Long Lake Management Plan

Phase II: Long Lake Hydrologic and Phosphorus Budgets

Prepared for
Long Lake Preservation Association

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with Assistance from:
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Executive Summary

The study described by this report was initiated by the Long Lake Improvement Association for the purpose of providing information to water resource managers and citizens regarding the management of Long Lake. The study determined that Long Lake is a mesotrophic to slightly eutrophic lake, which experiences slightly degraded water quality in the fall due to watershed runoff and internal loads of phosphorus. The lake is at a trophic level where it is very sensitive to even slight increases in nutrient loads.

During 1994, the Long Lake Preservation Association completed the first phase of a three phase project to develop a Lake Management Plan. The Phase I project was primarily a data collection project to evaluate the water quality of the lake and assemble requisite data for subsequent phases of the project. During Phase I, water quality data, lake level data, precipitation data, and watershed land use data were collected. The second phase of the project, described in this report, involved preparation of hydrologic and phosphorus budgets for existing watershed land use conditions. The third phase of the project involves the preparation of the management plan for Long Lake.

The 1994 water quality survey of Long Lake was designed to provide an understanding of the interacting physical, chemical, and biological processes controlling the water quality of Long Lake. The following items summarize the results of the Phase I portion of the Long Lake Management Plan:

- Long Lake has very good water quality.
- Long Lake, on average, is a mesotrophic lake (ideal for fisheries and for recreational use).
- Most sampling locations noted at least one measurement in the "mildly eutrophic" category ("mildly problematic" category).
- Results show the lake is vulnerable to problematic conditions if uncontrolled development of the lake's watershed were to occur.
- A management plan for the lake is needed to protect it.

Preparation of the 1994 hydrologic and nutrient 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 Long Lake. The following items summarize the results of the Phase II portion of the Long Lake Management Plan:

- Watershed runoff accounts for approximately 67 percent of the inflows to Long Lake, with subwatershed A and the Slim Lake subwatershed accounting for 40 percent of the total watershed inflows.

- Nearly 60 percent of the total phosphorus load to Long Lake comes from watershed surface runoff, with subwatershed A being the largest contributor. Other major contributors include atmospheric (17 percent) and internal loads (23 percent).

- Subwatersheds B, C, D and the Mud Lake subwatershed yield the largest amount of phosphorus based upon their percentage of the overall watershed area. Cropland contributes approximately 20 percent of the total load to Long Lake Basin B, under 10 percent to Long Lake Basins C and D, and is a negligible input for the remaining basins. Internal loading from the lake's bottom waters provides larger inputs to Long Lake Basins A (14 percent), C (18 percent), and D (25 percent), while providing 10 percent or less to the remaining basins. The water quality of Long Lake Basins C and D is mostly influenced by the phosphorus loads coming from their internal loads and respective upstream basins.

- Subwatersheds A and B contribute their phosphorus loads directly to the lake and, therefore, increased loadings following new watershed development is very undesirable. Also, because subwatersheds A and B contribute their phosphorus loads to the most upstream portions of the lake, phosphorus loading from these watersheds affects the water quality of the entire lake.

- A lake mass balance model has been calibrated to the 1994 lake water quality and can be used to model the effects of additional watershed development during Phase III of the overall Long Lake Management Plan. The management plan for the lake should address the control of septic system and other major phosphorus inputs as well as analyze the likely development scenarios for various portions of the watershed.

Development of a lake management plan affords the opportunity to establish long-term water quality goals for the lake. Different watershed development scenarios can be evaluated to determine acceptable (i.e., the water quality of the lake is within the established goal) and unacceptable (i.e., the water quality of the lake fails to meet its goal) development options. Diligent management of the lake and its watershed will preserve the current water quality and the current balance in the lake's ecosystem.

Introduction

Long Lake is known as one of the premier, high quality fisheries in the northwestern region of the state and has been dubbed the "Walleye Capital of Wisconsin". Located on the headwaters of the Brill River in southeastern Washburn County, it is the largest lake in the county. The lake is approximately 19 miles in length, has a shoreline length of approximately 99 miles, and a surface area of 3,474 acres. The lake has a maximum depth of 74 feet and an average depth of 26 feet. Its 43,433-acre watershed is largely undeveloped. The Long Lake physical morphometry is tabulated in Table 1. Watershed development consists of approximately 600 residences and several resorts along the lake's shoreline and some agricultural landuse near the lake. The Tomahawk Scout Reservation has preserved approximately 3,000 acres of land in its natural state, including approximately 8 miles of shoreline. Several streams and lakes contribute water flow to Long Lake including Slim Creek, Twin Lake, Big Devil Lake, Harmon Lake, Mud Lake, Little Mud, and a small tributary in Section 16. The lake has five developed public boat landings.

Table 1

Long Lake Physical Morphometry

Normal Elevation	1223.0 feet (MSL)
Surface Area @ Normal	3,474 acres
Maximum Depth	74 feet
Volume @ Normal	89,508 acre-feet
Mean Depth (Volume/Surface Area)	26 feet
Watershed Area to Lake Area Ratio	12.5 : 1

In presettlement times, the Long Lake basin consisted of at least three glacially formed lakes and their interconnecting streams. In the late 1800s, a dam was constructed to raise the water level approximately 8 feet, fusing these separate bodies of water into one whole. Loggers then used the lake to transport logs downstream. The raised water level, however, has resulted in a complex body of water. The lake contains several basins, and basin depths vary from 8 to 74 feet.

Since its "discovery" in the late 1800s as a logging site, development around the lake has been slowed and controlled. However, the Long Lake Preservation Association (LLPA) is concerned that additional development in the Long Lake watershed may result in degradation of the lake's fishery. The LLPA collected a limited amount of water quality data during 1991 through 1993 to determine the existing water quality of the lake. The data suggest Long Lake would be assigned a trophic status of Mesotrophic, thus verifying its good water quality. However, the data suggest that algal blooms during the late summer months result in mildly eutrophic conditions in some portions of the lake. The data indicate the lake's water quality is vulnerable to degradation should uncontrolled watershed development occur. Therefore, the LLPA initiated a three phase project to develop a management plan, designed to preserve the existing water quality of the lake. The three phases of the project include:

- **Phase I**—Collection of data

- **Phase II**—Preparation of hydrologic and phosphorus budgets for existing watershed land use conditions.

- **Phase III**—Preparation of the lake management plan.

This report discusses the methodology, results, and conclusions from Phase II of the Lake Management Plan development. The Phase II portion was primarily an evaluation of the hydrologic and phosphorus budgets of Long Lake and its tributary watershed to identify significant sources of nutrients and calibrate a lake water quality mass balance model to be used for the Phase III project.

Phase I Summary: Water Quality Study of Long Lake

The 1994 water quality survey of Long Lake was designed to provide an understanding of the interacting physical, chemical, and biological processes controlling the water quality of Long 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 which will help the LLPA complete its Lake Management Plan in the Phase III portion of the project.

Long Lake has five distinct basins, and samples were collected from each of the five basins. Sample locations are shown on Figure 1. Water samples were collected from Long Lake following ice-out and biweekly during the summer (late June through late August). Samples were collected from 0-2 meters (i.e., integrated composite samples) and analyzed for all water quality constituents. In addition, total phosphorus samples were collected from above and below the thermocline whenever it existed and from one-half meter above the lake bottom. When no thermocline was noted, one mid-column sample was collected and analyzed for total phosphorus.

