Bone Lake Management Plan

Phase III: Lake Management Plan

Prepared for
Bone Lake Management District

Prepared by
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with assistance from
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Executive Summary

The study described by this report was initiated by the Bone Lake Management District to provide information to Bone Lake Management District Commissioners, water resource managers, and citizens regarding the management of Bone Lake.

During 1996, the Bone Lake Management Commission completed the first phase of a three-phase project to develop a Lake Management Plan. Phase I was designed to assemble the requisite data to provide an understanding of the interacting physical, chemical, and biological processes controlling the water quality of Bone Lake. The project included taking periodic water samples from Bone Lake, two inflowing streams, and the lake's outlet during the June through September period and sending them to the Wisconsin Department of Hygiene Lab to be analyzed. Additional on lake activities included monitoring of water clarity (Secchi disc) and temperature, dissolved oxygen, and conductivity of the water column at two sites in the lake. On shore activities included monitoring the lake level and precipitation on a daily basis throughout the spring, summer, and fall. A study of the data collected led to the following conclusions (Barr, 1997) :

- Bone Lake exhibited excellent water quality during the early part of the summer.
- The lake's water quality deteriorated throughout the summer.
- Excessive algal blooms during August and September reduced the lake's water transparency to a level considered undesirable for recreational users.
- The lake's water quality problems result from excess phosphorus concentrations in the upper layers of the lake.
- Higher than expected yields of algae from the available phosphorus further exacerbated the lake's water quality problems.
- A management plan for the lake is needed to improve and protect its water quality.

During the summer of 1998, Bone Lake was not sprayed with an algicide to control algal blooms. A water quality monitoring program was completed during late July through mid September to determine the lake's total phosphorus, chlorophyll, and Secchi disc levels. The 1998 results were compared with the results of 1996. Copper sulfate was sprayed on portions of the lake each week during 1996. The 1998 data were generally similar to data collected during 1996 and indicate that spraying the lake with copper sulfate does not result in significant water quality improvement. The 1998 results indicate that the water quality results of 1996 and the water quality model based upon 1996 data are representative of current conditions.

Phase II involved preparation of hydrologic and phosphorus budgets for existing watershed land use conditions. The budgets were used to provide an understanding of the sources of phosphorus to Bone Lake and their effects on the lake's water quality.

A visit to the Bone Lake watershed during the fall of 1998 revealed that various portions of the lake's watershed are made up of depressions which do not directly contribute overland flow to Bone Lake under normal climatic conditions. Approximately 3,411 acres of the 11,977-acre total watershed area is essentially landlocked and does not contribute surface flow to the lake. Therefore, the hydrologic and phosphorus budgets for Bone Lake were revised to exclude contributions of landlocked areas of the watershed. Phosphorus budget results indicate:

66%

- About two thirds of the total phosphorus load to Bone Lake comes from surface runoff.

- Internal load (i.e., recycled phosphorus from the lake's sediments) comprises approximately 14 percent of the lake's annual load.

- The remaining load consists of contributions from septic systems (about 7 percent), and atmospheric deposition (i.e., dry deposition and direct rainfall on the lake surface, which cleans the air of its phosphorus, and contributes 13 percent of the annual load).

The third phase of the project, described in this report, involves the preparation of the Bone Lake Management Plan. The first step in the development of the management plan was the completion of a membership survey to assist with the establishment of a long-term water quality goal for the lake. A survey was sent to 553 property owners on Bone Lake and 252 completed survey forms were received (a 46 percent return rate). Survey results indicated the management goal of greatest importance to the members was improvement of the lake's water quality. The management goal of second greatest importance to the members was protection of the lake's water quality.

The second step in the development of the management plan was the establishment of long-term water quality goals for Bone Lake. In response to the membership survey, two goals were established for Bone Lake:

- The first goal is to achieve an average summer total phosphorus concentration in the lake's mixed surface waters (i.e., upper 6 feet) not to exceed 18 µg/L, the midpoint of the mesotrophic category (i.e., moderate phosphorus concentration, moderate productivity level). Goal achievement would result in 38 percent and 24 percent reductions in average summer total phosphorus concentrations in the north and south basins, respectively.

- The second goal is to protect the lake's water quality from additional degradation.

The third step in the development of the lake's management plan was the completion of water quality modeling scenarios to determine water quality improvements resulting from reduction of the lake's internal load and removal of phosphorus loading from shoreland septic systems. Water quality modeling was also completed to determine impacts from various watershed development scenarios and from the malfunction of all current septic systems. Finally, modeling was completed to determine mitigation of watershed development impacts by BMPs. Modeling results indicated:

- An alum treatment of Bone Lake to remove 90 percent of the current internal load is estimated to result in a summer average total phosphorus concentration of 17 µg/L (i.e., a 39 percent reduction) in the north basin and 15 µg/L (i.e., a 35 percent reduction) in the south basin. The alum treatment will achieve the lake's water quality improvement goal.

- Bone Lake's water quality is highly susceptible to increasing development within the lake's watershed. The annual average total phosphorus concentration in Bone Lake would be expected to increase by approximately 30 percent if an additional 50 percent of the watershed were developed into low density residences (i.e., cottages) and would increase by approximately 65 percent if the entire watershed were developed into low density residences.

- Protection of the water quality of Bone Lake will occur if structural Best Management Practices (BMPs) were instituted for all development scenarios. Structural BMPs were assumed to be detention basins that remove 60 percent of total phosphorus.

- Failure of all of the septic systems around the lakeshore would result in an estimated increase in the annual average total phosphorus concentration of 14 percent at the north basin and 22 percent at the south basin.

- Installation of a sanitary sewer system or holding tanks for all residences would result in less than 4 percent reduction in average summer total phosphorus concentration in the north basin and no change in the average summer total phosphorus concentration of the south basin.

The final step in the development of the lake's management plan was the recommendation of specific management actions to improve and preserve the quality of Bone Lake. The recommended actions include an alum treatment to improve the water quality of Bone Lake by reducing the quantity of phosphorus loaded to the lake by internal loading. To protect the water quality of Bone Lake under future development conditions, Best Management Practices (BMPs) to reduce the quantity of phosphorus in watershed runoff waters reaching the lake are recommended. BMPs include:

- Stormwater ordinance
- Shoreland ordinance
- Septic system ordinance
- Additional watershed BMPs

Details for these recommendations are found in the Bone Lake Management Plan section of this report.

A long-term water quality monitoring program is recommended to determine goal achievement of the Bone Lake Management Plan. Annual Secchi disc monitoring (i.e., the WDNR Self Help Program) and monitoring the mixed surface waters for total phosphorus and chlorophyll one year per every three years is recommended. Sample collection should be at a biweekly to weekly frequency (i.e., similar to the 1996 monitoring program).

Whenever feasible, the Bone Lake Management Commission should apply for additional lake management grant monies or lake protection grant monies to partially fund its projects.

Bone Lake Management Plan
Phase III: Lake Management Plan

Table of Contents

List of Tables

List of Figures

Introduction

Bone Lake in Polk County, Wisconsin, has a reputation as one of the better muskellunge lakes in the state. However, the lake is very fertile and has been experiencing problems with algal blooms and weed beds for more than 20 years. The local people were concerned about the lake and formed the Bone Lake Management District in 1975 under Chapter 33, Wisconsin Statutes. They requested and received technical assistance from the Office of Inland Lake Renewal, who conducted a one-year data collection program during 1977 through 1978. A report, entitled "*Feasibility Study Results, Management Alternatives*," was issued during 1980 (Wisconsin Department of Natural Resources, 1980). The study concluded that Bone Lake was a eutrophic body of water and ample nutrients were present to support an abundant aquatic "crop" of algae. The study concluded that significant quantities of phosphorus were being supplied to the algae from an inlake recycling mechanism. Alum treatment of the lake was recommended to reduce inlake phosphorus levels. Other management alternatives that were recommended included conducting macrophyte harvesting on selected areas, protecting the watershed and insuring the correction of existing inadequate shoreline disposal systems.

WDNR Fish Management and Water Resources personnel have cooperated with the Bone Lake organization to control the lake's algae and macrophyte problems while protecting the lake's critical areas. Management of the lake's algal blooms has been supported by the WDNR through the issuance of annual algicide permits to allow copper sulfate treatments of Bone Lake each summer. A survey to document aquatic plant "sensitive area" sites on the lake was conducted in 1988 and 1989. Eleven sites on Bone Lake were designated as sensitive areas because they provide valuable spawning, feeding, and nursery areas for fish populations, waterfowl, and other aquatic life (see Appendix A). Specific aquatic management recommendations were made. The WDNR uses the recommendations as a basis for decisions regarding macrophyte control permits (i.e., herbicide treatment or harvesting of macrophytes).

From 1989 through the present, a volunteer from Bone Lake has collected water transparency data through the WDNR "Self-Help" program. The data show a decline in the lake's water transparency throughout the summer as algal blooms increase. The data suggest the lake is eutrophic and that nutrients increase throughout the summer. In recent years, the Bone Lake Management District has been treating the lake with copper sulfate to manage its algal blooms. The lake has generally been treated with algicide weekly throughout each summer.

During 1993, a survey among property owners was completed to define concerns and desired actions to deal with riparian concerns. Many respondents favored a strengthening of the lake district and the development of a long-term management plan for the lake (Bone Lake Management District, 1993). Consequently, the Bone Lake Management District initiated a three-phase project to develop a management plan. The three phases of the project include:

- **Phase I**—Collection of data (Barr, 1997)
- **Phase II**—Preparation of annualized hydrologic and phosphorus budgets for existing watershed land use conditions (Barr, 1997)
- **Phase III**—Preparation of the lake management plan.

This report discusses the methodology, results, and conclusions from Phase III of the Lake Management Plan. The Phase III portion consisted of:

- A water quality monitoring program to determine whether not spraying the lake with an algicide results in water quality changes
- Revision of the hydrologic and phosphorus budgets to exclude landlocked portions of the watershed
- Establishment of long-term water quality goals for Bone Lake;
- An evaluation of water quality modeling to determine whether an alum treatment would achieve the lake's goal for water quality improvement;
- An evaluation of water quality modeling scenarios of Bone Lake and its tributary watershed to predict the effect of new sources of phosphorus following various levels of development;
- An evaluation of water quality modeling scenarios of Bone Lake and its tributary watershed to determine whether BMPs would protect the lake from degradation following various levels of development;
- An evaluation of water quality modeling scenarios of Bone Lake to determine impacts of failed septic systems and the impact of removing septic system inputs of phosphorus to the lake;
- A lake management plan to achieve the long-term water quality goals of Bone Lake;
- A long-term monitoring plan to determine goal achievement.

Phase I Summary: Water Quality Study of Bone Lake

The 1996 water quality survey of Bone Lake was designed to provide an understanding of the interacting physical, chemical, and biological processes controlling the water quality of Bone Lake. This information was used for model calibration during Phase II of the project. It was also designed to provide baseline water quality information for the lake to help the Bone Lake Management District complete its Lake Management Plan in the Phase III portion of the project. Table 1 presents the physical morphometry of Bone Lake.

Table 1. Bone Lake Physical Morphometry

Normal Elevation	1,152.0 feet (MSL)
Surface Area @ Normal	1,677 acres
Maximum Depth	38 feet
Volume @ Normal	36,460 acre-feet
Mean Depth (Volume/Surface Area)	22 feet
Total Watershed Area, including non-contributing area	11,977 acres
Watershed Area to Lake Area Ratio	7:1

Bone Lake has two distinct basins, and samples were collected from each of the two basins shown on Figure 1. Water samples were collected from Bone Lake biweekly during June and July and weekly from August through mid-September. Samples were collected from 0-2 meters (i.e., integrated composite samples) and analyzed for various water quality constituents including nutrients (i.e., phosphorus and nitrogen species), and biomass (i.e., chlorophyll analyses), and water quality indicator parameters (pH, and alkalinity). In addition, total dissolved phosphorus samples were collected at approximately 1.5 meter intervals from the 1.5 meter depth to approximately one-half meter above the lake bottom. In addition, measurements of Secchi disc transparency, temperature, dissolved oxygen, and specific conductance were completed during each sample event.

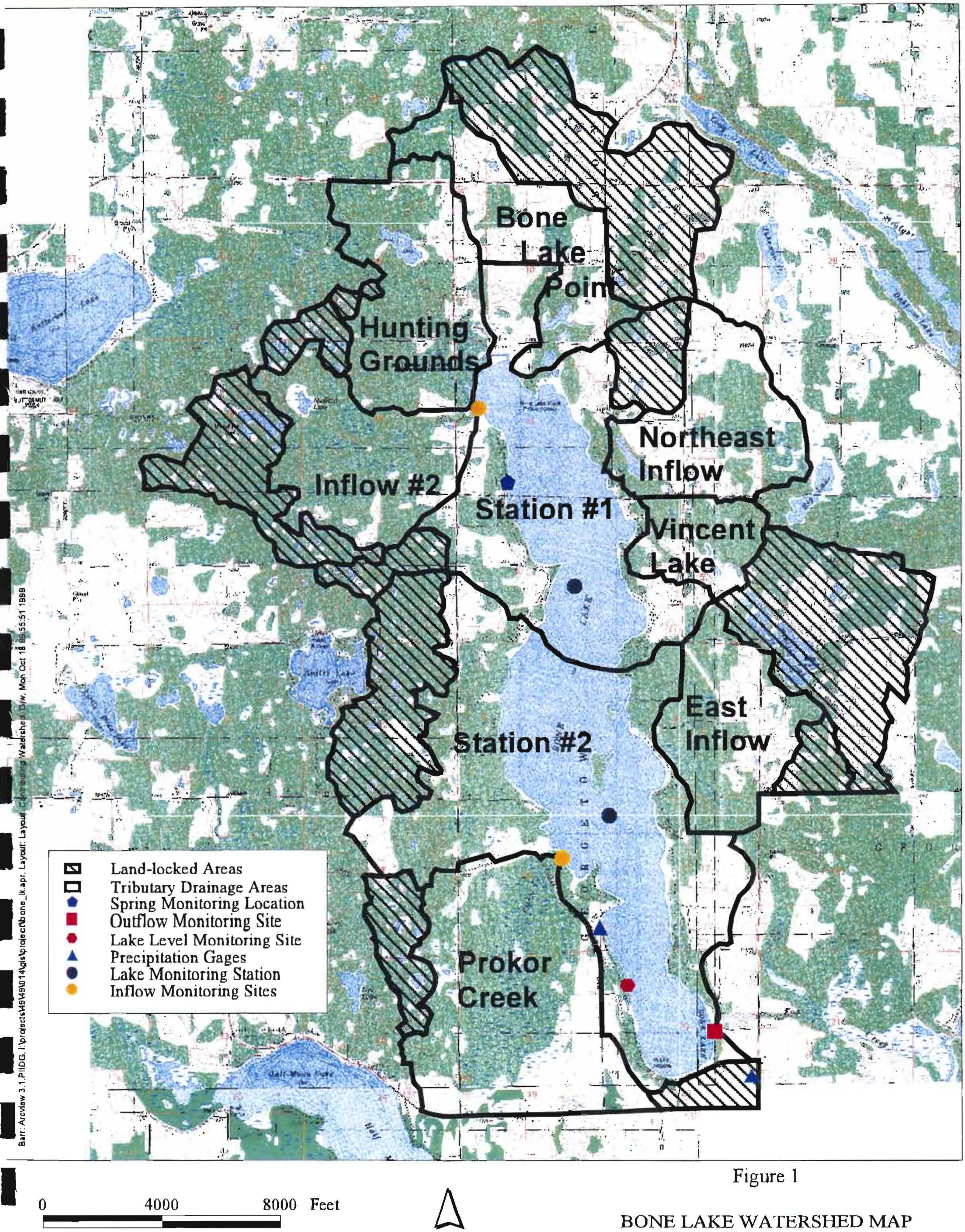


Figure 1

BONE LAKE WATERSHED MAP
BONE LAKE MANAGEMENT PLAN

1996 Bone Lake Water Quality

Data collected from Bone Lake during 1996 indicate its water quality is excellent during the spring and early summer period. However, the water quality deteriorated throughout the summer, and was considered poor during the late summer period. Results of each of the water quality monitoring parameters, below, are discussed in the following sections:

- Total Phosphorus
- Chlorophyll *a*
- Secchi Disc Transparency
- Temperature and Dissolved Oxygen

Total Phosphorus

Total phosphorus is the nutrient limiting algal growth within Bone Lake. As such, it indicates the lake's potential for algal growth, and indicates the lake's level of eutrophication. Total phosphorus data collected from Bone Lake during 1996 indicate the lake would have a designated trophic status of eutrophic. This means the lake is rich in nutrients and has a high productivity. Total phosphorus data collected from Bone Lake were within the mesotrophic (i.e., moderate amount of nutrients category) during the spring and early summer period and the eutrophic (i.e., nutrient rich) category during the late summer period. The lake's two basins exhibited similar phosphorus concentrations during the growing season. The average epilimnetic (i.e., surface waters—upper 6 feet) summer phosphorus concentrations at Stations 1 and 2 were 0.028 mg/L and 0.023 mg/L, respectively.

Chlorophyll *a*

Chlorophyll *a* is a pigment found within algae. Its measurement indicates the quantity of algae found within a lake, and provides a measure of a lake's level of eutrophication. Chlorophyll *a* data collected from Bone Lake indicate the lake's trophic status ranges from mesotrophic during the late spring period to eutrophic during the summer period. Similar chlorophyll *a* concentrations were observed in the two basins during the late spring and early summer period; however, the north basin (i.e., Station 1) exhibited higher chlorophyll *a* concentrations than the south basin during the late summer period. Summer average epilimnetic (i.e., surface waters—upper 6 feet) chlorophyll *a* concentrations at Stations 1 and 2 were 32.4 and 23.8 µg/L, respectively. The seasonal pattern of chlorophyll *a* concentrations was similar to phosphorus concentrations in the two basins, confirming that the lake's algal growth is directly related to phosphorus levels. The chlorophyll data indicate a relatively high yield of algal biomass resulted from the lake's available phosphorus.

Secchi Disc

Secchi disc transparency provides a measure of a lake's water clarity. Because increasing eutrophication is associated with decreasing water clarity, Secchi disc measurements can provide an indication of a lake's level of eutrophication. Secchi disc measurements in Bone Lake generally mirrored phosphorus and chlorophyll *a* concentrations. The data show that the lake's water transparency is largely determined by algal abundance and the lake's algal abundance is largely determined by the lake's phosphorus concentration. Based on a study by the Metropolitan Council of the Twin Cities metropolitan area (Osgood, 1989), the 1996 average summer Secchi disc transparencies at Stations 1 and 2 (1.7 and 1.8 meters, respectively) indicate that the lake generally experiences moderate recreational use-impairment.

Temperature and Dissolved Oxygen

Depth/time relationships or isopleths were used to determine the stratification (mixing) pattern at each Bone Lake sample site (i.e., temperature isopleths) and to assess the loss of oxygen near the lake bottom (i.e., oxygen isopleths). Temperature isopleths indicate Bone Lake was thermally stratified during the spring and summer period. The density difference between the warm surface waters and the cold bottom waters caused the hypolimnion (bottom waters) to be "sealed off" from the atmosphere by the epilimnion (surface waters). The oxygen in the hypolimnion (bottom waters) was not replenished by wind and wave action as occurred in the epilimnetic (surface) waters. Instead it was depleted by decomposition of organic matter. The dissolved oxygen isopleths indicated that extremely low dissolved oxygen concentrations were noted in the hypolimnion (bottom waters) at all sampling locations during the summer period. Oxygen depletions in the bottom waters of Bone Lake result in the release of phosphorus from its lake sediments. This release of phosphorus from the sediments is known as the lake's "internal load." The lake's thermal stratification can "seal off" most of the phosphorus rich bottom waters from the epilimnion (surface waters) until the fall overturn period. However, some of the phosphorus recycled from bottom sediments can diffuse into the epilimnion and contribute to increased algal growth during the late-summer months. Hence, the internal phosphorus load from the lake's bottom waters appears to be at least partially responsible for the increasing epilimnetic phosphorus concentrations during the late-summer period and is likely released into the surface waters during the fall overturn period.

Phase II Summary: Phosphorus Budget and Lake Water Quality Mass Balance Model

Preparation of the 1996 hydrologic and phosphorus budgets for existing watershed land use conditions was designed to provide an understanding of the sources of phosphorus and how the inputs affect the water quality of Bone Lake. The phosphorus budget prepared during the Phase II study estimated an annual total annual phosphorus load into Bone Lake of approximately 2,067 pounds, based upon the 1995-1996 data. The modeled water quality with this load was an average annual total phosphorus concentration of 0.047 mg/L for the north basin and 0.030 mg/L for the south basin. The modeled water quality was higher than the observed water quality (i.e., an average annual total phosphorus concentration of 0.028 mg/L for the north basin and 0.023 mg/L for the south basin). For this reason, additional adjustments were made to the watershed phosphorus export coefficients during the Phase III project. Also, the lake's water quality model was refined during the Phase III project. The results of the Phase III adjustments are discussed in the Phase III results section.

Phase III: Methods

The methods used for Phase III of the Lake Management Plan project are discussed in the following sections of this report. Included in the discussion are:

- 1998 Water Quality Monitoring Program
- Revised Hydrologic and Phosphorus Budget Determinations
- Membership Survey
- Water Quality Modeling to Determine Benefits of Reduced Internal Loading
- Water Quality Modeling to Determine Impacts of Septic Tank Malfunction or Removal
- Water Quality Modeling to Determine Impacts of Additional Watershed Development
- Water Quality Modeling to Determine Benefits of Best Management Practices (BMPs)

1998 Water Quality Monitoring Program

During the period July 23 through September 10, Bone Lake was monitored weekly by Bone Lake volunteers to determine the lake's water quality. A 0-2 meter (i.e., 0- to 6-feet) composite sample was collected from Stations 1 and 2 on each occasion and analyzed by the Barr Engineering Company Laboratory for total phosphorus and chlorophyll *a*. Secchi disc transparency was measured at each location on each sample occasion.

Revised Hydrologic and Phosphorus Budget Determinations

A visit to the Bone Lake watershed during the fall of 1998 revealed that various portions of the lake's watershed area are made up of depressions which do not directly contribute overland flow to Bone Lake under normal climatic conditions. Approximately 8,566 acres of the 11,977-acre total watershed area directly contribute overland flow to Bone Lake, while the remaining watershed area is essentially landlocked. Therefore, the hydrologic and phosphorus budgets for Bone Lake were revised to exclude contributions of landlocked areas of the watershed. The revised hydrologic and phosphorus annual loadings were then used to revise the Bone Lake water quality model (i.e., Dillon and Rigler, 1974, modified by Nurnberg, 1984). Table 2 summarizes the watershed revisions (i.e., landlocked and directly contributing subwatershed areas of the Bone Lake watershed).

Table 2. Bone Lake Subwatershed Areas

Subwatershed	Directly Contributing Watershed Areas (acres)	Non-Contributing Watershed Areas (acres)	Total Watershed Area, Including Non-Contributing Area (acres)
Station #1	1,485	324	1,809
Station #2	2,367	669	3,036
Inflow #2	690	518	1,208
Prokor Creek	1,184	101	1,285
Hunting Grounds	777	0	777
Bone Lake Point	590	930	1,520
East Inflow	568	101	669
Northeast Inflow	630	0	630
Vincent Lake	275	768	1,043
Total Watershed Area	8,566	3,411	11,977

Because of the changes to the directly contributing watershed area shown in Table 2, modifications were made to the watershed phosphorus export coefficients to calibrate the water quality model. The changes reduced the gap between the predicted and observed in-lake phosphorus concentrations noted during Phase II. A description of the methodology for the completion of the phosphorus budget, including revisions follows.

The watershed surface runoff component was estimated using an annual phosphorus export coefficient for each land use type within the direct subwatersheds. An annual phosphorus export coefficient of 0.04 lbs/ac/yr was used for the forested portions of the subwatersheds. This value closely corresponds with that observed by Taylor et al. (1971), Nicholson (1977) and Dillon and Kirchner (1975). The row cropland phosphorus export coefficient of 0.45 lbs/ac/yr, used in this analysis, agrees well with that observed by others (Bradford, 1974; Alberts et al., 1978). The non-row cropland export coefficient of 0.22 lbs/ac/yr, used in this analysis, generally agrees with that observed by Harms et al. (1974). The residential phosphorus export coefficient of 0.27 lbs/ac/yr corresponds with other published data (Much and Kemp, 1978; Mattraw and Sherwood, 1977. Finally, Harms et al. (1974) obtained a phosphorus export coefficient of 0.22 lbs/ac/yr, which corresponds well with the 0.18 lbs/ac/yr used for the pasture/CRP land use within the direct subwatersheds.

Internal loading was estimated for each of the lake basins using the total phosphorus data from the lake's water column. The summer internal load, for each basin, is the product of the fraction of hypolimnetic phosphorus released to the surface waters, the sediment phosphorus release rate, the fraction of the lake basin surface area experiencing anoxia, and the duration of hypolimnetic anoxia. The 1996 dissolved oxygen profiles of each basin were used to estimate the duration of anoxia (D.O. <0.5 mg/L). The fraction of each lake basin's total surface area experiencing anoxia was based on the depths of the observed summer anoxia and the morphometry of each basin. The average sediment total phosphorus release rate of 2.0 mg/m^2/day was estimated using the total phosphorus data from the lake's water column. This sediment release rate is lower than the release rates determined from the sediment phosphorus release experiment (approximately 6 mg/m^2/day) conducted as part of this study, but agrees well with the observed increase of total phosphorus over the anoxic portion of the hypolimnetic waters of each basin during the summer of 1996. Finally, the fraction of hypolimnetic total phosphorus released to the surface waters was estimated to facilitate the calibration of the lake mass balance model. For the calibrated model, this fraction was 0.20 for each basin. This release fraction agrees with that observed by Einsele (1936).

An atmospheric wet and dry deposition rate of 0.09 lbs/ac/yr, which agrees well with Wright (1976) and Burwell et al. (1975), was applied to the surface area of Bone Lake. The groundwater flow component of the phosphorus budget was determined using the inflow volume from the hydrologic budget and an average groundwater total phosphorus concentration of 0.020 mg/L, based on nearby sampling data collected by the WDNR (1988) and published by the Wisconsin Geological and Natural History Survey (1990). The watershed runoff component from the tributary subwatersheds was estimated using the export coefficients determined from the measured inflow concentrations and estimated runoff from each of the monitored watersheds. The Prokor Creek and Inflow #2 subwatershed total phosphorus export coefficients were 0.026 and 0.108 kg/ha/yr, respectively. The measured Prokor Creek export coefficient is significantly less than published values for other subwatersheds with similar land uses, and may reflect the nutrient removal capacity of the large wetland directly upstream of the outfall.

Phosphorus export rate computations, used in the WILMS model and published by the U.S. EPA for septic systems, were used to estimate an annual load from drain fields (Panuska, 1994). The equation used for Bone Lake estimated the septic system load as follows:

$$\textit{Total Septic System Load (kg/yr)} = Ec_{st} * \textit{Number of capita-years} * (1-SR)$$

Where:

Ec_{st}	=	export coefficient to septic tank systems (0.5 kg/capita/yr)
cap.-yrs.	=	# of people occupying a dwelling each year
	=	[(# of permanent residents/dwelling) * (# of permanent dwellings)] + [(# of seasonal residents/dwelling) * (x days/yr) * (# of seasonal dwellings)]
SR	=	weighted soil retention coefficient (85 for most likely value used in model)

The Bone Lake property owners survey results were used to determine the number of septic systems within each of the two lake basin areas and the total number of septic systems for both permanent and seasonal residences. The most likely soil retention coefficients of 90 and 40 were chosen for properly and improperly functioning systems, respectively. Ten percent of the septic systems were assumed to be improperly functioning, yielding a weighted soil retention coefficient of 85. Each permanent and seasonal dwelling unit was assumed to have three and five residents, 100 days per year. Finally, the USGS Quad Maps were used in conjunction with the number of septic systems within each township to assign the number of dwellings adjacent to each of the two lake basins of Bone Lake. The ratio of permanent to seasonal residences was kept the same as the total for each basin. The assumptions made regarding the septic system inputs agree well with the estimates made for Balsam Lake in Polk County, Wisconsin (Bursik, 1996).

