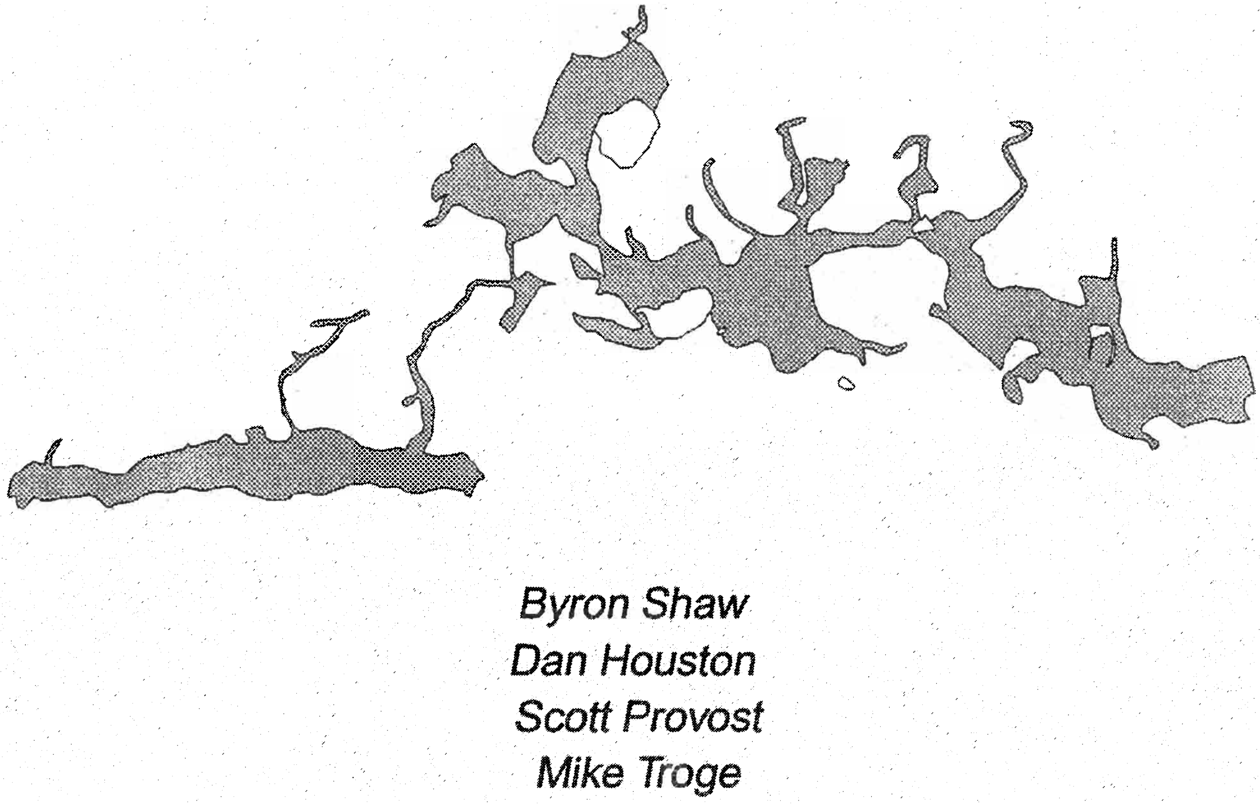
Legend Lake
Menominee Reservation/County, WI
Diagnostic Feasibility Study

Draft Final Report to the
Menominee Indian Tribe of Wisconsin
and
U.S. Environmental Protection Agency



Byron Shaw
Dan Houston
Scott Provost
Mike Troge
Steve Weber

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INTRODUCTION

Legend Lake is located in south east Menominee Reservation/County, Wisconsin. It is a 1,230 acre impoundment which was developed in the late 1960s by dredging/damming eight natural lakes. The lake is the result of a second home recreational development.

In the 1950s an Act of Congress terminated the Menominee Tribe; in 1961 the reservation became Menominee County. Economic development and property management was controlled by Menominee Enterprises, Inc., however, economic hardships occurred because there was only one major industry (a sawmill) to produce revenue for the county. A decision was made to increase revenues into the county by creating a large recreational development (Legend Lake) which includes recreational property that is salable to the general public. This project was executed by Menominee Enterprises, Inc. along with N.E. Isaacson and Associates, Inc. (Born and Stephenson, 1974). In the early 1970s the Menominee Tribe regained tribal and reservation status for the lands that made up Menominee County.

The lake was developed in three phases by constructing a series of temporary dams. The purpose of these dams was to facilitate the raising of the lake level within the three phases. Temporary dam #3 was removed upon the completion of all three phases. Permanent earthen dams were also constructed on the west end of Wah-toh-sah Lake and the east end of Pywaosit Lake and are still in place.

Some of the wetland areas to be flooded were excavated during construction, with some of this material dropped near the lake shore and covered with sand. Most of the surface flow was diverted towards the eastern outlet. The lake was then flooded until the water level was increased to between 1.2 and 4.3 m above the historic high water level (Kalinoski, 1982). After construction was completed, Legend Lake comprised 1,230 acres with 40 miles of shoreline. Raising the lake level also effected the elevation and flow direction of the groundwater. Excessive groundwater flow to the south raised lake levels out of the project area. To reduce this seepage and minimize impacts to downgradient lakes, clay was deposited in areas of high groundwater outflow (Born and Stephenson, 1974).

According to residents of Legend Lake who moved to the lake immediately following development, large areas of the lake were occupied by large macrophyte beds. It is possible that flooding the wetland and upland soils as well as soil disturbance associated with Legend Lake's construction may have been the initial sources of nutrients for early macrophyte problems.

In 1973, the Legend Lake Property Owner's Association (LLPOA) was formed, and the management of aquatic plants was assumed by this group. Private consultants, Mead and Hunt, were brought in to evaluate the macrophyte problem and offer methods of removal. The LLPOA was advised to try chemical treatments, including copper sulfate, but these methods offered very short term success and were quite costly. At that time, two weed harvesters were purchased and harvesting was conducted during the summer months. In recent years, harvesting of aquatic plants has been the only tool used to manage the excessive macrophytes.

The Menominee Tribe was concerned about the present and future water quality of Legend Lake. In the summer of 1991 a limnological study of the lake was performed by the Menominee Tribal Hydrologist and the University of Wisconsin-Stevens Point. The results of this survey confirmed that the Legend Lake system is showing signs of early eutrophication (UWSP, 1991).

The project described in this report was designed using the recommendations from the 1991 study. The 1991 study recommended further limnological studies be done to identify the lake's chemical and physical characteristics, and to determine the effects of the extensive real estate development on the lake. For long term progress in the reduction of excessive macrophyte growth, it was desirable to identify nutrient sources to the lake system; potential human related sources include septic systems, surface runoff, and fertilizer use. In addition, groundwater inflow and outflow data was needed to evaluate the nutrient dynamics and water flow characteristics of the lakes comprising the Legend Lake system. The three lakes south of Legend Lake (Round, LaMotte, and Sand Lakes) experienced changes in water level and chemistry as a result of the Legend Lake development and therefore, were also included in this study.

The primary goals of this project are to determine the causes and extent of water quality deterioration in Legend Lake and develop management alternatives to these problems. While the lake shore ownership and management is complex, many organizations combined to provide manpower and funds for this research. Those groups include: U.S. Environmental Protection Agency, Menominee Tribal Enterprises, Menominee Indian Tribe of Wisconsin, LLPOA, Legend Lake Protection and Rehabilitation District, and the University of Wisconsin-Stevens Point Environmental Task Force Program. This project consisted of several sub-studies which included evaluating groundwater chemistry and flow characteristics, sediment characteristics, seepage water chemistry and flow rates, surface water chemistry, quantitative and qualitative macrophyte studies, oxygen relationships, interrelationships between the Legend Lake Watershed and the impoundment, and the history of the surrounding area. In addition, a homeowners survey was conducted to evaluate the overall perception of the lake's residents regarding lake and fishing quality and causes for perceived problems.

LITERATURE REVIEW

Impoundment lakes undergo many changes beginning with the dredging of soils and flooding of wetland, agricultural, and/or forested lands and continuing for the life of the lake. One of the most common changes is eutrophication, which generally lowers the recreational and aesthetic values of lakes. The effects of eutrophication can include changes in water chemistry, excessive aquatic plant growth, filling of the lake with organic sediments, and changes in aquatic organism species composition and diversity (Ellis and Childs, 1973).

Dissolved Oxygen

Dissolved oxygen has been extensively researched in the field of limnology. The amount of attention paid to dissolved oxygen is appropriate considering its fundamental role in the survival and metabolism of aquatic organisms. The properties of oxygen solubility, and especially the dynamics of oxygen distribution in lakes, are basic to the understanding of the distribution, behavior, and physiological growth of aquatic organisms (Wetzel, 1985). The amount and distribution of oxygen also affects the solubility of many inorganic chemicals including nutrients.

Primary sources of dissolved oxygen are atmospheric input via wind mixing and photosynthesis. Streamflow and groundwater flow can also contribute to or result in a loss of dissolved oxygen content in a lake. Major sinks (losses) for dissolved oxygen are the respiration of aquatic plants and animals, the bacterial mediated decomposition of organic matter, and oxidation of reduced chemicals.

Productivity, morphology, and temperature have all been correlated to the rate of dissolved oxygen depletion from the water column of lakes (Hutchinson, 1957; Lasenby, 1975; Charlton, 1980; Mathias and Barica, 1980). Hutchinson measured the rate of dissolved oxygen depletion in milligrams per day that occurred below a square centimeter of upper hypolimnion surface area, known as the areal hypolimnetic oxygen deficit (AHOD), and proposed it to be an indicator of trophic status of lakes. The indicator was based on the idea that the dissolved oxygen depletion in the hypolimnion was indirectly related to the productivity of the layers above the hypolimnion. The production of phytoplankton in the upper layers caused organic matter to settle and oxygen to be consumed. Hutchinson used a square centimeter area of the upper surface of the hypolimnion to eliminate the influence of lake basin morphology when making comparisons between lakes.

The AHOD as an indicator fails when deficits are due to the oxidation of humic material or reduced substances brought in by effluent, streamflow, or groundwater. The source of carbon to the lake could not be assumed to be produced within the lake itself. However, lakes without outside carbon sources may also have oxidizable material accumulated as sediment over many years. This sediment oxygen demand extends upward into the hypolimnion. Lastly, shallow lakes or very clear lakes have limited application for the AHOD as a trophic state indicator because photosynthesis is taking place in the upper hypolimnion and there may be too low a deficit to be useful in comparisons (Hutchinson, 1957).

Empirical tests of the AHOD model looked for an association between hypolimnetic dissolved oxygen depletion and common measures of trophic status such as chlorophyll production by algae. The tests showed that respiration in the water column and at the sediment surface may not be proportional to the input of organic matter (Cornett and Rigler, 1980). The implication that dissolved oxygen depletion was related to factors in addition to trophic status was supported by the use of morphometry and temperature to explain a significant amount of the residual left by the correlation to productivity alone.

Another study looking at oxygen consumption found that hypolimnetic oxygen concentration represents hypolimnion thickness and temperature, as well as productivity (Charlton, 1980). Much of the available organic matter would be oxidized in the water in a thick hypolimnion, but more would be stored in sediments or oxidized during sediment oxygen consumption in a thin hypolimnion. The importance of hypolimnetic thickness was further demonstrated with rates of seston respiration in the water column. Rates of seston respiration were proportional to the in situ water temperature and to the concentration of chlorophyll *a*. Seston respiration was a larger proportion of the total respiration in the hypolimnion of lakes with a thick hypolimnion than in lakes with a shallow hypolimnetic water column (Cornett and Rigler, 1987).

Additional complicating factors of smaller lakes were identified as organic supply variables, productivity in areas other than in open water, colored organic material, and incomplete spring turnover (Charlton, 1980; Fulthorp and Paloheimo, 1985). Charlton (1980) also expected that the net effect of flushing was more important to hypolimnetic oxygen demand in small lakes. This was found in part by Fulthorpe and Paloheimo (1985) who noted that the flushing rate of the epilimnion added significantly to explaining the variance of calculated AHOD rates.

Anticipating a need for an alternative approach to predict changes in hypolimnetic dissolved oxygen, Cornett (1989) proposed a model that predicted the volumetric rate of dissolved oxygen depletion for a stratum of hypolimnion by using the estimated mass of phosphorus sedimented from the water column each year, the mean summer temperature of the stratum, and the morphometry of the stratum. Consistent with the findings of Charlton (1980) the rates of dissolved oxygen depletion are influenced by the effects of temperature, morphometry, and input of organic matter. The results suggest that there are strong interactions between the factors controlling net respiration and therefore, dissolved oxygen depletion is best described by a multi-factor model. The importance of temperature differences in making AHOD comparisons between lakes and over time was also noted by Lind (1987).

The dissolved oxygen depletion that occurs over winter in Legend Lake makes the potential winter kill of fish a concern. Although there have been no reported winter kills, dissolved oxygen depletion is severe in some of the lake basins. The study of ice-covered lakes allows for an assessment of dissolved oxygen control factors without atmospheric influences. In a study of ice-covered lakes, Mathias and Barica (1980) demonstrated that the rate of dissolved oxygen depletion corresponded to the sediment surface area. Correlations for morphology overshadowed trophic status. Only by removing the influence of morphology was trophic status predictive of winter dissolved oxygen depletion. Their study suggested that in winter the water column seston respiration is less important than the respiration of sediment material.

The rate of oxygen consumption by sediment is effected by mixing as the rate of dissolved oxygen depletion near the sediment boundary decreases as dissolved oxygen concentration decreases. An increase in velocity of the water near the sediments will therefore, increase the rate of dissolved oxygen depletion as the oxygen supply near the sedimented surface is continually replenished by mixing (Ellis and Stefan, 1989).

In comparing winter and summer dissolved oxygen depletion rates, it was suggested that winter dissolved oxygen depletion rates from depth profiles cannot be used as an indicator of metabolism (Linsey and Lasenby, 1985). The ice cover was not the sealed system that it was thought to be in the lakes studied. The system was open to winter oxygen influx from primary production, groundwater, meltwater, and rainwater.

Consideration is also given to the alternative dissolved oxygen sinks that are control factors. Photochemical reactions of humic substances and iron may have an influence. In shallow lakes with high inputs of organic matter or in bog lakes that receive high inputs of dissolved humic substances, chemical oxidation or photochemical oxidation may be significant (Wetzel, 1985). Oxygen depletion may also result, in part, from transmetalimnetic fluxes of reduced substances into the epilimnion (Stauffer, 1987b). In its migration from an anoxic hypolimnion, reduced iron may cause dissolved oxygen depletion directly by becoming oxidized and precipitate out and settle back to the sediment. As iron oxides precipitate and settle back to the sediment, they can form complexes with phosphates. Therefore, this cycle can reduce the supply of nutrients in the water column. The reduction in available phosphate can lead to lower primary production in the upper layers of the water column. The lower primary production results in low available organic carbon to demand oxygen upon decomposition. The iron cycle can therefore have an indirect impact on the dissolved oxygen. Cold weather events that cause the metalimnion to migrate downward were shown to increase the co-precipitation of phosphorous in the metalimnion with the forming iron oxides, thereby removing phosphorus from that portion of the upper hypolimnion (James, et.al., 1990).

High levels of iron are expected in Wisconsin lakes with large concentrations of organic matter (Lillie and Mason, 1983). Autumn increases of humic substances in the epilimnion are due to rainfall flushing of leaf litter. There is a migration of this material to the hypolimnion due to the adsorption of humic substances to iron with subsequent sedimentation (Tipping and Woof, 1983). Fe(II) from groundwater seepage would normally be oxidized at the sediment interface by dissolved oxygen in the lake, however, the presence of humic substances can allow further migration throughout the water column as iron-organic complexes. The oxidation of Fe(II) has been shown to be retarded for several days by the complexation with tannic acid, even in the presence of adequate oxygen (Theis and Singer, 1974). The presence of the resistant complex between tannic acid and Fe(II) also lessens the oxidation of the tannic acid. Manganese is thought to precipitate in a similar process of organic complexation.

Aquatic humus is the water extractable fraction of the soil humus (IE fluvic acid). The most active fraction of humus could be found in water originating from acid peat areas. Chemical oxygen demand (COD) is often used internationally for characterizing the humus content in a water sample. Biochemical oxygen demand (BOD) analysis is not considered a useful method because humus is difficult for microorganisms to decompose (Gjessing, 1976).

Oxygen is also consumed in humic-colored water by a photochemical ferrous-ferric catalytic cycle. The consumptive cycle with iron as the catalyst is the photoreduction of Fe(III) to Fe(II) by humic matter and subsequent oxidation of Fe(II) back to Fe(III) by dissolved oxygen. Rates of oxygen consumption are linear functions of iron and humic color concentration (Miles and Brezonik, 1981; Fulthrope and Paloheimo, 1985). This alternative sink for dissolved oxygen is important when the low productivity of colored waters does not account for the usual reasons for oxygen depletion.

Legend Lake is a unique combination of lake basins that exhibit the influences of the classical controlling factors, as well as some of the exceptional control factors, mentioned in the literature. To identify differences in oxygen depletion between the lake basins, the rate of loss over time was examined and the relative mass of oxygen lost was calculated. Data were gathered to compare the existence of the control factors that have been identified in previous studies. Once the data were gathered, associations between the control factors and the measures of dissolved oxygen depletion were described (Chapter 5.5).

Macrophytes

Traditional lake water quality evaluations center on phytoplankton populations and associated problems, however, aquatic macrophyte populations also play an important role in primary production processes in lake systems. Preliminary studies and the survey of property owners identified macrophytes to be a bigger problem than algae in Legend Lake (UWSP, 1991; Turyk and Shaw, 1994). These plants can provide habitat for fisheries, trap sediments from overland flow, and provide valuable photosynthetic properties for the ecosystem. Aesthetics is another important attribute of many species such as *Nuphar variegatum* (yellow pond lily) with their sight pleasing flowers. Aquatic macrophytes can also occur in nuisance levels in many water bodies, which can concern many lake users, especially if their favorite recreational activities are impaired.

Effective management of a lake's resources includes identifying all sources of nutrient input and outputs to the system. Most macrophyte control techniques treat excessive plant growth, but do not treat the causes which may cause excessive plant growth (Nichols, 1991). Addressing some of the causes of excessive plant growth can control plant growth. In addition, identifying the factors which influence the distribution of aquatic macrophytes is essential for effective management of aquatic plants.

Factors which affect aquatic macrophyte distribution and biomass have been investigated by many researches (Collins, et.al., 1987; Scheffer, et.al., 1992; Pip, 1989; Lodge, et.al., 1989). Brinson and Davis (1980) have outlined a number of factors which affect plant growth: fluctuating water levels, currents and waves, suspended sediments and their affects on submersed plants, growing season and dormancy, nutrient availability and uptake, biological factors, light attenuation and depth zonation, and turbidity.

Plant diversity is often influenced by the wide range of physical and chemical conditions to which various species have adapted (Davis and Brinson, 1980). This variation in life cycle, morphology, physiology, and reproduction, which somewhat reflects the diversity of their terrestrial ancestors (Arber, 1920), could account for the differences in species relationships to one another within heterogenous plant communities. These relationships can often only be determined on a lake by lake basis (Collins, et.al., 1978).

The influence of groundwater flow to surface water has been considered as a source of nutrients by many investigators since Birge and Juday (Brock, 1982). Groundwater can also be a source of nutrient loading to a drainage lake, especially for nitrogen and phosphorus (Brock,et.al., 1982). It has been estimated that 42% of nitrogen and 2.3% of phosphorus reaching surface water in Wisconsin are from groundwater (Schraufnagel,et.al., 1967; Lee, 1976).

It has been suggested that groundwater characteristics play a role in plant distribution in seepage lakes. The shallow waters are seen to be a dynamic system with both inputs and outputs of nutrients which may influence the over all chemistry of seepage (Brock, et.al., 1982). In field measurements of groundwater flow, McBride, et.al. (1975) found that flow was concentrated in a zone near shore and exhibited an exponential decrease in seepage rate with distance from shore at a rate of one order of magnitude for every 60 m of horizontal distance. Groundwater discharge velocity within this littoral area was found to positively influence the distribution of aquatic macrophytes in Sparkling Lake, Wisconsin by Lodge, et.al. (1989). Lillie and Barko (1990), found that no correlation existed between the rate of groundwater flow, but a relationship between groundwater inflow versus outflow showed positive correlation between plant biomass and groundwater inflow.

Lillie and Barko (1980), suggested that in areas where sediment characteristics were insufficient to support aquatic macrophyte growth, groundwater nutrient input may regulate the distribution and biomass of *Myriophyllum spicatum*. The concept that groundwater entering into the lake may flush dissolved nutrients into the overlying water has been found by Uttormark, et.al., (1974) and Lee, et.al. (1980).

Water collected in seepage meters was found to be higher in phosphorus and ammonia and lower in nitrate than in adjacent wells (Brock, et.al., 1982). Keeney, et.al. (1971), found that nitrate was being removed from the sediments before it enters the lake, probably as a result of the denitrification process in the sediment.

On-site wastewater disposal systems, often referred to as septic systems, are another potential source of nutrients that have recently received attention. It is not clear if on-site wastewater disposal systems are a major source of phosphorus for surface waters. Lee, et.al. (1978), conducted a review of this topic and concluded that it is unlikely that sufficient phosphate concentrations are transported from such systems to surface water to result in a significant contribution to eutrophication.

Other researchers believe that groundwater seepage which contains septic system effluent may provide a significant source of nutrient loading into drainage and seepage lakes (Lee, 1976; Lee, 1977; Brock, et al, 1982; Jones, 1979; and Ellis, 1973; Pappas, 1972). Lee (1976) confirmed the findings of Schraufnagel, et.al (1976), that in Wisconsin it is estimated that 42% of the nitrogen and 2.3% of the phosphorus that reaches surface waters is from groundwater seepage (Lee, 1976).

Many lake side homes are serviced by septic systems, thus, it is important to consider septic systems as a potentially significant source of nutrients (transported via groundwater) to the water and sediments of lakes. Recent studies have indicated that the dispersive capability and dilution potential of septic system contaminant plumes located in sand and gravel aquifers are much less than was previously thought, which results in nutrients to be transported via groundwater to lakes (Robertson, 1991; Shaw, et.al., 1993).

1.0 LEGEND LAKE

Legend Lake is located in Menominee Reservation/County, Wisconsin (Figure 1.1). Legend Lake is approximately seven miles long from western tip to eastern tip, has a surface area of 1,230 acres, and a maximum depth of 24.4 m. The lake is actually an impoundment made up of six groundwater drainage lakes connected by Linzy Creek that flows east to the South Branch of the Oconto River and two groundwater drainage lakes connected by a smaller stream that flows west to the Wolf River. A watershed divide occurs within Legend Lake. The eight lake basins were enlarged, connected by channels, and filled with an additional 1.2 to 4.3 m of water by damming the natural drainage streams. In addition to the surface outflow, there is also significant groundwater discharge to the lakes to the south of Legend Lake. Legend Lake and the historic lakes are shown in Figure 1.2 with their corresponding reference letter that will be used throughout this document. The town of Keshena is located at the western tip of the lake.

Figure 1.1. Location of Legend Lake in Menominee Reservation/County, WI.

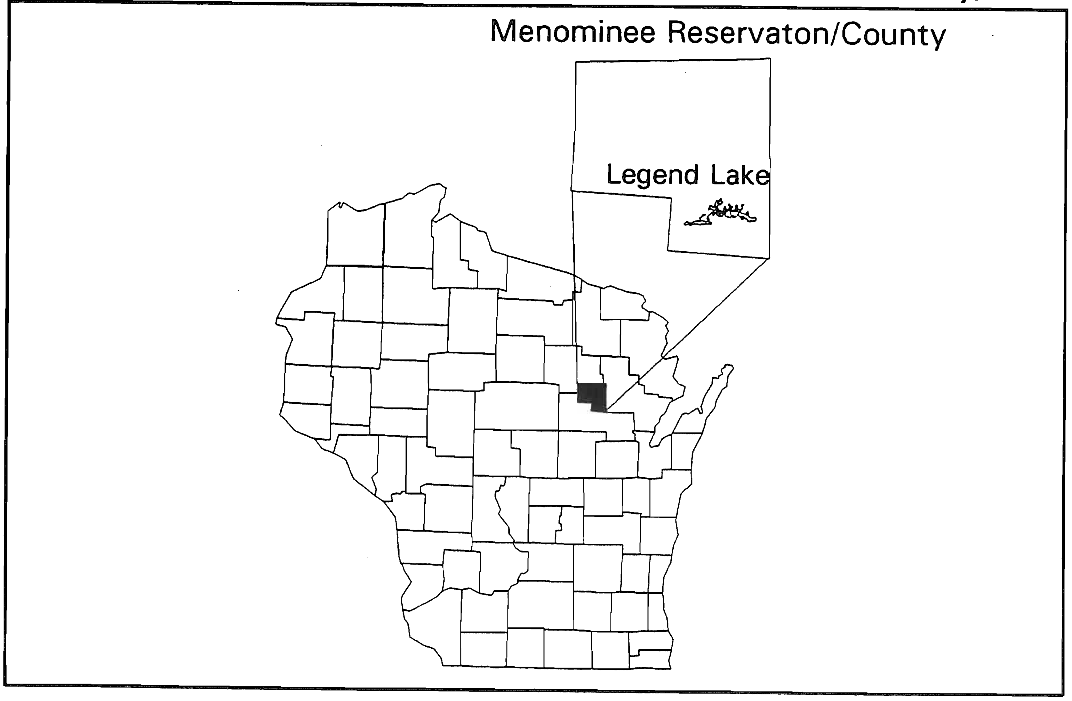
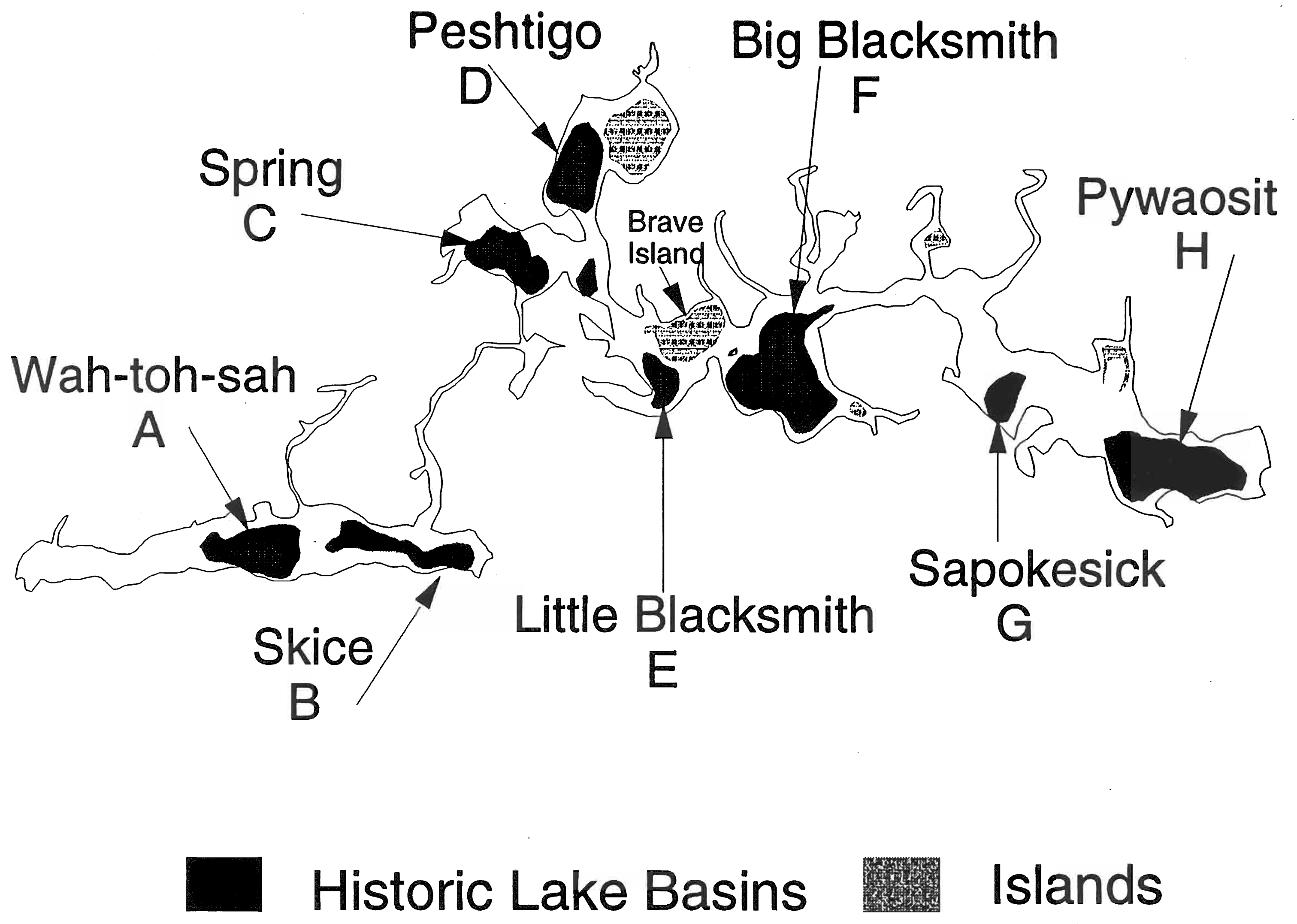


Figure 1.2. Map of Legend Lake showing the names and locations of the historic lakes and their corresponding letter that will be used in this report.



History

The Legend Lake impoundment was developed in the late 1960s and early 1970s by the newly organized Lake of the Menominees, a partnership formed by Menominee Enterprises, Inc. and Isaacson and Associates, Inc., to promote recreational real estate development in the county (Kalinoski, 1982). A 5,000 acre tract, located in the glacial sands area of the southeastern corner of the county was chosen for the project (Hoffman, 1977).

The impoundment was constructed in several phases using a series of temporary dams which allowed the lake levels to be raised in phases. Permanent earthen dams were also constructed on the west end of Wah-toh-sah Lake and the east end of Pywaosit Lake, and are still in place. During construction, many of the original stream channels were dredged for navigational purposes between lake basins. Two-thirds of the lake maintains typical lake characteristics and the remaining one-third is in the form of channels that connect each lake basin or channels that extend from the main lake system.

The original eight lakes had a total surface area of 376 acres. The historic lake basins were described as hardwater drainage lakes having mostly muck littoral zones and marsh-bog wetland shorelines (Andrews et al.,1963). During construction (1968 to 1971) many of the littoral zones were scoured, exposing lake bed parent material. In an attempt to suppress aquatic plant growth, once the water level was raised, some of the graded shorelines were blanketed with sand.

Some of the wetland areas were excavated, creating a larger lake system. Large areas of wetlands were retained by the developers to act as nutrient traps; however, some of these areas were subsequently flooded by rising water levels. As a result, floating bogs became a problem, so they were layered with sand to sink them (Born and

Stephenson, 1974). After construction was complete the water level increased to between 1.2 and 4.3 m above the historic high water level (Kalinoski, 1982). Legend Lake is now 1,230 acres with 40 miles of shoreline. The increased water level affects the groundwater flow and in some areas resulted in a reversal of the groundwater flow direction.

According to residents of Legend Lake, who moved to the lake immediately following development, large areas of the lake were occupied by large macrophyte beds. In 1973, the Legend Lake Property Owner's Association was formed and the management of these plants was taken on by this group. A private consultant (Hunt and Mead) was brought in to evaluate the macrophyte problem and offer methods of removal. The Association was advised to try chemical treatments, but these methods offered very short term success and were quite costly. Weed harvesting was conducted during the summer months using two weed harvesters that were purchased by the Association. In recent years, harvesting of aquatic plants has been the only tool used to manage these problems.

In the past, limnological sampling was conducted by the Wisconsin Department of Natural Resources (1971-1976), U.S. Geological Survey (1990-1991), University of Wisconsin-Stevens Point (1991), and the Menominee Tribal Hydrologist (1991). Current data shows severe oxygen depletion in the hypolimnion, yet low (<5 μg/l) chlorophyll values and good light penetration. Abundance of aquatic weeds, oxygen depletion, and localized occurrence of filamentous algae and blue green algae indicate the lake is undergoing eutrophication.

Lake Basin and Watershed

The Legend Lake Watershed is approximately 10,480 acres, with the lake located in the southern part of the watershed. This watershed is characterized by level to undulating topography. The northwestern part of the watershed has the greatest topography, while the northeastern part is primarily designated as wetlands (U.S.G.S., 1982). Most overland flow to the lake comes from the northern areas via three streams entering along the northwest end of the lake (Figure 1.3). Runoff from lake shore property also occurs.

Legend Lake lies in a geologic area of glacial pitted outwash originating from the meltwater of the Wisconsin glacial advance. These deposits are approximately 10,000 years old and cover Precambrian granite. Precambrian granitic and syenitic rock of the Wolf River batholith outcrops approximately one mile west of the study area and dips 8 m/mile (26 ft/mile) to the southeast to a depth greater than 30 m (100 ft), (Mudrey, et al., 1982; U.S.G.S, 1982). Soil types within the watershed and surrounding Legend Lake are predominantly Nimore sands with some shallow organic soils in local topographic depressions (NRCS, 1996). Water rapidly infiltrates into these soil types. Much of the organic soil found in the study area was excavated in the process of building Legend Lake.