1994 Long Lake Water Quality

Data collected from Long Lake during 1994 indicate its water quality is very good and is similar to the water quality noted in previous years. 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 Long Lake. As such, it indicates the lake's potential for algal growth, and is a good indication of the lake's level of eutrophication. Total phosphorus data collected from Long Lake during 1994 indicate the lake would have a designated trophic status of mesotrophic. This means the lake is receiving a moderate level of phosphorus loading and its water quality is very good. Average summer epilimnetic total

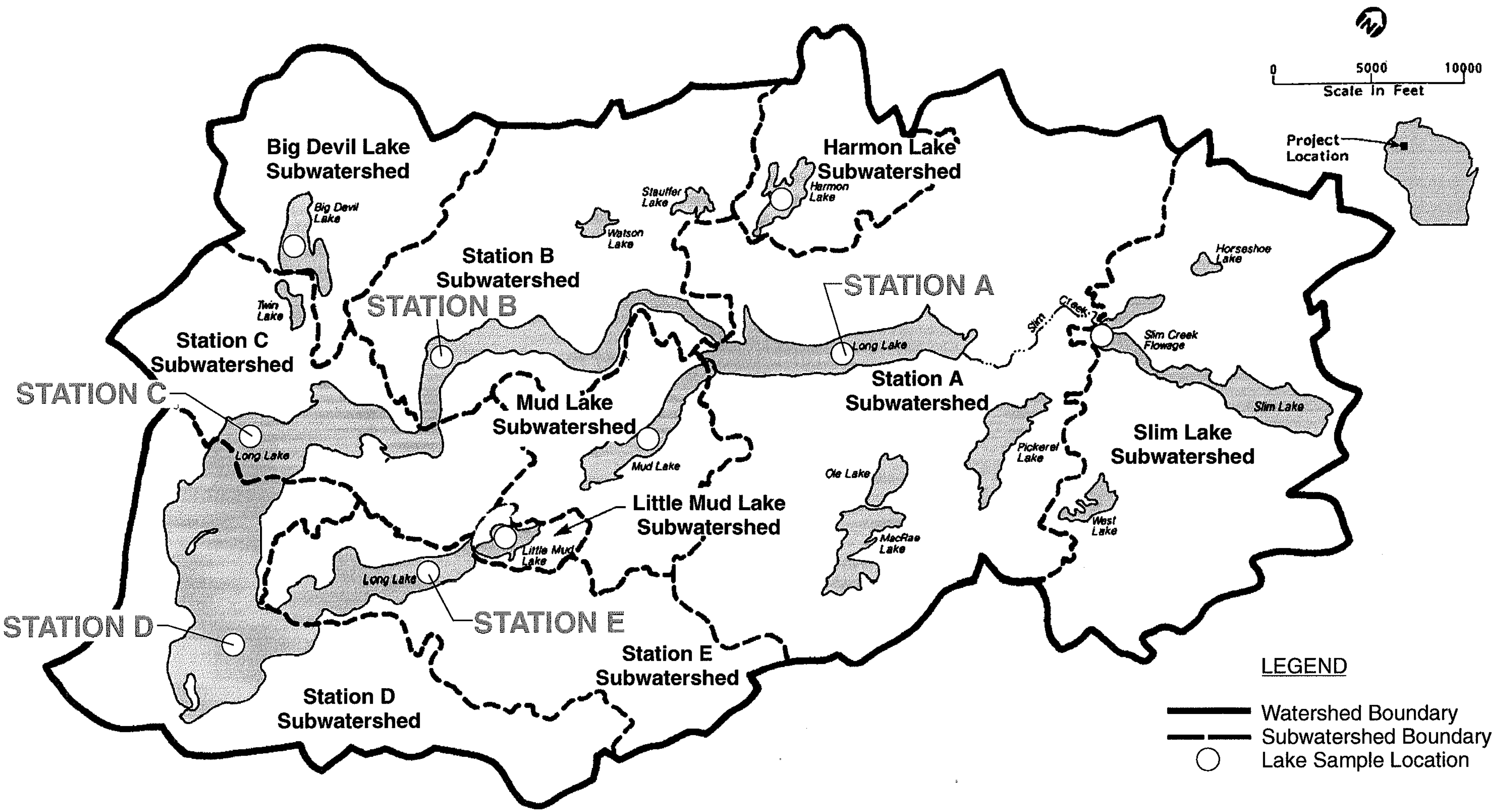


Figure 1

LONG LAKE WATERSHED

phosphorus concentrations from all five sample locations within Long Lake were within the mesotrophic category. In addition, nearly all individual sample points from these locations were within the mesotrophic category. Exceptions occurred during the late summer when concentrations at Stations C, D, and E were within the eutrophic category. Long Lake total phosphorus data collected at depths indicate phosphorus recycling from bottom sediments occurs during the summer months. These data indicate that judicious management of the lake's watershed is essential to preserving the lake's current mesotrophic trophic status.

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 Long Lake indicate the lake's trophic status ranges from mesotrophic to mildly eutrophic. Average summer chlorophyll a values from Stations B, C, and D were within the eutrophic category, while the average summer value from Station A was borderline mesotrophic/eutrophic. Station E noted an average summer value within the mesotrophic category. These data indicate algal yield from the lake's phosphorus concentration is slightly higher than expected. As indicated previously, average phosphorus concentrations were entirely within the mesotrophic category.

Algal populations increased throughout the summer at all Long Lake sample locations. Chlorophyll a values at all locations were within the mesotrophic category during the early summer and were within the eutrophic category during the late summer. Differences in the rate of increase of chlorophyll a values were noted at the individual sample locations. In general, stations at the northern end of the lake increased more rapidly than stations at the southern end of the lake.

Chlorophyll a data corroborate the phosphorus data and support the need for a management plan to prevent additional increases in the lake's algal population. The lake's current chlorophyll a concentrations are not considered problematic. However, the mildly eutrophic trophic status indicates that additional increases would likely result in problematic conditions during the summer period.

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 likely becomes available to be released into the surface waters during the fall overturn period.

1994 Watershed Lakes Water Quality Study

Data collected from lakes within the Long Lake watershed provide an indication of total phosphorus concentrations entering Long Lake from its subwatersheds. Mud Lake phosphorus concentrations were approximately four times higher than concentrations noted in Long Lake. Little Mud Lake and Slim Creek Flowage exhibited concentrations approximately three times and two times higher, respectively, than Long Lake concentrations. Harmon Lake and Big Devil Lake noted concentrations similar to concentrations measured in Long Lake.

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

- Evaluation of the Tributary Watershed
- Hydrologic Budget Determination
- Nutrient Budget and Lake Water Quality Mass Balance Model

Evaluation of the Tributary Watershed

The Long Lake watershed was divided into ten subwatersheds which included five of the tributary watershed lakes and the remaining areas draining directly to each of the lake basins. Table 2 shows the watershed areas for each of the ten subwatersheds. Figure 2 shows the percentage of the total Long Lake watershed that each of the subwatershed areas represents. Subwatersheds A and B and the Slim Lake subwatershed, alone, comprise approximately 50 percent of the total watershed area.

Table 2

Long Lake Watershed and Water Surface Areas

	Watershed Area (acres)	Water Surface Area (acres)
Watershed A	11,056	529
Watershed B	5,235	475
Watershed C	3,606	667
Watershed D	5,543	1,413
Watershed E	3,760	423
Slim Lake Watershed	6,844	315
Harmon Lake Watershed	1,776	101
Mud Lake Watershed	2,381	125
Big Devil Lake Watershed	2,909	194
Little Mud Lake Watershed	323	61
Total Watershed Area	43,433	4,303