Membership Survey

The Bone Lake Board of Commissioners at their October 22, 1998 meeting decided it was important to get input from all property owners in the district on what they wanted for short and long term water quality goals for Bone Lake. The Bone Lake Management District, working cooperatively with Barr Engineering Company and the Polk County Land Conservation Department, developed a survey instrument to survey all property owners in the Bone Lake Management District. In November of 1998 the survey was sent to 553 property owners on Bone Lake. A total of 252 completed survey forms were received (46 percent return rate). A copy of the survey is found in Appendix B.

Water Quality Modeling to Determine Benefits of Reduced Internal Loading

The Bone Lake water quality model (i.e., Dillon and Rigler, 1974, modified by Nurnberg, 1984), with revised watershed loadings (i.e., excluded landlocked areas of watershed; used revised phosphorus export coefficients) was used to determine the benefits of reduced internal loading to

Bone Lake. The internal load to the lake was reduced by 90 percent and the resultant water quality modeled.

Water Quality Modeling to Determine Impacts of Septic Tank Malfunction or Removal

The revised Bone Lake water quality model was used to determine the impacts of changes in septic system loading on the water quality of Bone Lake. A modeling scenario was completed in which all current Bone Lake septic systems were assumed to malfunction and the resultant lake water quality was estimated. A second modeling scenario was completed in which all current Bone Lake septic systems were assumed to contribute no phosphorus to the lake (i.e., assumed conversion to holding tanks or sanitary sewer installation) and the resultant lake water quality was estimated.

Water Quality Modeling to Determine Impacts of Additional Watershed Development

Development of portions of the watershed into cottages represents a potential source of water quality degradation for Bone Lake. Such degradation would be unacceptable to residents who, by responding accordingly to a survey, have expressed a desire to protect the lake's water quality. Consequently, impacts of additional watershed development and resultant water quality impacts to Bone Lake were modeled. Because low density residential development is believed to be the most likely type of development to occur in the Bone Lake watershed, low density development was used for all modeling scenarios. Development scenarios included residential development of an additional 20, 50, 80 and 100 percent of the watershed. The resultant water quality changes to Bone Lake were modeled for each development scenario. Because it is believed that additional residential development of the watershed may result in surface runoff from current landlocked areas, two lake water quality scenarios were modeled for each development scenario. The first scenario assumed all current landlocked areas will remain landlocked under all development scenarios. The second scenario assumed that 100 percent of the watershed contributed surface flow under all modeling scenarios. The two scenarios provide a range of conditions that are expected to occur should additional residential development occur in the watershed.

Water Quality Modeling to Determine Benefits of BMPs

Water quality modeling was completed to determine whether watershed BMPs can successfully protect Bone Lake from water quality degradation under various watershed development scenarios. Structural BMPs (detention basins) are believed to be the most effective protective measure to prevent water quality degradation of Bone Lake. Consequently, modeling was completed with structural BMPs in place to determine resultant Bone Lake water quality under various development scenarios. Structural BMPs were assumed to be wet detention ponds capable of removing 60 percent of the total phosphorus load entering the ponds. Development scenarios with structural BMPs included residential development of an additional 20, 50, 80, and 100 percent of the watershed. The resultant water quality of Bone Lake was modeled. Because it is believed that additional residential development of the watershed may result in surface runoff from current landlocked areas, two lake water quality scenarios were modeled. The first scenario assumed all current landlocked areas will remain landlocked under all development scenarios. The second scenario assumed that 100 percent of the watershed contributed surface flow under all modeling scenarios. The two scenarios provide a range of conditions that are expected to occur if BMPs are used to mitigate lake water quality impacts of additional residential development in the watershed.

Phase III: Results and Discussion

The Phase III Results and Discussion section presents the results of the 1998 water quality monitoring program, the revised hydrologic and phosphorus budgets, the revised lake water quality mass balance model, and the results of the membership survey. Finally, results of the following lake water quality modeling scenarios are presented:

- a scenario in which 90 percent of the current internal phosphorus load is removed
- a scenario in which all existing septic systems are assumed to malfunction
- a scenario in which all existing septic systems are assumed to contribute no phosphorus to the lake
- several development scenarios
- the use of Best Management Practices (BMPs) in conjunction with development scenarios

1998 Water Quality Monitoring Program

The results of the 1998 monitoring program (See Appendix C) were compared with the results of the 1996 monitoring program (i.e., Phase I). The comparison is presented in Table 3. During 1996, portions of Bone Lake were sprayed weekly with copper sulfate. The lake was not sprayed with copper sulfate during 1998. Even though there were some differences in climatic conditions, temperature, precipitation, and radiant energy during 1996 and 1998, no significant difference in water quality was noted. The data indicate that spraying the lake with copper sulfate does not result in a significant improvement in water quality. The results further indicate that the water quality results of 1996 and the water quality model based upon the 1996 results are representative of current conditions.

Table 3. Comparison of 1996 and 1998 Bone Lake Water Quality Data, July 23–September 10 Average Values

	Station #1 (North)			Station #2 (South)		
Year	Secchi (ft.)	Chlor. *a* (µg/L)	Total P. (µg/L)	Secchi (ft.)	Chlor. *a* (µg/L)	Total P. (µg/L)
1996	4.2	29.2	27	4.2	25	26
1998	3.9	22.6	26	3.9	23	28

Hydrologic Budget

A visit to the Bone Lake watershed during the fall of 1998 revealed that various portions of the lake's watershed area are made up of depressions which do not directly contribute overland flow to Bone Lake under normal climatic conditions. Approximately 8,566 acres of the 11,977-acre total 71% watershed area directly contribute overland flow to Bone Lake, while the remaining watershed area is essentially landlocked. Therefore, the hydrologic budget was revised. The revised hydrologic budget (i.e., excludes surface runoff contributions from noncontributing landlocked areas) is presented in Table 4. For comparison purposes, the hydrologic budget that assumes the entire watershed, including landlocked areas, contributes flow to the lake is also presented in Table 4.

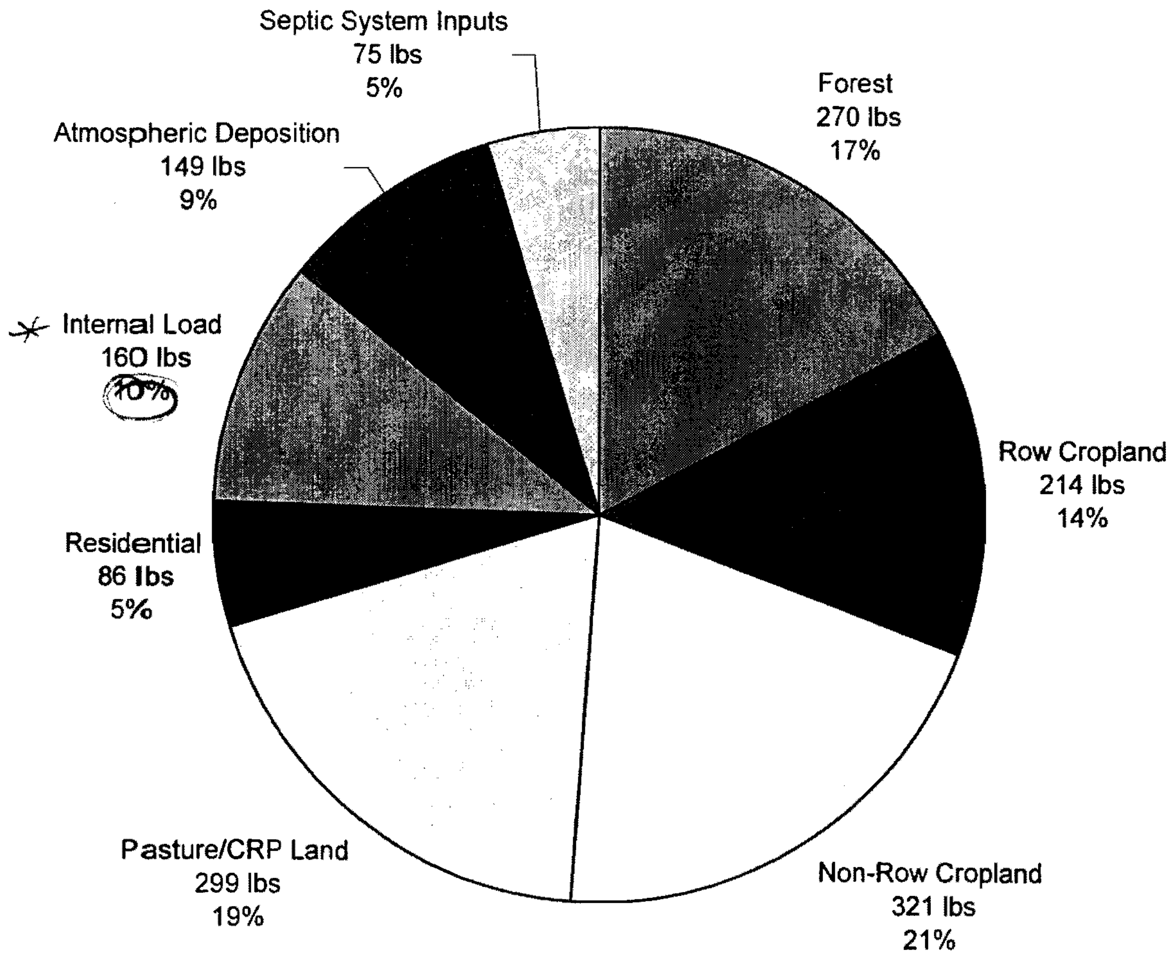
Table 4. Hydrologic Budget Comparison Between 100% of Watershed Contributing Surface Flow and Exclusion of Landlocked Areas

	100% Watershed Contributes Surface Flow		Revised to Exclude Landlocked Areas	
Parameter	**Station 1**	**Station 2**	**Station 1**	**Station 2**
Total Drainage Area, including watershed lakes and wetlands (Acres)	6,987	4,990	4,447	4,119
Annual Runoff Volume (Acre Feet)	2,212	1,385	1,330	1,081
Residence Time (Years)	6.55	5.22	10.42	7.42

Phosphorus Budget and Lake Water Quality Mass Balance Model

The phosphorus budget was also revised to exclude portions of the watershed that do not directly contribute overland flow to the lake. Phosphorus budget results are presented in Figures 2 through 7 and in Table 5. Phosphorus budgets presented in Figures 2 through 4 assume landlocked areas do not contribute surface flow to the lake. Figures 2 through 4 present phosphorus budget results for the whole lake, north basin, and south basin, respectively. Phosphorus budgets presented in Figures 5 through 7 assume the entire watershed contributes surface flow to the lake. Figures 5 through 7 present phosphorus budget results for the whole lake, north basin, and south basin, respectively.

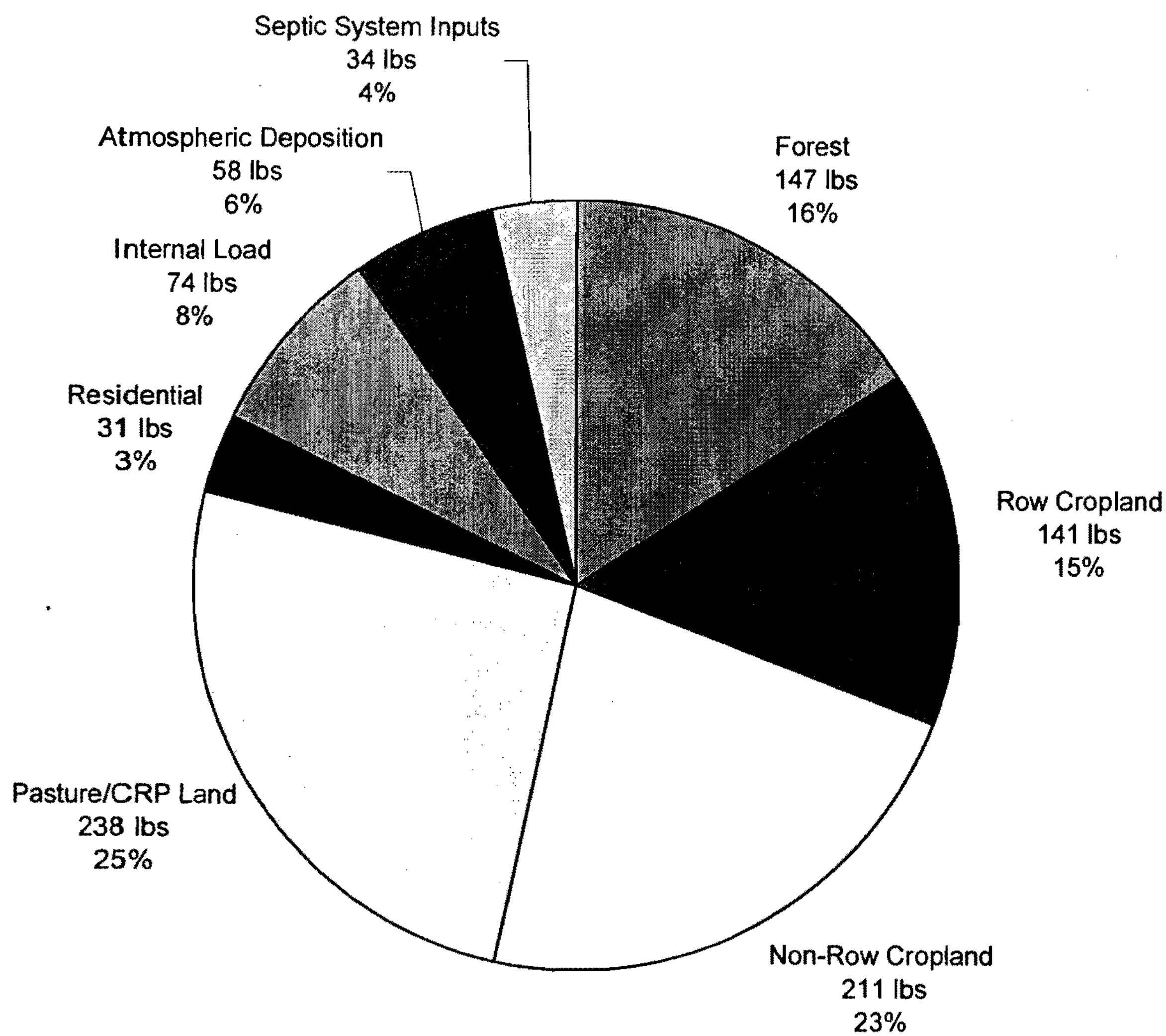
Bone Lake - Whole Lake
1996 Annual Phosphorus Budget