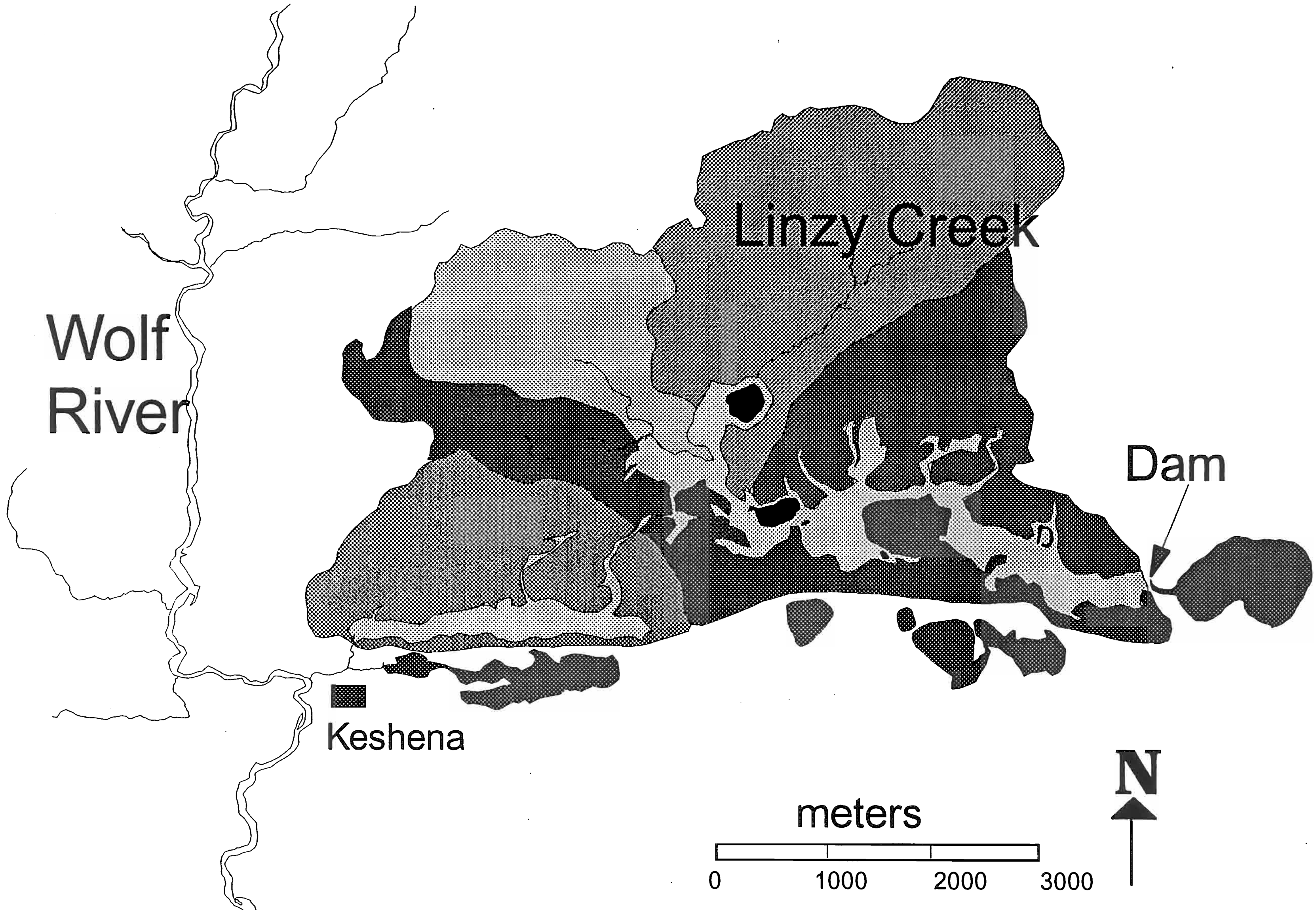
Morphometric data was collected for the entire Legend Lake system and is discussed in detail later in this document in the *Methods, Lake Hydrology* and *Water Budget* Sections. Maximum depths for the basins are as follows: 4.6 m (15 ft) - 1 basin, 10.7 m (35.1 ft) - 1 basin, 12.2 m (40 ft) - 3 basins, 21.3 m (69.9 ft) - 1 basin, and 21.9 m (71.8 ft) - 1 basin. Two inlets remain in the system that are located on the northern shores of the impoundment, both are remnants of the streams that connected the six original seepage lakes. Two outlets exist on the impoundment, located at the dams. The primary dam is located at the far eastern tip of the lake and a secondary dam is located at the far western tip of the lake near Keshena. The western outlet only discharges water during extremely high rainfall periods. Groundwater discharge also leaves from the southwestern lakes (Basins A and B) and from several basins at the eastern and southern end of the lake system. These amounts have been established and are presented later in this paper.

There are three public boat landings on Legend Lake, which are maintained by the LLPOA. The lake is accessible to the public from Highway 47/55 to County Highway VV. The access points are within one mile of Highway VV.

There are 2,728 lots in total that are part of the Legend Lake development, of which 45 percent (1,230) are lake front properties. As of 1993, approximately 60% of the lots were developed; these are serviced by private wells and septic systems. Many of the lots are occupied on a seasonal basis. More details about the human population at Legend Lake can be found in Section 3.

There is little development elsewhere in the watershed, it is 93% forested or covered with native vegetation (Hansen and Hole, 1967). No agriculture is present in the watershed, however, there is some timber harvesting. There are some land use ordinances which are enforced by Menominee County/Tribe.

Figure 1.3. Map of Legend Lake's watershed and sub-watersheds.



2.0 PROJECT OBJECTIVES

During the summer of 1991 the University of Wisconsin - Stevens Point and the Menominee Tribal Hydrogeologist conducted an initial limnological survey of Legend Lake (UWSP, 1991). The results of this survey indicated that the Legend Lake system is showing signs of premature eutrophication. It was recommended that further limnological and hydrological studies would be required to better identify the lakes' chemical profile, physical characteristics, and the effects of the extensive real estate development on the lake. Raising the water level of the original lakes resulted in changes in groundwater elevations and flow directions. Groundwater inflow and outflow data was needed to evaluate the nutrient dynamics and water flow characteristics of the lakes comprising the Legend Lake system. The three lakes south of Legend Lake experienced significant increase in water level and changes in water chemistry (Hoffman, 1977). These lakes (LaMotte, Round, and Sand) were also included in this study, as they serve as part of the outlet from Legend Lake. A better understanding of their relationship to Legend Lake was needed for management decisions.

The primary goals of this project were to determine if water quality degradation is occurring and the causes and extent of water quality degradation in Legend Lake and develop management alternatives which address these problems.

3.0 HOMEOWNERS' SURVEY (Condensed from Turyk and Shaw, 1994)

Survey Abstract

A homeowner survey was conducted as part of the study of Legend Lake. This survey helped to identify local residents opinions on water quality, fishing quality, lake use, and the impacts they may have on the lake. The results were used to make recommendations for the management of Legend Lake.

There was a 35.9% response rate to the survey. The questions were analyzed several ways: by the total survey response, by subgroups based on the duration of time spent annually at Legend Lake, and by the subgroups of non-Menominee Tribal Members and Menominee Tribal Members. We believe the separation by subgroups was necessary when great variations occurred in responses regarding lake uses and the potential impacts on the lake. These variations may be a result of differences in values, culture, income, economic, or other reasons. Sixty-one percent of the respondents rated the water quality at Legend Lake as excellent or very good. The primary water quality problem was identified as weeds, as identified by 53.5% of the respondents, with algae/scum identified by 20.3% of the respondents. This indicates there is an excess of nutrients, and their sources need to be identified. Possible sources of the nutrients are septic systems/phosphate detergents, lawn and garden fertilizers, or natural eutrophication. Several choices were presented in another question about the reason for decline in water quality. Heavy recreational use (31.6%) and development pressures (19.1%) were the top two reasons identified. Ninety-five percent of the respondents use the lake for recreational purposes with boating (91.0%), swimming (88.5%), and fishing (86.2%) being the most popular uses. Most of the boats used on Legend Lake (63.2%) are motorized, which results in an estimated annual marine gasoline use of 63,370 gallons. Fishing quality was most frequently rated as average (43.5%) or fair

(30.8%), 55.3% reported that the fishing has remained the same since the lake was developed. Heavy recreational use ranked as the highest (49.5%) reason for the decline in fishing quality. The top three practices recommended by the homeowners to improve Legend Lake are weed/algae cutting (11.7%), improve/continue fish stocking program (11.5%), and limit motorboat horsepower/speed/motors (9.3%). The results of a variety of other opinions, use characteristics and potential lake impacts are summarized in this report.

Survey Objectives

The objectives of the survey were:

1. To determine how much time people spend at Legend lake and the amount and type of development occurring around the lake;
2. To determine what the local perception is regarding Legend Lake's water quality and fishing quality;
3. To identify if and when problems were observed;
4. To obtain opinions about what corrective measures would alleviate perceived problems;
5. To determine the primary uses of Legend Lake and if the users believe their use is affecting water/fishing quality;
6. To acquire information about septic systems and products entering them, to be used in conjunction with the sub-study being done on the effects septic systems are having on Legend Lake;
7. To obtain information about fertilizer and pesticide use;
8. To gather data on private wells, and determine how informed the residents are about their wells and groundwater.

Survey Conclusions

This survey of residents owning property near Legend Lake has shown the variety of perceptions, aesthetic values, and lake uses of the people living on and around Legend Lake. The Legend Lake population was about one-third (948) of the potential population (2,800) at the time of this survey. Human impacts will increase as the population increases, so the design and implementation of a management plan for the lake area is desirable while impacts are minimal.

1. There are 728,390 person use days annually at Legend Lake. The predominant recreational activities and uses of Legend Lake are boating (91%), swimming (89%), fishing (86%), aesthetic appreciation (56%), and picnicking (27%).

2. The most popular boats owned and operated on Legend Lake were fishing boats (23%), pontoon boats (19%), ski boats (18%), canoes (16%), and paddle boats (10%).

3. We estimate 63,000 gallons of gasoline are used on Legend Lake annually (50 gallons of marine gas/acre of lake surface/year). Gas consumption for Menominee Tribal Members was only 2.9% of the 22,750 gallons reported being used by all the survey respondents. Gas use varied with the sub-populations primarily due to the types of boats used by each group.

4. Sixty-one percent of the respondents rated the water quality of Legend Lake as excellent or very good, and no one felt the lake had poor water quality. The top three water quality problems were identified as weeds (54%), algae/scum (20%), and litter (13%).

5. The five top rated reasons contributing to a decline in water quality were heavy recreational use, development pressures, septic tank use, soil erosion, and fertilizer use.

6. Fertilizer use was reported by 14% of the respondents. The closest distance to the lake for fertilizer application was most frequently reported between 20 and 100 feet (46%), followed by 6 to 20 feet (21%), and less than 5 feet (13%). Pesticide use was reported by 12% of the respondents.

7. Fishing quality was rated as average or fair by 74%. Thirty-eight percent of the respondents felt the quality of fishing has decreased since they have fished at Legend Lake; while 6.6% felt the fishing quality had improved.

8. The factors rated as highest contribution to a decline in fishing were development pressures, heavy recreation, fertilizer use, and septic tank use. The top three descriptions of the way fishing has changes were; fewer and/or smaller game fish (26%), more and/or smaller pan fish (17%), and fewer northern pike (8.3%).

4.0 METHODS

Sampling and Analysis

Numerous sub-studies, as well as a lake wide study were performed on Legend Lake. Table 4.1 identifies the type of samples that were collected, the lakes that were involved, and the study time periods.

Table 4.1. The types of samples, locations and the sampling period for sub-studies at Legend Lake.

Type of Sampling	Lakes Sampled	Sampling Period
Sediment	A-H	Winter 1993
Macrophytes	A-H	July 1993
Piezometers	A-H	Aug 92 - Aug 94
Mid-Lake	A-H	May 92 - Jan 94
Seepage Meters	A and B	May - July 1993
Sediment	A and B	May - July 1993
Macrophytes	A and B	May - July 1993
Multilevel Monitoring Wells	A and B	May - July 1993

The samples for water chemistry, chlorophyll, and sediment analyses were collected by students from the University of Wisconsin-Stevens Point and the members of the Environmental Services Department (ESD) of the Menominee Indian Tribe. Water chemistry, chlorophyll, and some sediment analyses were preformed by the Environmental Task Force Laboratory (ETF Lab) at the University of Wisconsin-Stevens Point. The remainder of the sediment analyses were preformed by the University of Wisconsin-Madison Soils and Plant Laboratory. The analytical procedures that were followed are detailed in the Legend Lake Diagnostic Feasibility Study Quality Assurance Project Plan (QAPP), (Shaw, 1993). A list of chemical analyses and the methods used can be found in Table 4.2. All water samples were kept on ice while being transported to the lab.

Table 4.2. Summary of characteristics and chemical analyses performed on surface water and groundwater samples.

Parameter		Method	Max. Holding Time
Field Determined Characteristics			
pH		Cole Parmer Field Meter	N/A
Specific Conductance		Cole Parmer Field Meter	N/A
Temperature		Cole Parmer Field Meter	N/A
Dissolved Oxygen		Cole Parmer Field Meter	N/A
Lab Analyzed Chemistries and Characteristics			
Alkalinity		Method no. I Sec. 2320B, APHA, 1989.*	14 day
Chloride		Method no. I Sec. 4500 - Cl E, APHA, 1989.*	28 day
Nitrate/nitrite N		Method no. I Sec. 4500-NO_3 F, APHA, 1989.*	28 day
NH_4-N		Technicon Industry Method no. 329-74 W/B.	28 day
Kjeldahl N		Technicon Industry Method no. 329-74 W/B.	28 day
Phosphorus	Total P	Method no. 4500-P F, APHA, 1989.*	48 hr
	Soluble	Method no. 4500-P F, APHA, 1989.*	48 hr
Calcium		Method no. I Sec 3111D, APHA, 1989.*	6 mo
Magnesium		Method no. I Sec. 3111B, APHA, 1989.*	6 mo
Total Hardness		Method no. I Sec. 2340C, APHA, 1989.*	6 mo
Calcium Hardness		Method no. I Sec. 3500-Ca, APHA, 1989	6 mo
Iron		Method no. I Sec. 3111B, APHA, 1989.*	6 mo
Sulfate		Method no. I Sec. 4500 SO_4, APHA, 1989.*	28 day
Manganese		Method no. I Sec. 3111B, APHA, 1989.*	6 mo
Algae		Method no. I Sec. 10200, APHA, 1989.*	
Silica		Method no. 3120B, APHA, 1989*	28 day
Chemical Oxygen Demand		Method no. 5220C, APHA, 1989*	28 day
Sulfide		Lachat Method no. 10-116-29-1-A	7 day
Potassium		Method no. 3111B, APHA, 1989*	6 mo
Sodium		Method no. 3111B, APHA, 1989*	6 mo
Chlorophyll		Method no. I sec. 10200H, APHA, 1989.*	28 day

* APHA, 1989. Standard Methods for the Examination of Water and Wastewater. 17th edition.

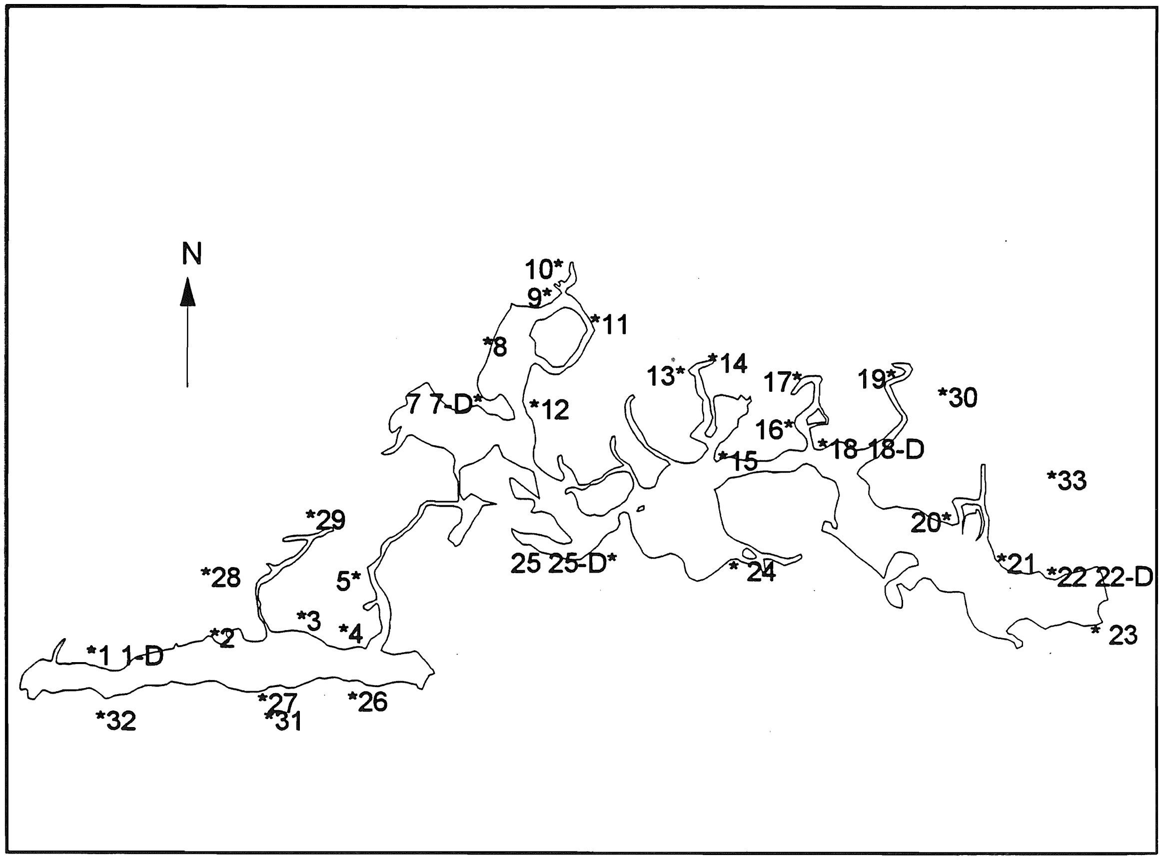
Groundwater

Area-Wide Water Quality Monitoring

Area wide water quality and hydraulic head elevations were determined by installing 38 piezometers throughout various locations in the watershed and around the lake shore on Legend Lake Property Owners Beach Clubs (undeveloped lots owned by the Lake Association) as shown in Figure 4.1. Sampling of the piezometers was done on a quarterly basis.

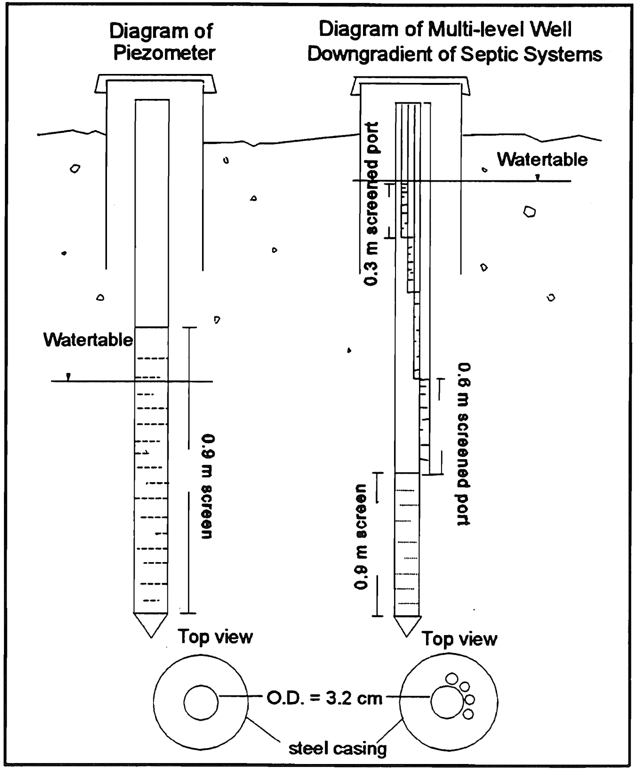
Piezometers were installed using a number of techniques. The ETF trailer mounted drill rig was used to place wells deeper than 6.7 m (22 ft) in areas that were

Figure 4.1. Location of the piezometer monitoring wells that were situated around Legend Lake. These wells were used for area wide water quality monitoring and to determine hydraulic head elevations.



accessible by truck and rig. A gas powered hand held auger head was used in areas where the water table was deeper than 1.8 m (6 ft) but not deeper than 6.7 m (22 ft). Bucket augers were used to install piezometers in areas with shallow groundwater (<2 m) or areas that prohibited the use of the ETF's drill rig.

Figure 4.2. Diagram of the piezometer and multi-level monitoring well designs.



Each piezometer was constructed using 3.2 cm (1.25 in) inside diameter (I.D.) schedule 40 PVC pipe and a 91 cm (3.0 ft) screen with a 0.25 mm (0.01 in) slot size (Figure 4.2). Thirty of the piezometers were installed with the screen bottom placed 76 cm (2.5 ft) below and the tops 15 cm (0.5 ft) above the water table. Five of the remaining ten piezometers were installed with screen tops a minimum of 5 m (15 ft) below the watertable and placed next to shallow piezometers to form well nests. This aided in the determination of vertical gradients. The other five piezometers were placed at distances greater than 152 m (500 ft) from the shore. These screens were also installed 0.6 m (2 ft) below the watertable.

After each piezometer was installed, the borehole was backfilled with native soil and bentonite was packed around the piezometer. A steel 20 cm (8 in) I.D. casing with cap and padlock was installed around the well to discourage localized contamination and tampering. All the piezometers were developed using a gas powered Honda model

WH15X, 3.5 horse centrifugal pump.

The elevation of the piezometers were surveyed to the nearest 0.3 cm (0.01 ft) above sea level using a Spectra-Physics Laserplane 650 laser level. The surveying commenced at an established benchmark.

Area hydrogeologic properties were defined using data from previous studies well logs, field tests, and exploratory borings. The studies that were used were completed by the U.S.G.S. (1982), Mudrey, et.al.(1982), and Hole (1967). Well logs supplied by the Wisconsin Department of Natural Resources (WDNR) and the Wisconsin Geological and Natural History Survey (WGNHS) were used to help determine stratigraphy in the watershed. Geologic cross sections were drafted to illustrate and aid in the definition of the geology of the area. Exploratory borings were done with the ETF drill rig when the drilling depth was less than 12 m (40 ft).

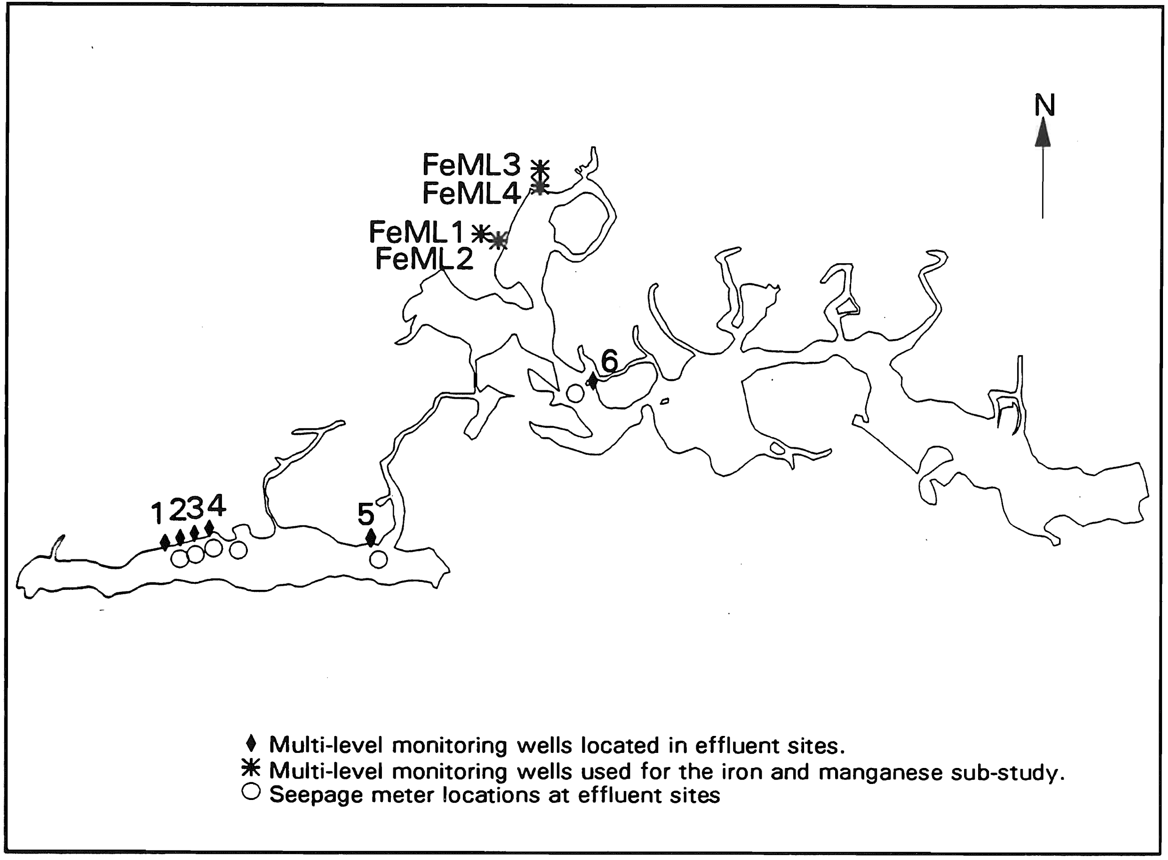
Head elevations were taken monthly from piezometers using a measured tape and a metal weight, commonly referred to as a popper. Potentiometric maps were constructed for four sampling dates and seasonal groundwater flowpaths were determined from these maps.

Septic System Monitoring Well Construction

Six sites were monitored on a monthly basis to determine the effects of septic system effluent on groundwater, enabling groundwater quality monitoring on a site specific basis as opposed to a basin wide area (Figure 4.3). These sites were also sampled as part of the seepage meter study.

Six septic plumes were identified in groundwater discharge sites around the lake. The identification of plumes was accomplished by boring holes in the shoreline 0.6 m (2 ft) below the watertable. Wells were installed and a sample was drawn. Five drops of 0.5 M silver nitrate ($AgNO_3$) was added to the sample to identify the presence of

Figure 4.3. Location of multilevel monitoring wells situated downgradient of effluent plumes for the sub-study on septic system impacts on the lake and in buried organic matter for the sub-study on iron and manganese reduction.



chlorides. A 125 ml sample preserved with Sulfuric Acid (H_2SO_4) was brought back to the ETF lab to be analyzed for nutrients and chlorides to confirm the identification of a plume. Each plume was monitored monthly by sampling a multi-level monitoring well downgradient of the septic system drainfield.

The multi-level monitoring wells were constructed to allow sampling groundwater from the watertable to a depth of 2.4 m (Figure 4.2). Each multi-level was constructed using a 3.2 cm (1.25 in) I.D. schedule 40 PVC pipe. Each well has a 91 cm (3.0 ft) screen with 0.25 mm (0.010 in) slot size. This functioned as a piezometer as well as a sampling port. In addition, two 0.9 cm (3/8 in) I.D. polypropylene sampling ports with a 2.0 foot (60 cm) screen and two 1.0 foot (30 cm) screens were attached to the main spine. These screens were made by wrapping a nylon mesh around equally spaced drilled holes in the tubing. The screens were placed to allow sampling to a depth of 2.4 m (8 ft) below the watertable.

Multi-level monitoring well installation was done by drilling a borehole using a series of 5.1 cm (2 in) diameter, fluted augers, and a gas powered ice auger head. After the wells were placed they were backfilled with native soil and a bentonite plug was placed around the well. A steel 20 cm (7.9 in) I.D. casing with cap and padlock was installed around the well to prevent localized contamination and tampering.

Groundwater Sampling and Analysis

All groundwater samples were drawn by a battery powered Masterflex L/S peristaltic pump using polypropelene and silicon tubing. The well and/or sampling ports were purged four times the volume prior to the acquisition of the sample. All samples were field filtered using a no. 2 Whattman prefilter and a sterilized 0.45 μ filter seated in an inline filtering device.

Groundwater samples were analyzed at the ETF laboratory for TP, Reactive P, NO_2+NO_3-N, NH_4, TKN, Cl, Fe, Mg, pH, conductivity, alkalinity, total hardness, Ca hardness, sulfate, and COD.

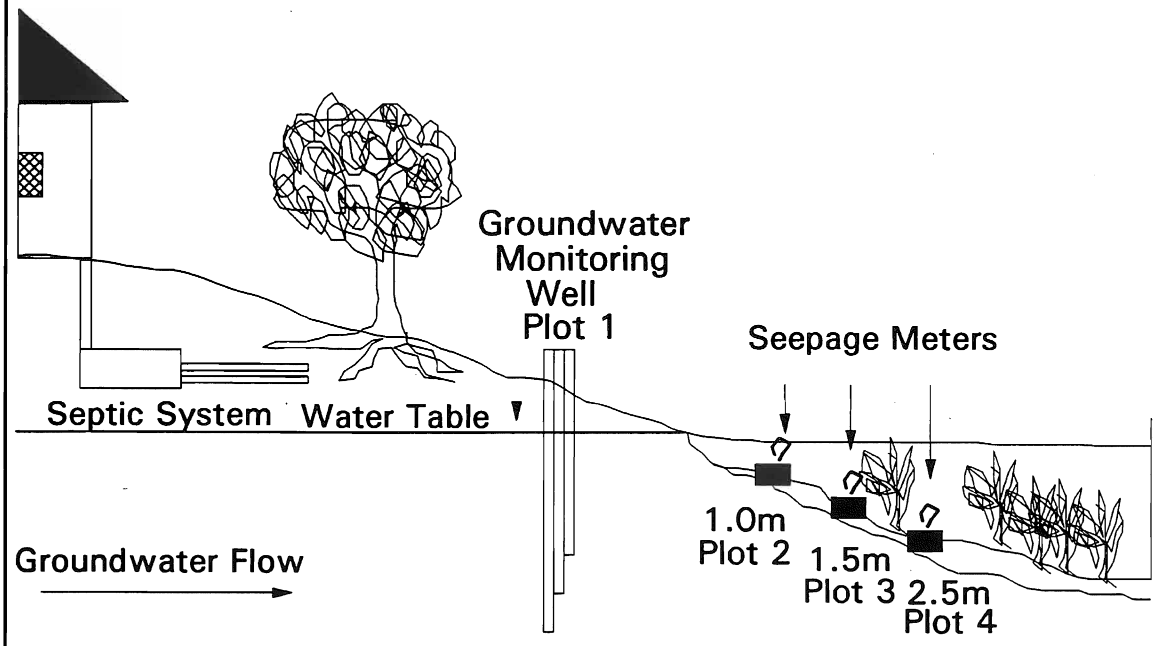
Seepage Water

Seepage Meter/Sediment/Macrophyte Study

Layout and Design of Seepage Meters

The Wah-toh-sah/Skice unit of the lake was selected to investigate the water chemistry and flow rates of groundwater moving into the lakes. These basins were chosen because this was the first region of the lake to be developed and contained a higher percentage of the year round residents. Groundwater flow patterns were established by Provost (unpublished) early on in the project within this basin, allowing

Figure 4.4. Layout of seepage meters and multi-level groundwater monitoring wells for each plot.

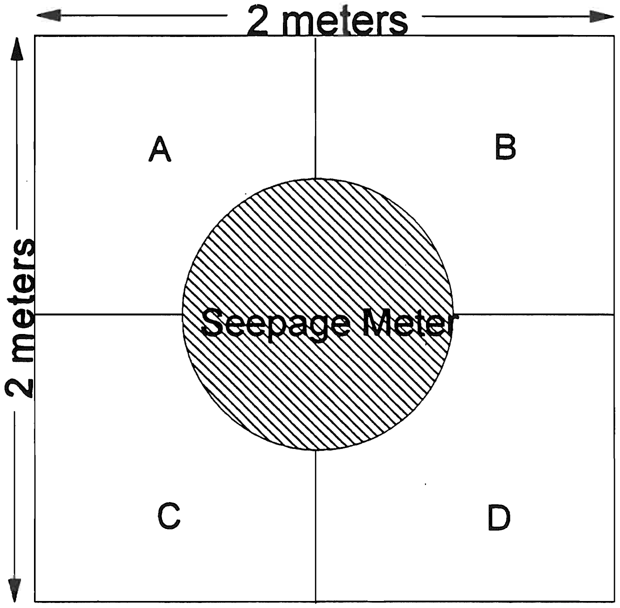


the investigators to more easily identify areas of groundwater inflow and outflow.

Three groups of sites were established representing the areas of groundwater inflow with septic effluent plumes, groundwater inflow without septic effluent plumes, and groundwater outflow sites. Replication within the treatments was as follows: ten sample sites were selected with eight sites located within groundwater inflow areas and two sites in outflow areas. The groundwater inflow areas were further divided into two groups, four where septic system effluent plumes are entering the lake, and four sites where an effluent plume does not exist.

To better understand the effects of lake water depth on plant distribution and groundwater inflow each site was divided into four sub-plots (Figure 4.4). The first plot was located on land within 3 m (10 ft) of the lake's high water mark. At this plot a multi-level well or monitoring well (as described above) was installed to identify the presence or absence of effluent plumes and the direction of groundwater flow, and allowed for collection of groundwater samples for chemical analysis. The second, third and fourth plots were established in the lake along a transect perpendicular to the shoreline at depths of 1.0 m (3 ft), 1.5 m (5 ft), and 2.5 m (8 ft), respectively. At each lake depth, a 2 x 2 m square plot was established. Each of the lake plots were further divided into four subplots (Figure 4.5). This division allowed for identification of where the sampling was to occur in respect to the shoreline and provided an avenue to randomize the sample collection at each subplot. Sampling of groundwater, seepage water, sediment, and macrophytes was conducted during the months of June, July and August of 1993.

Figure 4.5. Plot layout for seepage meters at each lake depth.



Sampling of Seepage Meters

Seepage meters were used to determine the flux of water entering the lake through lake sediments. These devices also allowed for the chemical analysis of seepage water after it passed through the lake sediment. Seepage meters were constructed according to Lee (1977) and installed into the lake bed using Self Contained Underwater Breathing Apparatus (SCUBA) at each of the groundwater inflow sites mentioned at lake depths of 1.0, 1.5, and 2.5 m (Figure 4.4). The seepage meter was placed in the center of each plot (Figure 4.5) and allowed to equilibrate prior to sampling for a period of at least 24 hours, as outlined in Lee (1977).

After placing the sample bag on these meters it became apparent that precipitation of iron from the seepage water and heavy algae growth was occurring within the bag. To inhibit this, 3 ml of 18N H_2SO_4 was added to the bags prior to sampling. This worked very well, but eliminated the ability to analyze for pH, conductivity, and alkalinity in these samples.

The meters inserted in the lake sediments at 2.5 m were not consistently sampled as they tended to float away most often due to the nature of the very soft sediments. During the second and third sampling periods, heavier weights were placed on the top to better secure them. This worked with varied success.