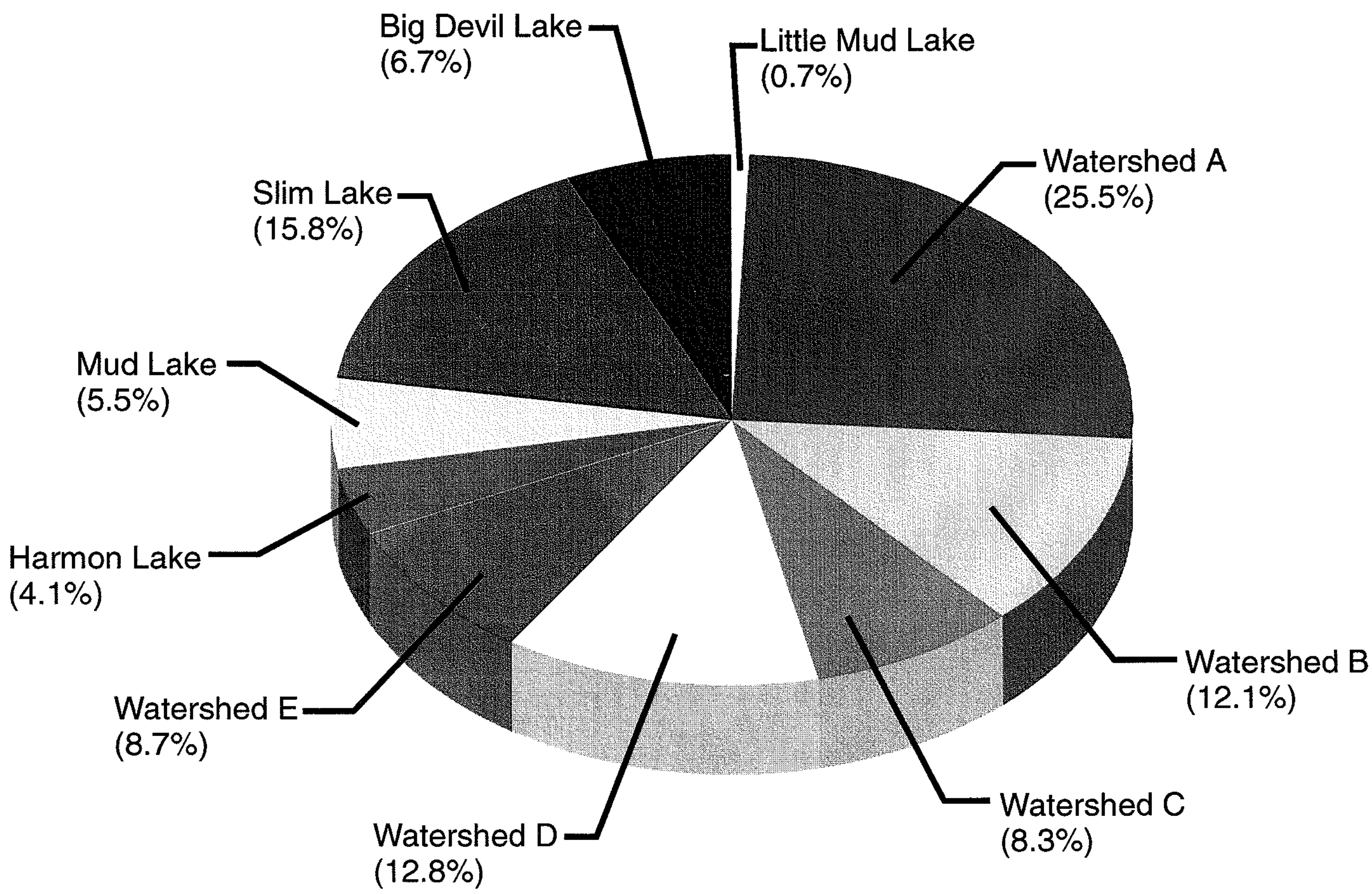


Figure 2

**LONG LAKE SUBWATERSHED
AREA PERCENTAGES**

Evaluation of watershed land use within the Long Lake tributary watershed was completed by the Natural Resource Conservation Service (Spooner Field Office). The evaluation consisted of a determination of watershed land use within each subwatershed. Specifically, acres of cropland, forestland, acres of Conservation Reserve Program (CRP) land, and other watershed land uses were determined.

Samples were collected from lakes within the Long Lake watershed to help determine average phosphorus concentrations. One lake within each subwatershed was monitored including Big Devil Lake, Harmon Lake, Slim Creek Flowage, Mud Lake, and Little Mud Lake. Sample locations are shown in Figure 1. The frequency of sample collection consisted of once following ice-out and on a monthly basis during the summer period (June through August). All samples were surface grab samples collected at arm's length below the lake surface and were analyzed for total phosphorus.

Hydrologic Budget Determination

Rain gages accurate to within 1/100th of an inch were installed at two locations within Long Lake's watershed and read daily by volunteers during the ice free period, to determine daily precipitation amounts. Measurements were made between April and November, 1994. Data from the Wisconsin State Climatologist for the Chetek Agricultural Experiment Station was used during the winter months to determine total precipitation amounts for the unmonitored periods. Evaporation from the lake water surface area, during the study period, was estimated using methods developed by Adolph Meyer (1944). This method uses average monthly temperature, wind speed, and relative humidity to predict monthly evaporation from water surfaces. Monthly temperature, wind speeds, and humidity used for input in the Meyer Watershed Model were also taken from 1994 data from the Chetek Agricultural Experiment Station.

A staff gage was installed and surveyed in on April 21, 1994. The gage was read on a daily basis during the period April 21 through November 19. The staff gage readings, together with an outlet rating curve and information supplied by the Washburn County Highway Department on operation of the dam, were used to determine daily lake volume changes and average lake outflow volumes.

A hydrologic (water) budget for Long Lake was determined by measuring or estimating the important components of the budget. The important components of the budget include:

- Precipitation
- Surface Runoff
- Lake Outflow
- Evaporation
- Groundwater Flow
- Change in Lake Storage

Due to the limited scope of the project, there is insufficient information to differentiate between groundwater and the surface runoff from the watershed. Compared to surface runoff, groundwater flow was assumed to be a small component of the Long Lake hydrologic budget. Since surface runoff from the watershed was unknown for this analysis, groundwater inflow to Long Lake was assumed to be negligible, and surface runoff was determined by solving the Long Lake water balance equation as presented below.

$$RO = OF + EVAP - P +/- S$$

Where:

RO	=	Watershed Runoff
OF	=	Lake Outflow
EVAP	=	Evaporation from the Lakes Surface
P	=	Direct Precipitation on the lake's surface
S	=	Change in Lake Storage

In order to estimate an annual yield of water from Long Lake's subwatersheds, the measured watershed runoff volumes were divided by the watershed area of the respective watershed to compute a yield value expressed in inches of water. The runoff yield was divided by the total precipitation for the monitored period. The resultant number represents the runoff coefficient for the watershed. The runoff coefficient was corrected to take into account the lake water surface area of each basin that was directly connected to Long Lake. This approach enables us to differentiate between the influence of precipitation and evaporation on the directly connected water surface areas and the actual surface runoff from the remainder of the surrounding watershed. The runoff coefficient and the precipitation data from the Chetek Agricultural Experiment Station were used during the unmonitored periods to determine the runoff amounts for the remainder of the year.

Phosphorus Budget and Lake Water Quality Mass Balance Model

Numerous researchers have demonstrated the relationship between phosphorus loads, water loads and lake basin characteristics to the observed in-lake total phosphorus concentration. The relationship was used to verify the annual phosphorus load into Long Lake based on average surface phosphorus concentrations, the lake's hydrologic budget, and lake basin characteristics. The relationship has many forms. The equation used for Long Lake was adapted from one developed by Dillon and Rigler (1974), modified by Nurnberg (1984) and has the form of:

$$P = \frac{L_A (1 - R_P)}{Q_S} + \frac{L_I}{Q_S}$$

Where:

P = is the mean phosphorus concentration

L_A = amount of phosphorus added per unit surface area of lake from all sources except from the internal load of the lake

R_P = the coefficient which describes the total amount of phosphorus retained by the sediments each year

= $15/(18+Q_s)$

Q_S = the outflow of the lake divided by its surface area

L_I = mass of phosphorus added to the lake from internal loading

In the case of Long Lake, all variables of the equation were measured or could be estimated based on data collected during the study. This equation was added to the Wisconsin Lake Model Spreadsheet (WILMS) (Panuska and Wilson, 1994) and compared with the other predictive lake water quality equations already present in WILMS.