Annual Load = 1,575 lbs.
(Assumes 100 Percent of Watershed Area Contributes Surface Flow)

Figure 2

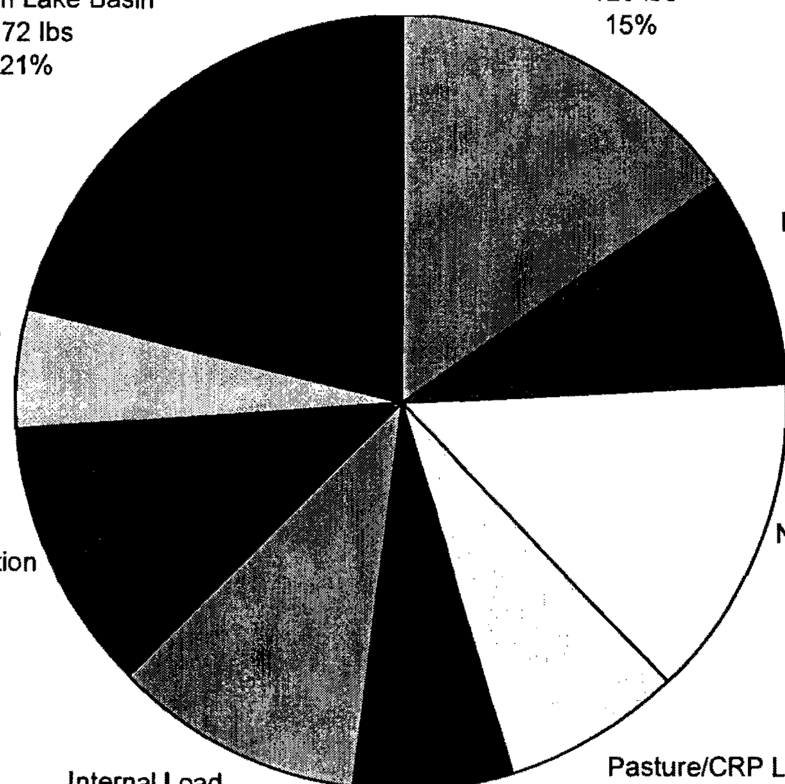
Bone Lake - Station 1
1996 Annual Phosphorus Budget



Annual Load = 934 lbs.
(Assumes 100 Percent of Watershed Area Contributes Surface Flow)

Figure 3

Bone Lake - Station 2
1996 Annual Phosphorus Budget

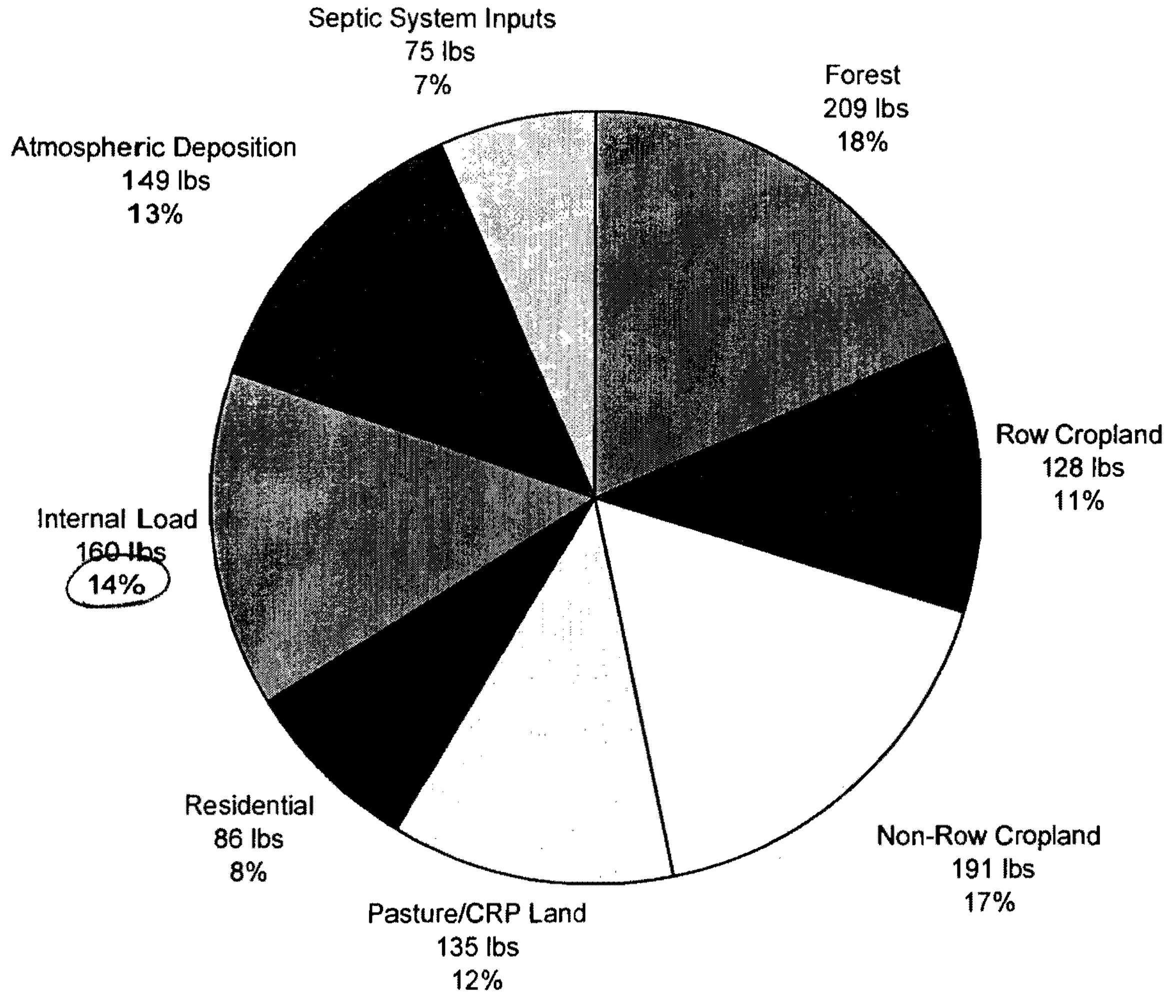


Annual Load = 813 lbs.
(Assumes 100 Percent of Watershed Area Contributes Surface Flow)

Figure 4

Bone Lake - Whole Lake

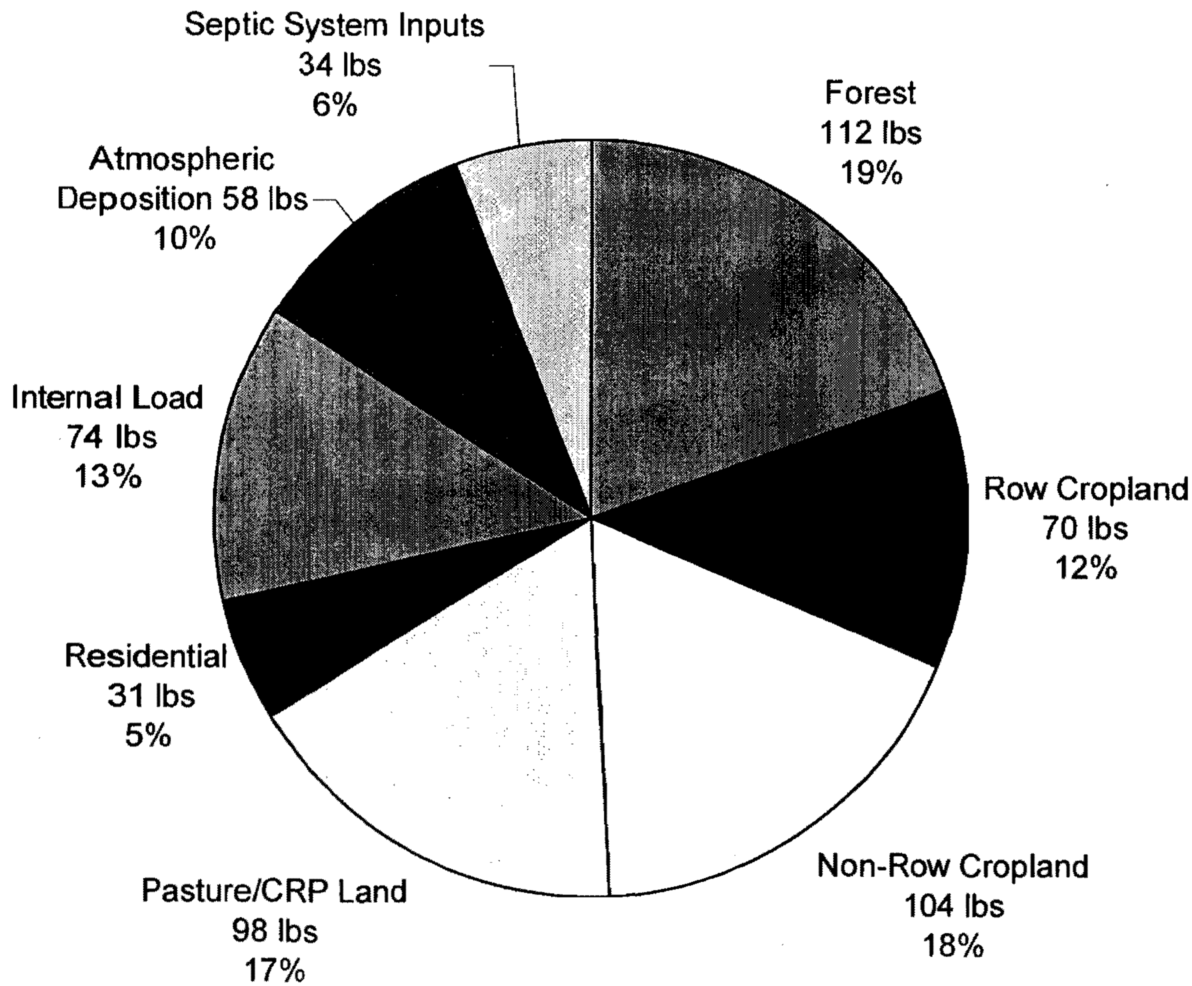
1996 Annual Phosphorus Budget



Annual Load = 1,133 lbs.
(Assumes Land Locked Areas of Watershed Do Not Contribute Surface Flow)

Figure 5

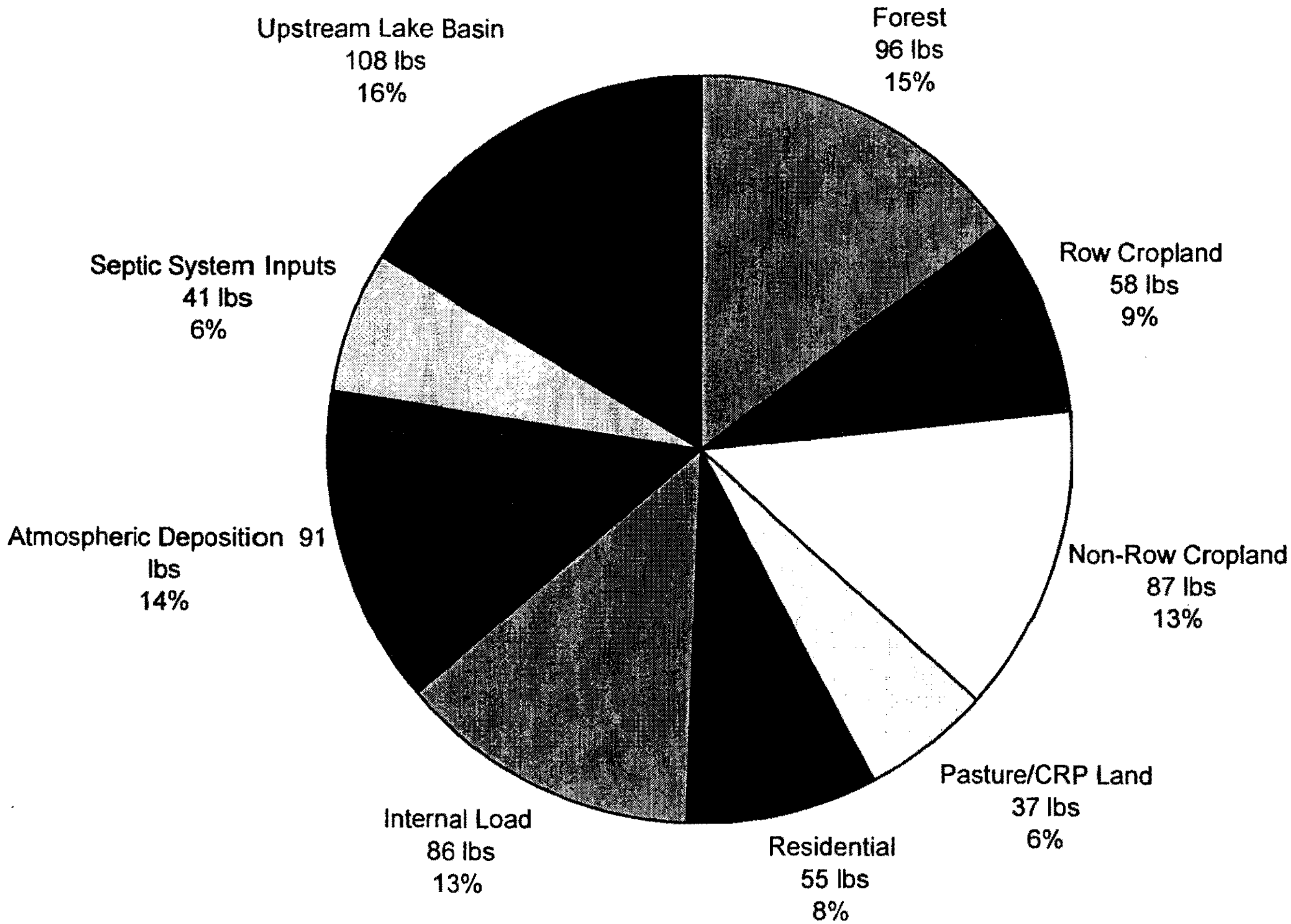
Bone Lake - Station 1
1996 Annual Phosphorus Budget



Annual Load = 582 lbs.
(Assumes Land Locked Areas of Watershed Do Not Contribute Surface Flow)

Figure 6

Bone Lake - Station 2
1996 Annual Phosphorus Budget



Annual Load = 660 lbs.
(Assumes Land Locked Areas of Watershed Do Not Contribute Surface Flow)

Figure 7

Table 5. Phosphorus Budget Comparison Between 100% of Watershed Contributing Surface Flow and Exclusion of Landlocked Areas

	100% Watershed Contributes Surface Flow		Revised to Exclude Landlocked Areas	
Parameter	**Station 1**	**Station 2**	**Station 1**	**Station 2**
Total Drainage Area, including watershed lakes and wetlands (Acres)	6,987	4,990	4,447	4,119
Total Annual Phosphorus Load (Kg/Year)	430	291	264	250

The resultant water quality of Bone Lake was modeled. Table 6 presents a comparison of the modeled water quality of Bone Lake, assuming landlocked areas do not contribute surface flow. For comparison purposes, the modeled lake water quality, assuming 100 percent of the watershed area contributes surface flow, is presented.