Seepage water samples were collected and stored in 250 ml sample bottles. Sample preservation was in accordance with APHA (1989).

Sediments

Winter Sampling

During January of 1993, a sediment survey was performed on Legend Lake. Since the lake was ice covered, it enabled us to collect information about the sediment that would otherwise be very difficult to obtain. The transects were laid at various intervals around the lake. Several transects were located where they crossed the deepest sections of each lake basin, while the remaining transects filled in the voids.

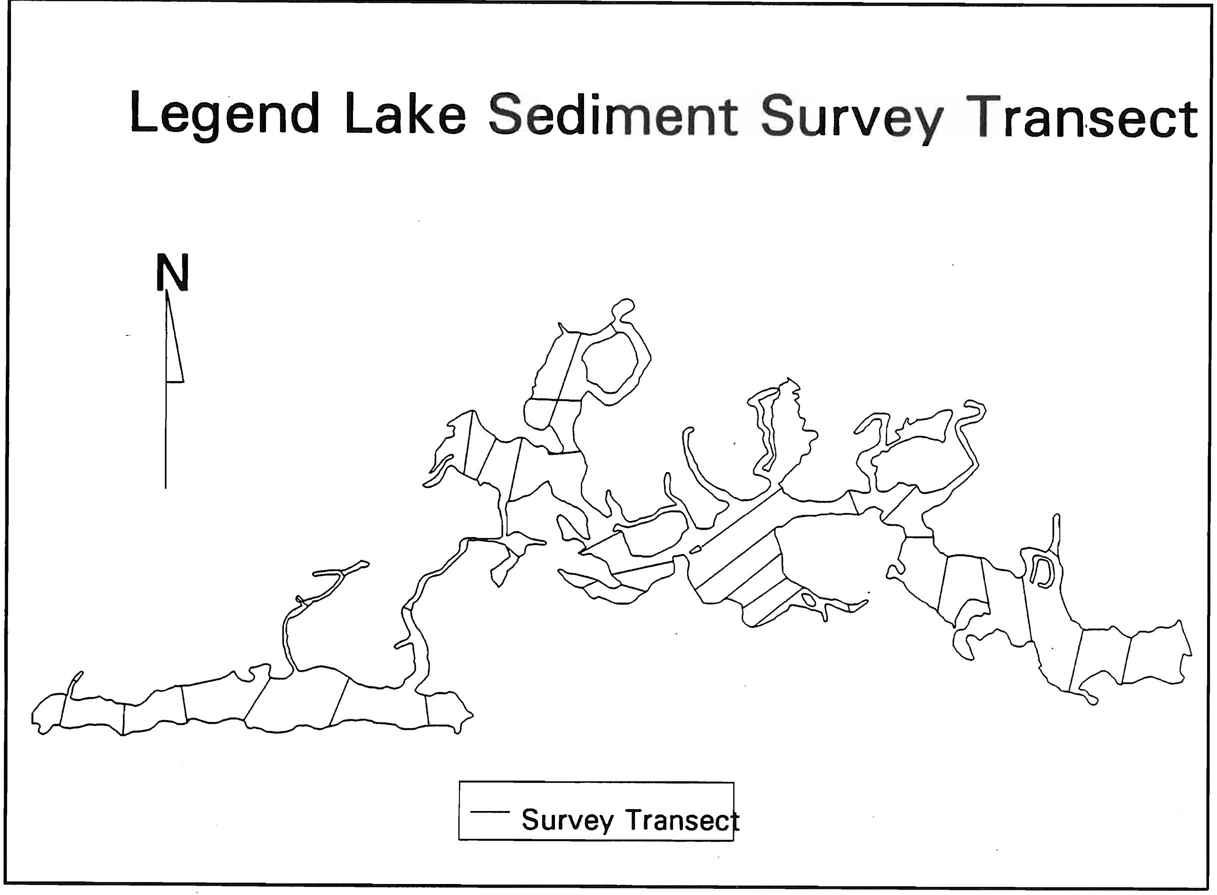
Several sampling sites were located on each transect where samples were taken at various depths to obtain a profile with depth (Figure 4.6). At each sample site an ice auger was used to drill a hole, depth to sediment was determined using a Secchi disk, a measurement of sediment thickness was determined, and a sediment sample was taken for laboratory analysis. Distances from each sample site were measured using a tape measure. At the ends of each transect, parcel addresses were used for quick location identification.

To measure sediment thickness, several sections of aluminum pipe were connected and lowered into the water. The depth was measured when the sediment surface was reached as well as when the pole could no longer penetrate the sediment. The difference of these measurements was the sediment thickness. Two different methods were used to collect sediment samples. For shallower depths (less than 4.6 m or 15 ft), a 0.6 m (2 ft), 5.1 cm (2 in) I.D. PVC pipe was connected to a metal pipe and lowered into the water. Once the sediment surface was reached, the PVC pipe was forced into the sediment as far as it could go, pulled up and the sediment that remained in the pipe was placed in a plastic bag and stored in a cooler. For deeper depths (greater than 4.6 m or 15 ft), a Wildco Bottom Sediment Sampler was dropped in the water and allowed to penetrate the sediment under its own weight. A messenger was dropped to trigger the trap door and the sediment that was trapped was placed in a plastic bag and stored in a cooler.

Seepage Meter/Sediment/Macrophyte Study

In addition to the winter sediment sampling, sediment cores were collected from each lake sampling plot in Basins A and B for each sample date described previously for seepage meters. A composite sample for each depth was derived by collecting one sediment core from each of four subplots. Samples were obtained by means of a simple device using a 61 cm (24 inch) length of P.V.C. schedule 40 5.1 cm (2 inch) pipe. This core sampler was inserted into the upper 25 cm (10 in) of sediment and a rubber stopper was inserted into the top of the pipe to create a suction. The sample was then extracted from the lake bottom. Sediment samples were transferred from the corer to 0.946 liter food grade containers for storage on ice until delivery to the ETF laboratory.

Figure 4.6. Plan view map of transects used for sampling sediments and lake water.



At the ETF laboratory, a sub-sample of each of the samples was taken for NO_2+NO_3-N and NH_4 analysis. The remaining sample was oven dried at 60°C until a constant weight was obtained. The hardened sediment cakes were then ground by mortar and pestle and sieved through a number 10 screen. This sample was divided with one half retained at the ETF laboratory and the second half sent to the University of Wisconsin - Madison, Soils and Plant laboratory where the following analysis were performed: TP, TN, TK, Ca, Mg, Cu, NO_2+NO_3-N, NH_4, available P, and available K.

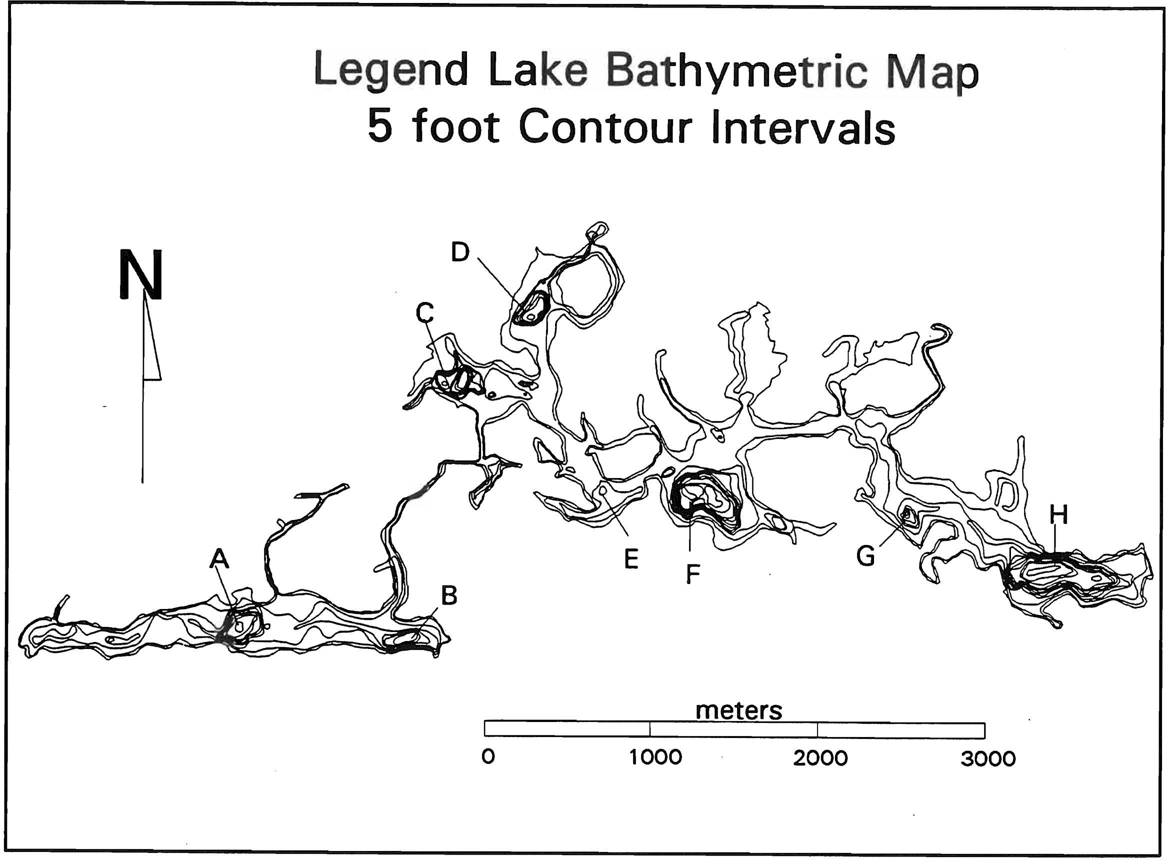
Lake Sampling

Lake sample site locations were selected to provide representative water samples for the entire lake system in the deepest area of each lake, as shown in Figure 4.7. Inlet and outlet sampling was done to determine the nutrient inflow and outflow.

The water columns of each of the eight lake basins that make up Legend Lake were sampled at the deepest part of the lake basins. Three neighboring lakes (LaMotte, Sand, and Round Lakes) that were not part of the Legend Lake development and are not connected by surface channels, were also sampled at the deepest part of their lake basins. These three lakes are downgradient and receive some of the groundwater flow from Legend Lake (Hoffman, 1977). Water samples were collected using a peristaltic pump at each of the eleven sites from three depths in the water column (sometimes referred to in this study as epilimnion, metalimnion, and hypolimnion although these are technically seasonal thermal strata). Six depths were sampled at two sites (Basins A and F). Bi-monthly samples were taken at sites A and F between spring and fall turnover. Monthly samples were taken between spring and fall turnover for all other sites in 1992 and 1993. Ice-on samples were taken in January of 1993 and 1994. Separate samples bottles were either left unpreserved or were preserved for specific chemicals in accordance with EPA guidelines for sample preparation using sulfuric acid, nitric acid, or zinc acetate. Samples were stored and transported on ice to the ETF Lab, where the following analyses were performed: COD, alkalinity, total hardness, silica, sulfate, sulfide, P and N, Fe, and Mn. The water samples were analyzed in the ETF laboratory according to the methods prescribed in the QAPP (Shaw, 1993). At each sample site the epilimnion was also measured for water clarity using a Secchi disk, and one liter water samples were collected using a 6 m (20 ft) PVC hose and a depth integrated sampler for chlorophyll *a* analysis.

Secchi Disk measurements were conducted on the shaded side of the boat using a standard eight inch diameter black and white Secchi disk attached to a calibrated line. The readings were recorded in 0.1 m (0.3 ft) units (Houston, 1994).

Figure 4.7. Bathymetric map of Legend Lake. Contours are at 1.5 m intervals.



Dissolved Oxygen Profiles

Field measurements of dissolved oxygen, temperature, conductivity, and pH were made at each of the deep hole sites on each sampling date. The measurements for these four characteristics were taken at 0.5 m below the surface and at 1 m increments, beginning with 2 m below the surface and ending approximately 1 m above the sediment. During open water seasons, these measurements were obtained on site using a Cole Parmer multi-characteristic meter where the probe was in the sample stream of water pumped using a peristaltic pump and hose reel assembly. Additional profiles were measured for each of the deep hole sites twice during ice-on, and along several basin transects during June 1993 and January 1994 using a Yellow Springs Instruments Model 50B Dissolved Oxygen Meter having a 100 foot cable probe.

Macrophytes

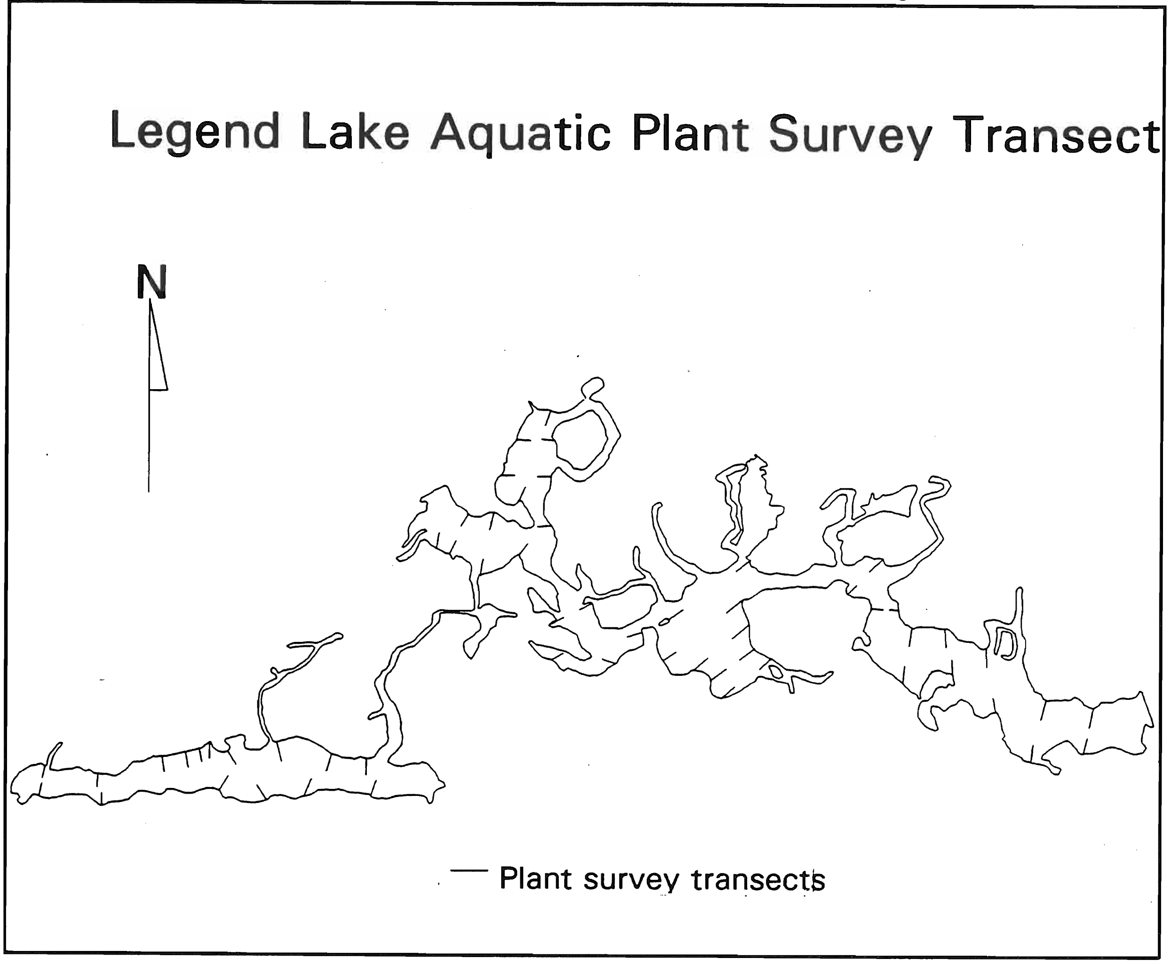
Two aquatic macrophyte sampling and analysis projects were included in this study. The first one corresponds with the seepage meter study, the second incorporates a whole lake macrophyte survey done July 1993.

Seepage Meter/Sediment/Macrophyte Study

Aquatic macrophyte samples were collected at each lake site using SCUBA. The macrophytes at each depth were sampled from the subplots and labeled corresponding to sampling dates for each lake depth. Three 0.1 m^2 square samples were collected from within three of the four subplots at each depth near the area of seepage meter placement and sediment core removal (Figure 4.8). The plants were stored in polyethylene plastic bags and transported in a ice chest to the ETF laboratory. Macrophyte samples were washed using distilled water to remove any marl or sediment deposition. The plants were then sorted by species and the roots were removed. A wet weight was obtained for each species at each depth and oven dried to constant mass at 60°C. This was used to calculate plant biomass. The dried tissue was then ground through a Wiley mill using a 0.5 mm screen and stored in polyethylene bags prior to tissue analysis.

Plant tissue was analyzed by the University of Wisconsin - Madison, Soil and Plant Laboratory for the following chemicals: T.P., T.N., T.K., Ca, Mg, S, Bo, Mn, Zn, Cu, Fe, Al, $NO_2 + NO_3$-N, NH_4, available P, and available K.

Figure 4.8. Map of transects used for macrophyte sampling in Legend Lake.



Lake Macrophyte Survey

In July 1993, a macrophyte survey was performed throughout the whole Legend Lake Basin using a SCUBA technique. Fifty-nine transects were placed throughout the lake perpendicular to the shore, with a maximum length of 46 m (150 ft). Placement of these transects corresponded to the placement of sediment sampling transects that were established during January 1993 (Figure 4.6) as one objective was to identify relationships between sediment and plant characteristics. The transect locations were also identified using the parcel numbers within each subdivision. A series of plots were placed at 0.4, 0.9, 1.5, and 2.4 m (1.5, 3, 5 and 8 ft) depths for each transect.

A 2 m^2 circle was used to delineate the plot boundary, which was further divided into 4 equal quadrants. Information that was collected for each quadrant was species presence, bottom type, distance from shore, an estimate of relative abundance, and a 0.1 m^2 biomass sample which was wet weighed. The relative abundance estimate was based on a value system with 1 representing very little plant matter and a 5 representing very high amounts of plant matter. The sampling design was based on a modification of the methods developed by Jessen and Lound (1962).

Lake Morphology

Bathymetric maps of the lake basins were completed by UWSP students early in 1992. These maps provided the depth contours that were entered as a coverage into the geographic information system (GIS). The depth contours facilitated the division of the present day Legend Lake into sections that correspond to the historic lake basins and channels. The definition of separate lake basins and depth contours within the GIS enabled the calculation of separate lake basin volumes. The GIS produced an area corresponding to each depth contour, and a volume for the strata of water between two depth contours was estimated using the summation of a series of truncated cones:

$$V=\frac{h}{3[A_1 + A_2 + \sqrt{(A_1A_2)}]}$$

Where h is the thickness of the strata, A_1 is the area of the upper boundary, and A_2 is the area of the lower boundary of the strata. These strata volumes were summed to arrive at lake basin volumes. Figure 4.9 exhibits these results.

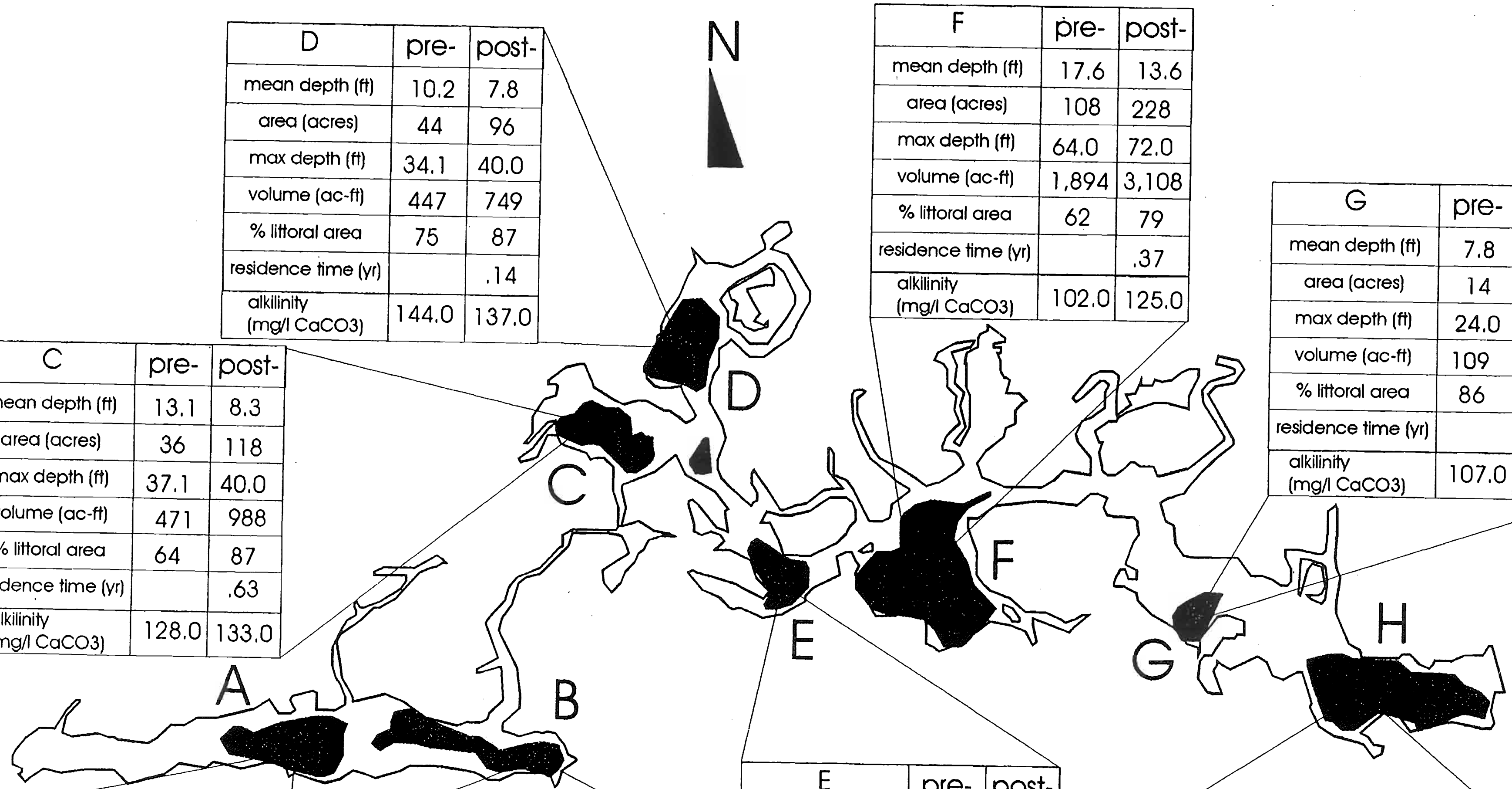
Each separate lake basin was then subdivided into volumes for the epilimnion, metalimnion, and hypolimnion. Table 4.3 shows the relative volumes for each of these strata by basin during maximum summer stratification. The boundaries of each thermal stratum were identified using the average August 1992 and 1993 profiles of temperature vs. depth at the deep hole sites (Lasenby, 1975). The inflection point was designated where the first derivative of the falling limb of each profile reached a minimum. The boundaries of the metalimnion were defined as, where the best fit line drawn through the inflection point and along the falling limb bisected the best fit lines drawn through the upper and lower depth profiles. Identifying these strata allowed a fixed layer of water in each basin to be monitored over time for chemical concentrations and dissolved oxygen depletion rates.

The fetch of each basin was measured along the direction of the prevailing winds (Table 4.4). The direction of wind during the spring and fall turnover are more critical than other periods. The Green Bay, Wisconsin weather station measured

Table 4.3. Depth to hypolimnion and relative volumes of thermal strata for eight Legend Lake basins and two downgradient lakes. (Houston, 1994)

Basin	Name	Depth to Hypolimnion	% Volume Epilimnion	% Volume Metalimnion	% Volume Hypolimnion
A	Wah-toh-sah	8.4	86.2	11.8	2.0
B	Skice	8.4	88.5	11.2	0.4
C	Spring	7.4	72.2	21.2	6.6
D	Peshtigo	7.0	68.2	22.9	8.9
E	L. Blacksmith	n/a	99.8	0.2	0.0
F	Blacksmith	9.4	62.6	18.0	19.4
G	Sapokesick	7.8	95.5	3.8	0.7
H	Pywaosit	10.0	61.5	28.2	10.3
I	Round Lake	7.0	52.9	42.7	4.5
K	LaMotte Lake	8.2	41.2	40.2	18.6

Figure 4.9. Lake basin characteristics before and after the development of Legend Lake. Characteristics include mean and maximum depth, area, volume, percent littoral zone, and estimated residence time.



A	pre-	post-
mean depth (ft)	9.5	10.2
area (acres)	48	311
max depth (ft)	36.1	40.0
volume (ac-ft)	458	3,185
% littoral area	75	84
residence time (yr)		1.35
alkilinity (mg/l CaCO3)	116.0	134.0

B	pre-	post-
mean depth (ft)	6.5	11.5
area (acres)	45	(A)
max depth (ft)	21.0	29.9
volume (ac-ft)	291	(A)
% littoral area	88	77
residence time (yr)		(A)
alkilinity (mg/l CaCO3)	80.0	132.0

C	pre-	post-
mean depth (ft)	13.1	8.3
area (acres)	36	118
max depth (ft)	37.1	40.0
volume (ac-ft)	471	988
% littoral area	64	87
residence time (yr)		.63
alkilinity (mg/l CaCO3)	128.0	133.0

D	pre-	post-
mean depth (ft)	10.2	7.8
area (acres)	44	96
max depth (ft)	34.1	40.0
volume (ac-ft)	447	749
% littoral area	75	87
residence time (yr)		.14
alkilinity (mg/l CaCO3)	144.0	137.0

E	pre-	post-
mean depth (ft)	4.5	6.4
area (acres)	24	94
max depth (ft)	9.8	15.1
volume (ac-ft)	111	602
% littoral area	100	99
residence time (yr)		.09
alkilinity (mg/l CaCO3)	135.0	125.0

F	pre-	post-
mean depth (ft)	17.6	13.6
area (acres)	108	228
max depth (ft)	64.0	72.0
volume (ac-ft)	1,894	3,108
% littoral area	62	79
residence time (yr)		.37
alkilinity (mg/l CaCO3)	102.0	125.0

G	pre-	post-
mean depth (ft)	7.8	7.0
area (acres)	14	180
max depth (ft)	24.0	35.1
volume (ac-ft)	109	1,252
% littoral area	86	95
residence time (yr)		.12
alkilinity (mg/l CaCO3)	107.0	111.0

H	pre-	post-
mean depth (ft)	18.0	16.3
area (acres)	85	212
max depth (ft)	59.0	69.9
volume (ac-ft)	1,531	3,446
% littoral area	53	67
residence time (yr)		.33
alkilinity (mg/l CaCO3)	73.0	111.0

prevailing directions and average wind speeds (mph) as follows: April NE 12, May NE 11, June SW 10, October SW 10, and November SW 12 (U.S. Dept. Commerce, 1968). An additional measurement was made along the southwest vector from the deep hole site to the windward shore of each basin.

Figure 4.9 shows lake characteristics for the Legend Lake basins both before and after the construction of Legend Lake. These characteristics include mean and maximum depth, area, volume, percent littoral zone, and estimated residence time.

Table 4.4 Lake basin fetch from southwest wind direction.

Basin	Name	Southwest Fetch (m)	Windward Distance (m)
A	Wah-toh-sah	442	193
B	Skice	428	170
C	Spring	380	202
D	Peshtigo	642	316
E	L. Blacksmith	265	135
F	Blacksmith	1052	215
G	Sapokesick	527	144
H	Pywaosit	550	350
I	Round Lake	420	172
K	LaMotte Lake	872	490

Climatological Data

Climatological data for precipitation and temperature was obtained from the State Climatology Office. Comparative stream discharge data was obtained from the USGS Water Resource Data - Wisconsin.

The inlet and outlet streams did not have continuous flow gages installed. The estimated annual water budget relies on the extrapolation of 13 instantaneous discharge measurements taken throughout the study. Each stream discharge value was grouped by season so that an annual mean discharge could be computed from the seasonal means. The annual mean discharges are to represent the two year period only.

To determine whether the extrapolated annual mean discharges of these streams were representative of the annual discharge, continuous discharge data for the Oconto River near Gillett, WI was seasonally and annually averaged using the same dates as the Legend Lake stream discharge data. Using this method resulted in the computed mean annual discharge for the Oconto River within 3% of the published discharge value. This gives us confidence that there were sufficient readings taken on Legend Lake to accurately measure inflow and outflow. The computed value slightly overstated the true value based on Oconto River comparisons.

Geographic Information System

The geographic information system pcARCINFO was used to create maps of Legend Lake, it's components, and it's watershed. Data that was obtained from the substudies was entered into the pcARCINFO system to generate coverages (maps) of soils, chemical concentrations in groundwater, macrophyte distribution, sediment depth, and bathymetric maps of the lake. These coverages can be used for spacial analyses and can be layered to produce maps that show interrelationships between various components of the system. The databases that are used to make these coverages can be used to measure distances and area, which can be useful in volume calculations.

This GIS system consists of several coverages including soils, glacial geology, and the terrestrial vegetation of the area in addition to the water resource information. The data used was taken from surveys conducted by the Wisconsin Geological and Natural History Survey (1964), lake contours (Wisconsin, 1992), lake sediment thickness (this study), delineated parcels, watershed and sub-watersheds (USGS, 1982), regional hydrology, road network, and regional contours (Menominee Tribal Environmental Services). In addition, sampling results from this Legend Lake Project (1992 to 1994) was incorporated into the system. This included data from the surface water, groundwater, lake sediment, and the aquatic plant surveys.

5.0 PROJECT RESULTS

Lake Hydrology and Water Budget

It was important for the purpose of this project to investigate the availability and movement of water so that estimates could be obtained for hydraulic loading rates and hydraulic residence times of the lake basins. However, there is not a lot of information about the detailed hydrology of the Legend Lake watershed, which would have benefited this project. Unfortunately, it was beyond the scope of this project to make determinations of watershed basin responses to specific water events.

Legend Lake Watershed

Figure 5.1.1 shows the Legend Lake watershed. The watershed has four outlets for water (designated O-1, O-2, O-3, and O-4). There are two streams originating within the watershed that feed the lake basins (designated I-1 and I-2). All of the lake basins that make up Legend Lake are connected by channels. The separate lakes along the southern boundary (Round, Sand, LaMotte, and Keshena) are considered part of the watershed because of groundwater connections.

The watershed was divided into sub-watersheds based on topography as shown in Figure 5.1.1. The land and surface water areas that make up the sub-watersheds and total watershed areas are shown in Table 5.1.1.

Flow Patterns

A review of the hydrologic challenges that faced the Legend Lake developers shows that flow patterns were not predictable (Born and Stephenson, 1974). Before construction, the area consisted of two separate watersheds: (1) Wah-toh-sah Creek, a tributary of the Wolf River, flowed west out of two connected drainage lakes, Wah-toh-sah and Skice, (2) Linzy Creek, a tributary of the Oconto River, flowed to the east and combined the Peshtigo-Spring Lake drainage basins with the drainage lakes

Table 5.1.1. Legend Lake subwatershed areas and lake basin areas.

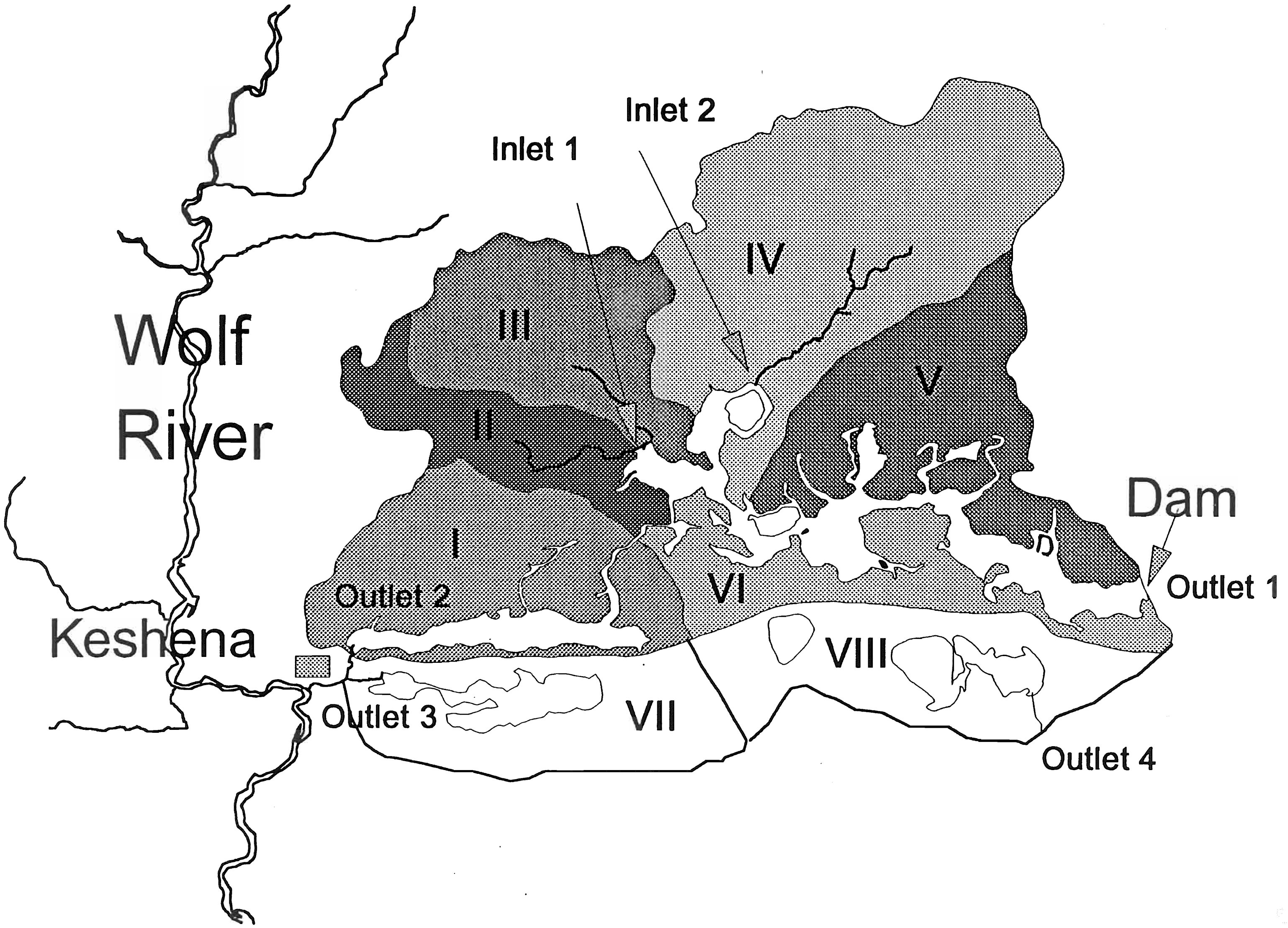
Sub-watershed	Area (Hectares)	Area (Acres)
I	623.8	1,541
II	332.4	821
III	536.3	1,325
IV	1,180.3	2,917
V	631.5	1,560
VI	380.4	940
Legend Lake (See Below)	498.8	1,233
Brave I	12.4	31
F1 Island	.7	2
F2 Island	.3	1
D Island	14.1	35
H Island	1.8	4
Subtotal	4,213.4	10,411
VII - LaMotte	552.0	1,364
VIII - Sand/Round	550.0	1,359
Total	5,315.5	13,134

Legend Lake Basin	Name	Surface Area (Hectares)	Surface Area (Acres)
A&B	Wahtohsah/ Skice	114.5	283
C	Spring	47.8	118
D	Pestigo	38.8	96
E	L. Blacksmith	37.6	93
F	Blacksmith	102.0	252
G	Sapokesick	63.5	157
H	Pywaosit	85.7	212
	Main Channel	8.9	22
	Total	498.8	1,233

Blacksmith, Pywaosit, and Moshawguit. Figure 5.1.1 shows the pre-development drainage patterns of the Legend Lake watershed.