The overall Long Lake phosphorus budget was determined using the tributary lake water quality data and corresponding watershed runoff volumes. These data were combined with the export rates for each of the phosphorus input sources within the direct watersheds to estimate the total loads to each of the lake's basins. The phosphorus budget for Long Lake was determined by measuring or estimating the important components of the budget. The important components of the budget include:

- Watershed Surface Runoff from Forested, Row Cropland, Non-Row Cropland, and Pasture/CRP Landuses

- Internal Loading
- Atmospheric Wet and Dry Deposition on the Lake Surface
- Septic System Loading
- Monitored Tributaries

The watershed surface runoff component was estimated using an annual phosphorus export coefficients for each landuse type within the direct subwatersheds. An annual phosphorus export coefficient of 0.08 lbs/ac/yr was used for the forested portions of the subwatersheds. This corresponds with the most likely default coefficient in the WILMS model (Panuska and Wilson, 1994), as well as that observed by Singer and Rust (1974). The total phosphorus export coefficient of 1.16 lbs/ac/yr observed by Hensler et al. (1970) was used for the row cropland landuse. The non-row cropland phosphorus export coefficient of 0.58 lbs/ac/yr, used in this analysis, agrees very well with that observed by others (Burwell et al., 1975; Converse et al., 1976). Finally, Harms et al. (1974) obtained a phosphorus export coefficient of 0.22 lbs/ac/yr, which was used for the pasture/CRP landuse within the Long Lake subwatersheds.

Internal loading (L_I in the above equation) 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 1994 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 sediment total phosphorus release rate of 6 $mg/m^2/day$ was estimated using the lake's trophic status and a relationship developed by Nurnberg et al. (1986). This sediment release rate agrees well with the observed increase of total phosphorus over the anoxic portion of the hypolimnetic waters of each basin during the summer of 1994. 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 ranged from 0.15 to 0.32 for all basins except Basin C. This range agrees well with that observed by other researchers (Nurnberg, 1985). A larger fraction (0.80) was used for Basin C because it had a considerably larger epilimnetic (surface) layer and flushing rate than the other basins. This release fraction agrees with that observed by Nurnberg and Peters (1984).

An atmospheric wet and dry deposition rate of 0.27 lbs/ac/yr, used as the most likely export coefficient in the WILMS model (Panuska and Wilson, 1994), was applied to the surface area of Long Lake. The watershed runoff component from the tributary lakes was estimated using the measured lake concentrations and estimated runoff from each of the tributary watersheds.

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. The equation used for Long Lake estimated the septic system load as follows:

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

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)*(permanent dwellings) + (# of seasonal residents/dwelling)*(days/yr)*(seasonal dwellings)
SR	=	weighted soil retention coefficient (85 for most likely value used in model)

The LLPA determined the number of septic systems within each of the three townships surrounding the lake and determined 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 four residents, on an average. The seasonal dwelling units were assumed to have been occupied 100 days per year, while each of the 21 Long Lake resorts were assumed to have an average of ten residents throughout the year. Finally, the USGS Quad Maps were used in conjunction with the number septic systems within each township to assign the number of resorts and dwellings adjacent to each of the five basins of Long Lake. The ratio of permanent to seasonal residences was kept the same as the total for each of the five basins. The assumptions made regarding the septic system inputs agree well with the estimates made for both Balsam and Antler Lakes in Polk County, Wisconsin (Bursik, 1996).

Phase II: Results and Discussion

Watershed Land Use Evaluation

The following watershed land-use evaluation was completed by the Natural Resource Conservation Service, Spooner Area Office. The Long Lake watershed is shown on Figure 1.

The 43,433-acre watershed tributary to Long Lake primarily consists of undeveloped forestland. Cropland comprises less than 6 percent of the watershed, approximately 2,176 acres (excluding pasture). Approximately 401.8 acres are known to be considered highly erodible land (HEL). The area contains three known dairy farms and a few livestock (beef cattle and sheep, animal numbers unknown) farms.

The cropland has an average rotation of 1 year corn, 1 year oats, and then the land is seeded to 4 or more years of hay. Therefore, average soil loss is well below the tolerable level. Spring moldboard plowing is the most common type of tillage done. A few people are trying to reduce tillage, with some even experimenting with no-till.

The soils in the Long Lake watershed vary greatly from silt loam texture to areas primarily sandy in surface texture. The majority of soil in the watershed has a sandy loam texture surface. The watershed soils are underlain primarily by acid sand and gravel, thereby promoting very good drainage. A small amount of the soil in the watershed (approximately 5 percent) is considered an organic soil comprised of peat and muck.

The woodland in the Long Lake watershed is primarily Aspen and Northern Hardwood. The Northern Hardwood cover typically consists of Red Oak, White Oak, and Paper Birch interspersed with Quaking Aspen, Basswood, White and Red Pine. In some areas Red and Sugar Maple make up the understory suggesting a change in timber cover in the future. Quaking Aspen is the dominant species of Aspen in the Aspen cover type.

A fringe of development is found immediately adjacent to Long Lake consisting of approximately 600 residences and several resorts. The Tomahawk Scout reservation has preserved approximately 3,000 acres of land in its natural state, including approximately eight miles of shoreline.

A discussion of land-use within each subwatershed follows.

Slim Lake Subwatershed

The Slim Lake subwatershed is primarily dominated by woodland. Approximately 355.3 acres of cropland is noted. Fifty of these acres appear to have been planted with a permanent grass cover. About 87 acres per year are planted in some type of row crop (corn or small grain). There presently are no known dairy farms in this subwatershed.

Harmon Lake Subwatershed

The Harmon Lake subwatershed currently does not contain cropland. This subwatershed is dominated by woodland, with the majority of the woodland owned by the County.

Big Devil Lake Subwatershed

Approximately 740.1 acres of cropland are located in this subwatershed. The cropland has an average rotation of 1-year corn, and 1-year oats seeded to 4 years of hay. The land in this subwatershed is all privately owned. Snapbeans, sweet corn, and potatoes are also grown in this area besides the normal corn-oats-hay rotation prevalent throughout the watershed.

Little Mud Lake Subwatershed

This area is dominated primarily by woodland in public and private ownership with no cropland. There are no known livestock operations of any kind in this area and no highly erodible land.

Mud Lake Subwatershed

This subwatershed area contains approximately 179.2 acres of cropland. The area also has one active dairy farm.

Station A Subwatershed

This subwatershed has approximately 98.2 acres of cropland. Much of this subwatershed is Washburn County Woodland. There are no known dairy farms in this subwatershed. Of the 98 acres of cropland, 12 acres is enrolled in the Conservation Reserve Program (CRP), and another 58 acres is primarily grassland. The cropland has an average rotation of 1-year corn, and 1-year oats seeded to 4 years of hay.

Station B Subwatershed

This subwatershed has approximately 402.6 acres of cropland. The area is predominantly privately owned, but the northern portion of this subwatershed is in county ownership. There is one known dairy farm present. The cropland has an average rotation of 1-year corn, and 1-year oats seeded to 4 years of hay, although snapbeans, sweet corn and potatoes are also planted from time to time.

Station C Subwatershed

This subwatershed has approximately 123.3 acres of cropland. All of the land in this subwatershed is privately owned. There are no known dairy farms present. The cropland has an average rotation of 1-year corn and 1-year oats, and then the land is seeded to 4 years of alfalfa hay.

Station D Subwatershed

This subwatershed has approximately 272.5 acres of cropland. There is also one dairy farm present in the subwatershed. The cropland has an average rotation of 1-year corn, and 1-year oats seeded to 4 years of hay.

Station E Subwatershed

This subwatershed has 4.6 acres of cropland. The majority of this subwatershed is wooded with large portions of it containing public and private land.