Table 6. Water Quality Modeling Comparison Between 100% of Watershed Contributing Surface Flow and Exclusion of Landlocked Areas

	100% Watershed Contributes Surface Flow		Revised to Exclude Landlocked Areas	
Parameter	**Station 1**	**Station 2**	**Station 1**	**Station 2**
Average Annual Total Phosphorus Concentration (μg/L)	29	19	33	22

The modeled average annual total phosphorus concentration under current conditions (i.e., landlocked areas excluded) is somewhat higher than the observed concentration at Station 1 (i.e., observed concentration of 28 μg/L and modeled concentration of 33 μg/L) and very close to the observed concentration at Station 2 (i.e., observed concentration of 23 μg/L and modeled concentration of 22 μg/L).

The lake's average annual concentration of phosphorus was estimated to be higher when landlocked areas were assumed to contribute no surface flow than when the entire watershed was assumed to contribute surface flow. Most of the watershed's landlocked areas are forested and, consequently, surface runoff from these areas is estimated to contain low concentrations of phosphorus. When these forested areas are assumed to contribute surface flow to the lake, the low phosphate runoff waters from the forested areas dilute the higher phosphate runoff waters from other land uses before the composite surface runoff enters the lake. Consequently, the composite surface runoff waters entering the lake are estimated to have a lower phosphorus concentration than the runoff waters from non-forested areas of the watershed. However, exclusion of the landlocked forested areas results in estimated phosphorus concentrations of runoff waters that are higher than concentrations of runoff waters that include landlocked forested areas. Consequently, when these forested areas are assumed to be landlocked, the higher phosphate waters from other land uses enter the lake undiluted and are estimated to have a greater impact on the lake's water quality (i.e., result in higher average total phosphorus concentration of lake water).

Membership Survey Results

Members of the Bone Lake Management District were surveyed to determine their:

- Perception of lake's current water clarity
- Support of water quality improvement projects
- Water clarity goal for the lake
- Recreational activities under current water quality conditions
- Recreational activities under ideal water quality conditions
- Lake management goals

A total of 553 surveys were mailed and 252 responses were received (i.e., 46 percent return rate). Survey results are presented in Appendix B. The survey results indicated:

- Most respondents perceived the lake's current water clarity as somewhat cloudy (40 percent) or clear (39 percent); a few respondents perceived the lake's water clarity as murky (11 percent) or very cloudy (10 percent).

- Most respondents support projects to improve the lake's water quality (63 percent), assuming a portion of the project cost will be born by property owners, including the respondents.

- Most respondents believe the lake's water clarity goal should be clear (81 percent); a few respondents believe the goal should be somewhat cloudy (11 percent) or crystal clear (8 percent).

- Respondents indicated the primary use of Bone Lake is fishing. Other major uses were motorized boating and swimming.

- Under ideal water quality conditions, the primary use of Bone Lake would be swimming. Other major uses would be fishing and motorized boating.

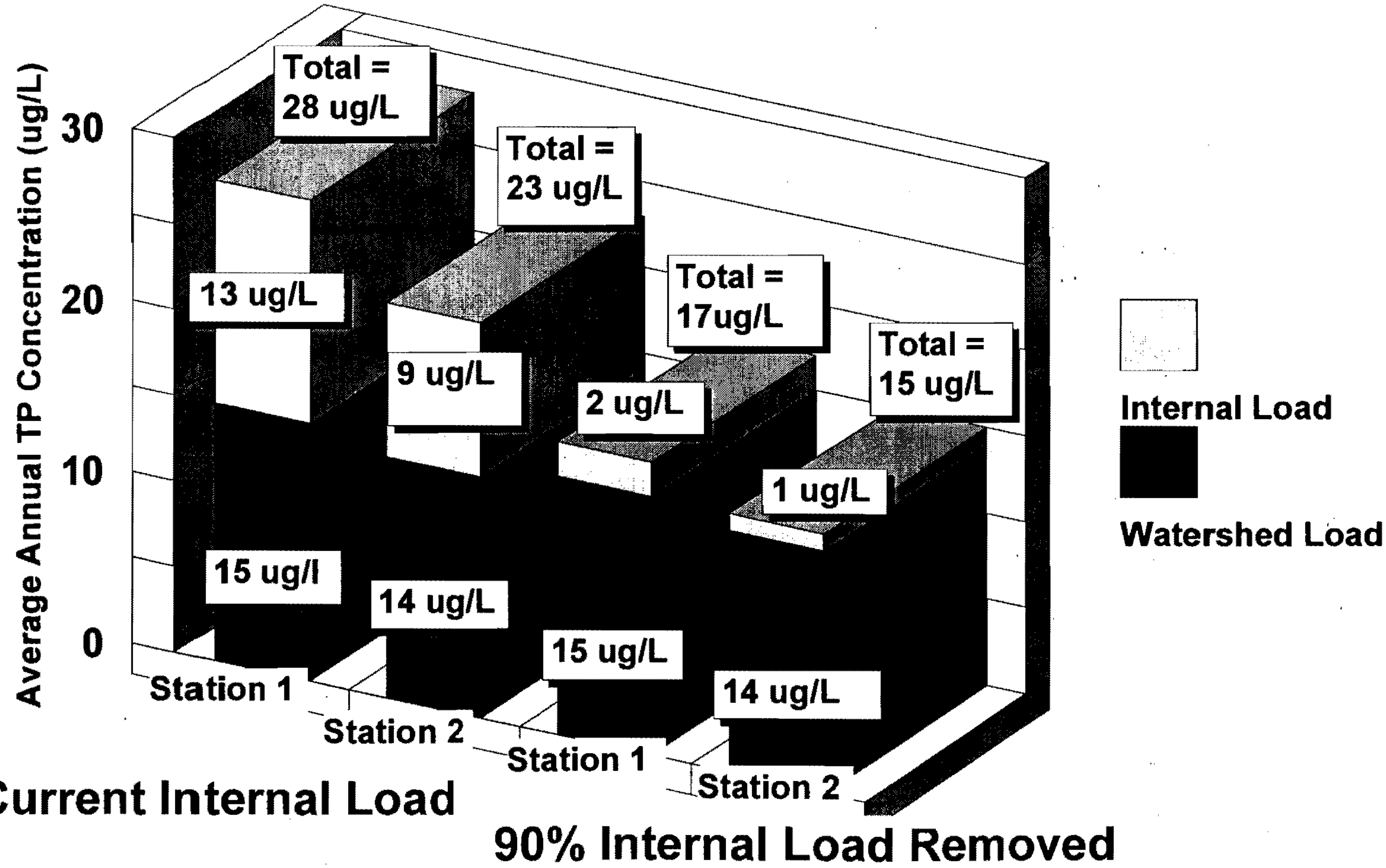
- Respondents indicated improvement of the lake's water quality to be the primary lake management goal. Respondents indicated protection of the lake's water quality to be the second most important lake management goal.

Lake Water Quality Modeling of Internal Phosphorus Load Reduction

Because a majority of survey respondents indicated a desire for improvement of the lake's water quality, modeling was completed to determine resultant water quality improvements from an alum treatment of the lake. An alum treatment would reduce the lake's internal phosphorus load, the phosphorus re-released from the lake's sediments back into the water. Alum added to the lake would form a floc layer on the bottom of the lake. The floc layer would act as a kind of phosphorus barrier by combining with (and trapping) the phosphorus as it is released from the sediments. This would reduce the amount of internal recycling of phosphorus in the lake and improve the lake's water quality.

Lake water quality modeling was completed to determine the expected water quality changes following a 90 percent removal of the current internal phosphorus load. Modeling results are presented in Figure 8. Average annual phosphorus concentrations would be reduced 39 percent and 36 percent at the north and south basins, respectively, following the internal phosphorus load reduction.

Bone Lake Average Annual TP Conc.
Current Int. Load & 90% Removal



Assumes Current Non Contributing Area Does Not Contribute Surface Flow

Figure 8

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Lake Water Quality Modeling of Septic System Malfunction/Removal

Lake water quality modeling was completed to estimate impacts of both increased and decreased phosphorus loading from septic systems. The following two scenarios were modeled:

- All current septic systems were assumed to malfunction
- All current septic systems were assumed to contribute no phosphorus to the lake (i.e., removal assumed because of replacement with holding tanks or installation of a sanitary sewer)

Modeling results are presented in Figure 9. Malfunction of all current septic systems is estimated to result in north and south basin increases in the average annual total phosphorus concentrations of 14 percent and 22 percent, respectively. The resultant water quality degradation would further exacerbate the lake's current water quality problems.

Removal of all phosphorus loading from septic systems is estimated to result in a 3 percent decrease in the average annual total phosphorus concentration of the north basin and no change in the average annual total phosphorus concentration of the south basin. The results indicate no appreciable improvement in water quality would result from a sanitary sewer system.

Lake Water Quality Modeling of Development Scenarios

Bone Lake survey respondents indicated that protection of the lake's water quality was an important water quality management goal. Because future developments within the lake's watershed may result in water quality degradation, lake water quality modeling was completed to estimate impacts of increased development in the watershed. Increased development within the watershed is likely to result in increased surface runoff. Consequently, increased surface runoff may result in surface flow contribution from areas within the watershed that are currently landlocked. A range of surface runoff conditions was estimated for the lake by modeling two conditions:

- Current landlocked areas were assumed to contribute no surface flow to the lake
- The entire watershed was assumed to contribute surface flow to the lake

For each condition (i.e., landlocked or 100 percent of watershed contributing), four development scenarios were modeled to estimate the lake's water quality under 20 percent, 50 percent, 80 percent, and 100 percent increases in watershed development. Modeling results are presented in Figures 10 and 11 and in Table 7.

Reserved for

Bone Lake Average Annual TP Conc.
Septics: Current, Malfunction, Removal

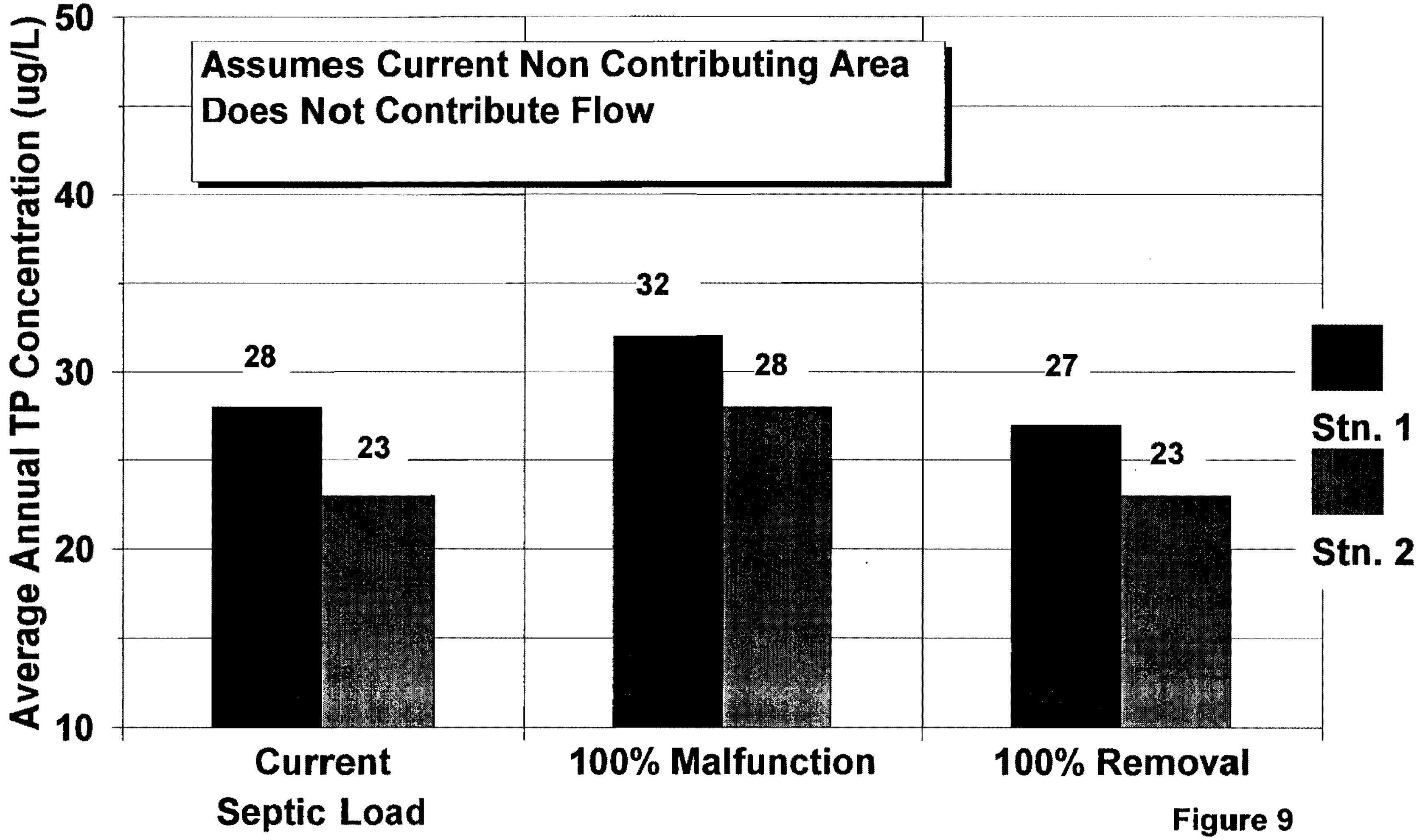

Figure 9

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Bone Lake Average Annual TP Conc. Development Scenarios From 0-100%