The first phase of construction of Legend Lake was to dam Wah-toh-sah Creek in order to raise the water level of Wah-toh-sah and Skice Lakes, however, it was only partly successful as the quantity of water was insufficient to fill the lake. It was found

Figure 5.1.1.. Legend Lake watershed and subwatershed showing surface inlets and outlets.

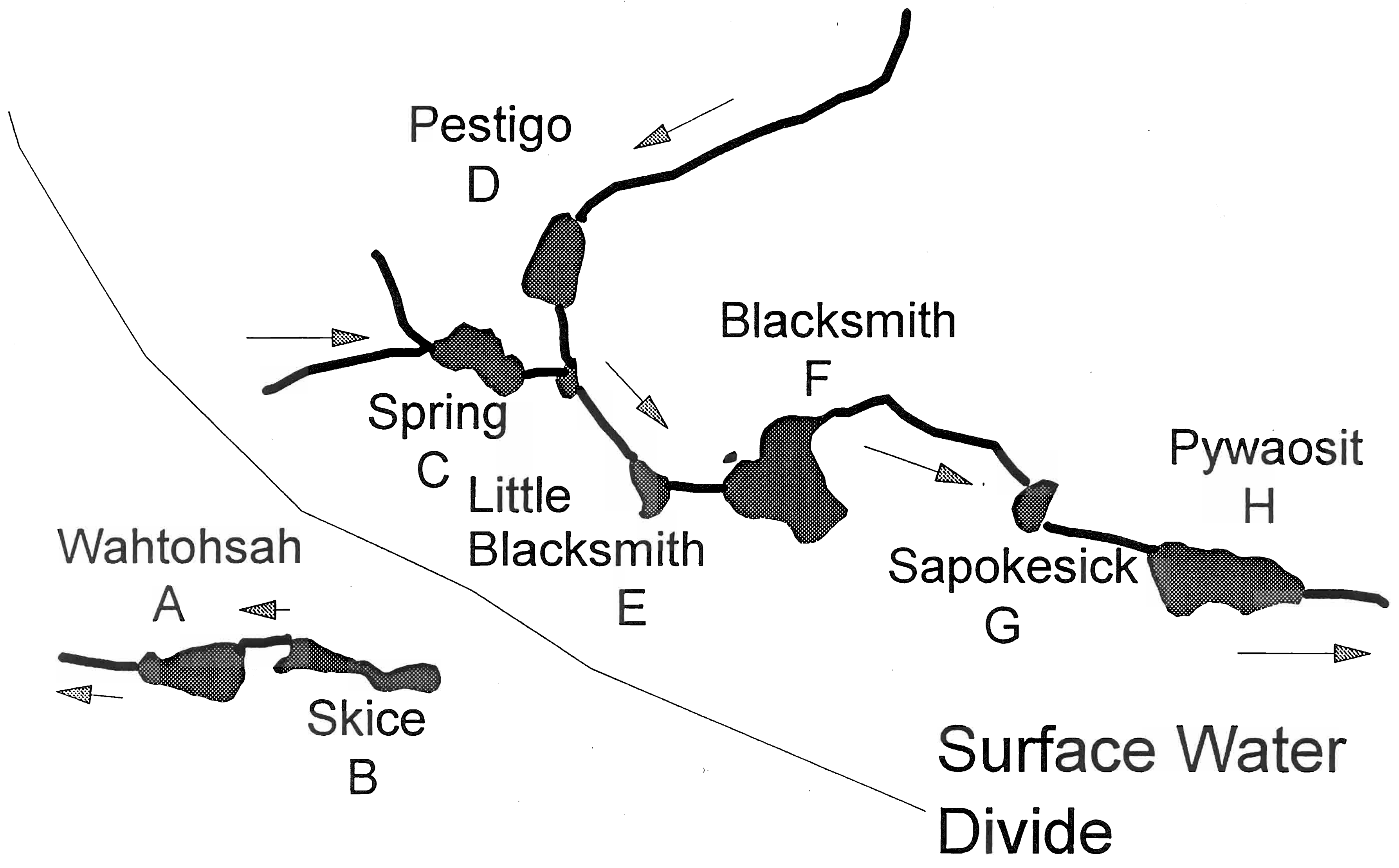


that the natural groundwater flow through the northwest perimeter was low and the raising of the water table caused a reversal in the groundwater flow between LaMotte and Wah-toh-sah Lakes, so LaMotte Lake is now receiving water as groundwater flow from the north (Hoffman, 1977).

A one mile long channel was constructed to the north to capture water from the Peshtigo-Spring basin. Based on erroneous topographic information, a temporary dam was approved and constructed across Linzy Creek at the western end of Little Blacksmith Lake to divert water to the south through the channel. A revised survey indicated that the dam was not necessary. The dam constructed at the eastern edge of the project would have been sufficient to cause enough water to be diverted.

The present-day direction of surface water flow was checked on two occasions in the one mile long channel connecting lake basin B to C. This was done through the ice by releasing a dye in one hole and timing the appearance of the dye to holes spaced five feet north and south of the dye release hole. On January 13, 1994, the flow was from south to north; on March 11, 1994, the flow had reversed to flow from north to south. At the time the water was found to be moving north, the discharge at the dam was greater than the discharge of the stream inlets. This is the normal situation when there is a net discharge of surface water. Conversely, at the time the water was found to be moving south, the discharge at the dam was less than the discharges of the stream inlets. This unusual situation occurs when the lake levels are raised in spring, during snow melt, or after heavy rain.

Figure 5.1.2. Pre-development drainage patterns of the Legend Lake watershed.



Runoff Estimation

Even if the computed discharges for the watershed that were discussed previously are representative for the period, the values computed are still not necessarily the same as total runoff from the watershed. Some water leaves the watershed by groundwater as well as through the streams. The Legend Lake impoundments have a history of seepage around the dam and through groundwater to downgradient lakes (Born and Stephenson, 1974; Hoffman, 1977). Groundwater gradients identified in a this study show groundwater leaving in several directions from the eastern and western lake basins; therefore, it should be expected that watershed runoff is greater than outlet stream discharge.

Total runoff from the watershed area could be estimated by two methods: (1) use a comparable watershed for which discharge data is available, or (2) balance the water budget equation. Both of the approaches were used for Legend Lake (Houston, 1994).

Flow data was obtained from the USGS gaging station located on the Oconto River near Gillett, WI. The Oconto River watershed has daily discharge data available for comparison. The Oconto watershed at Gillett has a drainage area of 705 square miles (1,826 km^2) with the 20.5 square mile (53 km^2) Legend Lake watershed as part of its headwaters. The overall land use of the two watersheds is different. Agricultural areas found in the Oconto River watershed are not found in the Legend Lake watershed. On the other hand, climate, soils, and geology are similar. The Oconto River watershed produced 12.63 and 16.69 inches of runoff for the water years 1992 and 1993, respectively, for a mean runoff of 14.66 inches. This compares to a long term average of 11.2 inches indicating that both years were above normal for precipitation and river flows.

Table 5.1.2. Streamflow data used in the computation of estimated annual stream discharge (cfs) and data for the same date sampled on the Oconto River. Data are inches.

	Inlets		Outlets				
DATE	Spring Lake I-1	Linsey Creek I-2	East Dam O-1	West Dam O-2	Hwy VV O-3	Pine Lake O-4	Oconto River
WINTER							
01/11/94	1.9	5.2	9.8	0.0			490
03/11/94	2.5	5.3	2.0		3.3	EST	580
MEAN	2.2	5.3	5.9	0.0	3.3	1.5	535
SPRING							
06/15/92	0.4	6.8	22.8	0.0	2.6	2.1	418
05/17/93	2.0	9.8	27.5	0.1	4.2	3.2	1,190
06/01/93	2.7	11.8	34.1	0.1	6.7	4.5	1,190
06/15/93	2.2	8.1	24.6	0.1	6.6	5.0	1,390
MEAN	1.8	9.1	27.2	0.1	5.0	3.7	1,047
SUMMER							
07/13/92	0.8	7.5	8.9	0.0	4.9	1.4	519
07/27/92	0.1	3.9	5.9	0.0	3.2	1.0	328
08/10/92	0.0	3.7	26.3	0.1		0.9	346
08/26/92	2.9	10.9		0.0	3.2	1.3	343
06/30/93	2.1	10.8	36.8	0.1	6.5	5.1	1,430
08/02/93	1.5	2.9	8.3	0.0	3.9	1.1	543
MEAN	1.2	6.6	17.2	0.0	4.3	1.8	585
FALL							
11/08/93	2.1	8.3	4.3	0.0	3.2	2.3	983
ESTIMATED ANNUAL MEAN (CFS)	1.9	7.3	13.7	0.0	4.0	2.3	787
ACRE-FT	1,341	5,305	9,899	20	2,874	1,674	570,120

SUMMARY	**CFS**	**ACRE-FT**	**AREA ACRES**	**RUNOFF INCHES**
INLET STREAMS	9.2	6,646		
OUTLET STREAMS	20.0	14,467	13,134	13.2
OCONTO R.	787.0	570,120	451,200	15.2

Table 5.1.2B. Comparison of inlet and outlet flows for Legend Lake to the total discharge for Oconto River.

	CFS	Acre-Ft	Area Acres	Runoff Inches
Legend Lake Inlet Stream	9.2	6,646		
Legend Lake Outlet Stream	20.0	14,467	13,134	13.2
Oconto River Est. Flow from Gillette WI Gaging Station	787	570,120	451,200	15.2
Oconto River Flows from Total Flow Record				14.7

Water Budget - Legend Lake Watershed

Balancing the water budget equation required a determination of precipitation, evapotranspiration (ET) and change in storage. It was assumed that long term storage changes were zero as the lake levels were the same at the beginning and end of this project.

A mean runoff of 14.66 inches (Table 5.1.3) was calculated for the land surface areas of the watershed. This amount includes surface runoff, interflow, and groundwater discharge to the lake basins. For the lake surface areas, net precipitation of 8.3 inches was used (38.12 inches precipitation less 23.46 inches evapotranspiration corrected for .78 lake pan coefficient, US Dept. Commerce, 1983). The water budgets shown in **Table 5.1.4** were constructed using the sub-watershed areas as well as surface water and groundwater flow patterns. For example, the LaMotte sub-watershed budget was calculated from the known amounts of net precipitation falling on the lake surface area, runoff from the land surface area, and the discharge at the Highway VV outlet (O-3) to solve for the influx of groundwater from the northern Legend Lake basin. The amount of groundwater flow from Legend Lake basin to LaMotte basin then became a calculated quantity in the Wah-toh-sah/Skice sub-watershed water balance equation. Each sub-watershed was treated in sequence in order to solve for interbasin channel and groundwater flows that could not be measured directly. Based on this water budget, 2,134 acre-feet (13 percent) leaves the watershed as groundwater and 14,447 acre-feet (87 percent) leaves as streamflow through surface outlets.

Table 5.1.3. Legend Lake water balances that result from comparing Oconto and Legend Lake hydrologic characteristics.

	Precipitation - ET ± Storage = Runoff
1992	34.33 - 21.70 ± 0 = 12.63 inches
1993	41.91 - 25.22 ± 0 = 16.69 inches
Mean	38.12 - 23.46 ± 0 = 14.66 inches

Table 5.1.4 Water budgets in acre feet of water per year for Legend Lake subwatersheds and the total watershed. Data based on 1992 and 1993 water years.

	Total Watershed	LaMotte Subshed	Wahtohsa Skice Subshed	Spring Subshed	Pestigo Subshed	Round/ Sand Subshed	Little Blacksmith Subshed	Blacksmith Subshed	Sapokesick Subshed	Pywaosit Subshed
Inputs										
Precipitation										
Surface Water	1,114 c	126 c	196 c	82 c	66 c	165	64 c	160 c	109 c	147 c
Land	7,405 c	1,444 c	1,883 c	122	61	1,377 c	38 c	1,405 c	953 c	122 c
Stream Inlets	6,646 s			1,341	5,305					
Subshed Imports										
Groundwater	1,416	1,284 f				132 f				
Channel Inlets							6,977 p	7,079 p	8,645 p	9,706 p
Total Input	16,581	2,854	2,078	1,545	5,432	1,674	7,079	8,645	9,706	9,975
Outputs										
Stream Outlets	14,447 m	2,854 m	20 m			1,674 m				9,899 m
Groundwater	2,134 f		2,058 pf							76 fp
Channel Outlets				1,545 f	5,432 f		7,079 f	8,645 f	9,706 f	
Total Output	16,581	2,854	2,078	1,545	5,432	1,674	7,079	8,645	9,706	9,975

Notes:

Units are in **Acre-Feet Per Year**

c	calculated from land/water area multiplied by runoff (Table 5.1.3)
f	calculated amount needed to balance the water budget
m	measured discharges extrapolated to annual quantity
p	quantity determined from adjacent watershed budget

Hydraulic Loading and Residence Time

Information from the estimated water budgets and from the lake basin morphometry was used to compute the hydraulic loading rates of each lake basin (Table 5.1.5) and the hydraulic residence time of each lake basin (Table 5.1.6).

Table 5.1.5. Hydraulic loading rates by lake basin for Legend and LaMotte lakes.

	Lake Basin	Water Budget Inputs (Acre-Ft)	Lake Basin Area (Acres)	Hydraulic Loading Rate (Ft/Year)	Hydraulic Loading Rate (M/Year)
A&B	Wahtohsah/Skice	2,078	311	7.3	2.2
C	Spring	1,545	118	13.1	4.0
D	Pestigo	5,432	96	56.6	17.2
E	L.Blacksmith	7,079	94	76.1	23.2
F	Blacksmith	8,645	228	37.3	11.4
G	Sapokesick	9,706	180	61.8	18.8
H	Pywaosit	9,975	212	47.1	14.3
J	Sand				
K	LaMotte	2,854	182	15.7	4.8

Table 5.1.6. Hydraulic residence time by lake basin for Legend and LaMotte lakes.

	Lake Basin	Water Budget Outputs (Acre-Ft)	Lake Basin Volume (Acre-Ft)	Hydraulic Residence Time (Years)	Hydraulic Residence Time (Days)
A&B	Wahtohsah/Skice	2,078	3,186	1.35	492
C	Spring	1,545	988	0.63	229
D	Pestigo	5,432	749	0.14	52
E	L.Blacksmith	7,079	602	0.09	31
F	Blacksmith	8,645	3,114	0.37	134
G	Sapokesick	9,706	1,052	0.12	43
H	Pywaosit	9,975	3,446	0.33	121
J	Sand				
K	LaMotte	2,854	3,530	1.24	451

Lake Water Quality Monitoring and Trophic State of Each Lake

Lake water quality monitoring was performed throughout the project period as described in the section on surface water methods. Table 5.2.1 summarizes the chemical properties of each lake basin as weighted annual means and as seasonal mean values. For annual mean values, the results of the chemical analysis for each depth have been weighted by the volume of the lake basin stratum that brackets each depth. Therefore, a high concentration found in a low volume hypolimnion does not distort the results that are presented. Sampling efforts were greater during the summer than during the early and late winter; so to present a representative annual mean, the data was first averaged by season then the seasonal means were averaged to yield an annual mean.

In addition to phosphorous, other measures were taken to assist in the diagnosis of the trophic state and general water chemistry of each lake basin. Water transparency was measured by Secchi disk depth. Algae was measured using chlorophyll *a* concentrations. Table 5.2.2 shows the three water characteristics and their range of values within the water quality index for Wisconsin lakes as presented by Lillie and Mason (1983). Table 5.2.3 shows the results of the Secchi disk measurements for this project. Separate averages were computed for spring turnover, summer, and fall turnover with all the results ranging from good to very good.

Table 5.2.4 shows the results of the chlorophyll *a* analysis. The results were also averaged by season. These measures of algae indicate that the lake basin sites have water quality that ranges from good to excellent, according to the index in Table 5.2.2. Table 5.2.5 shows the seasonal mean values of total phosphorus from the epilimnion of each sample site. The total phosphorus results indicate that the lake basin water quality ranges from good to very good. The relatively low nutrient loading

Table 5.2.1. Summary of Legend Lake Oxygen, Morphometric, Hydrologic, Nutrient, and Chemistry Data by Lake Basin.

Characteristic	Units	A	B	C	D	E	F	G	H	I	J	K
Oxygen Depletion												
Winter Loss	%	70	77	71	63	78	49	29	25	64		62
Winter VOD	mg/m^3/d	71	79	37	26	47	32	10	13	45		36
Carbon Sources												
Sediment O.M.	%	17.7	32.1	26.9	27.6	7.5	13.2	0.2	7.2			
Aquatic Plants	g/m^2	430	430	422	479	359	460	300	271			
Chlorophyll a	ug/l	3.8	1.9	3.5	1.0	4.2	4.6	3.0	1.9	1.4	3.3	3.1
Secchi(Summer)	m	2.4	3.4	2.7	3.1	2.4	3.3	2.8	3.9	3.4	2.5	3.3
Fall C:N water		11.3	10.7	19.7	25.3	27.4	30.6	37.9	19.7	26.2		10.2
Littoral Zone	%	83.0	77.0	81.0	91.0	99.0	59.0	6.0	49.0	51.0		54.0
Hydraulic												
Loading Rate	m/yr	2.2	2.2	4.0	17.2	23.2	11.4	18.8	14.3			4.8
Residence Time	days	492	492	229	52	31	134	43	121			451
Morphometric												
Volume	m^3x10E6	2.1	1.3	1.2	0.9	0.7	3.9	1.7	4.1	1.1	0.9	4.3
Surface Area	Hectare	74	40	48	39	38	102	64	86	23	42	74
Mean Depth	m	3.0	3.0	2.5	2.5	2.0	3.8	2.2	4.7	4.7	2.2	5.9
Maximum Depth	m	12.2	9.1	12.2	12.2	4.6	21.9	10.7	21.3	11.3	8.5	22.2
Total Phosphorus												
Vol. Weighted Mean	ug/l	15	21	22	18	13	23	15	15	17	14	39
Spring Epilim.	ug/l	19	36	16	25	13	14	14	12	11	11	16
Summer Hypolim.	ug/l	77	46	164	112	21	110	40	81	55	42	197
React P VWMean	**ug/l**	**6**	**6**	**8**	**7**	**4**	**18**	**6**	**8**	**4**	**5**	**25**
Nitrogen												
TKN VWMean	mg/l	0.42	0.55	0.39	0.39	0.35	0.37	0.31	0.32	0.29	0.36	0.69
Spring Epilim.	mg/l	0.29	0.88	0.34	0.43	0.34	0.34	0.33	0.23	0.26	0.30	0.26
Summer Hypolim.	mg/l	1.92	1.13	1.54	1.54	0.38	0.89	1.60	0.82	1.55	1.67	1.54
Ammonium												
Summer Hypolim.	mg/l	1.20	0.39	1.14	1.27	0.03	0.54	1.17	0.77	1.07	1.23	1.33
NO_2+NO_3 VWMean	**mg/l**	**0.04**	**0.05**	**0.04**	**0.04**	**0.04**	**0.06**	**0.04**	**0.08**	**0.07**	**0.04**	**0.06**
N/P Ratio VWMean	mg/l	3.06	2.86	1.95	2.38	3.00	1.86	2.33	2.67	2.11	2.86	1.92
Total Iron VWMean	mg/l	0.03	0.02	0.48	0.45	0.09	0.35	0.10	0.32	0.11	0.20	0.34
Summer Hypolim.	mg/l	0.11	0.04	7.69	8.53	0.30	2.19	7.35	3.82	2.29	4.68	1.16
T. Manganese VWMean	mg/l	0.03	0.04	0.68	0.48	0.08	0.42	0.06	0.31	0.13	0.13	0.57
Summer Hypolim.	mg/l	0.97	1.04	3.71	5.72	0.32	2.54	5.44	2.53	2.60	2.67	1.12
Sulfate VWMean	mg/l	12.0	11.2	9.0	8.1	7.8	7.0	6.6	6.4	9.0	7.2	5.2
Chloride VWMean	mg/l	3	3	2	1	2	2	2	1	3	3	3
T. Hardness VWMean	mg/l	152	157	158	150	141	145	124	129	82	80	165
Alkalinity VWMean	mg/l	147	144	154	147	135	140	117	123	77	76	167

VWMean = Volume Weighted Mean

Table 5.2.2. Water quality index for Wisconsin lakes. (Lillie and Mason, 1983)

Water Quality Index	Approximate Secchi Disk Depth (m)	Approximate Chlorophyll a (μg/l)	Approximate T.Phosphorus (μg/l)
Excellent	>6.0	<1	<1
Very Good	3.0-6.0	1-5	1-10
Good	2.0-3.0	5-10	10-30
Fair	1.5-2.0	10-15	30-50
Poor	1.0-1.5	15-30	50-150
Very Poor	<1.0	>30	>150

After Lillie & Mason (1983)

Table 5.2.3. Water transparency of Legend Lake sample sites as measured by Secchi disk depth.

	Secchi Disk Depth (m)		
Lake Basin (Site)	May 1992 & 1993 Mean	Summer Mean	November 1992 & 1993 Mean
Wah-toh-sah (A)	3.1	2.4	3.8
Skice (B)	3.3	3.4	3.7
Spring ©	2.6	2.7	2.3
Peshtigo (D)	2.5	3.1	2.3
L. Blacksmith (E)	3.0	2.4	2.6
Blacksmith (F)	4.0	3.3	2.5
Sapokesick (G)	4.5	2.8	3.1
Pywaosit (H)	5.5	3.9	2.7
Round (I)	3.5	3.4	2.6
Sand (J)	2.9	2.6	2.0
LaMotte (K)	5.0	3.4	3.4

Table 5.2.4. Seasonal mean values of chlorophyll *a* for the Legend Lake sample sites shown as an average of 1992 and 1993 data.

Chlorophyll a (µg/l)

Lake Basin (Site)	May Mean 1992&1993	Summer Mean 1992&1993	November Mean 1992&1993
Wah-toh-sah (A)	1.5	3.8	4.1
Skice (B)	2.4	1.9	5.5
Spring ©	1.4	3.5	8.6
Peshtigo (D)	2.0	1.0	1.5
L. Blacksmith (E)	1.5	4.2	3.5
Blacksmith (F)	1.0	4.6	2.0
Sapokesick (G)	0.5	3.0	1.4
Pywaosit (H)	0.5	1.9	2.0
Round (I)	3.0	1.4	7.1
Sand (J)	0.5	3.3	1.2
LaMotte (K)	0.7	3.1	2.8

Table 5.2.5. Seasonal mean values of total phosphorus from the epilimnion of the Legend Lake sample sites average of 1992 and 1993 data.

Total Phosphorus (µg/l)

Lake Basin	Mean Epilimnetic Concentrations		
	Spring 1992&1993	Summer 1992&1993	Fall 1992&1993
Wah-toh-sah (A)	19	12	11
Skice (B)	36	16	17
Spring (C)	16	13	21
Peshtigo (D)	25	14	19
L. Blacksmith (E)	13	16	10
Blacksmith (F)	14	13	14
Sapokesick (G)	14	11	11
Pywaosit (H)	12	14	18
Round (I)	11	15	34
Sand (J)	11	11	15
LaMotte (K)	16	13	16

from the watershed along with moderate marl precipitation (which removes phosphorus from solution particularly in summer months) are believed to be the primary reasons for the favorable water quality conditions present in these lakes.

The lakes experiencing increased algae growth and decreased Secchi Disk readings in fall, associated with fall turnover or the influx of nutrients from runoff are Spring, Peshtigo, Blacksmith, Pywaosit, Round, and Sand. These lakes also experienced increased total phosphorus in the fall samples. Pywaosit and Round lakes both exhibited increases in total phosphorus from spring through fall as well as having their highest chlorophyll concentrations in the fall samples. This is believed to be due to transport of phosphorus from upgradient lakes during fall runoff and from lake turnover circulating phosphorus that had been released from sediments in the anoxic hypolimnion.

Nutrients

Nutrients impact the rate of dissolved oxygen depletion indirectly. The availability of nutrients may determine the quantity and types of primary producers in the lake basins which will eventually create a demand on the oxygen supply as the organic matter is decomposed.

Water column ratios of nitrogen to phosphorus (Table 5.2.6) suggest that since each lake basin has a ratio greater than 7, phosphorus is the limiting nutrient (Vallentyne, 1974). This moves the focus to the sources of phosphorus. The lake basins are generally low in the amount of total phosphorus concentrations. The application of the Trophic State Index (Carlson, 1977) based on summer epilimnion concentrations of total phosphorus places all of the lake basins on the

Table 5.2.6. Mean seasonal epilimnetic ratios of nitrogen to phosphorus at the Legend Lake sites.

Basin	Epilimnion	
	Fall	Spring
A	53	16
B	30	25
C	21	25
D	18	18
E	41	28
F	25	26
G	31	25
H	27	22
I	9	26
J	31	29
K	33	18

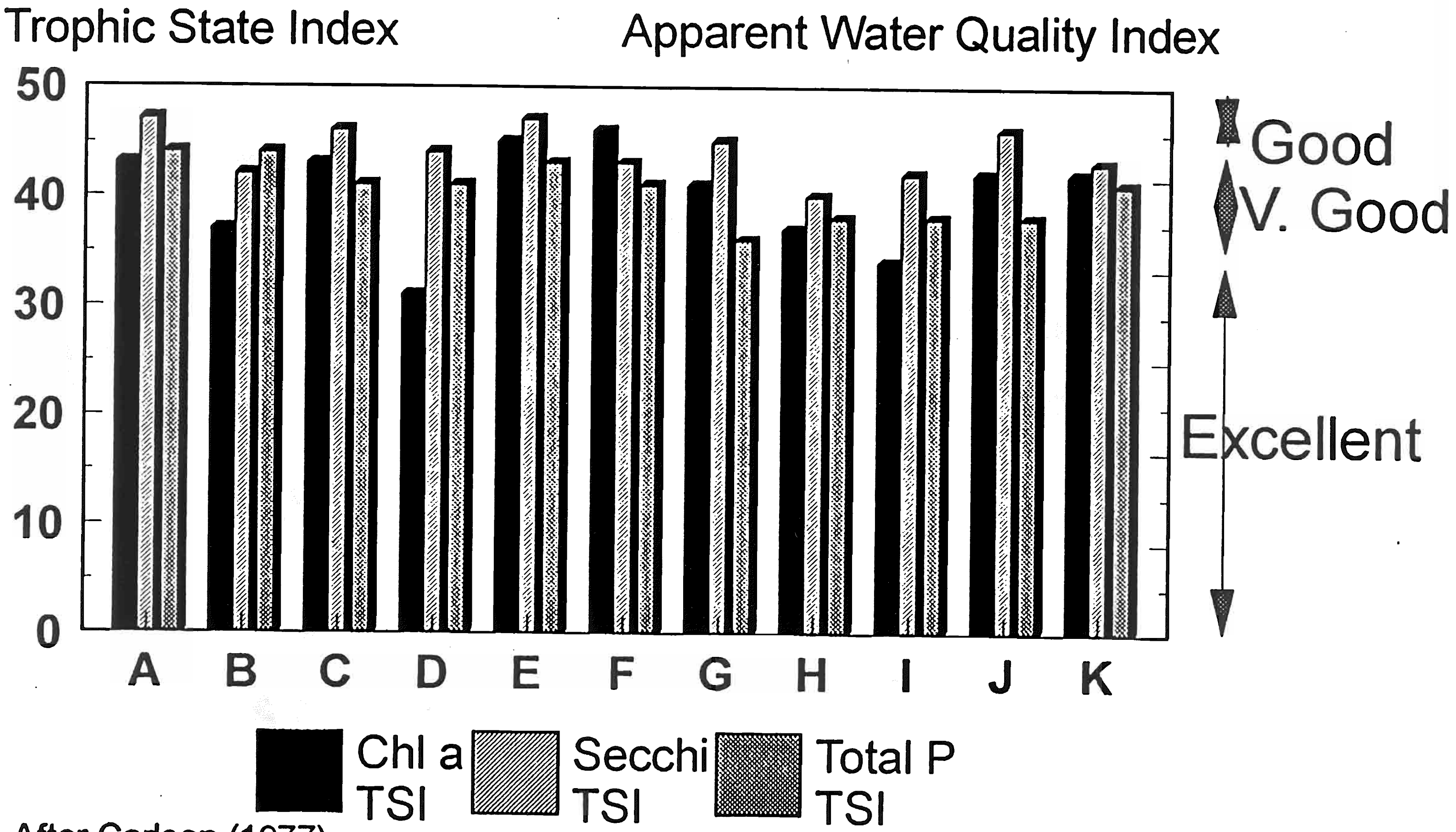
border between the mesotrophic and oligotrophic class (Figure 5.2.1). This designation does not account for the abundant macrophyte production. Moreover, the rates of dissolved oxygen depletion if viewed alone would put many of the lake basins in the eutrophic class.

Phosphorus is not abundant in this non-agricultural watershed. The phosphorus that does enter the water column is quickly removed by plant uptake or precipitation to the sediment. Removal by marl precipitation also occurs by co-precipitation with calcium carbonate. The rate of marl precipitation is greatest during periods of high photosynthesis and higher pH. Another delivery of phosphorus to the sediments occurs by complexation with iron oxide precipitates. The iron cycle in these lake basins is an important control on the phosphorus availability. In either mode of phosphate complex formation, precipitation, and sedimentation, a long hydraulic residence time enhances deposition. On the other hand, morphometric features of shallowness and long fetch promote the mechanical re-suspension of phosphorus, both of these factors vary widely between the Legend Lake basins.

Each basin experiences a significant change in chemical composition on an annual basis. This is due primarily to the thermal and chemical stratification that develops between periods of spring and fall mixing. Figure 5.2.2 exhibits the concentrations of total iron measured during the periods of maximum summer stratification for each sample site. Note the elevated levels greater than 7 mg/l in basins C, D, and G. These differences are a function of several interacting factors that are discussed in more detail in Houston, 1994. During the stratification period, as oxygen is depleted negative redox potentials develop and an Fe/Mn redox cycle is established (Hutchinson, 1957; Davidson, et al, 1982). This redox cycle influences the internal cycles of other chemical species including nitrogen and phosphorus essential for aquatic plant growth (Wetzel, 1975). The full development of the stratification occurs in the late summer to early fall.

Figure 5.2.3 shows the mean phosphorus concentration (ug/l) measured in the summer hypolimnion at each sample site.

Figure 5.2.1. Trophic state index for each of chlorophyll *a*, Secchi disk, and total phosphorus measures by Legend Lake basin.



After Carlson (1977)

Figure 5.2.2. Total Iron (mg/l) mean concentrations for Legend Lake Basins and LaMotte Lake summer stratification periods of 1992 and 1993.