Rainfall, Evaporation and Lake Outlet Data

As previously mentioned, rain gages were installed at two locations within Long Lake's watershed and read daily by volunteers during the ice free period, to determine daily precipitation amounts. Total average precipitation during the 1994 (monitored) ice free period was 26.81 inches. During one very large storm event from September 12-16, 1994, the two volunteers measured rainfall amounts of 7.09 and 7.90 inches. Data from the Wisconsin State Climatologist for the Chetek Agricultural Experiment Station was used during the winter months to determine total precipitation amounts for the unmonitored periods. According to the Chetek data, approximately 4.15 inches (water equivalent) of precipitation occurred during the unmonitored portion of 1994.

The monthly evaporation rates estimated from the Meyer Watershed Model ranged from zero inches (in April) to 2.83 inches (in September). Monthly evaporation rates were translated into daily evaporation rates to allow estimation of the hydrologic budgets on an event basis. The daily evaporation rates were assumed to be the same for each day of each month. Total estimated evaporation during 1994 was 18.89 inches.

A staff gage was installed, and surveyed in, near the lake outlet to develop a stage-storage curve for determining the change in storage within the lake at the various lake levels. The gage was read on a daily basis during the period April 21 through November 19. The monitored lake water surface elevations ranged from 1222.31 feet MSL (on November 19) to 1223.42 feet MSL (on September 16). The low lake surface elevation occurred following winter drawdown by the dam operator and the high lake surface elevation resulted from the 7-plus inch storm event from September 12-16, 1994. The normal water surface elevation is 1223.0 feet MSL.

The staff gage readings, together with information supplied by the Washburn County Highway Department on operation of the dam, were used to determine daily lake outflow volumes. The Long Lake dam is typically operated such that the roller gate within the principal spillway is open approximately 3 to 4 inches during the spring, summer and early fall. Winter drawdown is typically done by closing the principal spillway gate and allowing the water surface to approach 1222.0 feet MSL prior to winter freeze-up. During 1994, the roller gate was opened all the way on September 14, and was left open 8 inches on July 11 and September 21 following large rainfall events.

Hydrologic Budget

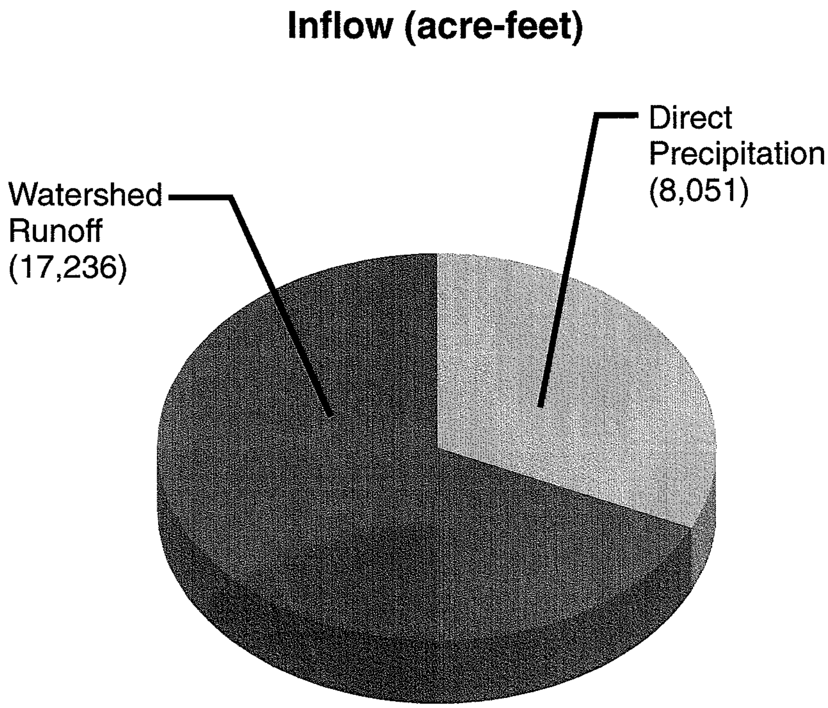
Table 2 shows the watershed and water surface areas for each of the lakes and sub-basins that are directly connected to Long Lake. The 1994 hydrologic budget for Long Lake is presented on Figure 3. As the budget indicates, watershed runoff and direct precipitation play an important role in providing water to Long Lake. Watershed runoff represents 67 percent of the inflows to Long Lake with direct precipitation providing the remainder. The figure also shows that evaporation was significantly less than precipitation during 1994. Ordinarily, evaporation would be expected to be approximately the same as the observed annual precipitation amount. Average evaporation for this portion of Wisconsin is 28 inches (Linsley, Jr., 1982). However, the low evaporation amount is attributed to below average temperatures observed in 1994.

The large amount of watershed runoff which reached the lake during 1994 indicates that watershed runoff has a relatively large impact on the water quality of Long Lake. The majority of the storm event runoff which reached the lake came from the direct subwatersheds and the Slim Lake subwatershed. Subwatershed A and the Slim Lake subwatershed are the largest subwatersheds and experienced enough runoff during 1994 to account for approximately 40 percent of the total watershed inflows. Watersheds B and D combined to provide another 22 percent of the total watershed inflows to Long Lake.

The hydrologic budget is an important factor in determining the breakdown of nutrient loads into Long Lake. Because phosphorus is the parameter of most concern, the discussion of nutrient budgets will be limited to phosphorus only.

Phosphorus Budget and Lake Water Quality Mass Balance Model

As previously mentioned, the tributary lake water quality data and corresponding watershed runoff volumes combined with the export rates for each of the phosphorus input sources within the direct watersheds were used to estimate the total loads to each of the lake's basins. The computations revealed that the total annual phosphorus load into Long Lake is approximately 5,674 pounds per year, based on 1994 data. The results of the phosphorus loading budgets are presented in Table 3. Phosphorus export rates, used in the WILMS model and published by the



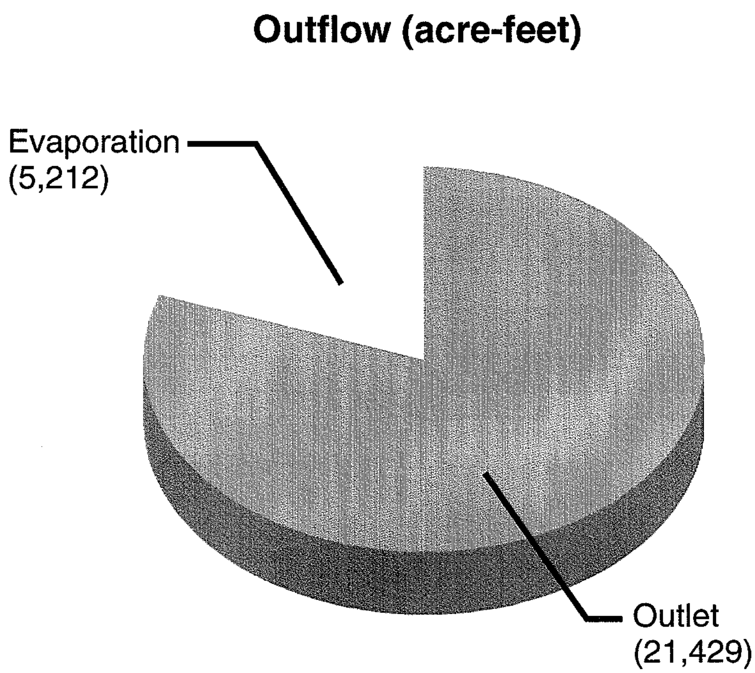


Figure 3

1994 LONG LAKE HYDROLOGIC BUDGET

Phosphorus Sources	Annual Load (lbs)	% of Total
Drain Fields/Septic Systems	233*	4.1
Atmospheric Deposition	938	16.5
Watershed Loading	3,214	56.7
Internal Load	1,289	22.7
TOTAL LOAD	5,674	100

* Estimated Value. Actual Value May Range From 19 to 498 Pounds or 0.3% to 8.8% of the Total Load.