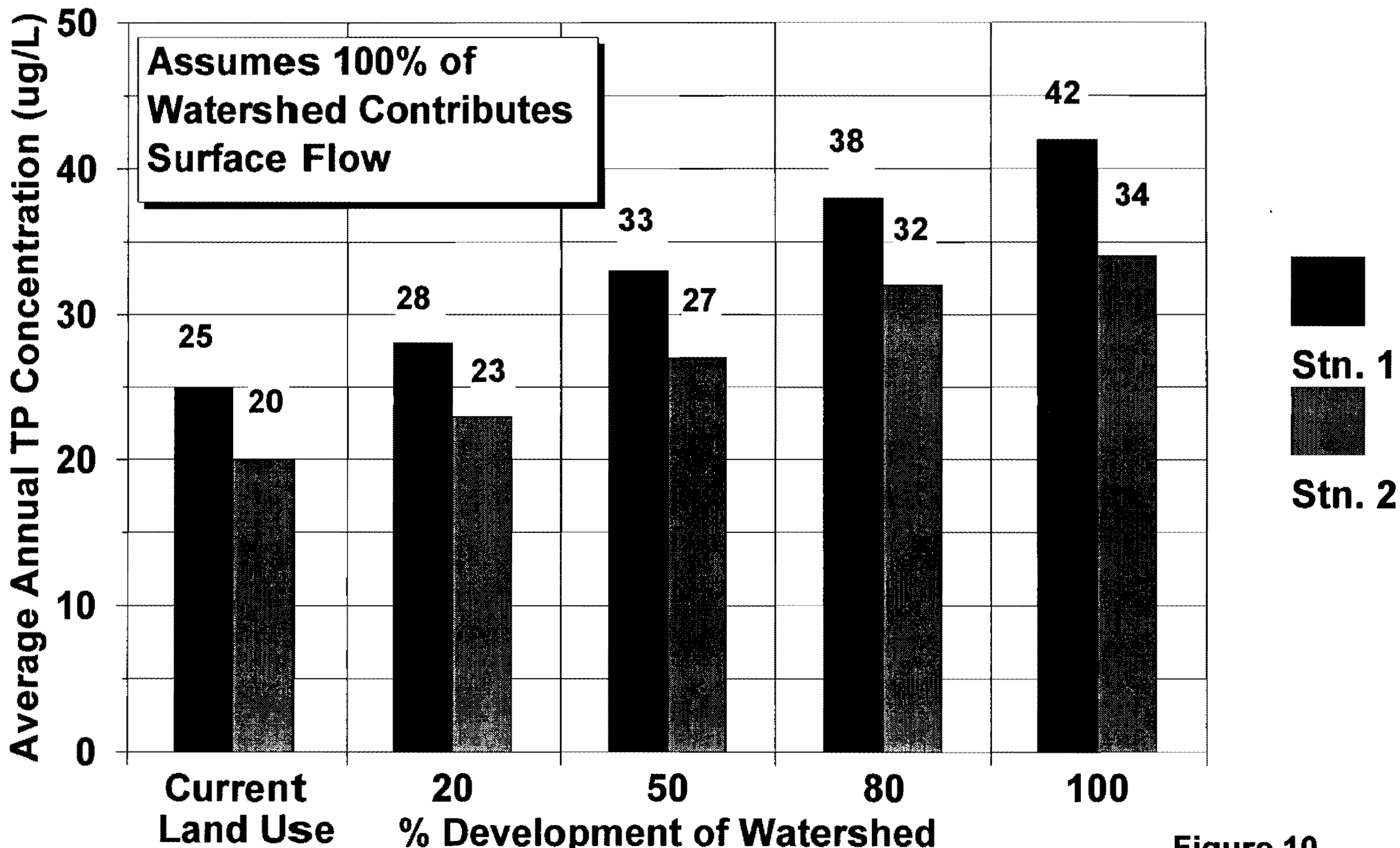

Figure 10

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Bone Lake Average Annual TP Conc. Development Scenarios From 0-100%

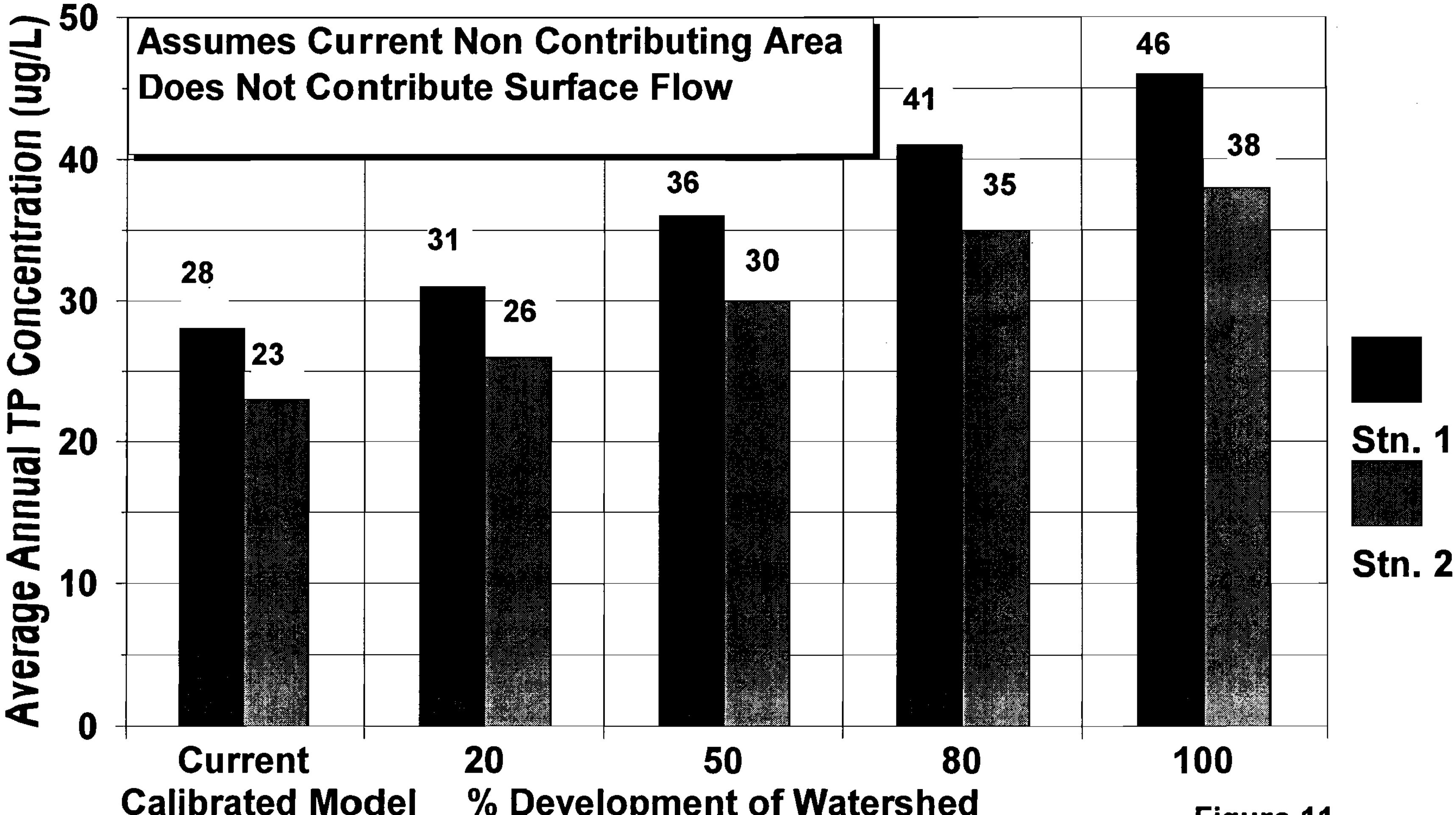

Figure 11

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Table 7. Percent Increase In Bone Lake Average Annual Total Phosphorus Concentration Under Various Development Scenarios

	Percent Increase in Average Annual Total Phosphorus Concentration Under Various Development Scenarios			
	% Increase in Watershed Development			
Basin/Condition	20	50	80	100
Basin 1:				
Assumes 100% of Watershed Contributes Surface Flow	10	31	52	66
Assumes Current Landlocked Areas Contribute No Surface Flow	12	30	48	64
Basin 2:				
Assumes 100% of Watershed Contributes Surface Flow	16	37	58	68
Assumes Current Landlocked Areas Contribute No Surface Flow	14	32	50	64

Modeling results indicate Bone Lake's water quality is expected to degrade should increased watershed development occur. The rate of lake water quality degradation is estimated at 0.6 percent increase in average annual total phosphorus concentration per each percent increase in watershed development, assuming current landlocked conditions. Assuming 100 percent of the watershed contributes surface flow, the average rate of lake water quality degradation is estimated at 0.7 percent increase in average annual total phosphorus concentration per each percent increase in watershed development. The north (basin 1) and south (basin 2) basins are estimated to exhibit the same rate of degradation (e.g., each basin is expected to exhibit a 0.6 percent increase in average annual total phosphorus concentration per each percent increase in watershed development, assuming current landlocked conditions).

Lake Water Quality Modeling of Development Scenarios with BMPs

Because watershed development is expected to result in water quality degradation, water quality modeling was completed to determine whether management practices can successfully protect Bone Lake from water quality degradation under various watershed development scenarios. All of the watershed development scenarios discussed in the previous section "Lake Water Quality Modeling of Development Scenarios" were modeled with structural BMPs in place to determine resultant Bone Lake water quality. As discussed in the methods section, structural BMPs are assumed to be detention basins that remove approximately 60 percent of the phosphorus load. Modeling results are presented in Figures 12 and 13 and in Table 8.

Table 8. Percent Increase in Bone Lake Average Annual Total Phosphorus Concentration Under Various Development Scenarios with BMPs

	Percent Increase in Average Annual Total Phosphorus Concentration Under Various Development Scenarios with BMPs			
	% Increase in Watershed Development			
Basin/Condition	20	50	80	100
Basin 1: Assumes 100% of Watershed Contributes Surface Flow	NC	NC	NC	NC
Assumes Current Landlocked Areas Contribute No Surface Flow	NC	NC	NC	NC
Basin 2: Assumes 100% of Watershed Contributes Surface Flow	NC	NC	NC	NC
Assumes Current Landlocked Areas Contribute No Surface Flow	NC	NC	NC	NC

NC = Negligible Change (i.e., <10%).

Modeling results indicate BMPs are expected to effectively mitigate lake water quality degradation resulting from increased watershed development. With BMPs, the rate of lake water quality degradation is estimated to be negligible. BMPs are expected to mitigate more than 90 percent of the water quality degradation resulting from increased development.

Bone Lake Average Annual TP Conc. Development Scenarios With BMPs

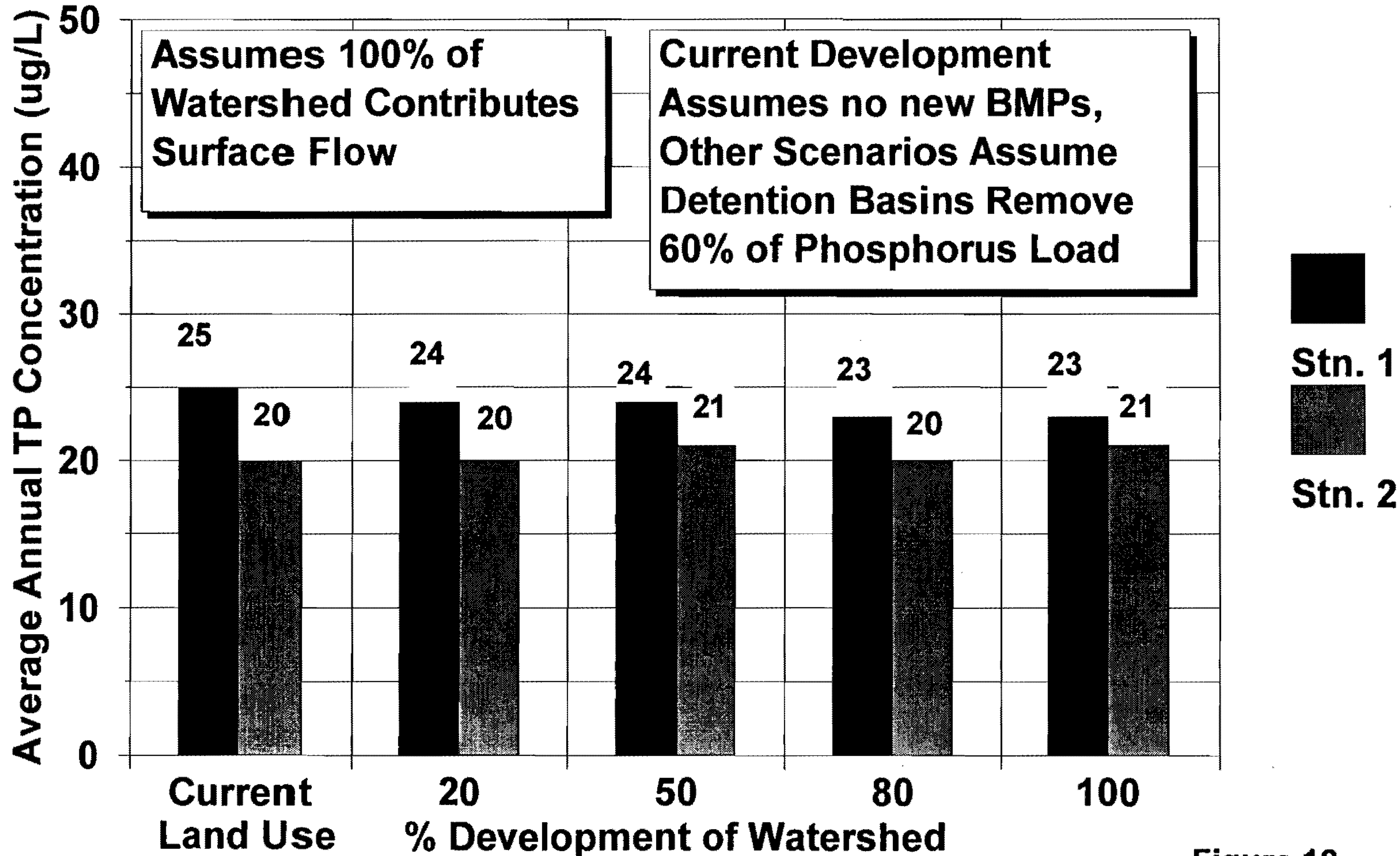

Figure 12

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Bone Lake Annual Average TP Conc.
Development Scenarios With BMPs