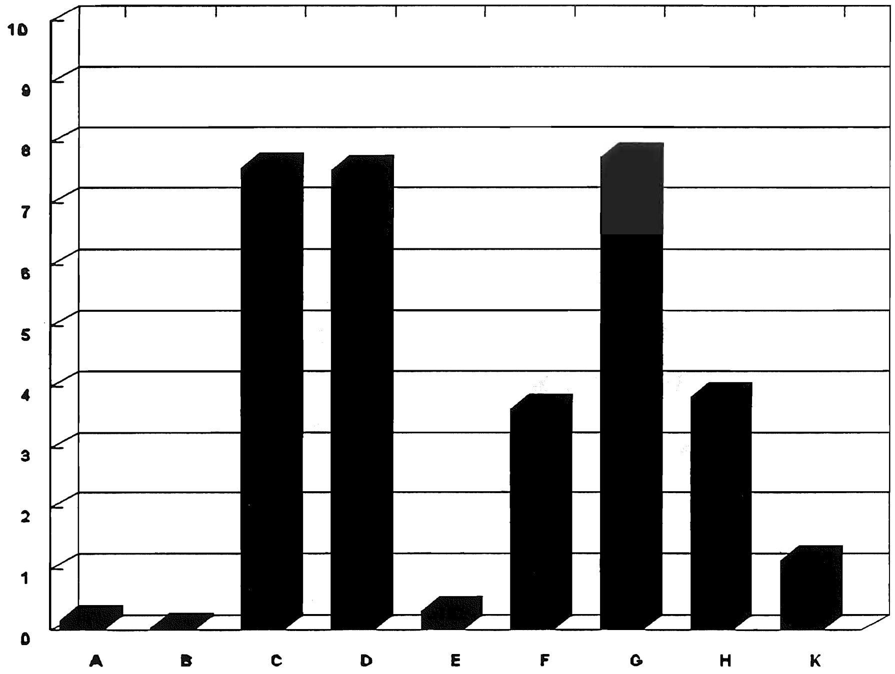
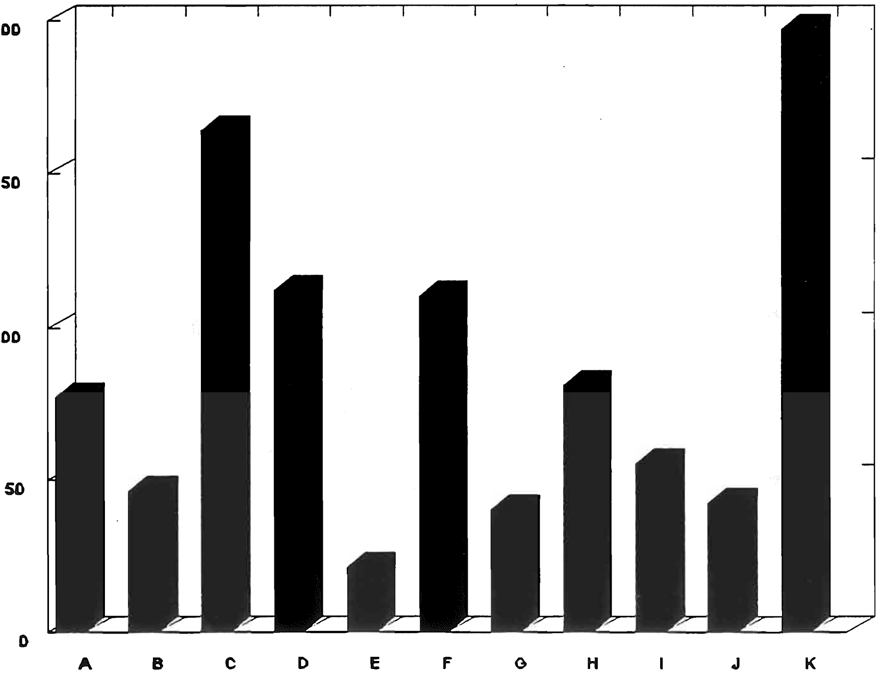


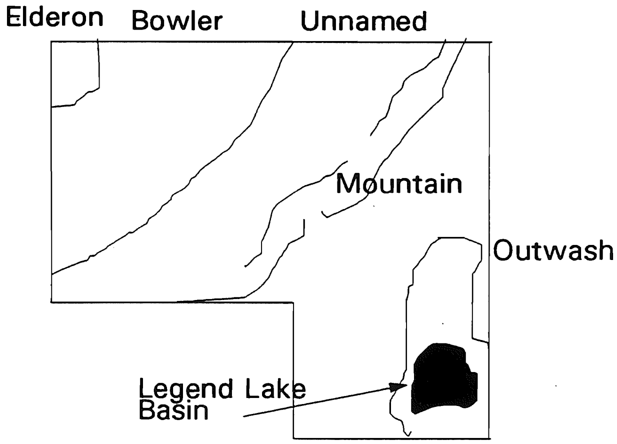
Figure 5.2.3. Mean hypolimnetic concentrations of total phosphorus (ug/l) during summer stratification for Legend Lake Basins and LaMotte Lake.



Geology and Groundwater

During the Wisconsinan stage of the Pleistocene period, part of the Green Bay Lobe made several advances and retreats across Menominee county in a northwesterly direction. The advances and retreats left four moraines (see figure 1.). The landscape of the county was altered significantly by glacial activity. There is evidence of active ice deposits as well as post-glacial outwash deposits. Menominee county is underlain by granitic and syenitic bedrock of the southern extension of the Canadian Shield. The bedrock is comprised of a variety of rock types associated with the Wolf River batholith. These consist of Huronian-Laurentian age granite, gneiss, gabbro and metamorphosed sedimentary rocks (Hanson and Hole, 1965). In the extreme southeast corner of the county, near the Legend Lake basin, bedrock is composed of quartz monzomite (Mudrey et al, 1982).

Figure 5.3.1. Location of 4 moraines, outwash deposits and Legend Lake in Menomonee County, Wisconsin.



Outcrops of the bedrock occur in the central part of the county along the Wolf River and its floodplain. From the outcrops along the Wolf River, bedrock dips to the south east about 26 feet/mile (USGS 1992).

The surficial deposits of the county are composed of glacial till and outwash. According to Hansen and Hole (1965), 72.1 percent of the total area is till and 26.2 percent is glacial outwash. The glacial outwash is located chiefly in the southeastern part of the county. Thickness of the glacial deposits varies locally, however, the glacial deposits thicken toward the southeast to a maximum depth of a 180 feet (USGS, 1992).

Thwaites (1943), indicated that there were three glacial advances across the county, the last being approximately 15,000 years before present. These advances left three predominant morainic systems across the county. The first was the Elderon morainic system. The Elderon morainic system stretches across the northwest corner of the county. This is primarily composed of brown till with a rolling topography. There are brown outwash deposits that sporadically cover the till.

Ice contact deposits separate this morainic system from the Bowler system. The Bowler morainic system crosses the county from the north central edge to the southwestern corner of the county. The deposits are composed of brown till and are covered with brown outwash more completely than the Elderon system. Also found in the brown till areas of the Bowler system are many drumlins which are oriented from the northwest to the southeast.

The third morainic system is the Mountain system. It is comprised of reddish brown till that extends from the northeastern corner to the south central edge of the county. The Mountain system is the western limit of the brown till associated with the other systems. The drumlins in this system are oriented from northwest to southeast, and are fewer than in the Bowler system. The Mountain system has a large amount of water-laid deposits and many kettles that have formed lakes and lowlands. Glacio-lucustrine deposits are commonly found in the central part of the Mountain morainic system. These sediments are brown sands and some silts in lowland areas. The Mountain system is also covered with rolling to undulating coarser outwash sand and gravel.

There is another discontinuous recessional moraine between the Bowler and Mountain morainic system which is unnamed. The unnamed moranic system is composed of brown till, similar to the Bowler and Elderon systems. It is dotted with drumlins and has several eskers in the center of the system. Granitic outcrops are found in the central part of the system where the ancient channel for the Wolf River may have existed.

The Legend Lake watershed is characterized by level to undulating topography. A thick mantle of glacial drift, primarily outwash sand and till, cover precambrian granite. Precambrian granitic and syenitic rock of the Wolf River batholith outcrops approximately one mile west of the Legend Lake study area.

The Legend Lake basin lies almost entirely on glacial outwash sands which overly the Mountain morainic system (Figure 5.3.1). According to Thwaites (1943), the reddish brown till of the Mountain system is colored with iron oxides and has the same origin as the reddish brown till of the Green Bay region. Thwaites further stated that Menominee county resembles a "staircase" with the treads being outwash plains over till and the risers as being moraines. Legend Lake lies on a major outwash plain in the county.

Near Legend Lake, the reddish brown till can be found at or near the surface by the outlet of Beaver Bay northeast of Basin A. This may be the result of construction and not a natural outcrop. Well driller reports also report reddish clay in the vicinity of the Spirit Ridge subdivision in the north-central region of Legend Lake.

Well drilling logs supplied by the Wisconsin Department of Natural Resources and the Wisconsin Geological Natural History Survey were used to draft geological cross sections of the Legend Lake basin. t is evident that sandy outwash overlies till, and according to cross sections, outwash covers the till to about 830 feet (MSL). From approximately 830 to greater than 750 feet (MSL) fine sandy clay till covers Precambrian Granite.

Legend Lake is primarily surrounded by sandy outwash soils except where the old pre-construction basins penetrate the sandy clay till aquifer. This suggest prior to construction, sandy clay till may have been the primary source of groundwater recharge for the lakes and possibly some recharge from the sandy outwash overlying the till. The sandy outwash over the till may have been the primary aquifer for groundwater flow to the lake due to the increased hydraulic conductivity. Cross sections and pre-construction groundwater flow maps indicate that the watertable was at or near the outwash and till interface. Seasonal fluctuations in water table elevations may have controlled which material the groundwater would be located in. As the water table rose due to construction, the sandy outwash became a primary aquifer for Legend Lake for both groundwater inflow and outflow areas.

Groundwater flow was seriously impacted by the construction of Legend Lake. Changes to groundwater flow characteristics were most evident in the south-western portions of the watershed. Originally groundwater flowed from LaMotte Lake to the former Wahtohsa and Skice lakes (Lake Basins A & B respectively), after construction, the groundwater gradient was reversed resulting in groundwater flowing from Legend Lake to LaMotte Lake (Hoffman, 1977).

Round, Sand and Little Sand lakes suffered from increased water levels and shoreline flooding as a result of Legend Lake construction. After construction was completed, an attempt was made to lessen the effects of alterations to groundwater flow which caused increased watertable elevations on downgradient lakes. A channel was excavated connecting the three downgradient lakes to provide drainage, however the water levels in Sand and Little Sand Lakes were still two feet higher then pre-Legend Lake. A clay layer was then applied along the south shoreline of Legend Lake and along the shoreline near the eastern dam to prevent groundwater outflow from raising the water levels of the downgradient lakes. This clay layer decreased groundwater flow somewhat to down gradient lakes Round, Sand and Little Sand lakes but was not sufficient to totally decrease water levels and shoreline flooding (Born and Stephenson, 1974).

Pre-construction Groundwater Flow

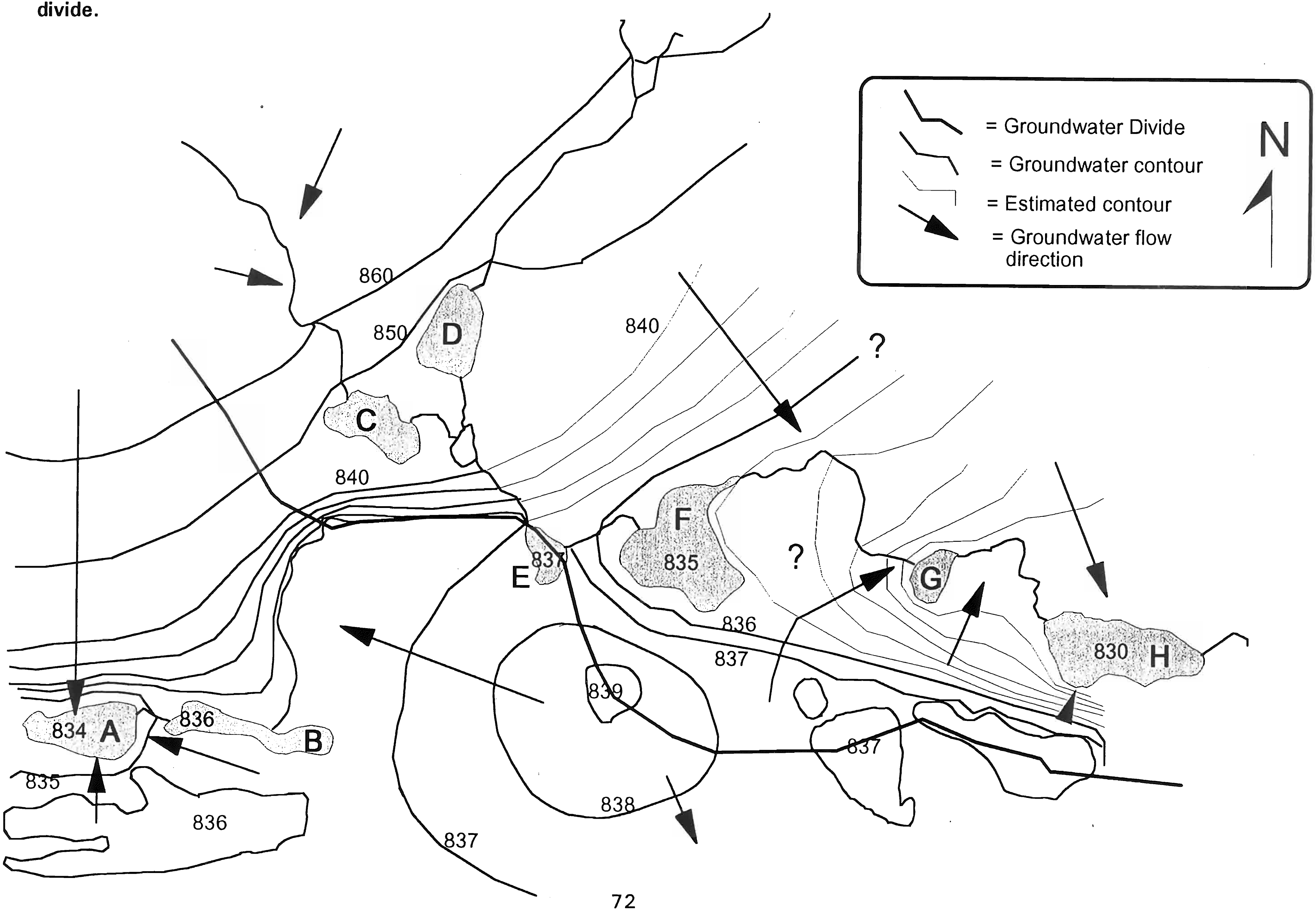
Prior to the construction of Legend Lake, groundwater flowed primarily from the northwest and discharged into the pre-construction basins and also flowed from the south and discharged into the same basins and their tributaries. A groundwater divide that followed very closely to the natural watershed divide separated groundwater flow from the Wah-toh-sah Creek watershed and the Linzy Creek watershed (Figure 5.3.2). It appears that Round, Sand and Little Sand Lakes were recharge mounds along the southern groundwater divide.

Water table elevations of the pre-construction period suggest that the primary watertable aquifer material was significantly different from the outwash sand aquifer that is currently influencing groundwater inflow and outflow (exceptions occur in Basins C and D). According to geological cross sections, the principle aquifer of the natural lakes was a fine sand clay mix characteristic of the glacial till in the area. Born and Stephenson (1974), reported there were difficulties obtaining sufficient groundwater flow from the silty aquifer material when Wah-toh-sah and Skice Lake levels were being raised. Also, horizontal hydraulic gradients near the shoreline are much greater than current gradients, suggesting an aquifer material of lower permeability or the influence of finer textured lake sediments around the shore. The outwash sand that overlies the finer glacial till became the predominant water table aquifer as lake levels were raised. This aquifer material allows for more rapid groundwater flow and less attenuation of pollutants. This change in dominant aquifer material was largely responsible for the water problems observed in downgradient lakes.

Post-construction Groundwater Flow

The raising of the lake levels altered the natural flow of groundwater. Raising the lake level to approximately 844 feet (msl) raised the water table at the western and

Figure 5.3.2. Pre-construction groundwater contour map with flow direction, watertable elevations, and groundwater divide.



eastern ends of the lake by ten and fourteen feet, respectively. This resulted in a dramatic decrease in horizontal hydraulic gradients in the north central and eastern regions of the watershed and reversals of groundwater gradients in the eastern and southwestern portions of the watershed.

A groundwater divide is still present in the south-central area of the watershed. This divide is similar to the pre-construction divide and separates groundwater flow from the Wah-toh-sah and the Linzy Creek watershed, however the gradients are reduced. Figure 5.3.3 illustrates the present generalized groundwater flow patterns, watertable elevations of the Legend Lake basin, and groundwater divide.

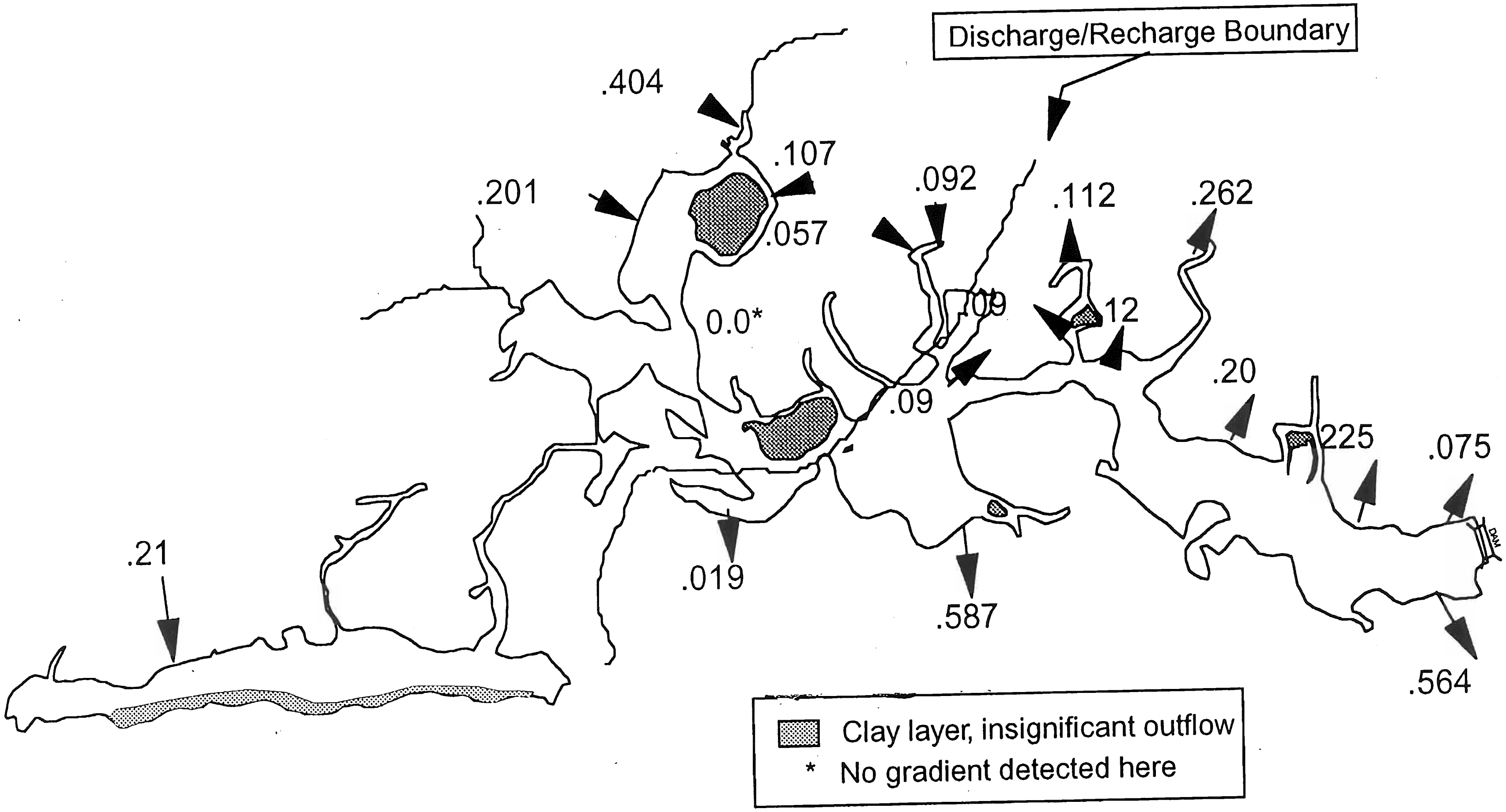
After construction was completed, Legend Lake was raised to a nearly uniform elevation. Surface water elevations at the east and west ends of the lake differ seasonally, resulting in fluctuations in the direction of surface water flow through the channel connecting the east and west end. Houston (1994), determined that when the discharge at the east dam is greater than the discharge at the stream inlets, water flows north along the mile long channel connecting Basin A/B to the remaining basins. The opposite of this occurs when the discharge at the dam is less than the discharge at the stream inlets. These fluctuations occur during periods when the lake levels are being raised or lowered.

These fluctuations did not significantly alter regional groundwater flow patterns but did alter localized flow. Figure 5.3.3 illustrates areas of groundwater inflow and outflow to the lake. Areas of fluctuating inflow (discharge) and outflow (recharge) were approximated by comparing watertable elevations from piezometers near the shore and surface water elevations. These areas demonstrated both groundwater discharge and recharge to and from Legend Lake and areas of near stagnation. When the discharge at the dam is less then the stream inlets, surface water elevations rise above water table elevations causing changes in areas of groundwater recharge or discharge. Similarly, when lake levels are lowered groundwater previously flowing away from the lake may change direction and flow toward the lake.

Development in these areas may have less effect on surface water quality from nutrient transport via groundwater due to discontinuous discharge. Areas of continuous groundwater inflow can be impacted the most severely by improper land use management. This can lead to degrading surface water quality of Legend Lake.

Land use practices in areas of continuous groundwater recharge are highly unlikely to affect the quality of Legend Lake via groundwater flow, however surface runoff in these areas can cause detrimental effects. Other lakes downgradient of outflow areas can be affected by groundwater flow from these outflow areas.

Figure 5.3.3. **Present (post-construction) groundwater contour map with flow direction, watertable elevations, and groundwater divide.**



Buried Organic Sediments

Installation of wells around the shoreline of Basin D indicated disturbed soil conditions in various locations. The disturbed sites consisted of a one to three foot blanket of fine to medium sand overlying soil high in organic material. Exploratory borings showed that the organic material was up to seven feet thick and underlain by a gleyed mineral soil. These sites were discovered while installing monitoring wells for water table elevations and monitoring of ambient groundwater quality.

Wells 9 and 11 were placed in the buried organic material; groundwater obtained from these wells exhibited much higher Fe, Mn, fluorescence, and NH_4-N and lower dissolved oxygen concentrations than groundwater from Wells 8, 10, and 12 which were placed in undisturbed soil (Table 5.4.1).

Table 5.4.1. Average groundwater chemistry (mg/l) in groundwater upgradient of the buried organic material (Wells 8, 10, and 12) and groundwater in the buried organic material (Wells 9 and 11).

Well Number	NO_2+NO_3-N	NH_4	TKN	Fe	Mn	D.O.
8	0.4	<0.01	0.05	0.72	0.01	4.4
9	0.1	12.35	13.85	10.59	1.06	0.0
10	<0.2	0.03	0.10	0.036	0.01	2.1
11	0.2	0.80	7.39	10.35	0.25	0.3
12	0.2	0.10	0.37	0.22	0.21	3.7

Additional multi-level monitoring wells were installed to further evaluate the impact of buried organic material. Table 5.4.2 shows average concentrations of iron, manganese, NO_2+NO_3-N, NH_4-N, TKN, and dissolved oxygen levels for monitoring well FeML-1, installed upgradient of the buried organic material and FeML-2 installed in the buried organic material on the North Star Beach Club.

FeML-1 displayed groundwater quality expected in undisturbed conditions. Nitrogen levels are low, iron and manganese concentrations are slightly elevated, and dissolved oxygen concentrations are very good and suggesting the existence of oxidizing conditions. FeML-2 exhibits groundwater quality of reduced conditions, most likely caused by the decay of buried organic material. Ammonium concentrations are very high and dissolved oxygen levels are negligible compared to the upgradient well FeML-1. Average Fe and Mn concentrations are moderately high in the upgradient well and much higher in buried organic material, which is consistent with low dissolved oxygen levels.

Table 5.4.2. Average groundwater chemistry (mg/l) in groundwater upgradient of the buried organic material and groundwater in the buried organic material from monitoring wells ML-1 and ML-2.

Well Number	NO_2+NO_3-N	NH_4	TKN	Fe	Mn	D.O.
FeML-1	< 0.2	0.06	0.19	0.28	0.30	9.9
FeML-2	< 0.2	1.01	1.10	3.50	0.97	0.6*

*Oxygen was probably introduced into sample; value is likely 0

Monitoring at another site at the North Star Beach Club on the north side of Basin D displayed similar conditions. Sampling Well FeML-3 upgradient of the buried organic material showed that nitrogen concentrations were above ambient groundwater concentrations, probably due to an upgradient septic system. Iron and manganese concentrations were low consistent with presence of dissolved oxygen in groundwater. Iron concentrations were higher in FeML-1 by a factor of ten, this difference in iron concentrations in the two upgradient wells is probably due to different iron bearing minerals in the aquifer material. There was no evidence of disturbed soil conditions in the two upgradient wells. Dissolved oxygen concentrations were significantly lower in FeML-3 than the other upgradient well FeML-1, but still showed moderately high concentrations. Table 5.4.3 shows the contrast between upgradient groundwater and groundwater in the buried organic material near the shore at this site.

Table 5.4.3. Average groundwater chemistry (mg/l) in groundwater upgradient of the buried organic material and groundwater in the buried organic material from monitoring wells ML-3 and ML-4.

Well Number	NO_2+NO_3-N	NH_4	TKN	Fe	Mn	D.O.
FeML-3	4.2	0.03	0.19	0.05	0.02	5.0
FeML-4	0.4	9.99	12.41	12.51	2.25	<1

Monitoring well FeML-4 displayed higher concentrations of Fe, Mn, and NH_4-N than the other wells tested. These high concentrations and low oxygen concentrations indicate reduced conditions. These data indicate that buried organic material in its state of decay is causing a reduced environment in various locations around the shore, causing iron and manganese to become mobile and creating an oxygen demand to surface water after being transported by groundwater flow. In addition to a potential oxygen demand to surface water from Fe, Mn, and NH_4-N, possible acidification of surface water from the oxidation of NH_4 and other reduced chemicals may occur. Another potential problem is the release of nutrients to surface water which can enhance the growth of algae and aquatic macrophytes in the lake.

Houston 1994, evaluated the potential oxygen demand quite extensively and determine that the Basin D had the greatest oxygen demand from Fe, Mn, NH_4-N, and HS than any other Legend Lake basin (total oxygen demand averaged 7.6 mg/l). Using the same method, the total oxygen demand in groundwater is very high in the buried organic material around the shore than in upgradient groundwater. Table 5.4.4 summarizes the oxygen demand in upgradient groundwater and groundwater within the buried sediments.

It is apparent from this investigation that the buried organic material has a potential oxygen demand on surface water. Prior to construction Peshtigo Lake was a

Table 5.4.4. Comparison of groundwater from upgradient (FeML-1 and 3) and buried organic material (FeML-2 and 4) wells for potential oxygen demand from iron, manganese, and ammonium.

Well	Constituent	Average Conc. (mg/l)	Mole Factor	Oxygen Demand (mg/l)	Total Demand (mg/l)
FeML-1	NH4	0.03	2.00	.06	
	Fe	0.28	.25	.07	
	Mn	0.03	0.5	.01	0.1
FeML-2	NH4	1.01	2.00	2.05	
	Fe	3.5	.25	.87	
	Mn	0.97	0.5	.48	3.4
FeML-3	NH4	0.03	2.00	.06	
	Fe	0.05	.25	.01	
	Mn	0.02	0.5	.01	.08
FeML-4	NH4	9.99	2.00	19.98	
	Fe	12.51	.25	3.12	
	Mn	2.25	0.5	1.12	24.2

small drainage lake with wetland and bog material around the shoreline (Andrews, et al., 1963, Hansen and Hole, 1963). The source of the buried organic material is most likely a result of construction activity when the lake was developed, dredged material was deposited on shore and covered with one to three feet of sand.

Basin D is not the only basin where this has occurred. Basin E and F also show evidence of buried organic material but are in areas of low groundwater inflow or where both inflow and outflow occur seasonally. Therefore, associated lake areas will be less impacted than Basin D where major groundwater inflow areas are present.

Dissolved Oxygen Depletion

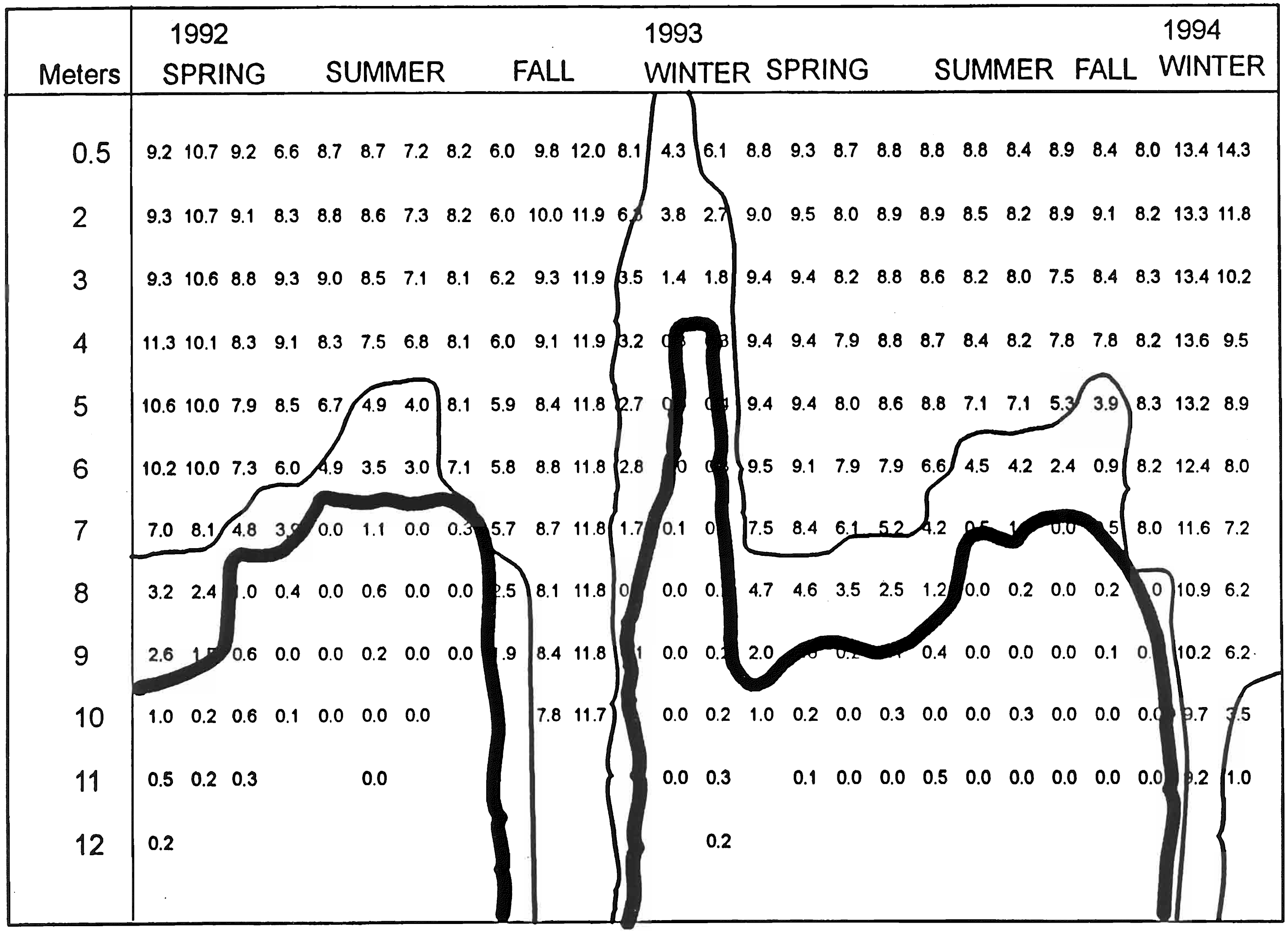
This section contains the results of the dissolved oxygen measurements for each of the lake basins over the two year period of this study. The dissolved oxygen profiles are presented as isopleth graphs. The oxygen profiles and basin morphometry were used to calculate oxygen mass. The depletion of oxygen over time was quantified as both rates of loss and as relative percent losses.

The frequency of sampling allowed the determination of dissolved oxygen changes over short periods of time. Changes with depth were identified. The volumetric concentration of dissolved oxygen, at a given point in time, had better precision because of the one meter sampling interval. Comparisons between lake basins were possible because of consistency of sampling methods and timing.

The dissolved oxygen profiles of each lake basin are exhibited in the isopleth graphs (Figures 5.5.2 to 5.5.12). This is the basic data that was recorded in the field. Both years of data are presented within each table.