Table 3

1994 LONG LAKE PHOSPHORUS BUDGET

U.S. EPA for septic systems, and the septic system survey information were used to estimate an annual load of 233 pounds per year from drain fields. Depending on the soil retention capacity and export rates assumed for this computation, this value may actually range from 19 to 498 pounds or 0.3 percent to 8.8 percent of the total load. An atmospheric wet and dry deposition rate used by the WILMS model of 0.27 lbs/ac/yr was applied to the surface area of Long Lake. The computation indicates that the atmospheric component of the load is approximately 938 pounds per year. The watershed runoff component was estimated using the measured lake concentrations and estimated runoff from each of the tributary watersheds along with phosphorus export coefficients for each of the direct subwatersheds. The result is an estimate of 3,214 pounds per year from the watershed surface runoff. Internal loading represents the remaining 1,289 pounds of phosphorus into the lake. Due to the limited scope of the project, there is insufficient information to differentiate the groundwater loading from the septic system inputs of phosphorus.

The relative phosphorus loading components of the budget were broken down and Figure 4 shows the contributions from each of the subwatersheds. Based on the estimates, approximately 57 percent of the total phosphorus load comes from watershed runoff with subwatershed A being the largest contributor. On an annual basis, the individual surface runoff contributions to the total watershed load show that subwatershed A and subwatershed B comprise 15 percent and 12 percent, respectively. Other major contributors besides watershed runoff inflows include atmospheric (17 percent) and internal loads (23 percent). Subwatersheds contributing insignificant loads of phosphorus (i.e., less than 1 percent of the annual load) include Harmon Lake, Big Devil Lake, and Little Mud Lake.

Figure 5 shows the subwatershed percentages of Long Lake's total watershed area and runoff phosphorus load. The figure reveals that no one subwatershed contributes a majority of the annual load. Rather, the load is distributed between the various subwatersheds. Watershed A not only occupies the largest surface area, but it also represents the highest overall load. Other major contributors include subwatershed B with approximately 20 percent of the annual runoff load and subwatershed D with 16 percent.

Figure 6 presents the ratios of the annual watershed phosphorus load percentages to watershed area percentages for each of the subwatersheds. The ratios, or the phosphorus yield, from the subwatersheds varies greatly. Lowest yield is characterized by Big Devil Lake, while subwatershed B contributes the highest yield. While subwatershed A contributes the largest

