/12

SELECT LAKEMEAN
APPEND BLANK
REPLACE ANNUALTP WITH TANNUALTP
REPLACE SPRINGTP WITH TSPRINGTP
REPLACE SUMMERTP WITH TSUMMERTP

CLOSE ALL

RETURN   && TO DBASE DOT PROMPT

****** END OF MAIN ROUTINE *********
*************************************
*************************************


**************
* PROCEDURES *
**************

*********************
 PROCEDURE SET_ENVIR
*********************
CLEAR
SET TALK OFF
SET BELL OFF
SET SCOREBOARD OFF
SET SAFETY OFF

RETURN

********************
 PROCEDURE SET_VARS
********************
PUBLIC TWEEK,TLAKETP,VOLUME,HYPOAREA,SURFAREA,TFLOW,TFLOWFRAC
PUBLIC RO,RF,SIG,SEDLOSSTP,OUTFLOWTP,TWEEKTP,TEXTERNAL
PUBLIC TRF,TSEDREL,TINTERNAL,WEEKRAIN,TRAINFRAC,TPRAINYEAR,TRAINTP
PUBLIC NPS,TNPS,TNPSTP,TPS,TPSTP,TPSTP,SEPTIC,SHOREHOMES,TSEPTICTP
PUBLIC ANNUALSUM,TANNUALTP,SPRINGSUM,TSPRINGTP,SUMMERSUM,TSUMMERTP


TWEEK     = 0          && WEEK 1 = JANUARY 1ST
RO        = 0          && LAKE RETENTION TIME FOR WEEK STEP
TRF       = 0          && CALIBRATED WEEKLY RETENTION FACTOR
SIG       = 0          && LOSS FROM SEDIMENTATION FOR WEEK STEP
TLAKETP   = 9          && INITIAL TOTAL P AND FOR EACH WEEK STEP IN MG/M^3
VOLUME    = 210000000  && LAKE VOLUME IN M^3
HYPOAREA  = 73000000   && SURFACE AREA OF THE HYPOLIMNION AT 150 M IN M^2
TFLOW     = 0          && TOLTÉN FLOW AT WEEK STEP IN M^3/S
TFLOWFRAC = 0          && WEEKLY FRACTION OF ANNUAL TOLTÉN FLOW
SEDLOSSTP = 0          && WEEKLY [TP] LOST TO SEDIMENTS IN MG/M^3
OUTFLOWTP = 0          && WEEKLY [TP] LOST TO TOLTÉN RIVER OUTFLOW MG/M^3
TSEDREL   = 0          && SEDIMENT TP RELEASE RATE MG/M^2-WEEK
TINTERNAL = 0          && WEEKLY [TP] FROM SEDIMENTS IN MG/M^3
TWEEKRAIN = 0          && TOTAL PRECIPITAION FOR WEEK STEP
TRAINFRAC = 0          && WEEKLY FRACTION OF ANNUAL PRECIPITATION
```

```
TPRAINYEAR= 1500       && ESTIMATED ANNUAL TP IN PRECIPITATION (KG/YEAR)
TRAINTP   = 0          && WEEKLY [TP] IN PRECIPITATION IN MG/M^3
NPS       = 112357     && ANNUAL NPS LOAD IN KG/YR (RECKHOW ET AL 1980)
TNPS      = 0          && WEEKLY NPS LOAD IN KG/WEEK
TNPSTP    = 0          && WEEKLY [TP] FROM NONPOINT SOURCES IN MG/M^3
TPS       = 268        && WEEKLY LOAD FROM PUCÓN WWTP IN KG/WEEK
TPSTP     = 0          && WEEKLY [TP] FROM PUCÓN WWTP IN MG/M^3
SEPTIC    = 0.5        && KG/HOUSE/YEAR (MATTSON AND ISSAC, 1999)
SHOREHOMES= 4000       && ESTIMATE OF SHORELINE HOUSES ON SEPTIC SYSTEMS
TSEPTICTP = 0          && WEEKLY [TP] FROM SEPTIC SYSTEMS IN MG/M^3
TEXTERNAL = 0          && WEEKLY [TP] FROM EXTERNAL SOURCES IN MG/M^3
TWEEKTP   = 0          && WEEKLY CHANGE IN TP CONCENTRATION
ANNUALSUM = 0          && YEAR SUM OF WEEKLY TP CONCENTRATIONS
TANNUALTP = 0          && YEAR MEAN OF WEEKLY TP CONCENTRATIONS
SPRINGSUM = 0          && SPRING SUM OF WEEKLY TP CONCENTRATIONS
TSPRINGTP = 0          && SPRING MEAN OF WEEKLY TP CONCENTRATIONS
SUMMERSUM = 0          && SUMMER SUM OF WEEKLY TP CONCENTRATIONS
TSUMMERTP = 0          && SUMMER MEAN OF WEEKLY TP CONCENTRATIONS

RETURN

********************
 PROCEDURE OPEN_DBFS
********************

SELECT 1
USE SEDIMENT     && CALIBRATED WEEKLY SEDIMENT TP RELEASE RATE
SELECT 2
USE FLOW         && FROM TOLTÉN RIVER OR ESTIMATE FROM RAINFALL
SELECT 3
USE LAKECONC     && CAPTURES MODEL OUTPUT OF WEEKLY LAKE TP CONCENTRATIONS
ZAP
SELECT 4         && CAPTURES MODEL OUTPUT OF SEASONAL MEAN LAKE TP CONC.
USE LAKEMEAN
ZAP

RETURN

******************
* END OF PROGRAM *
******************
```