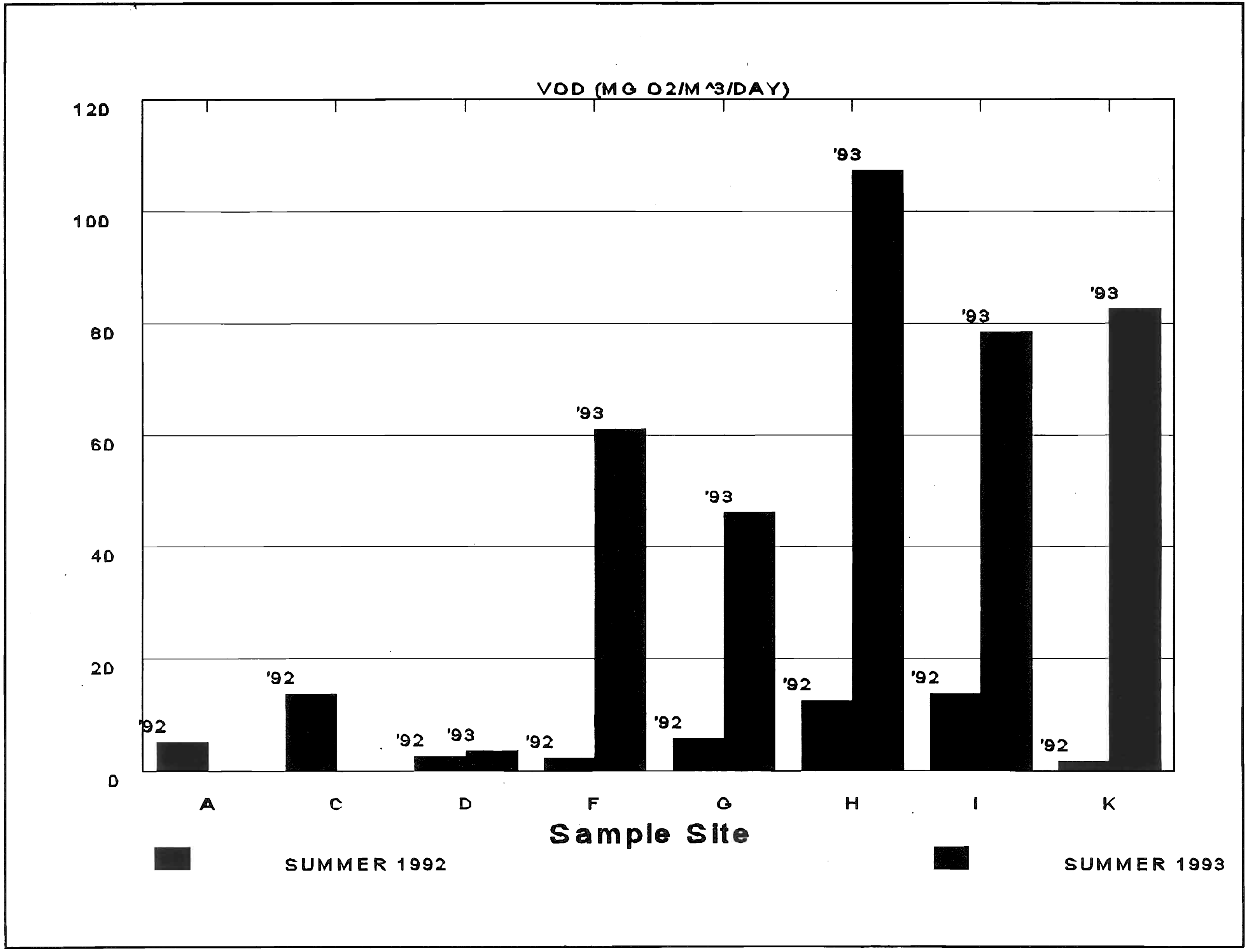
Figure 5.5.1 shows the summer volumetric oxygen depletion rates (VOD, mg O_2 m^{-3} d^{-1}) for the strata located in the middle of each lake basin's hypolimnion (sites B and E are excluded because these lake basins do not develop well defined hypolimnions). Note the variation between the two periods measured. Because the rate was determined using a best fit line, it was dependent upon the initial spring dissolved oxygen concentration. The initial concentrations of dissolved oxygen in both May 1992 and 1993 were low. Hutchinson (1938) noted that low initial concentrations can be a problem because the rate of dissolved oxygen depletion decreases as the dissolved oxygen concentration approaches zero. With any hypolimnion that goes anaerobic, the VOD rate will be understated unless the initial measurement was at or near saturation. It is, therefore, doubtful whether these regression methods can be applied to the data gathered in the summer hypolimnion of these lake basins. The complete depletion of hypolimnetic dissolved oxygen so early in the growing season may also be an indication that there is incomplete spring turnover in some of these lake basins. Sampling in April

Figure 5.5.2. Site A (Wah-toh-sah) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line)



Meters	1992 SPRING				SUMMER					FALL		1993 WINTER			SPRING				SUMMER			FALL		1994 WINTER	
0.5	9.2	10.7	9.2	6.6	8.7	8.7	7.2	8.2	6.0	9.8	12.0	8.1	4.3	6.1	8.8	9.3	8.7	8.8	8.8	8.8	8.4	8.9	8.4	8.0	13.4	14.3
2	9.3	10.7	9.1	8.3	8.8	8.6	7.3	8.2	6.0	10.0	11.9	[illegible]	3.8	2.7	9.0	9.5	8.0	8.9	8.9	8.5	8.2	8.9	9.1	8.2	13.3	11.8
3	9.3	10.6	8.8	9.3	9.0	8.5	7.1	8.1	6.2	9.3	11.9	3.5	1.4	1.8	9.4	9.4	8.2	8.8	8.6	8.2	8.0	7.5	8.4	8.3	13.4	10.2
4	11.3	10.1	8.3	9.1	8.3	7.5	6.8	8.1	6.0	9.1	11.9	3.2	[illegible]	[illegible]	9.4	9.4	7.9	8.8	8.7	8.4	8.2	7.8	7.8	8.2	13.6	9.5
5	10.6	10.0	7.9	8.5	6.7	4.9	4.0	8.1	5.9	8.4	11.8	2.7	[illegible]	[illegible]	9.4	9.4	8.0	8.6	8.8	7.1	7.1	5.3	3.9	8.3	13.2	8.9
6	10.2	10.0	7.3	6.0	4.9	3.5	3.0	7.1	5.8	8.8	11.8	2.8	[illegible]	[illegible]	9.5	9.1	7.9	7.9	6.6	4.5	4.2	2.4	0.9	8.2	12.4	8.0
7	7.0	8.1	4.8	3.9	0.0	1.1	0.0	0.3	5.7	8.7	11.8	1.7	0.1	[illegible]	7.5	8.4	6.1	5.2	4.2	0.5	[illegible]	0.0	[illegible]	8.0	11.6	7.2
8	3.2	2.4	[illegible]	0.4	0.0	0.6	0.0	0.0	2.5	8.1	11.8	[illegible]	0.0	[illegible]	4.7	4.6	3.5	2.5	1.2	0.0	0.2	0.0	0.2	[illegible]	10.9	6.2
9	2.6	[illegible]	0.6	0.0	0.0	0.2	0.0	0.0	[illegible]	8.4	11.8	[illegible]	0.0	0.2	2.0	[illegible]	[illegible]	[illegible]	0.4	0.0	0.0	0.0	0.1	[illegible]	10.2	6.2
10	1.0	0.2	0.6	0.1	0.0	0.0	0.0			7.8	11.7		0.0	0.2	1.0	0.2	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	9.7	3.5
11	0.5	0.2	0.3			0.0							0.0	0.3		0.1	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	[illegible]	1.0
12	0.2													0.2												

Figure 5.5.1 - Summer hypolimnetic VOD rates by Legend Lake sample site.



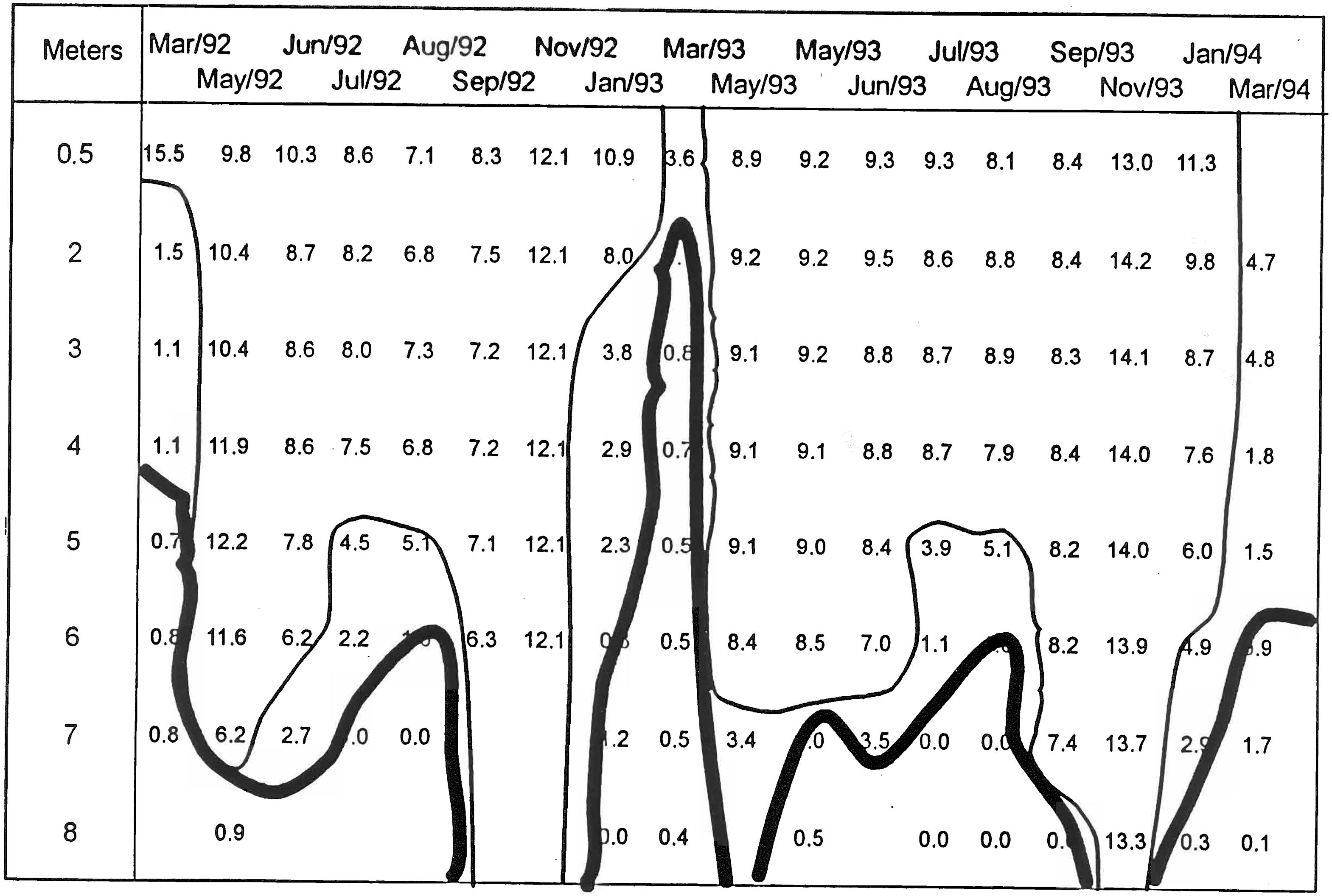
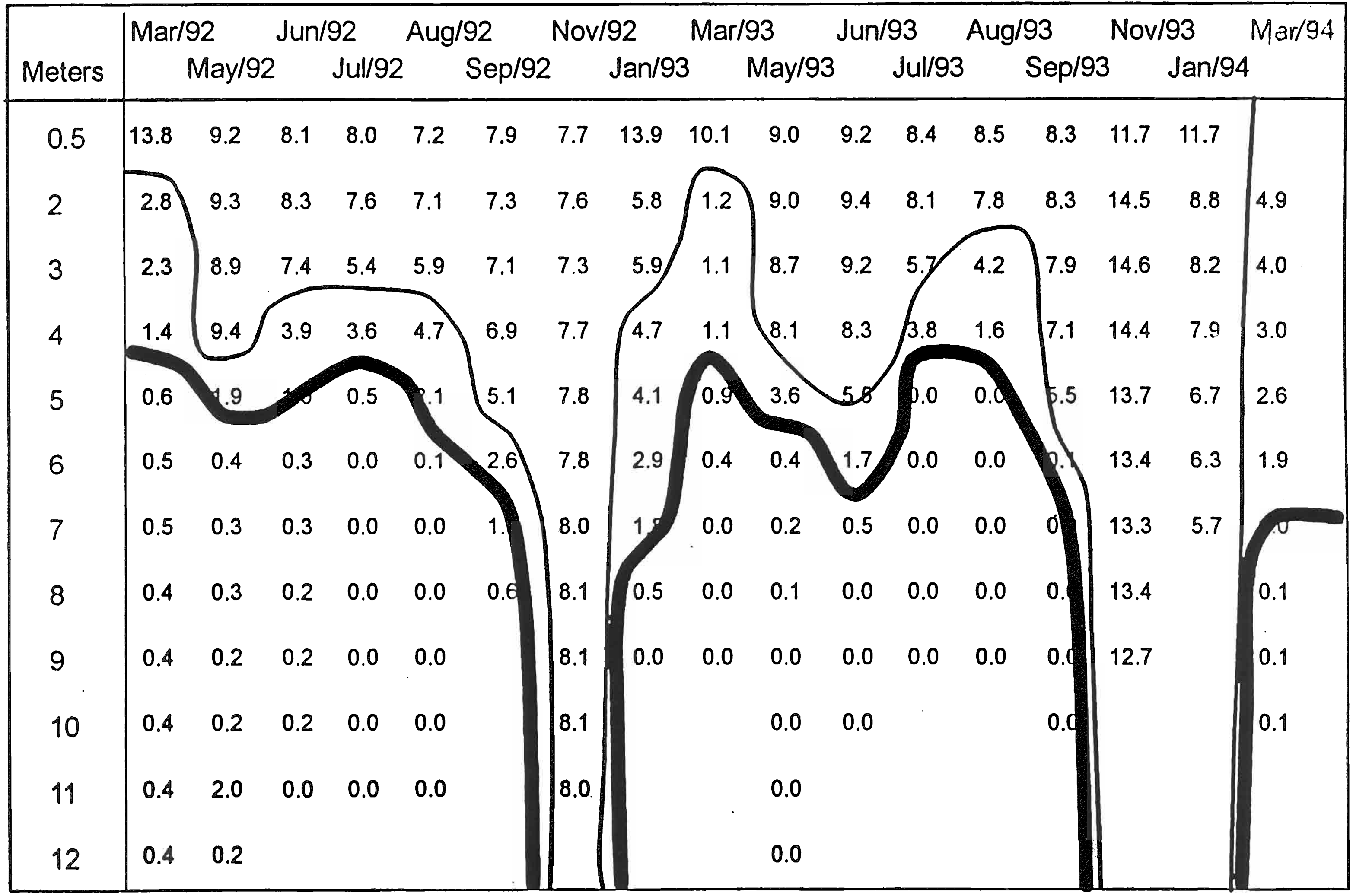


Figure 5.5.3. Site B (Skice) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).

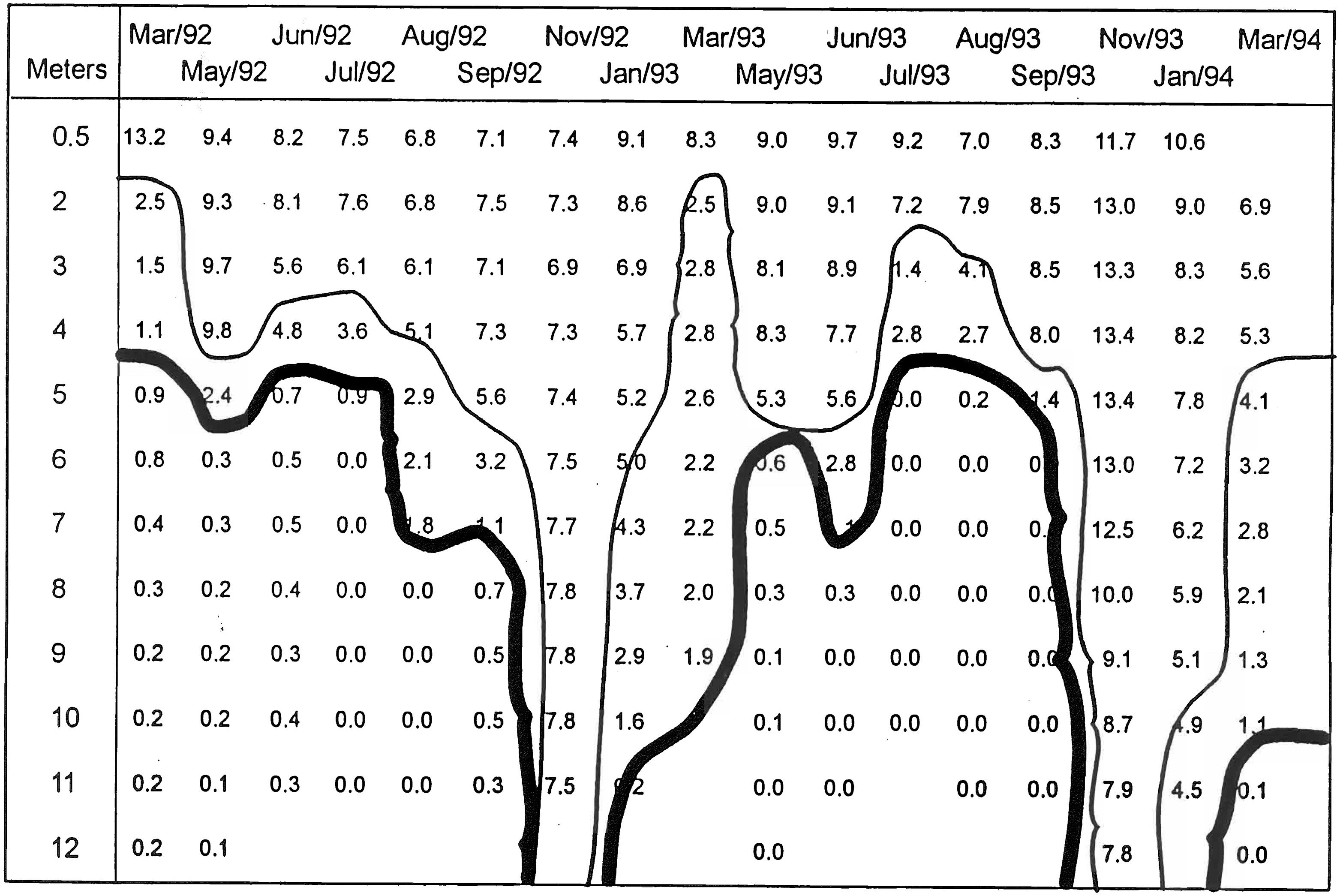
Meters	Mar/92	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93	Jan/94	Mar/94
0.5	15.5	9.8	10.3	8.6	7.1	8.3	12.1	10.9	3.6	8.9	9.2	9.3	9.3	8.1	8.4	13.0	11.3	
2	1.5	10.4	8.7	8.2	6.8	7.5	12.1	8.0	[illegible]	9.2	9.2	9.5	8.6	8.8	8.4	14.2	9.8	4.7
3	1.1	10.4	8.6	8.0	7.3	7.2	12.1	3.8	0.8	9.1	9.2	8.8	8.7	8.9	8.3	14.1	8.7	4.8
4	1.1	11.9	8.6	7.5	6.8	7.2	12.1	2.9	0.7	9.1	9.1	8.8	8.7	7.9	8.4	14.0	7.6	1.8
5	0.7	12.2	7.8	4.5	5.1	7.1	12.1	2.3	0.5	9.1	9.0	8.4	3.9	5.1	8.2	14.0	6.0	1.5
6	0.8	11.6	6.2	2.2	[illegible]	6.3	12.1	[illegible]	0.5	8.4	8.5	7.0	1.1	[illegible]	8.2	13.9	4.9	[illegible]
7	0.8	6.2	2.7	[illegible]	0.0			[illegible]	0.5	3.4	[illegible]	3.5	0.0	0.0	7.4	13.7	2.9	1.7
8		0.9						[illegible]	0.4		0.5		0.0	0.0	[illegible]	13.3	0.3	0.1

Figure 5.5.4. Site C (Spring) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



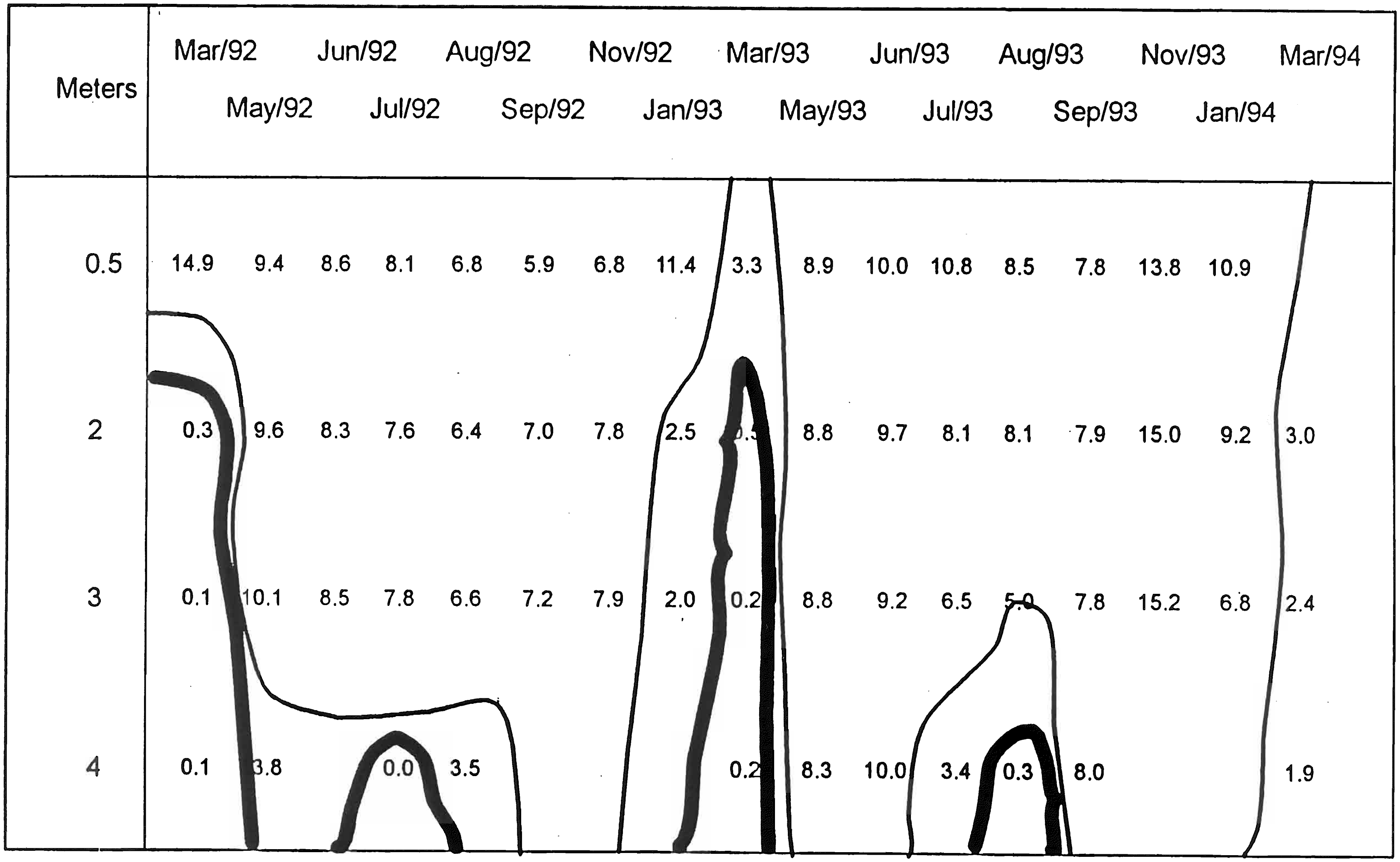
Meters	Mar/92	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93	Jan/94	Mar/94
0.5	13.8	9.2	8.1	8.0	7.2	7.9	7.7	13.9	10.1	9.0	9.2	8.4	8.5	8.3	11.7	11.7	
2	2.8	9.3	8.3	7.6	7.1	7.3	7.6	5.8	1.2	9.0	9.4	8.1	7.8	8.3	14.5	8.8	4.9
3	2.3	8.9	7.4	5.4	5.9	7.1	7.3	5.9	1.1	8.7	9.2	5.7	4.2	7.9	14.6	8.2	4.0
4	1.4	9.4	3.9	3.6	4.7	6.9	7.7	4.7	1.1	8.1	8.3	3.8	1.6	7.1	14.4	7.9	3.0
5	0.6	1.9	[illegible]	0.5	[illegible]	5.1	7.8	4.1	0.9	3.6	5.8	0.0	0.0	5.5	13.7	6.7	2.6
6	0.5	0.4	0.3	0.0	0.1	2.6	7.8	2.9	0.4	0.4	1.7	0.0	0.0	0.1	13.4	6.3	1.9
7	0.5	0.3	0.3	0.0	0.0	1.	8.0	1.	0.0	0.2	0.5	0.0	0.0	0	13.3	5.7	.0
8	0.4	0.3	0.2	0.0	0.0	0.6	8.1	0.5	0.0	0.1	0.0	0.0	0.0	0.	13.4		0.1
9	0.4	0.2	0.2	0.0	0.0		8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7		0.1
10	0.4	0.2	0.2	0.0	0.0		8.1			0.0	0.0			0.0			0.1
11	0.4	2.0	0.0	0.0	0.0		8.0			0.0							
12	0.4	0.2								0.0							

Figure 5.5.5 Site D (Peshtigo) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



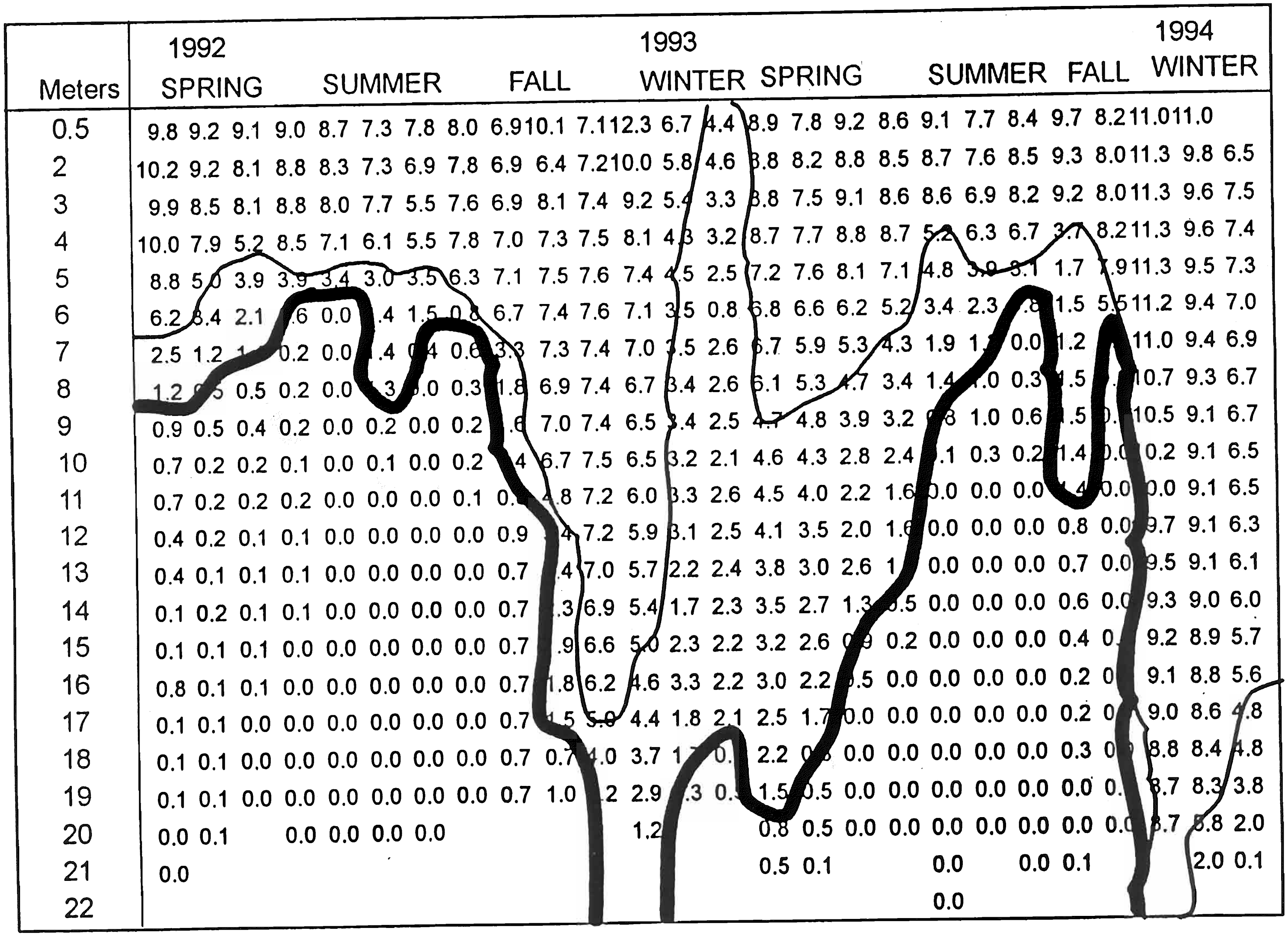
Meters	Mar/92	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93	Jan/94	Mar/94
0.5	13.2	9.4	8.2	7.5	6.8	7.1	7.4	9.1	8.3	9.0	9.7	9.2	7.0	8.3	11.7	10.6	
2	2.5	9.3	8.1	7.6	6.8	7.5	7.3	8.6	2.5	9.0	9.1	7.2	7.9	8.5	13.0	9.0	6.9
3	1.5	9.7	5.6	6.1	6.1	7.1	6.9	6.9	2.8	8.1	8.9	1.4	4.1	8.5	13.3	8.3	5.6
4	1.1	9.8	4.8	3.6	5.1	7.3	7.3	5.7	2.8	8.3	7.7	2.8	2.7	8.0	13.4	8.2	5.3
5	0.9	2.4	0.7	0.9	2.9	5.6	7.4	5.2	2.6	5.3	5.6	0.0	0.2	1.4	13.4	7.8	4.1
6	0.8	0.3	0.5	0.0	2.1	3.2	7.5	5.0	2.2	0.6	2.8	0.0	0.0	0.0	13.0	7.2	3.2
7	0.4	0.3	0.5	0.0	1.8	1.1	7.7	4.3	2.2	0.5	1	0.0	0.0	0.0	12.5	6.2	2.8
8	0.3	0.2	0.4	0.0	0.0	0.7	7.8	3.7	2.0	0.3	0.3	0.0	0.0	0.0	10.0	5.9	2.1
9	0.2	0.2	0.3	0.0	0.0	0.5	7.8	2.9	1.9	0.1	0.0	0.0	0.0	0.0	9.1	5.1	1.3
10	0.2	0.2	0.4	0.0	0.0	0.5	7.8	1.6		0.1	0.0	0.0	0.0	0.0	8.7	4.9	1.1
11	0.2	0.1	0.3	0.0	0.0	0.3	7.5	0.2		0.0	0.0		0.0	0.0	7.9	4.5	0.1
12	0.2	0.1								0.0					7.8		0.0

Figure 5.5.6. Site E (L. Blacksmith) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



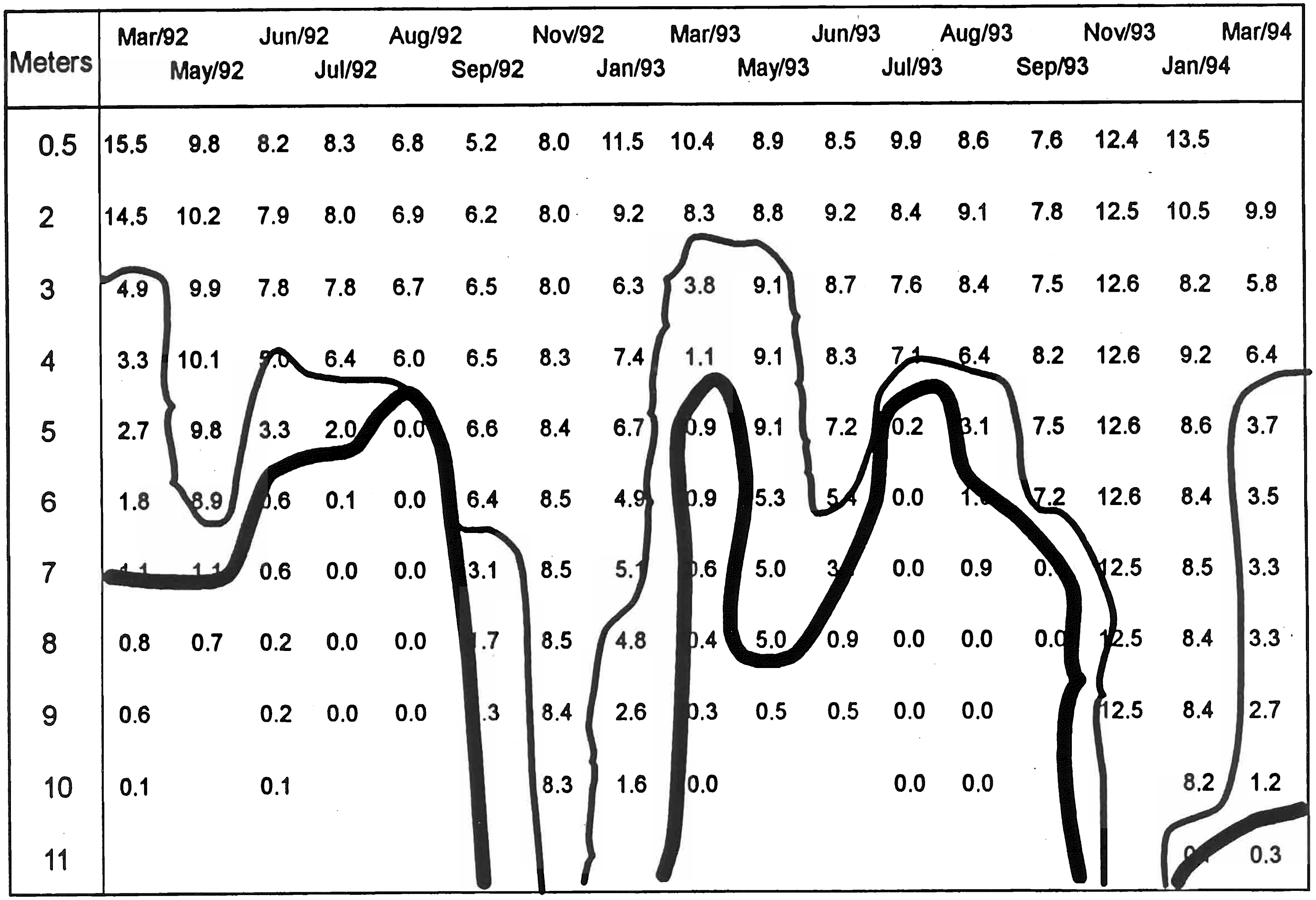
Meters	Mar/92	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93	Jan/94	Mar/94
0.5	14.9	9.4	8.6	8.1	6.8	5.9	6.8	11.4	3.3	8.9	10.0	10.8	8.5	7.8	13.8	10.9	
2	0.3	9.6	8.3	7.6	6.4	7.0	7.8	2.5	0.5	8.8	9.7	8.1	8.1	7.9	15.0	9.2	3.0
3	0.1	10.1	8.5	7.8	6.6	7.2	7.9	2.0	0.2	8.8	9.2	6.5	5.0	7.8	15.2	6.8	2.4
4	0.1	3.8		0.0	3.5				0.2	8.3	10.0	3.4	0.3	8.0			1.9

Figure 5.5.7. Site F (Blacksmith) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