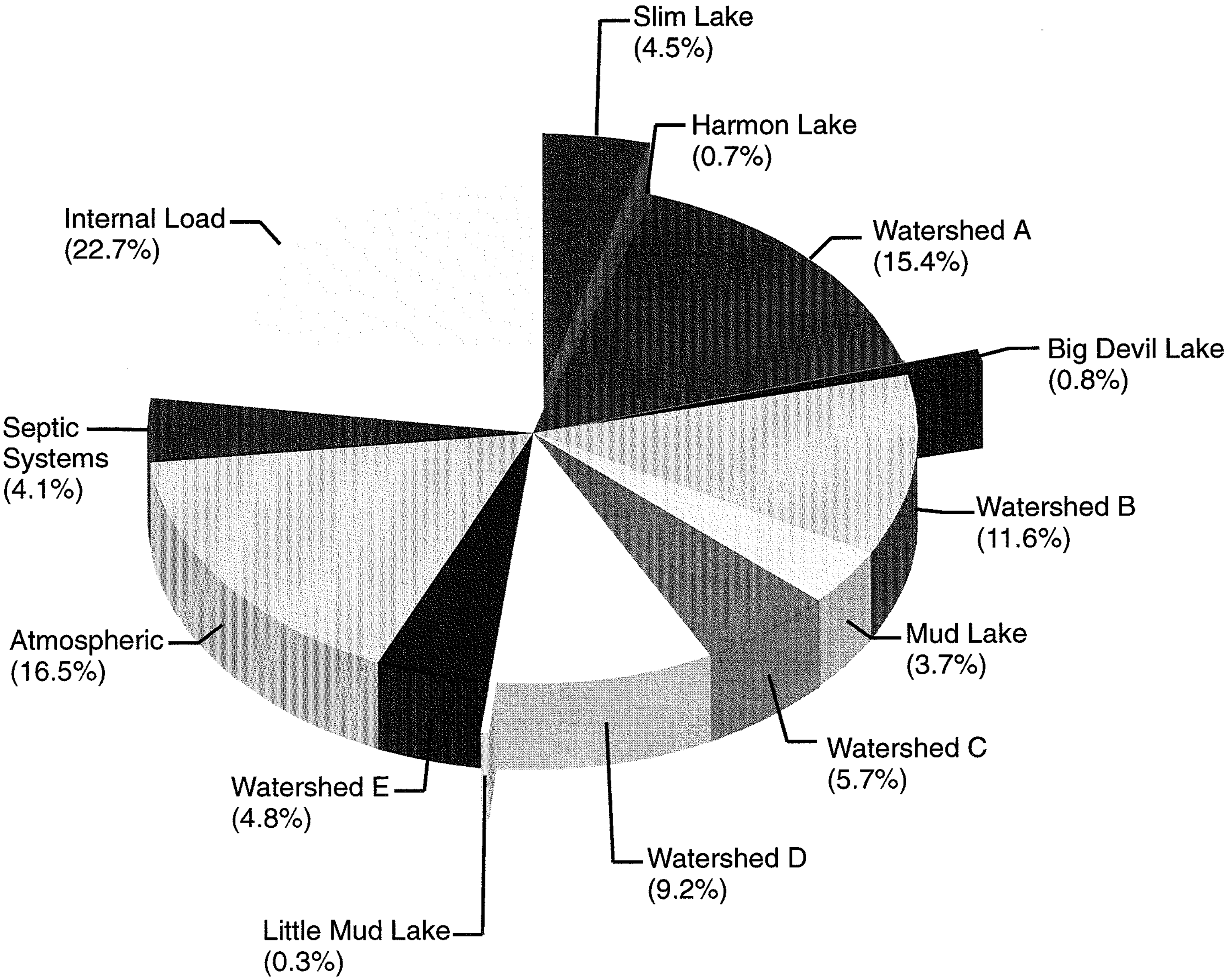


Figure 4

LONG LAKE PHOSPHORUS LOADING BUDGET
JANUARY 1 - DECEMBER 31, 1994

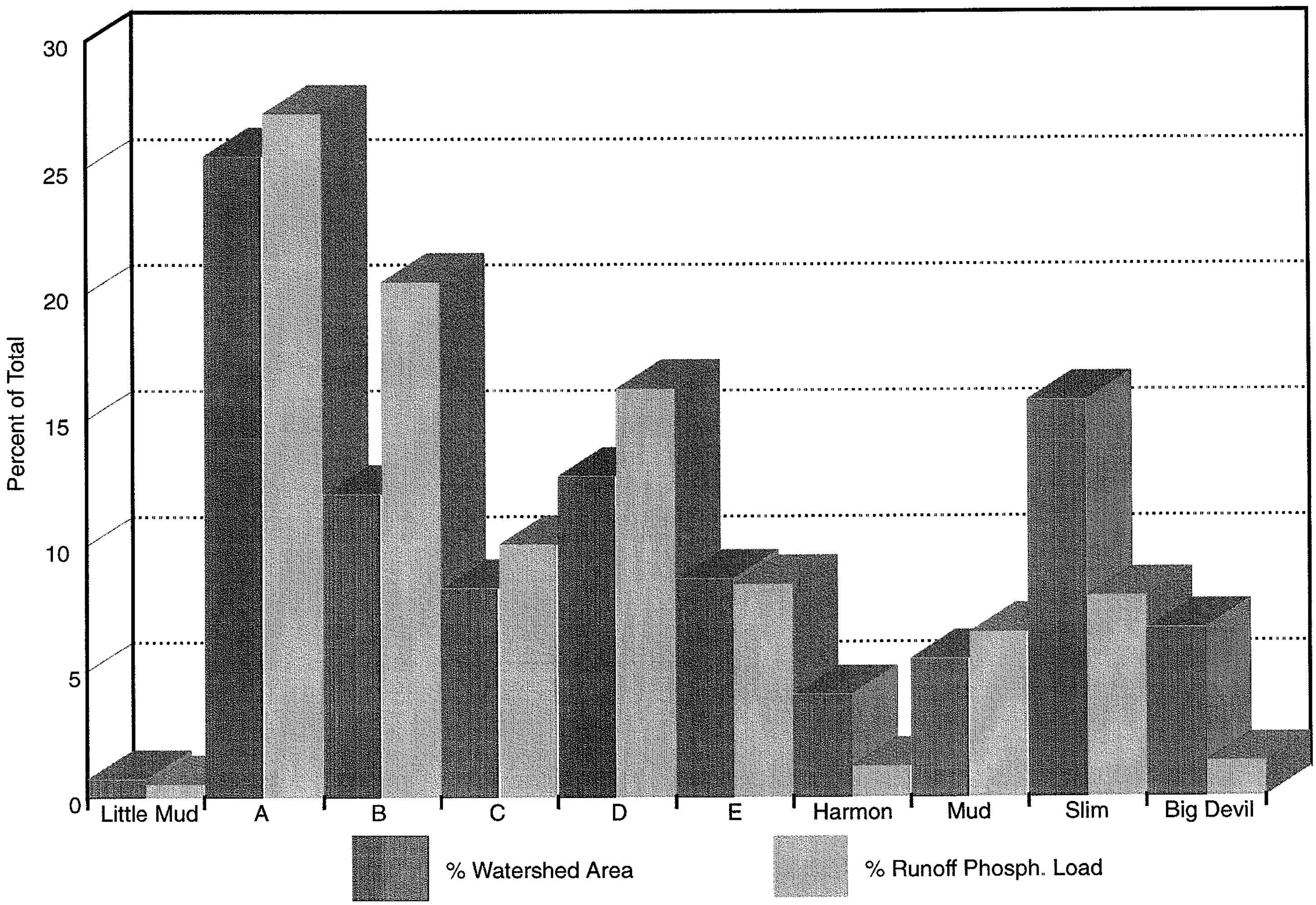


Figure 5

LONG LAKE SUBWATERSHEDS
% WATERSHED AREA AND % RUNOFF PHOSPHORUS LOAD

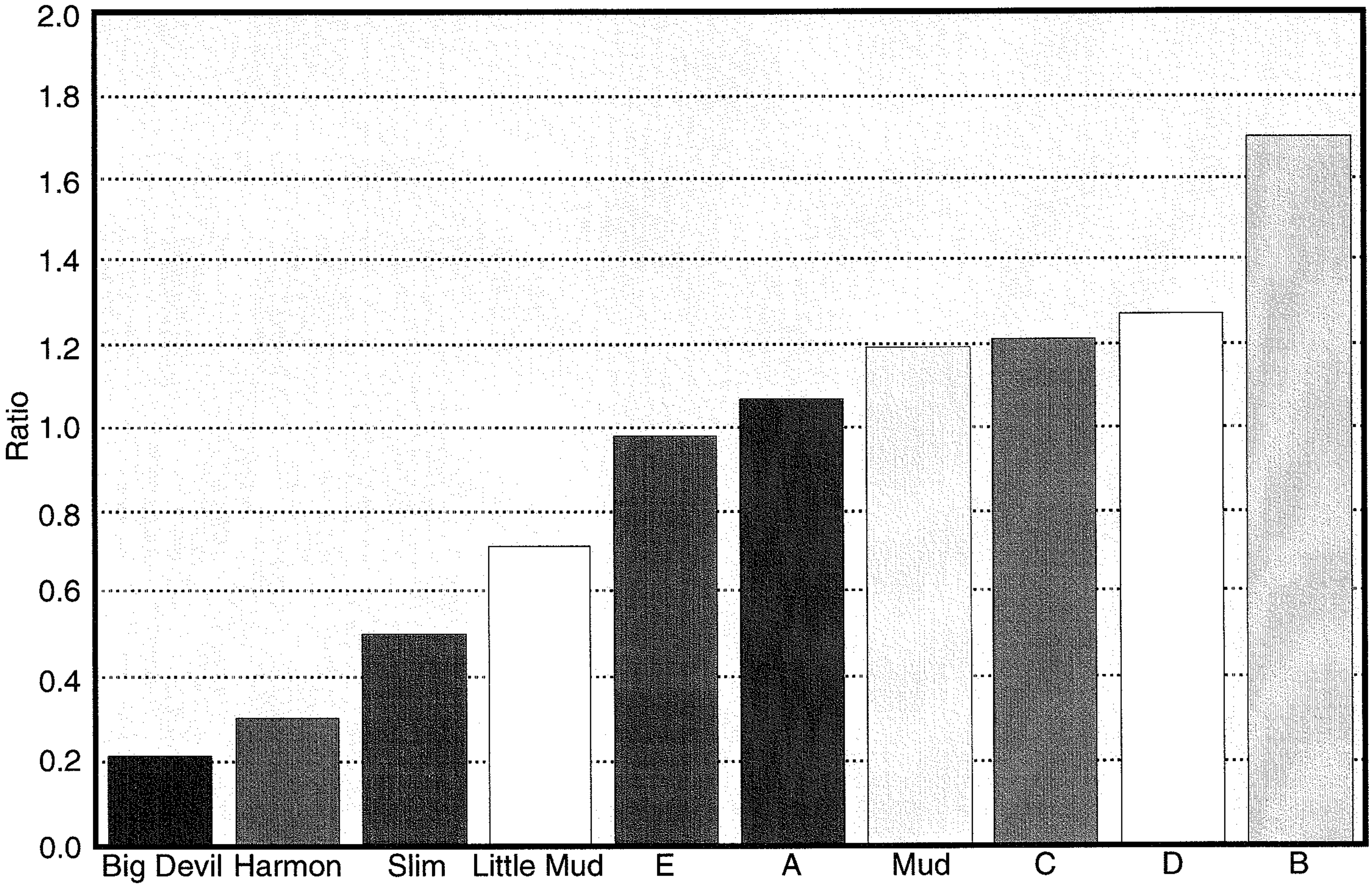


Figure 6

RATIO OF ANNUAL WATERSHED RUNOFF PHOSPHORUS LOAD % TO WATERSHED AREA %

overall load to Long Lake, its yield is approximately midway in the range exhibited by the Long Lake subwatersheds. With the exception of Mud Lake (which has a phosphorus yield percentage larger than 1.0), the remaining tributary lakes are contributing a significantly smaller percentage of the watershed phosphorus load than their subwatershed areas would suggest. This is undoubtedly due to the phosphorus assimilation, or removal, taking place within the basins of these tributary lakes. Mud Lake's higher phosphorus yield is likely due to more intense landuse within its subwatershed and its comparatively lower capacity for removing its incoming phosphorus load.

Figure 7 shows the relative contribution of phosphorus inputs to the Long Lake basins expressed both as a percentage of each basin's total load and each basin's absolute load. The monitored tributary component of the bar graphs represents the phosphorus inputs entering the lake basins from the Slim Lake, Harmon Lake, Mud Lake, Big Devil Lake and Little Mud Lake subwatersheds. The upstream lake component of the bar graphs represent the inputs from the upstream basins of Long Lake. Basins A and E are on the upstream ends of each leg of Long Lake and the forested landuses make up approximately 90 percent of their watershed areas. However, the results show that the forested landuse represents only 60 percent of the phosphorus inputs to both basins. The figure shows that cropland represents approximately 20 percent of the total load to Basin B, under 10 percent to Basins C and D, and is a negligible input for the remaining basins. Internal loading from the lake's bottom waters provides larger inputs to Basins A (14 percent), C (18 percent), and D (25 percent), while providing 10 percent or less to the remaining basins. The graphs also show that the water quality of Basins C and D is influenced most by the phosphorus loads coming from the respective upstream basins and from their internal loads.