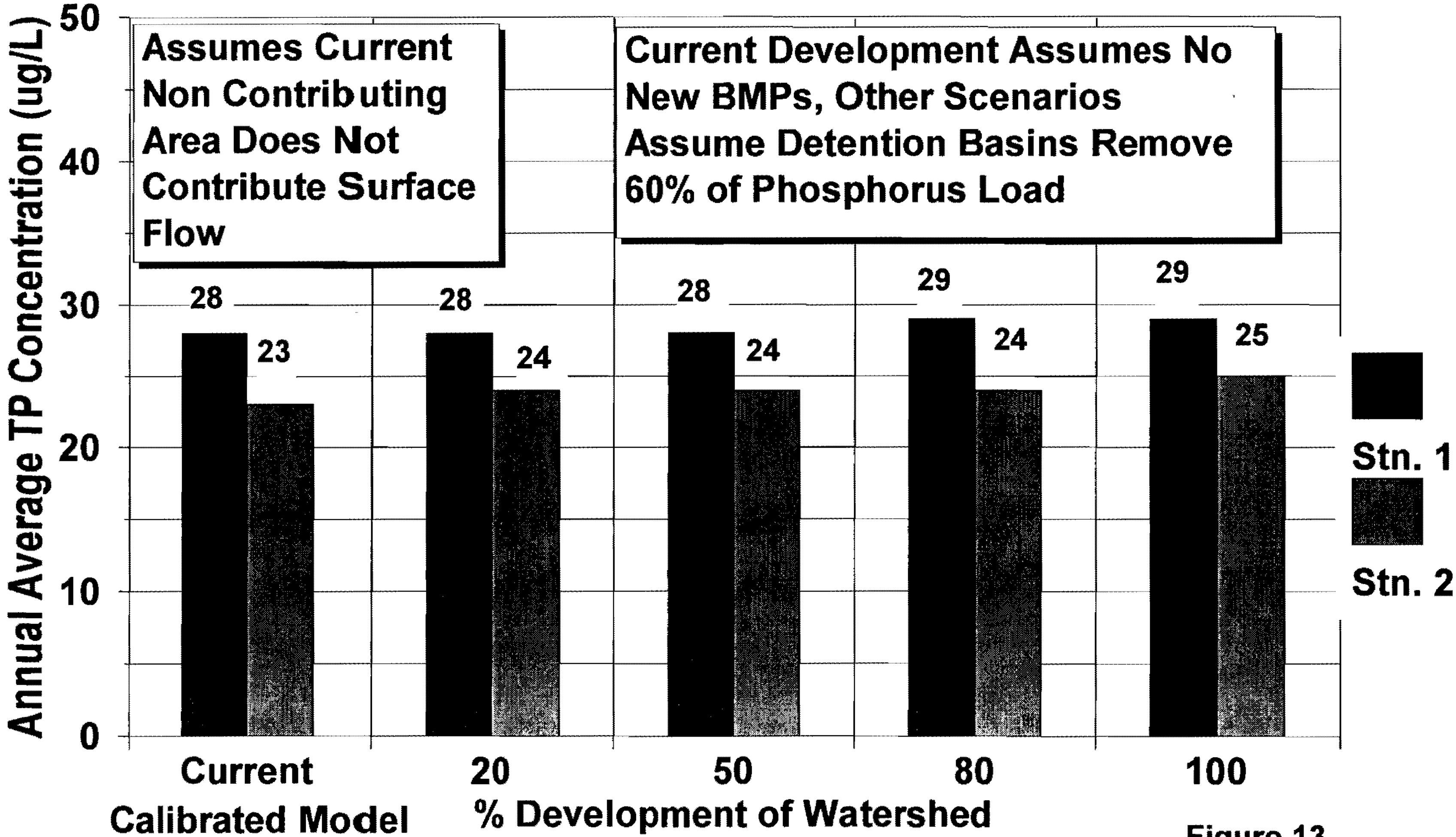

Figure 13

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Lake Water Quality Modeling of Development Scenarios with BMPs and Internal Load Reduction

Because Bone Lake survey respondents indicated water quality improvement and water quality protection were important water quality management goals, modeling scenarios were completed to evaluate achievement of the two goals concurrently. As discussed previously, reduction of the lake's internal load would result in water quality improvement and use of BMPs would protect the lake from development impacts. Consequently, water quality modeling scenarios were completed to determine whether the lake's improved water quality following internal load reduction would be protected under various watershed development scenarios with BMPs. All of the watershed development scenarios discussed in the previous section "Lake Water Quality Modeling of Development Scenarios with BMPs" were modeled with 90 percent of the internal load removed to determine resultant Bone Lake water quality. Modeling results are presented in Figures 14 and 15. Modeling results indicate BMPs are expected to effectively mitigate lake water quality degradation from increased watershed development. Consequently, the lake's improved water quality following internal phosphorus load reduction would be protected by BMPs under all watershed development scenarios.

Bone Lake Average Annual TP Conc.
Dev. Scenarios W/BMPs & Remove Int. P

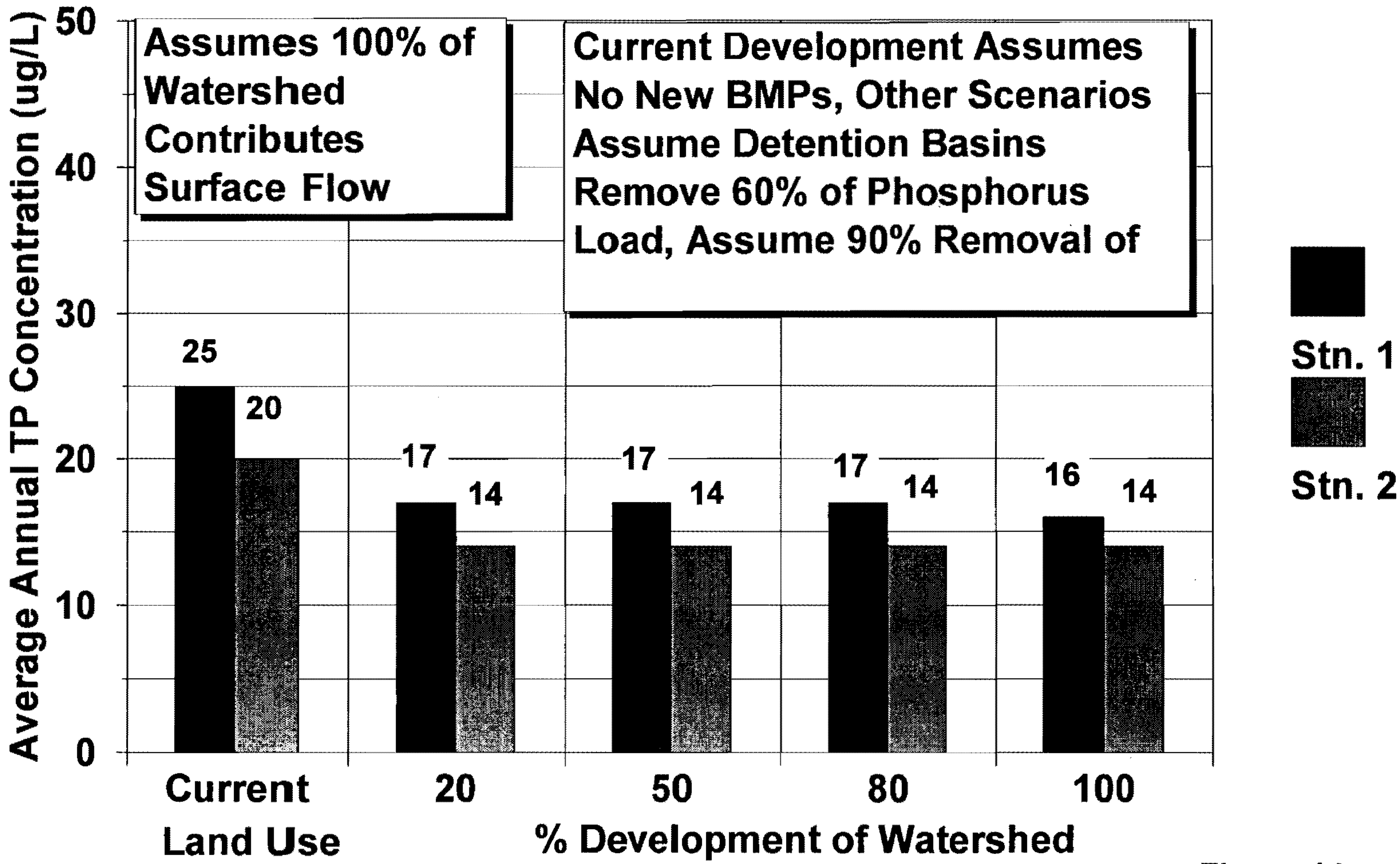

Figure 14

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Bone Lake Average Annual TP Conc.
Dev. Scenarios W/BMPs & Remove Int. P

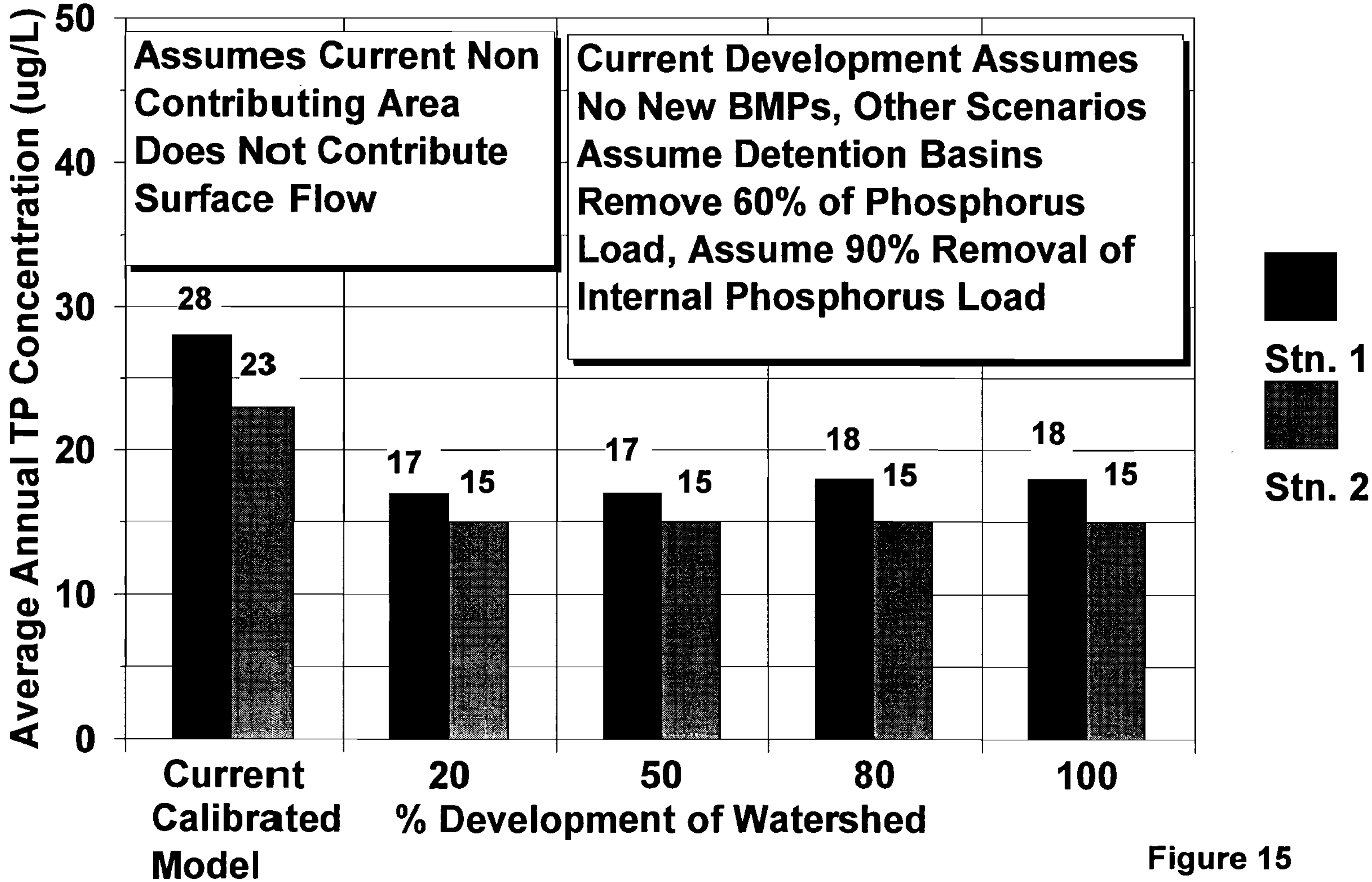

Figure 15

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Prior to the development of a lake management plan, the following questions are answered:

1. What is the water quality of the lake under existing watershed development conditions?
2. What is the long-term water quality goal of the lake?
3. Does the current water quality of the lake achieve its water quality goal?
4. What will be the water quality of the lake if unchecked development is allowed to occur?
5. Will the lake's water quality goal be met if unchecked development is allowed to occur?

If the answer to question five is no, the following question is asked.

6. Can the lake's water quality goal be achieved with the implementation of lake and/or watershed management practices?

If the answer to question six is yes, a lake management plan is completed to outline the management practices which must be implemented to achieve the lake's long-term water quality goal.

The above six questions were answered prior to the development of the Bone Lake Management Plan. The answers are as follows:

1. The current water quality of Bone Lake is within the mesotrophic category during the spring and early summer and the eutrophic category during the late summer period. This means the lake is moderately rich in phosphorus and its water quality is good during the spring and early summer period. However, the lake is rich in nutrients and its water quality is poor during the late summer period. Based on a study by the Metropolitan Council (Osgood, 1989), the 1996 average summer Secchi disc transparencies at Stations 1 and 2 (1.7 and 1.8 meters, respectively) indicate that the lake generally experiences moderate recreational use impairment.