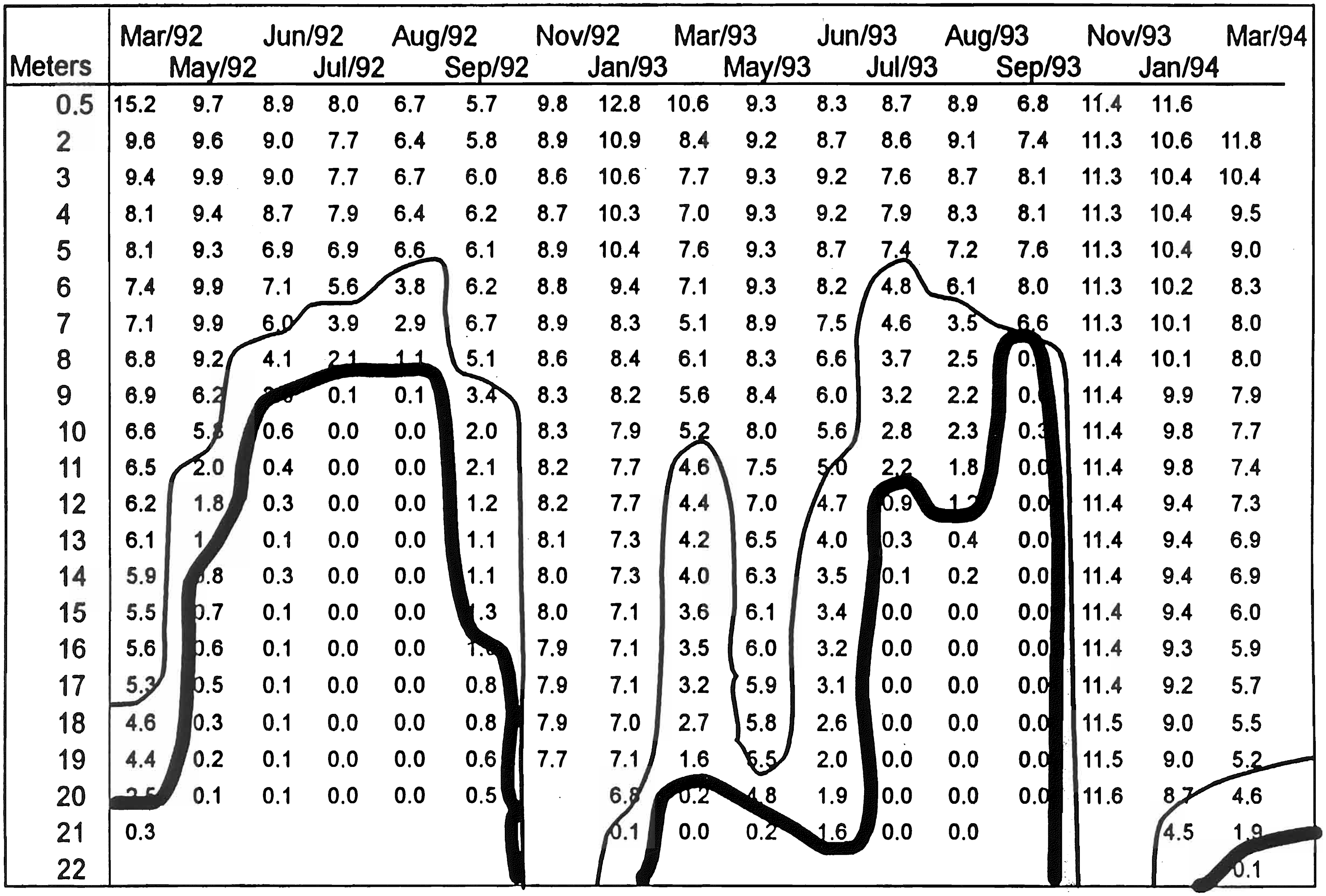
Meters	1992											1993											1994		
	SPRING				SUMMER				FALL				WINTER	SPRING				SUMMER			FALL		WINTER		
0.5	9.8	9.2	9.1	9.0	8.7	7.3	7.8	8.0	6.9	10.1	7.1	12.3	6.7	4.4	8.9	7.8	9.2	8.6	9.1	7.7	8.4	9.7	8.2	11.0	11.0	
2	10.2	9.2	8.1	8.8	8.3	7.3	6.9	7.8	6.9	6.4	7.2	10.0	5.8	4.6	8.8	8.2	8.8	8.5	8.7	7.6	8.5	9.3	8.0	11.3	9.8	6.5
3	9.9	8.5	8.1	8.8	8.0	7.7	5.5	7.6	6.9	8.1	7.4	9.2	5.4	3.3	8.8	7.5	9.1	8.6	8.6	6.9	8.2	9.2	8.0	11.3	9.6	7.5
4	10.0	7.9	5.2	8.5	7.1	6.1	5.5	7.8	7.0	7.3	7.5	8.1	4.3	3.2	8.7	7.7	8.8	8.7	5.2	6.3	6.7	3.7	8.2	11.3	9.6	7.4
5	8.8	5.0	3.9	3.9	3.4	3.0	3.5	6.3	7.1	7.5	7.6	7.4	4.5	2.5	7.2	7.6	8.1	7.1	4.8	3.9	3.1	1.7	7.9	11.3	9.5	7.3
6	6.2	8.4	2.1	.6	0.0	.4	1.5	0.8	6.7	7.4	7.6	7.1	3.5	0.8	6.8	6.6	6.2	5.2	3.4	2.3	.8	1.5	5.5	11.2	9.4	7.0
7	2.5	1.2	1.	0.2	0.0	.4	0.4	0.6	3.3	7.3	7.4	7.0	3.5	2.6	6.7	5.9	5.3	4.3	1.9	1.	0.0	1.2	[illegible]	11.0	9.4	6.9
8	1.2	0.5	0.5	0.2	0.0	3	.0	0.3	1.8	6.9	7.4	6.7	3.4	2.6	6.1	5.3	4.7	3.4	1.4	.0	0.3	.5	[illegible]	10.7	9.3	6.7
9	0.9	0.5	0.4	0.2	0.0	0.2	0.0	0.2	.6	7.0	7.4	6.5	3.4	2.5	4.7	4.8	3.9	3.2	0.8	1.0	0.6	.5	0.	10.5	9.1	6.7
10	0.7	0.2	0.2	0.1	0.0	0.1	0.0	0.2	4	6.7	7.5	6.5	3.2	2.1	4.6	4.3	2.8	2.4	.1	0.3	0.2	1.4	0.0	0.2	9.1	6.5
11	0.7	0.2	0.2	0.2	0.0	0.0	0.0	0.1	0.	4.8	7.2	6.0	3.3	2.6	4.5	4.0	2.2	1.6	0.0	0.0	0.0	.4	0.0	0.0	9.1	6.5
12	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.9	.4	7.2	5.9	3.1	2.5	4.1	3.5	2.0	1.6	0.0	0.0	0.0	0.8	0.0	9.7	9.1	6.3
13	0.4	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.7	.4	7.0	5.7	2.2	2.4	3.8	3.0	2.6	1	0.0	0.0	0.0	0.7	0.0	9.5	9.1	6.1
14	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.7	.3	6.9	5.4	1.7	2.3	3.5	2.7	1.3	.5	0.0	0.0	0.0	0.6	0.0	9.3	9.0	6.0
15	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.7	.9	6.6	5.0	2.3	2.2	3.2	2.6	0.9	0.2	0.0	0.0	0.0	0.4	0.	9.2	8.9	5.7
16	0.8	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.7	1.8	6.2	4.6	3.3	2.2	3.0	2.2	.5	0.0	0.0	0.0	0.0	0.2	0	9.1	8.8	5.6
17	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.5	5.0	4.4	1.8	2.1	2.5	1.7	0.0	0.0	0.0	0.0	0.0	0.2	0	9.0	8.6	4.8
18	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	4.0	3.7	1.	0.	2.2	0.	0.0	0.0	0.0	0.0	0.0	0.3	0	8.8	8.4	4.8
19	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	.2	2.9	.3	0.	1.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.	8.7	8.3	3.8
20	0.0	0.1		0.0	0.0	0.0	0.0					1.2			0.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7	.8	2.0
21	0.0														0.5	0.1			0.0		0.0	0.1			2.0	0.1
22																			0.0							

Figure 5.5.8 Site G (Sapokesick) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



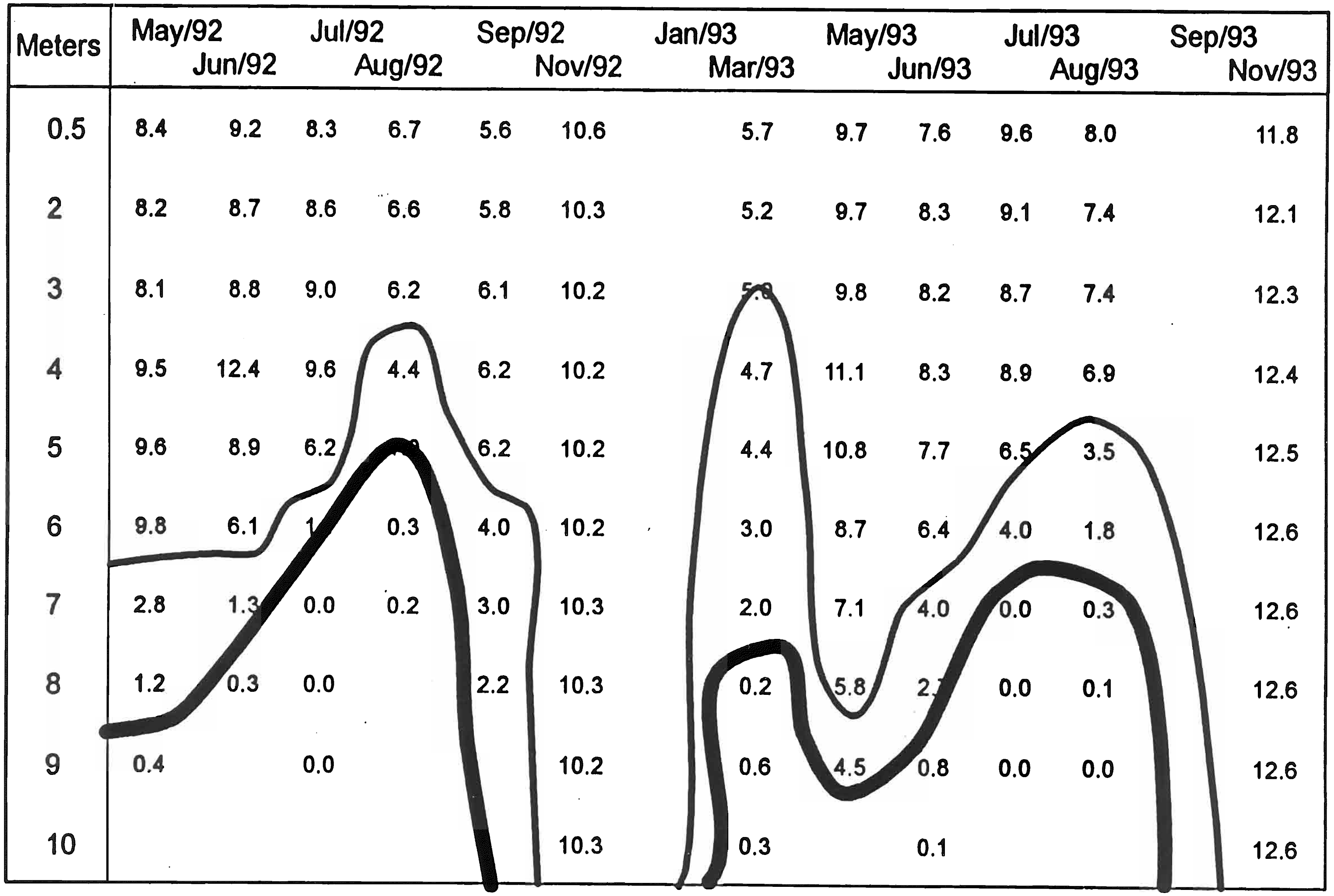
Meters	Mar/92	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93	Jan/94	Mar/94
0.5	15.5	9.8	8.2	8.3	6.8	5.2	8.0	11.5	10.4	8.9	8.5	9.9	8.6	7.6	12.4	13.5	
2	14.5	10.2	7.9	8.0	6.9	6.2	8.0	9.2	8.3	8.8	9.2	8.4	9.1	7.8	12.5	10.5	9.9
3	4.9	9.9	7.8	7.8	6.7	6.5	8.0	6.3	3.8	9.1	8.7	7.6	8.4	7.5	12.6	8.2	5.8
4	3.3	10.1	5.0	6.4	6.0	6.5	8.3	7.4	1.1	9.1	8.3	7.1	6.4	8.2	12.6	9.2	6.4
5	2.7	9.8	3.3	2.0	0.0	6.6	8.4	6.7	0.9	9.1	7.2	0.2	3.1	7.5	12.6	8.6	3.7
6	1.8	8.9	0.6	0.1	0.0	6.4	8.5	4.9	0.9	5.3	5.4	0.0	1.	7.2	12.6	8.4	3.5
7	1.1	1.1	0.6	0.0	0.0	3.1	8.5	5.1	0.6	5.0	3.	0.0	0.9	0.	12.5	8.5	3.3
8	0.8	0.7	0.2	0.0	0.0	.7	8.5	4.8	0.4	5.0	0.9	0.0	0.0	0.0	12.5	8.4	3.3
9	0.6		0.2	0.0	0.0	.3	8.4	2.6	0.3	0.5	0.5	0.0	0.0		12.5	8.4	2.7
10	0.1		0.1				8.3	1.6	0.0			0.0	0.0			8.2	1.2
11																0.	0.3

Figure 5.5.9. Site H (Pywaosit) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



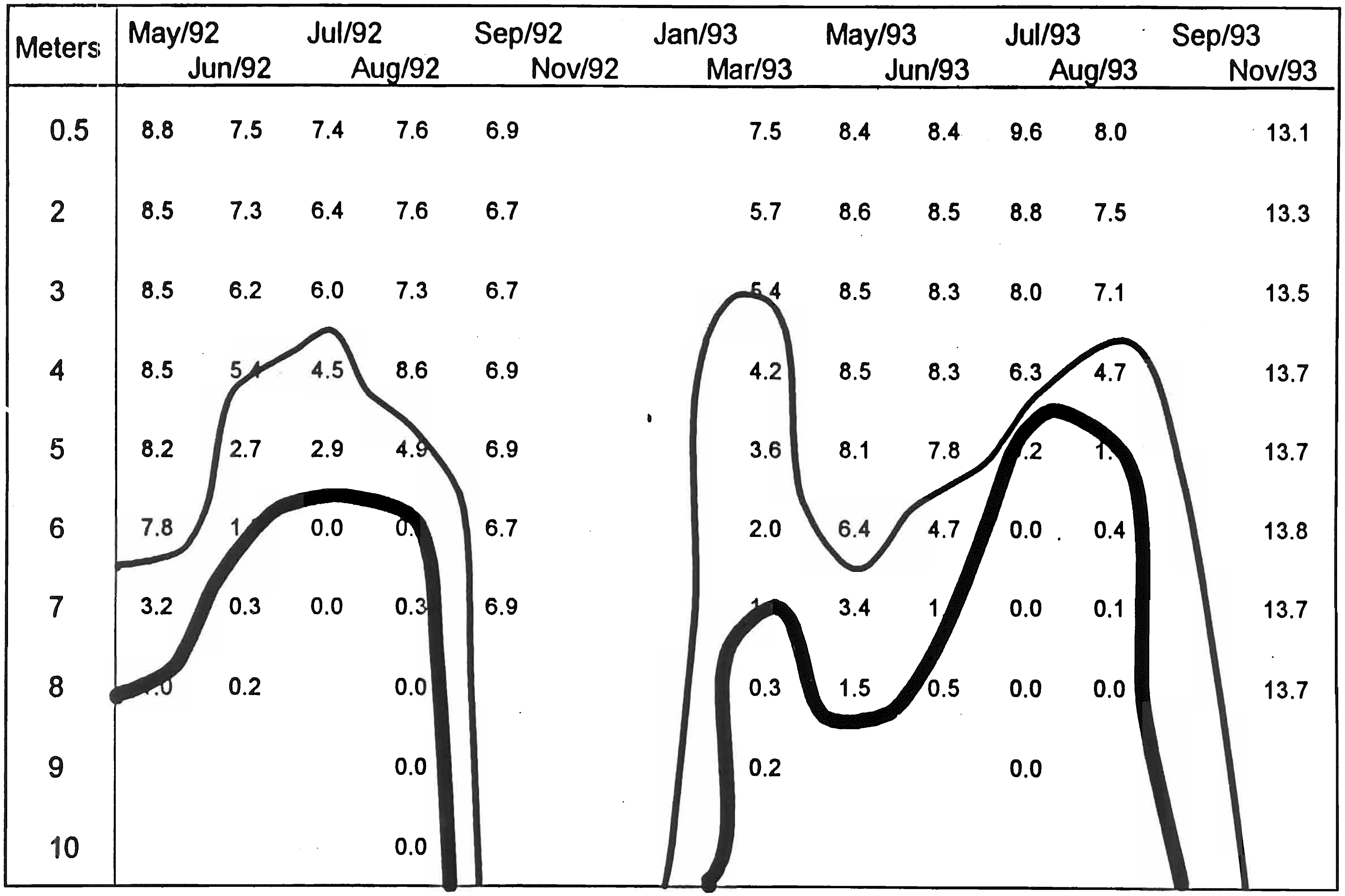
Meters	Mar/92	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93	Jan/94	Mar/94
0.5	15.2	9.7	8.9	8.0	6.7	5.7	9.8	12.8	10.6	9.3	8.3	8.7	8.9	6.8	11.4	11.6	
2	9.6	9.6	9.0	7.7	6.4	5.8	8.9	10.9	8.4	9.2	8.7	8.6	9.1	7.4	11.3	10.6	11.8
3	9.4	9.9	9.0	7.7	6.7	6.0	8.6	10.6	7.7	9.3	9.2	7.6	8.7	8.1	11.3	10.4	10.4
4	8.1	9.4	8.7	7.9	6.4	6.2	8.7	10.3	7.0	9.3	9.2	7.9	8.3	8.1	11.3	10.4	9.5
5	8.1	9.3	6.9	6.9	6.6	6.1	8.9	10.4	7.6	9.3	8.7	7.4	7.2	7.6	11.3	10.4	9.0
6	7.4	9.9	7.1	5.6	3.8	6.2	8.8	9.4	7.1	9.3	8.2	4.8	6.1	8.0	11.3	10.2	8.3
7	7.1	9.9	6.0	3.9	2.9	6.7	8.9	8.3	5.1	8.9	7.5	4.6	3.5	6.6	11.3	10.1	8.0
8	6.8	9.2	4.1	2.1	1.1	5.1	8.6	8.4	6.1	8.3	6.6	3.7	2.5	[illegible]	11.4	10.1	8.0
9	6.9	6.2	[illegible]	0.1	0.1	3.4	8.3	8.2	5.6	8.4	6.0	3.2	2.2	[illegible]	11.4	9.9	7.9
10	6.6	5.8	0.6	0.0	0.0	2.0	8.3	7.9	5.2	8.0	5.6	2.8	2.3	0.3	11.4	9.8	7.7
11	6.5	2.0	0.4	0.0	0.0	2.1	8.2	7.7	4.6	7.5	5.0	2.2	1.8	0.0	11.4	9.8	7.4
12	6.2	1.8	0.3	0.0	0.0	1.2	8.2	7.7	4.4	7.0	4.7	0.9	[illegible]	0.0	11.4	9.4	7.3
13	6.1	[illegible]	0.1	0.0	0.0	1.1	8.1	7.3	4.2	6.5	4.0	0.3	0.4	0.0	11.4	9.4	6.9
14	5.9	0.8	0.3	0.0	0.0	1.1	8.0	7.3	4.0	6.3	3.5	0.1	0.2	0.0	11.4	9.4	6.9
15	5.5	0.7	0.1	0.0	0.0	1.3	8.0	7.1	3.6	6.1	3.4	0.0	0.0	0.0	11.4	9.4	6.0
16	5.6	0.6	0.1	0.0	0.0	[illegible]	7.9	7.1	3.5	6.0	3.2	0.0	0.0	0.0	11.4	9.3	5.9
17	5.3	0.5	0.1	0.0	0.0	0.8	7.9	7.1	3.2	5.9	3.1	0.0	0.0	0.0	11.4	9.2	5.7
18	4.6	0.3	0.1	0.0	0.0	0.8	7.9	7.0	2.7	5.8	2.6	0.0	0.0	0.0	11.5	9.0	5.5
19	4.4	0.2	0.1	0.0	0.0	0.6	7.7	7.1	1.6	5.5	2.0	0.0	0.0	0.0	11.5	9.0	5.2
20	2.5	0.1	0.1	0.0	0.0	0.5		6.8	0.2	4.8	1.9	0.0	0.0	0.0	11.6	8.7	4.6
21	0.3							0.1	0.0	0.2	1.6	0.0	0.0			4.5	1.9
22																	0.1

Figure 5.5.10. Site I (Round Lake) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



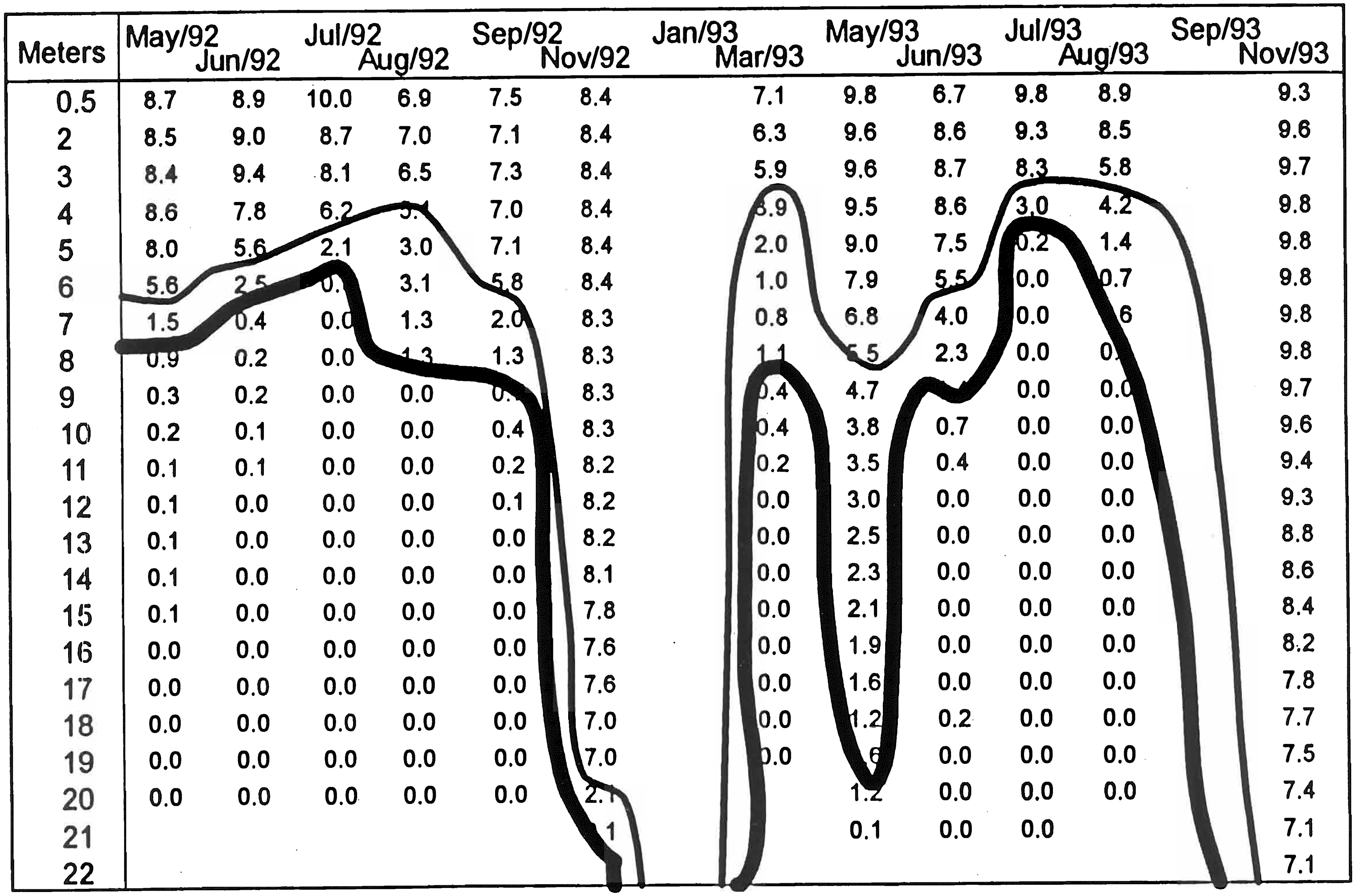
Meters	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93
0.5	8.4	9.2	8.3	6.7	5.6	10.6		5.7	9.7	7.6	9.6	8.0		11.8
2	8.2	8.7	8.6	6.6	5.8	10.3		5.2	9.7	8.3	9.1	7.4		12.1
3	8.1	8.8	9.0	6.2	6.1	10.2		5.8	9.8	8.2	8.7	7.4		12.3
4	9.5	12.4	9.6	4.4	6.2	10.2		4.7	11.1	8.3	8.9	6.9		12.4
5	9.6	8.9	6.2	[illegible]	6.2	10.2		4.4	10.8	7.7	6.5	3.5		12.5
6	9.8	6.1	[illegible]	0.3	4.0	10.2		3.0	8.7	6.4	4.0	1.8		12.6
7	2.8	1.3	0.0	0.2	3.0	10.3		2.0	7.1	4.0	0.0	0.3		12.6
8	1.2	0.3	0.0		2.2	10.3		0.2	5.8	2.7	0.0	0.1		12.6
9	0.4		0.0			10.2		0.6	4.5	0.8	0.0	0.0		12.6
10						10.3		0.3		0.1				12.6

Figure 5.5.11. Site J (Sand Lake) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



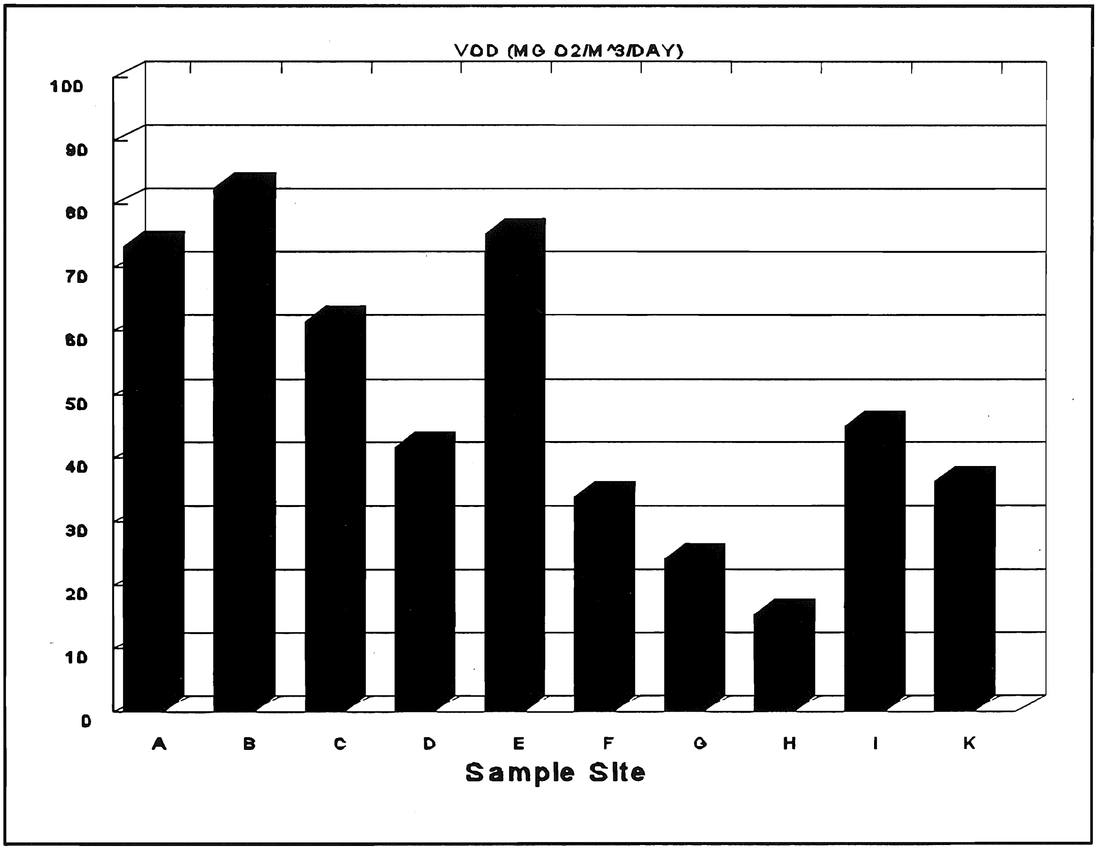
Meters	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93
0.5	8.8	7.5	7.4	7.6	6.9			7.5	8.4	8.4	9.6	8.0		13.1
2	8.5	7.3	6.4	7.6	6.7			5.7	8.6	8.5	8.8	7.5		13.3
3	8.5	6.2	6.0	7.3	6.7			5.4	8.5	8.3	8.0	7.1		13.5
4	8.5	5.	4.5	8.6	6.9			4.2	8.5	8.3	6.3	4.7		13.7
5	8.2	2.7	2.9	4.9	6.9			3.6	8.1	7.8	.2	1.		13.7
6	7.8	1	0.0	0.	6.7			2.0	6.4	4.7	0.0	0.4		13.8
7	3.2	0.3	0.0	0.3	6.9			1	3.4	1	0.0	0.1		13.7
8	.0	0.2		0.0				0.3	1.5	0.5	0.0	0.0		13.7
9				0.0				0.2			0.0			
10				0.0										

Figure 5.5.12. Site K (LaMotte) dissolved oxygen concentrations with depth (meters) from May 1992 through March 1994. Isopleths shown for 1 ppm (thick line) and 5 ppm (thin line).



Meters	May/92	Jun/92	Jul/92	Aug/92	Sep/92	Nov/92	Jan/93	Mar/93	May/93	Jun/93	Jul/93	Aug/93	Sep/93	Nov/93
0.5	8.7	8.9	10.0	6.9	7.5	8.4		7.1	9.8	6.7	9.8	8.9		9.3
2	8.5	9.0	8.7	7.0	7.1	8.4		6.3	9.6	8.6	9.3	8.5		9.6
3	8.4	9.4	8.1	6.5	7.3	8.4		5.9	9.6	8.7	8.3	5.8		9.7
4	8.6	7.8	6.2	3.[illegible]	7.0	8.4		3.9	9.5	8.6	3.0	4.2		9.8
5	8.0	5.6	2.1	3.0	7.1	8.4		2.0	9.0	7.5	0.2	1.4		9.8
6	5.6	2.5	0.[illegible]	3.1	5.8	8.4		1.0	7.9	5.5	0.0	0.7		9.8
7	1.5	0.4	0.0	1.3	2.0	8.3		0.8	6.8	4.0	0.0	[illegible]6		9.8
8	0.9	0.2	0.0	1.3	1.3	8.3		1.1	5.5	2.3	0.0	0.[illegible]		9.8
9	0.3	0.2	0.0	0.0	0.[illegible]	8.3		0.4	4.7	[illegible]	0.0	0.0		9.7
10	0.2	0.1	0.0	0.0	0.4	8.3		0.4	3.8	0.7	0.0	0.0		9.6
11	0.1	0.1	0.0	0.0	0.2	8.2		0.2	3.5	0.4	0.0	0.0		9.4
12	0.1	0.0	0.0	0.0	0.1	8.2		0.0	3.0	0.0	0.0	0.0		9.3
13	0.1	0.0	0.0	0.0	0.0	8.2		0.0	2.5	0.0	0.0	0.0		8.8
14	0.1	0.0	0.0	0.0	0.0	8.1		0.0	2.3	0.0	0.0	0.0		8.6
15	0.1	0.0	0.0	0.0	0.0	7.8		0.0	2.1	0.0	0.0	0.0		8.4
16	0.0	0.0	0.0	0.0	0.0	7.6		0.0	1.9	0.0	0.0	0.0		8.2
17	0.0	0.0	0.0	0.0	0.0	7.6		0.0	1.6	0.0	0.0	0.0		7.8
18	0.0	0.0	0.0	0.0	0.0	7.0		0.0	1.2	0.2	0.0	0.0		7.7
19	0.0	0.0	0.0	0.0	0.0	7.0		0.0	[illegible]6	0.0	0.0	0.0		7.5
20	0.0	0.0	0.0	0.0	0.0	2.1			1.2	0.0	0.0	0.0		7.4
21						[illegible]1			0.1	0.0	0.0			7.1
22														7.1

Figure 5.5.13. Average 1992 and 1993 winter water column VOD rates by sample site.



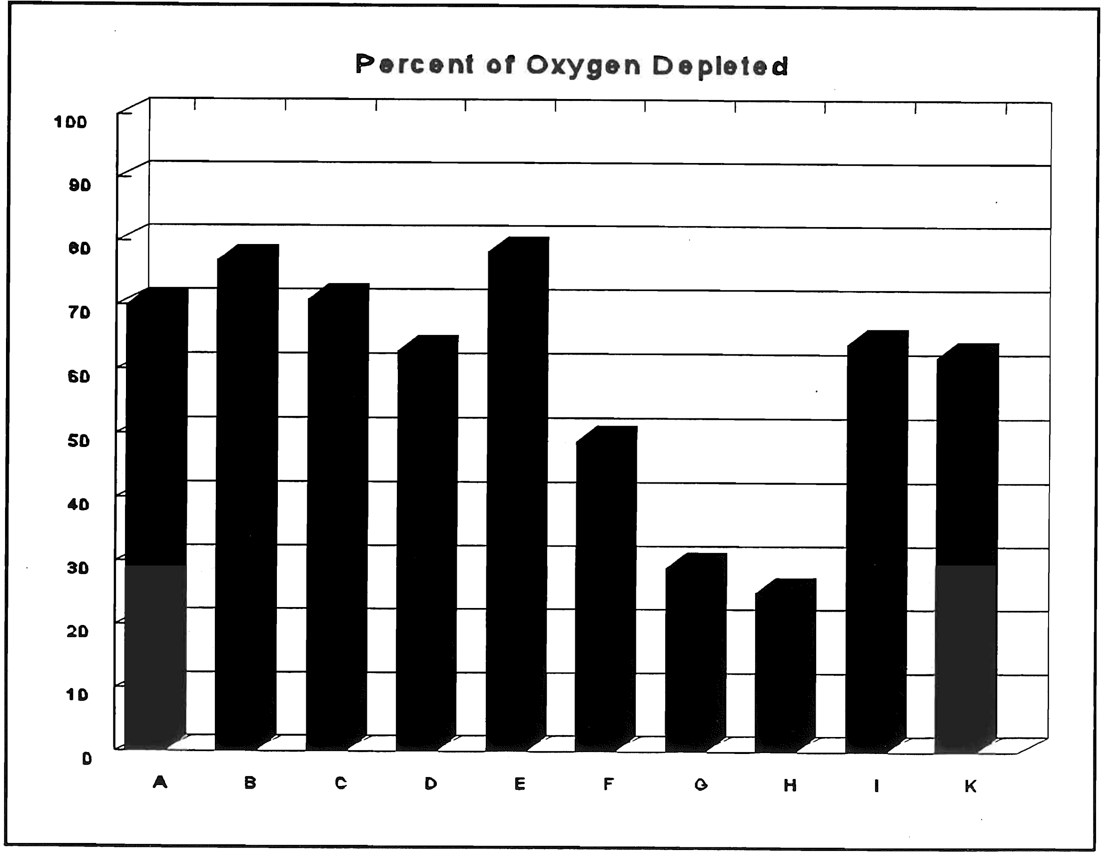
might have allowed for a better determination of the extent of spring turnover.