Each of the phosphorus input loadings were used to calibrate the lake mass balance model to the water quality observed in each of the lake's basins during 1994. During 1994, both the evaporation (as previously mentioned) and the average annual runoff from the Long Lake watershed were less than normal (5.2 inches as opposed to 11.8 inches). The fraction of total phosphorus in the bottom waters that would be released to the lake basin epilimnion (or surface water) following fall turnover, used to estimate internal load, was the only refinement that had to be made to the original phosphorus loading estimates to calibrate the mass balance model. With the exception of Basin C, the predicted average total phosphorus concentration from the calibrated model is slightly higher than the observed concentration in each of the basins. This is probably due to the fact that the average observed concentration only includes data from May through the end of August, in 1994. The average observed concentration would likely be larger (and therefore,

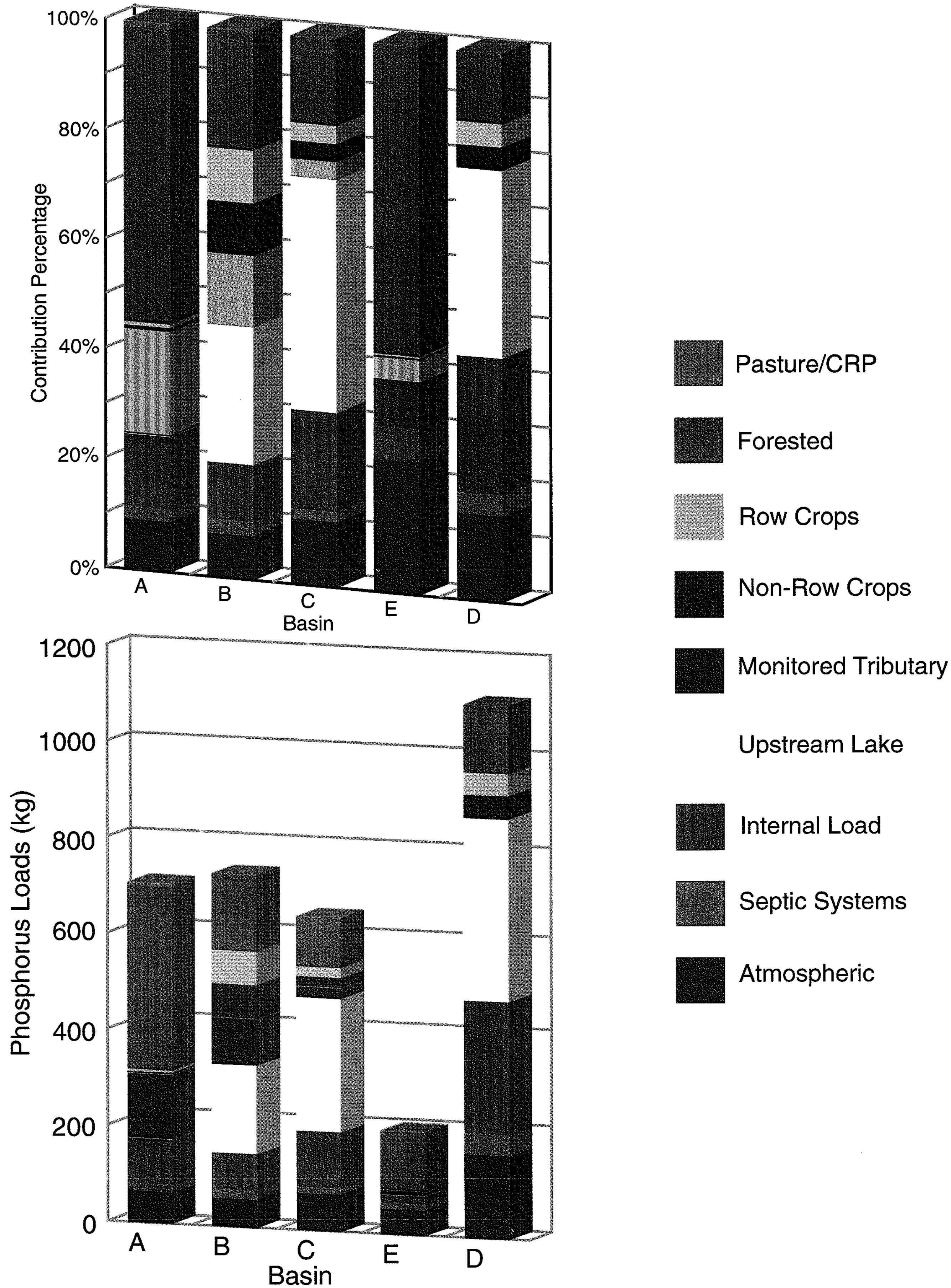


Figure 7

RELATIVE CONTRIBUTION OF PHOPHORUS INPUTS TO LONG LAKE BASINS

very close to the predicted concentrations) if total phosphorus data had been collected in September and October, following fall turnover. The calibrated lake mass balance model will be used to model the effects of additional watershed development on the water quality of the lake (with average climatic conditions) during Phase III of the overall Long Lake Management Plan. Hydraulic loading rates to the lake will be changed during the Phase III portion of the plan to compare development scenarios under normal climatic conditions.

The most likely sites for development in the near future are found in subwatersheds A, B, and Mud Lake. Subwatersheds A and B contribute their phosphorus loads directly to the lake and, therefore, increasing their loads is very undesirable. Also, because subwatersheds A and B contribute their phosphorus loads to the most upstream portions of the lake, phosphorus loading from these watersheds affects the water quality of the entire lake. Mud Lake currently contributes a relatively low phosphorus load relative to the other subwatersheds. However, the 400-acre development proposed for this subwatershed would greatly increase both its yield and annual contribution to Long Lake. If this development is constructed, some form of stormwater detention or treatment should be provided to ensure that the phosphorus loadings to Mud Lake (and then on to Long Lake) are no greater than that which presently exists. In general, new development or changes to more intense landuses within the subwatersheds of the tributary lakes (such as Mud Lake) will have a smaller effect on Long Lake's water quality than if the same landuse changes were made to Long Lake's direct subwatersheds (such as subwatershed A, etc.).

As the budgets indicate, phosphorus inputs into Long Lake primarily result from the subwatersheds, internal and atmospheric sources. The data suggest that with increased watershed development the greatest potential for increased nutrient loads into Long Lake will be from the lake's tributary watershed and drain fields.

Recommendations and Management Actions

An evaluation of 1994 Long Lake water quality data, together with water quality data collected during 1991 through 1993, indicates the lake has very good water quality. However, mildly eutrophic conditions during the late summer exemplify the need for judicious management to prevent additional degradation. Further eutrophication of Long Lake may upset the current balance between the lake's phytoplankton, zooplankton, and fisheries communities, thus adversely impacting the lake's fishery. Water quality degradation may also result in additional algal blooms and a dominance by the nuisance blue-green algae. Such a change would be detrimental to the lake's recreational usage. Diligent management of the lake and its watershed, however, will preserve the current water quality and the current balance in the lake's ecosystem.

Most of the lake's watershed is currently undeveloped and consists of woodland. Uncontrolled development of the watershed would likely result in significant degradation of the lake's water quality. Development of a management plan for Long Lake and its watershed, however, affords the opportunity to evaluate different watershed development scenarios. The Phase III portion of the Long Lake Management Plan development will:

- Establish a long-term water quality goal for Long Lake;
- Explore development scenarios and their impacts on the water quality of Long Lake; and
- Develop a management plan for Long Lake and its watershed which achieves its long-term water quality goal.

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