2. Two long-term water quality goals have been selected for Bone Lake. The first lake water quality goal is to improve the lake's water quality. The specific goal selected was an average annual epilimnetic (i.e., upper 6 feet) total phosphorus concentration not to exceed 18 µg/L, the midpoint of the mesotrophic category (i.e., moderate phosphorus concentration, moderate productivity level). Goal achievement would result in 38 percent and 24 percent reductions in

average summer total phosphorus concentrations in the north and south basins, respectively. The second lake water quality goal of is to protect the lake's water quality from additional degradation. The goal includes prevention of degradation under current water quality conditions and prevention of degradation under the improved water quality condition (i.e., average annual epilimnetic total phosphorus concentration of 18 μg/L).

3. The current water quality of Bone Lake does not achieve its long-term goal to achieve an average annual epilimnetic total phosphorus concentration of 18 μg/L. Consequently, water quality improvement must occur to achieve this goal.

4. Unchecked development of the lake's watershed will cause degradation of the lake's water quality. The degree of water quality degradation increases with increasing development. Implementation of structural BMPs during watershed development mitigates the adverse impacts of development. Consequently, BMPs protect the lake's water quality under all development scenarios.

5. The lake's long-term goal will not be met if unchecked development is allowed to occur without the implementation of BMPs..

6. The lake's water quality goals can be achieved with the reduction of the internal phosphorus load and the implementation of BMPs to mitigate watershed development impacts.

The following management plan outlines the management practices which must be implemented to achieve Bone Lake's long-term water quality improvement and preservation goals. The plan improves the water quality of Bone Lake by reducing the lake's internal phosphorus load and protects Bone Lake by requiring structural BMPs to mitigate watershed development impacts. BMPs reduce the quantity of phosphorus loaded to the lake under future development conditions.

The Bone Lake Management Plan addresses the following:

wrong order

- Alum Treatment of Bone Lake
- Watershed Best Management Practices (BMPs
- Recommended Monitoring

Alum Treatment of Bone Lake

It is proposed that Bone Lake be treated with the chemical alum to improve its water quality. The alum treatment will provide safe, effective and long-term control of the amount of algae in Bone Lake. Consequently, the treatment will result in cleaner, clearer water and a more pleasurable environment for recreation on and around Bone Lake.

Alum (aluminum sulfate) is a compound derived from aluminum, the earth's most abundant metal. Alum has been used in water purification and wastewater treatment for centuries and in lake restoration for decades.

Alum is used primarily to control the internal loading of phosphorus from the sediments of the lake bottom. Alum reduces the growth of algae by trapping the nutrient phosphorus, the algae's food source, in sediments. Like most other plants, algae require phosphorus to grow and reproduce. Algal growth is directly dependent on the amount of phosphorus available in the water. Without available phosphorus, algae cannot continue to grow and reproduce.

Alum is injected into water several feet below the surface. On contact with water, alum becomes aluminum hydroxide (the principal ingredient in common antacids such as Maalox). This fluffy substance, called floc, settles to the bottom of the lake.

On the way down, it interacts with phosphorus to form an aluminum phosphate compound that is insoluble in water. As a result, phosphorus in the water is trapped as aluminum phosphate and can no longer be used as food by algae. An added bonus occurs as the floc settles downward through the water. It collects other suspended particles in the water, carrying them down to the bottom and leaving the lake noticeably clearer.

On the bottom of the lake, the floc forms a layer that acts as a kind of phosphorus barrier by combining with (and trapping) the phosphorus as it is released from the sediments. This reduces the amount of internal recycling of phosphorus in the lake.

An alum treatment of Bone Lake is estimated to cost approximately $314,000. The cost estimate assumes a total of 445,000 gallons of alum applied to areas of the lake at least 5 feet deep. The recommended application rate is 6.0, 11.9, and 17.9 grams of aluminum per square meter at the 5-10, 10-15, and greater than 15-foot depths, respectively. The recommended liquid alum application rate is 109, 218, and 327 gallons per acre at the 5-10, 10-15, and greater than 15-foot depths, respectively. The surface area of the lake at the three depth intervals is 130, 112, and 1,203 acres at the 5-10, 10-15, and greater than 15-foot depths, respectively. The alum application is assumed to occur over a 14-day period.

Following the treatment, the lake's average annual total phosphorus concentration is expected to be 17 µg/L in the north basin and 15 µg/L in the south basin. The improved water quality achieves the lake's improvement goal of an average annual total phosphorus concentration of 18 µg/L or less. Benefits from the treatment are estimated to last approximately 10 years.

The estimated treatment dose was based upon the lake's phosphorus internal load, determined from sediment phosphorus release experiments completed during the Phase I study. Recent research indicates the effectiveness and longevity of an alum treatment is determined by the extractable phosphorus content of the lake's sediments. Consequently, determination of alum dose from sediment extractable phosphorus data is considered a more precise estimate of dose than estimation of dose from sediment phosphorus release data. To insure that the alum dose selected for Bone Lake effectively accomplishes the lake's water quality improvement goal and lasts approximately 10 years, measurement of the extractable phosphorus content of the lake's sediments is recommended. If this recommendation is implemented, duplicate cores will be collected from the north and south basins (i.e., Stations 1 and 2) and the upper 5 centimeters of each core will be analyzed for extractable phosphorus. A recommended alum dose will then be computed, based upon Rydin, E. and Welch, E. B. (1998).

Watershed Best Management Practices

Modeling results indicate watershed best management practices are needed to achieve the lake's water quality protection goal. Four watershed management practices are proposed:

- Stormwater ordinance
- Shoreland ordinance
- Septic system ordinance
- Additional watershed best management practices

Stormwater Ordinance

A Polk County ordinance to regulate development/redevelopment is proposed to mitigate the impacts of watershed development on the lake's water quality. Modeling results indicate such regulation is necessary to achieve the lake's water quality protection goal and that such an ordinance to restrict phosphorus loading from the lake's watershed will protect the lake from degradation under all watershed development conditions. A proposed stormwater ordinance, presented in Appendix D, provides erosion control design standards, has lawn fertilizer regulations, requires submission of a stormwater management plan and performance bond. The proposed ordinance should apply to the entire Bone Lake watershed. A key feature of the ordinance is the requirement to treat all stormwater runoff from all developed/redeveloped sites, except shoreland development. All nonshoreland owners/developers will be required to construct an on site detention basin or contribute money towards the construction of a regional facility. A 60 percent total phosphorus removal efficiency will be required for all on-site and regional detention basins. Treatment of all watershed runoff resulting from watershed development is necessary to achieve the Bone Lake water quality goal under future watershed development conditions. Therefore, it is recommended that Polk County pass the proposed ordinance presented in Appendix D. An additional model ordinance that may be considered is included in the "Wisconsin Construction Site Best Management Practice Handbook" (WDNR, 1994).

Shoreland Ordinance

A shoreland ordinance to regulate shoreland development/redevelopment is proposed. Because shoreland development is excluded from the requirement to treat runoff in a detention basin, a buffer strip requirement is recommended to treat runoff from shoreland areas. The ordinance will become important as redevelopment of shoreland property occurs with the passage of time.

A buffer strip is a permanently vegetated area (i.e., not mowed grass, however) whose function is to remove pollutants from runoff waters and to slow the flow of runoff waters, thereby encouraging infiltration. Buffer strips remove phosphorus from runoff waters and, therefore, restrict phosphorus loading to lakes from shoreland property. Buffer strips provide a means of mitigating impacts from redevelopment by removing additional pollutants from runoff waters. A national survey of 36 local buffer programs revealed the median width selected for a buffer was 100 feet (Heraty, 1993). Schueler (1995) recommends a minimum base width of at least 10 feet to provide adequate stream protection relative to phosphorus removal. The results of studies of buffer programs indicate a 100-foot-wide buffer strip would provide adequate phosphorus removal to protect the water quality of Bone Lake from shoreland development/redevelopment impacts. It is recommended that Polk County pass an ordinance requiring a 100-foot buffer strip for all new developments and redevelopments on Bone Lake shoreland lots to achieve the lake's long-term water quality protection goal. Effective and attractive buffer strip designs are presented in *Lakescaping for Wildlife and Water Quality* (1999).

Septic System Ordinance

Modeling results indicate water quality degradation will result from malfunctioning shoreland septic systems. Therefore, the Bone Lake Management District should work with Polk County to establish a septic system ordinance for the Bone Lake watershed. All septic systems must be tested when properties change hands or building permits are issued for development or redevelopment. Systems failing to pass the test must be brought into compliance before sale of property can take place or issuance of a building permit.

Additional Watershed Best Management Practices (BMPs)

A visit was made to the Bone Lake watershed to evaluate the need for watershed BMPs. The evaluation results indicated BMPs are currently used throughout the Bone Lake watershed. Only three recommendations for BMPs were identified. Figure 16 shows the three locations within the watershed that would benefit from BMP implementation. The locations and recommended BMPs are:

- Erosion problem at one location within the Vincent Lake subwatershed—The Bone Lake Management District should work with an engineer to identify and implement feasible erosion control BMPs.
- Horse farm adjacent to Inflow #2—The Bone Lake Management District should work with the farmer to insure that the animals are not allowed to enter the stream.
- Dairy farm within an area that does not contribute surface flow to the lake— If development occurs within this subwatershed, the Bone Lake Management District should work with an engineer to insure that flow from the dairy farm area does not enter Bone Lake.

In addition, it is recommended that watershed residents refrain from using phosphorus fertilizers unless soil testing indicates the soil is deficient in phosphorus. An education program to discourage the use of phosphorus fertilizers is recommended. Locations where non phosphate fertilizers may be purchased should be communicated to watershed residents.

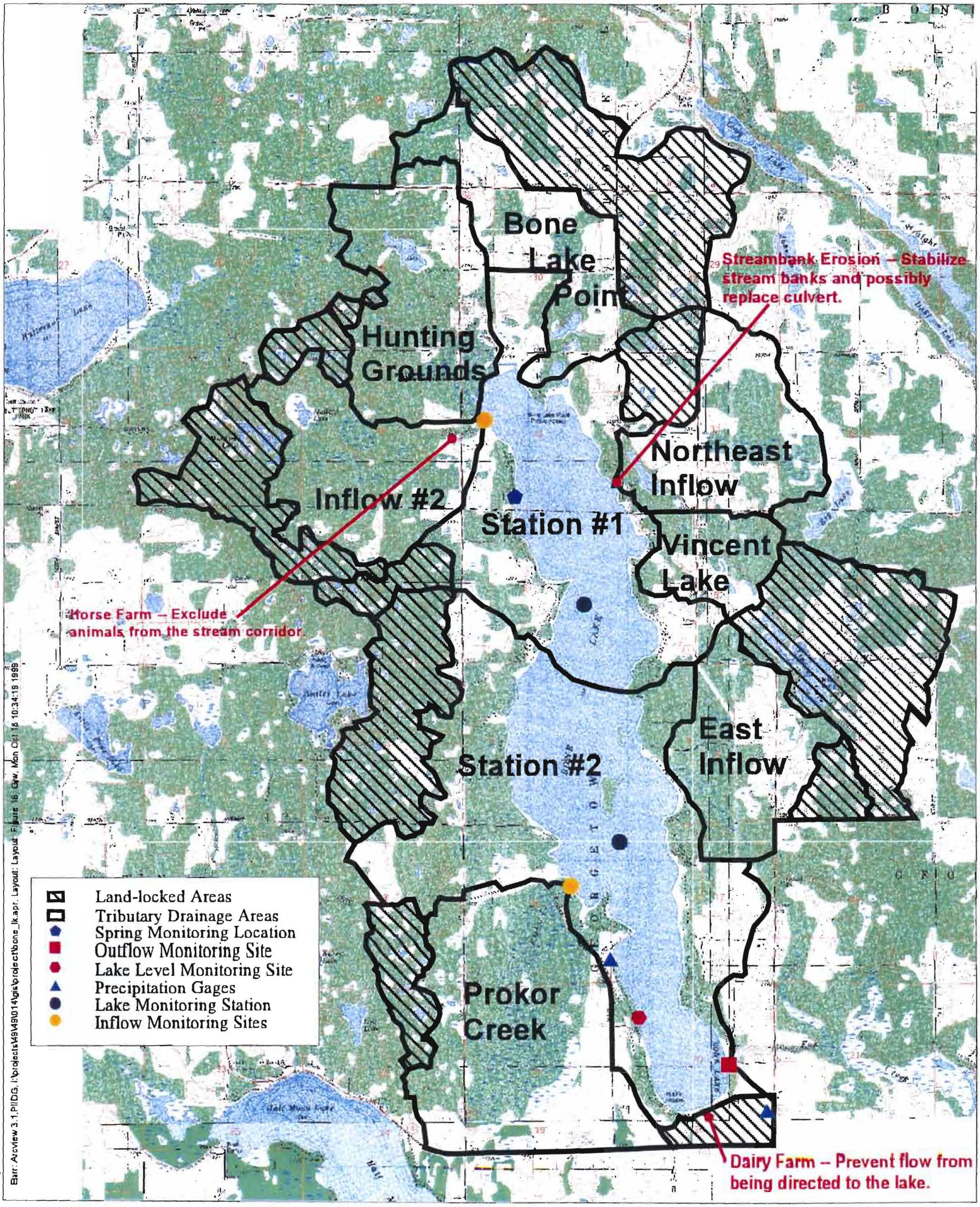

Figure 16

0 4000 8000 Feet

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RECOMMENDED WATERSHED MANAGEMENT SITES
BONE LAKE MANAGEMENT PLAN

Recommended Monitoring

The success or failure of a lake management plan is determined from the plan's ability to achieve the water quality goal of the lake being managed. Therefore, a long-term water quality monitoring program is needed to determine goal achievement of the Bone Lake Management Plan. A lake resident currently monitors the lake's Secchi disc transparency annually as a participant in the WDNR Self Help program. Continued participation is recommended to determine any changes in the lake's water quality that may occur. In addition, monitoring the mixed surface waters (i.e., 0-2 meter composite sample) for total phosphorus and chlorophyll *a* one year per every three years is recommended. A monitoring frequency similar to the 1996 monitoring program is recommended. The data will be used to determine goal achievement.

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