As an alternative, Figure 5.5.13 shows the average of 1992 and 1993 winter VOD rates for the entire water column at each sample site. The initial dissolved oxygen measurements were at fall turnover for the winter VOD rate determination. All lake basins were near 100% saturation at fall turnover. The VOD calculated during the winter does not have the problem of diminishing rates: calculated values were based on a beginning 100% saturation point through the period of linear depletion and did not include data beyond mid-March. This measurement allows us to make a comparison of how rapidly oxygen has been depleted in each of the lake basins over winter, which is the most critical season for possible fish kill due to oxygen depletion.

Relative Oxygen Deficit

The oxygen mass data can also be viewed as relative deficits. At the fall 1993 turnover, all of the lake basins were nearly 100% saturated with dissolved oxygen. The percent loss in the lake basin oxygen mass between spring and late winter is the relative deficit. The mean dissolved oxygen depleted by late winter (mid-March) as a percentage of the fall turnover mass is shown in Figure 5.5.14. As expected, the lake basins with the higher rate of depletion are also the ones that have a greater relative depletion. The relative oxygen depletion is more relevant to the concern for winterkill; it highlights the lake basins that are at greater risk by measuring the extent of total lake depletion rather than the rate of depletion.

Figure 5.5.14. Mean March oxygen percentage depletion relative to November 1993 fall turnover oxygen concentration by site.



The lake basins with high relative oxygen depletions (Sites A, B, C, D, and E) also had March 1993 dissolved oxygen levels of less than 5 mg/l throughout the water column. Also, Sites A, B, and E had dissolved oxygen levels below 1 mg/l within 2 to 3 meters of the surface. The low oxygen levels in these particular lake basins threatens the survival of fish and reduces habitat. If the low oxygen levels are prolonged, fish kills may result in future years when ice and snow cover is extreme.

Groundwater Seepage, Sediment, and Aquatic Plant Relationships

A major focus of this project was to study the potential impact of septic systems on groundwater and subsequent effects on lake sediment and aquatic plants. The following discussion presents the results of this sub-study. More detailed analysis is presented in Weber, 1994.

Seepage Meter Flow

Seepage inflow to lakes is generally highest near the lake shore and decreases with distance from shore (McBride and Pfannkoch, 1975; Lee et al., 1980; and Shaw and Prepas, 1990). This appeared to be the case with the seepage measured in Legend Lake (Figure 5.6.1) where the largest contribution of seepage was within the 0 - 1.5 m lake depths. The seepage meter sample sites are defined in Table 5.6.1.

Seepage meter volumes collected from each of the two treatment groups (described in the methods section) indicated varied amounts of flow during each sampling. Comparison of mean seepage discharge (Q) values between the Effluent (1.36 $l/m^2/day$) and Inflow (0.82 $l/m^2/day$) treatment were significantly different ($p = 0.05$). Average seepage discharge values at the 1 m and 1.5 m lake depths were higher on average for Effluent sites (1.9 $l/m^2/day$) than at the Inflow sites (0.93 $l/m^2/day$). This was not the case for the 2.5 m lake depth, where seepage discharge was greater in the inflow areas where no septic effluent was present (Figure 5.6.1). The reason for the differences between the 1 m and 1.5 m depth is not easily explained; however, the differences associated with the 2.5 m depth could be due to the occurrence of the 5% higher organic matter content of the Effluent site sediment (20%) than at the non-effluent Inflow sites (15%). The higher concentration of organic matter could be impeding water flow through these sediments. Disturbance of sediments near developed lots may result in more seepage than the undisturbed sediments at the undeveloped

Inflow sites. The distribution of individual plant species root systems may also affect sediment permeability resulting in varied seepage.

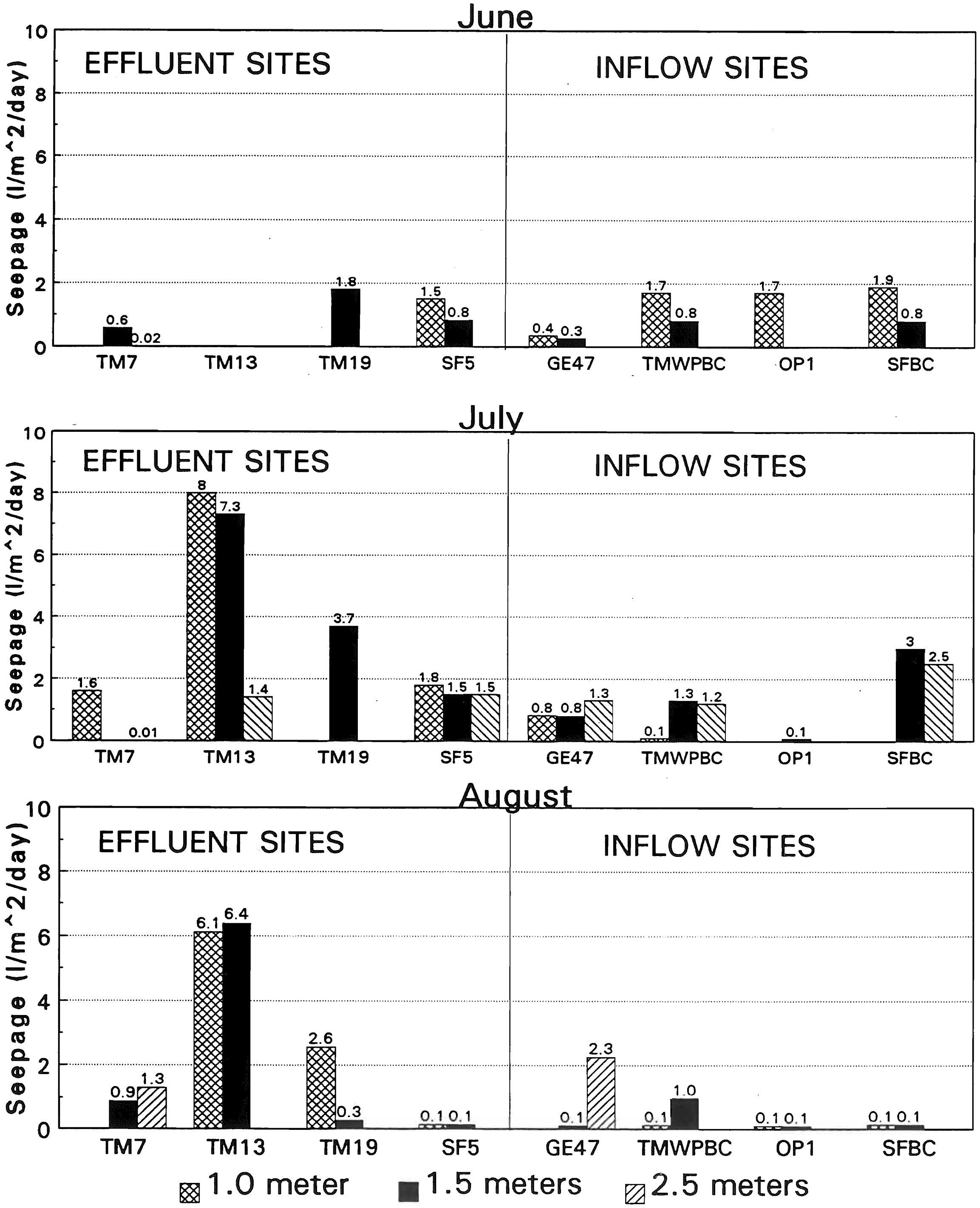
The distribution of seepage meter discharge was not only affected by lake depth, but also time. Brock et al., (1982) addressed the two types of variability in groundwater seepage site to site and day to day, and it is this day to day variability which is not easily accounted for since it is affected by meteorological factors that effect groundwater gradients.

Average seepage values during the month of June were less than 2 l/m^2/day, but increased slightly in most of the sites during July and August (Figure 5.6.1). The site located at TM13 appeared to display the highest rates of discharge, on average, over the sampling periods. In those cases when data was missing it was a result of seepage meter tampering and other human activities such as boating traffic, water skiing and swimming. The discrepancies in the seepage meter data may reduce the confidence levels of the discharge data when considering growing season or depth averages and the analysis of seasonal trends or treatment effect.

Table 5.6.1. Sample site designations for each treatment group by subdivision and lot number.

Effluent Sites	Inflow Sites	Outflow Sites
Tallmoon 7 (TM7)	Grey Eagle 47 (GE47)	White Cloud Overlook (WCOL) (WCOL)
Tallmoon 13 (TM13)	Tallmoon/Whispering Pines Beach Club (TMWPBC)	Setting Sun 19 (SS19)
Tallmoon 19 (TM19)	Otter Pond 1 (OP!)	
Spotted Fawn 5 (SF5)	Spotted Fawn Beach Club (SFBC)	

Figure 5.6.1. Seepage meter discharge (l/m^2/day) for June, July, and August for eight sites in Legend Lake.



Seepage Chemistry

Lake water chemistry has been found to play an important role in the distribution of aquatic macrophyte biomass and species. There have been a number of studies which have looked at various relationships between plant biomass and nitrate, phosphorus, chloride, pH, and free carbon dioxide (Moyle, 1945). Other studies have looked at alkalinity and conductivity and their impact on the distribution of plants (Seddon, 1972).

Three of the four sites located in the Effluent areas exhibited significantly higher concentrations of available nitrogen ($NH_4^+ + NO_3^-$) over the course of the summer than those sites in the Inflow areas ($p=0.05$) (Table 5.6.2)(Figure 5.6.2). This also held true for soluble reactive phosphorus in the Effluent areas displaying significantly higher levels than those in Inflow areas ($p = 0.001$) (Table 5.6.2)(Figure 5.6.3). However, Spotted Fawn 5 exhibited low levels of nitrogen and phosphorus in seepage water. Soluble reactive phosphorus did show a decline in concentration over the summer, while available nitrogen increased or stayed the same. This is similar to trends in extractable phosphorus and available nitrogen found in sediment samples.

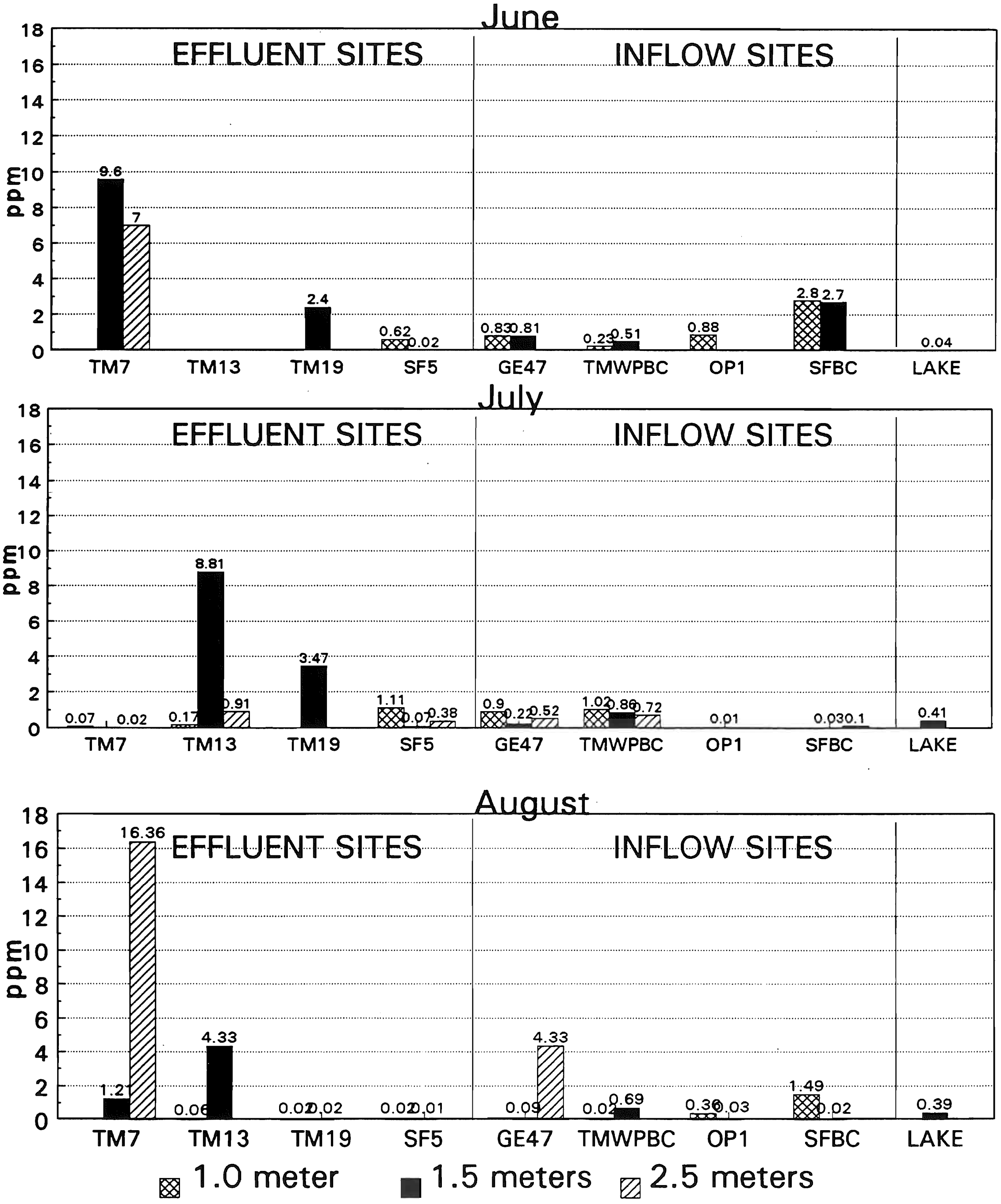
Table 5.6.2. Seepage meter mean and median available nitrogen and phosphorus concentrations (mg/l) for two treatments.

Variable	Mean		Median	
	Effluent	Inflow	Effluent	Inflow
Available Nitrogen	2.31	0.84	0.81	0.61
Soluble Reactive Phosphorus	0.45	0.04	0.17	0.03

The decline in soluble reactive phosphorus may be attributed to decrease in solubility related to the mineral inactivation, marl formation, or biological uptake. The increase in available nitrogen is believed to be related to the release of nitrogen in the decomposition of organic matter found in the lake sediments and/or to biological transformation of Nitrate-N from groundwater.

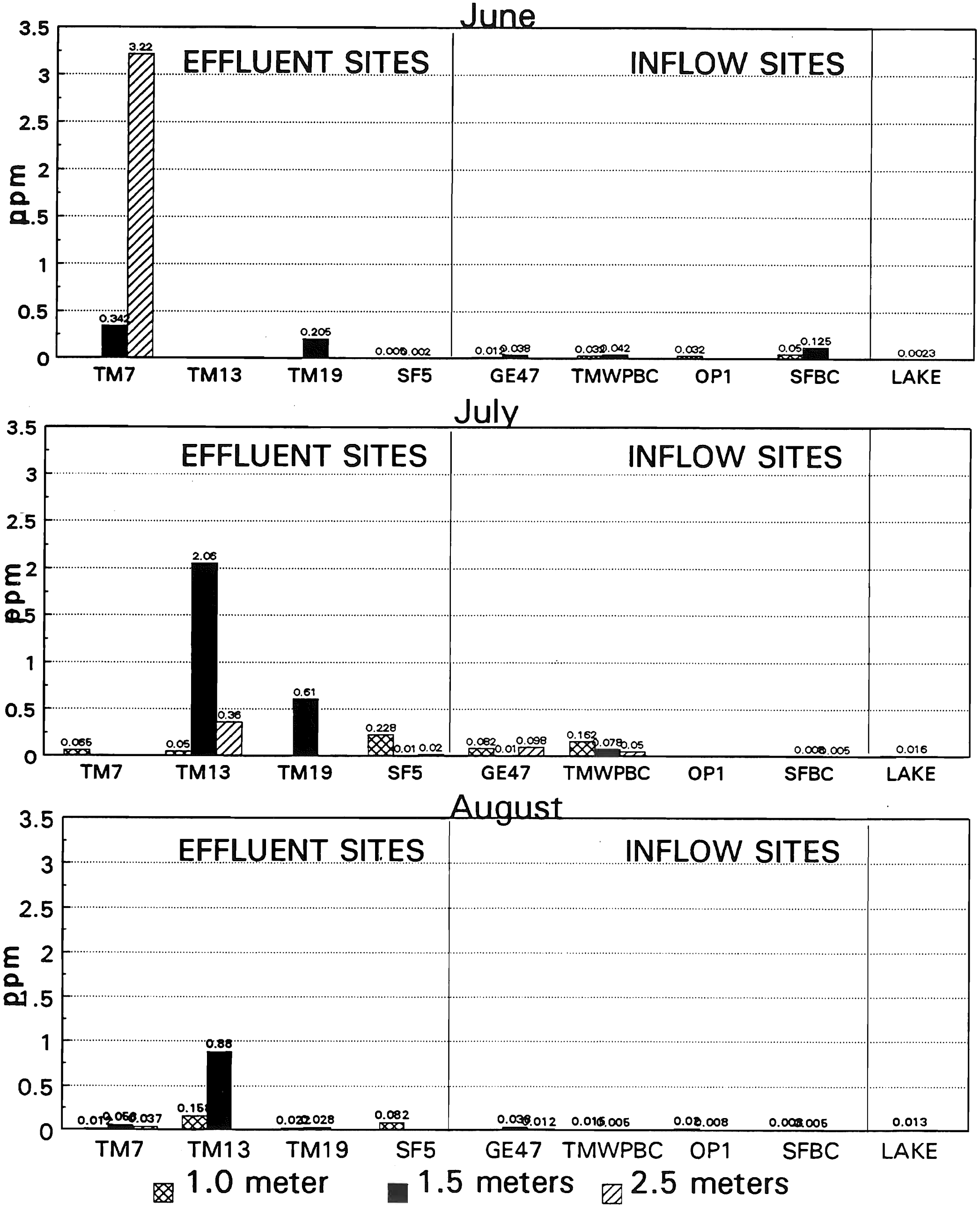
Chloride values fluctuated considerably between the sample periods. This may relate to the fluctuation in the location and concentration of effluent plumes, as caused by the amount of groundwater recharge from precipitation, and the amount of septic system usage which can be seasonal for some residences (Figure 5.6.4).

Figure 5.6.2. Seepage meter ammonia nitrogen concentration (mg/l) for June, July and August 1993 for eight sites in Legend Lake.



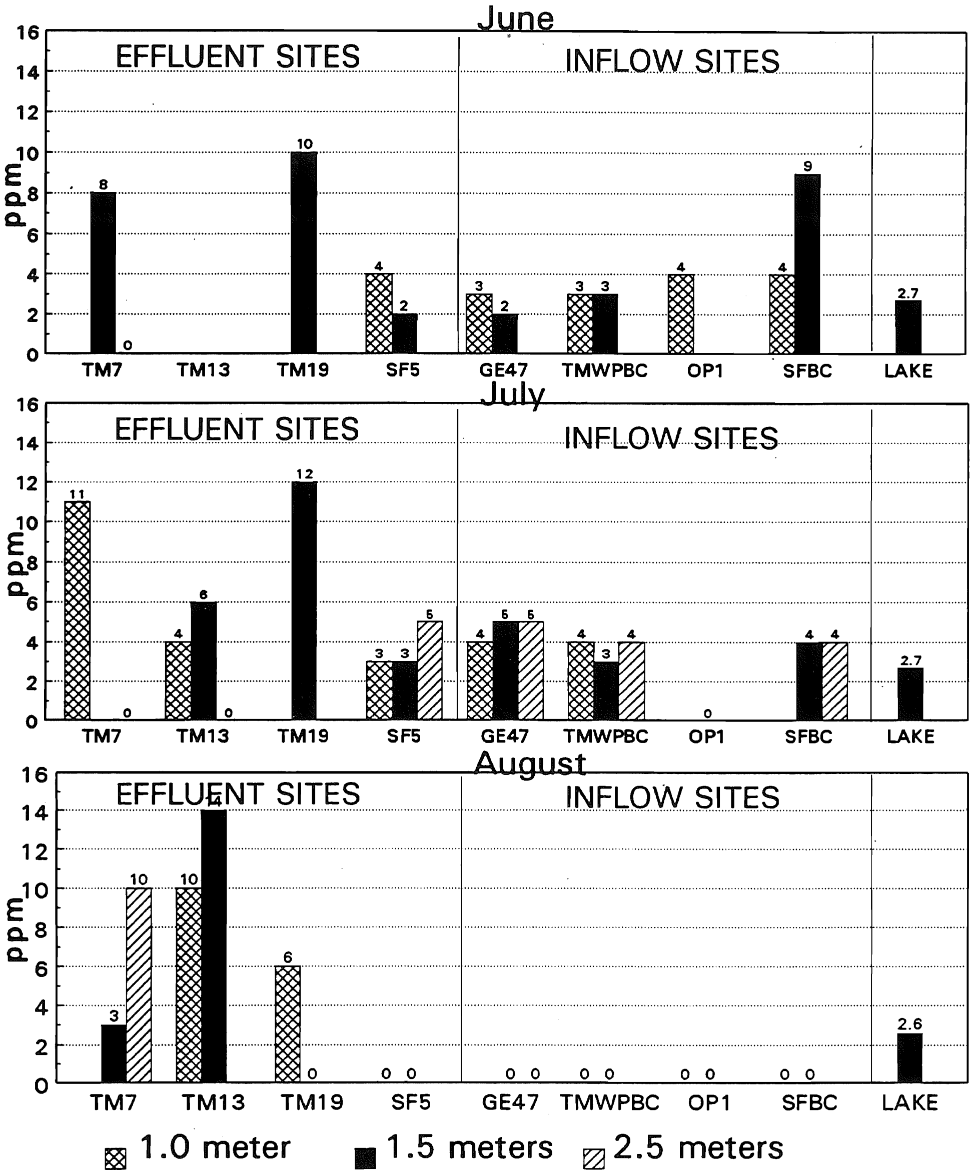
*Lake Values collected from 2.0m depth

Figure 5.6.3. Seepage meter soluble reactive phosphorus concentration (mg/l) for June, July, and August 1993 for eight sites in Legend Lake.



*Lake value collected from 2.0m depth

Figure 5.6.4. Seepage meter chloride concentrations (mg/l) for June, July and August 1993 for eight sites in Legend Lake.



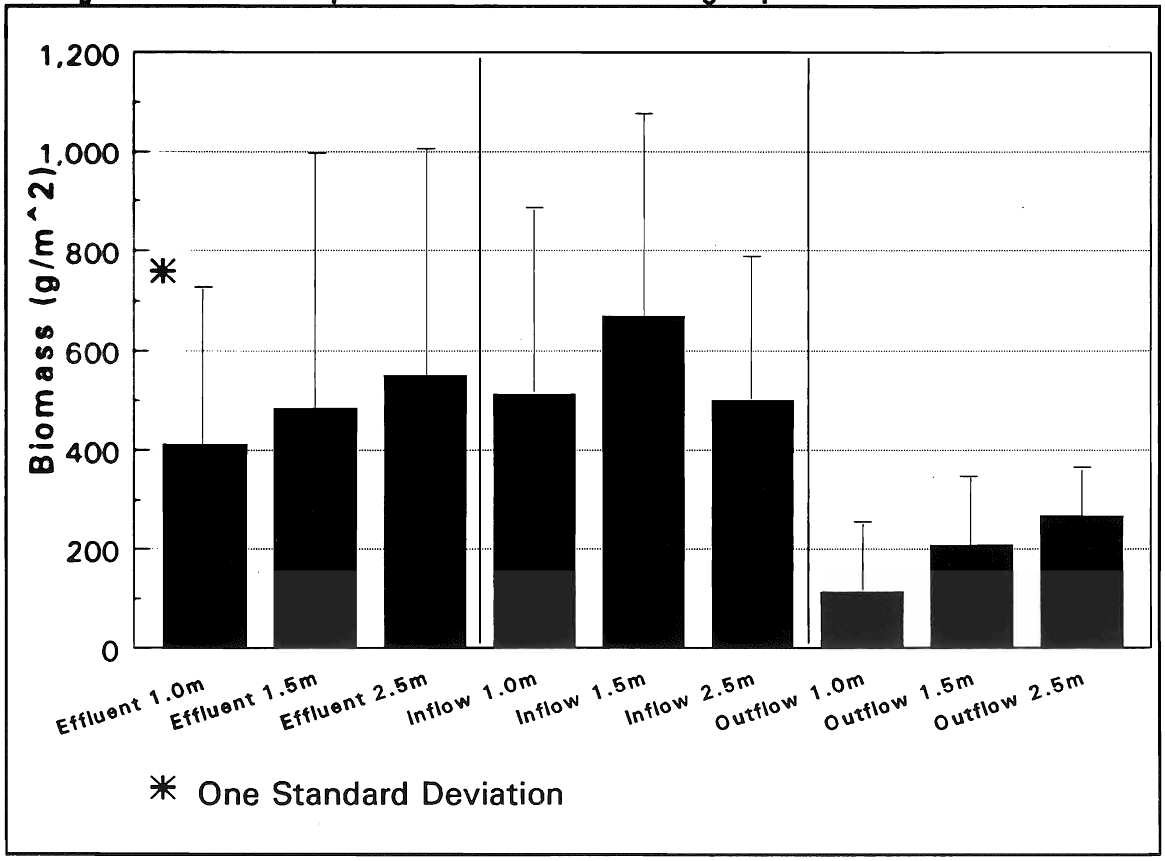
*Lake values collected from 2.0m depth

Results of Macrophyte Study in Basins A and B

Plant Biomass and Species Distribution Within the Seepage Meter Study Sites

Aquatic macrophyte biomass was not equally distributed between the sites in the study treatments. Dunn's pairwise multiple comparison analysis indicated that biomass found within the Effluent and the Inflow treatments were not statistically different ($p > 0.05$), but that these treatments were both significantly different from the Outflow areas ($p < 0.05$) (Figure 5.6.5). To develop viable management options which meet the needs of both the lake ecosystem and the property owners, it is necessary to understand the reason for the differences in nuisance plant densities perceived by property owners. These perceptions are due to the physiological

Figure 5.6.5. Distribution of aquatic macrophyte biomass (g/m^2) averages for June, July and August 1993 with depth between the treatment groups.



differences between aquatic plant species and the actual difference in biomass between the three treatment groups. The measurement of plant biomass alone may not be the most effective tool in determining aquatic plant problem areas.

The analysis of species assemblages may provide the manager with a better understanding of perceived or actual problem areas. Species distribution was analyzed based on the percentage of total biomass associated with each of the species found in each of the three treatments (Figure 5.6.6).

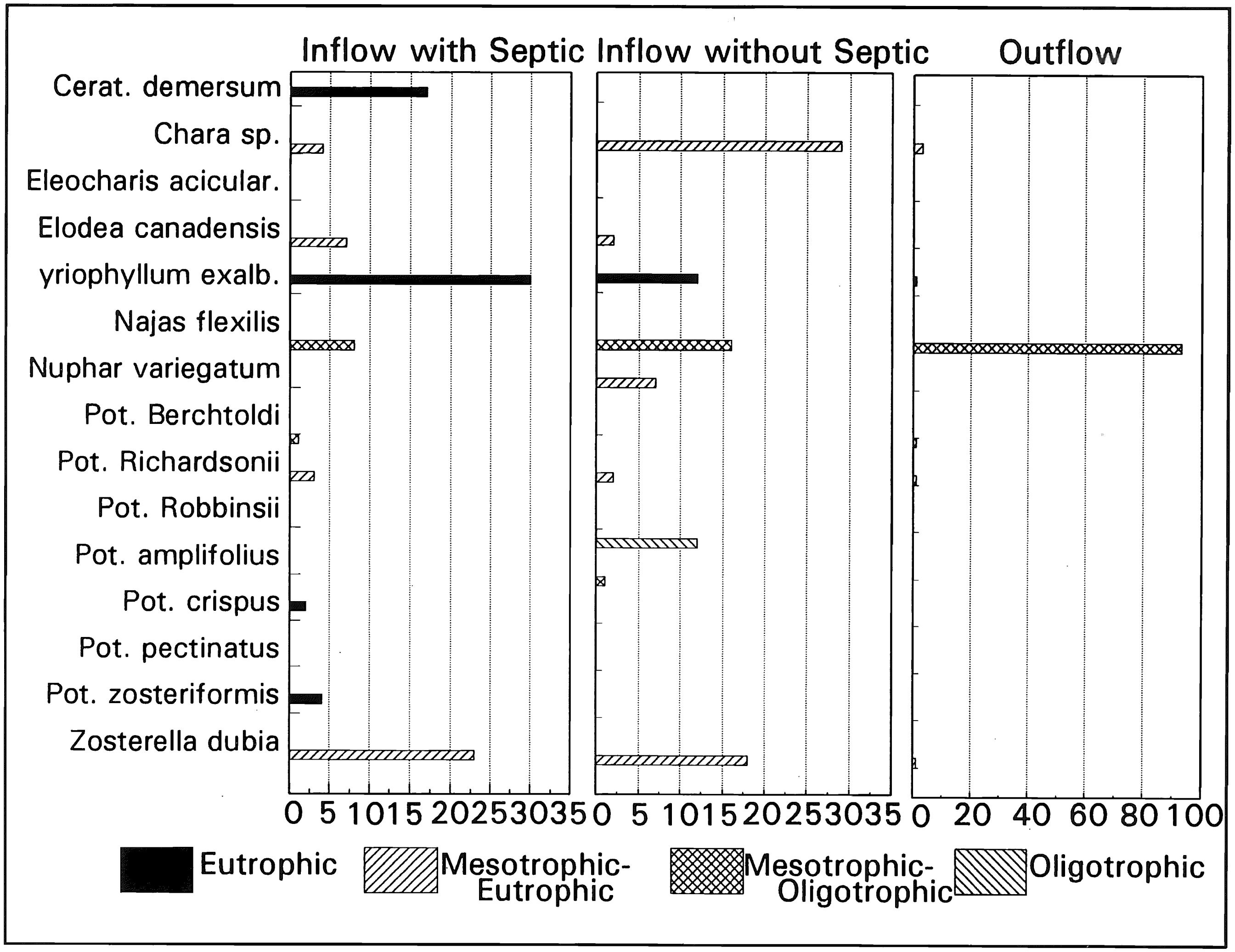
Comparing the assemblage groups which occurred within the treatments indicated that a different group of dominant species occurred within each treatment (Figure 5.6.6). Those sites associated with the effluent were comprised of predominately *Myriophyllum exalbescens, Ceratophyllum demersum and Zosterella dubia. Potamogeton crispus* was also found exclusively in these areas also but only during the early growing season. These species have been found to prefer nutrient rich waters and areas of disturbance (Best, 1980; Davis and Brinson, 1980; Freckmann, 1993; and Seddon, 1972). Both of these characteristics are found within these areas due to human activity. These species also tend to grow to the water surface where they interfere with recreation.

Inflow sites tended to be dominated by Chara sp., *Zosterella dubia*, and *Najas flexilis*. *Potamogeton Robbinsii* and *Potamogeton amplifolius* were also found in the Inflow areas. These species tend to be associated with less disturbed sites (Davis and Brinson, 1980; Freckmann, 1993; and Seddon, 1972).

Groundwater outflow sites were dominated by *Najas flexilis*. *Najas flexilis* has been found to inhabit a great variety of habitat types.

Consideration of the growth forms of these species, assemblages may provide some answers to the reason for the perceived differences in plant material between treatments and suggest which areas will lend themselves to harvesting practices. Those species found in the effluent areas tend to display a taller growth habit occupying more of the water column than the species found in the other treatments. The actual amount of plant biomass within these areas, as mentioned earlier, was not significantly different from biomass in Inflow areas, but the species distribution and growth habit gave the appearance of more plant biomass.

Figure 5.6.6. Distribution of aquatic macrophyte species as percent of the total treatment biomass by treatment and trophic class for each species.



Values based on samples collected during June, July, and August 1993.

Plant Tissue Chemistry

Tissue nutrient concentration within submersed macrophytes can be highly variable (Filbin and Barko, 1985). Boyd (1978), reported that it appeared that the same species growing in different water bodies showed considerable variation of elements, and that some elements such as nitrogen, sulfur, phosphorus, and potassium have been found to be absorbed mostly during the early part of the growth cycle.

Myriophyllum Exalbescens Analysis

To determine if the observations made by Boyd (1978) held true for the same species within the same water body but located within different habitats, a comparison of a single species found within all of three treatments was made (Table 5.6.2). The need to understand the nutrient relationships within a species can be important in understanding the impacts of harvesting or sediment removal on a lakes nutrient budget or potential for plant growth related to sediment or groundwater inflow. According to Mutzar et al. (1978), it is important to consider the species composition of a site in relation to nutrient removal. In his work it was found that *Potamogeton* sp. and *Myriophyllum* sp. will remove greater quantities of most elements than would, for example, *Vallisneria* sp. *Myriophyllum exalbescens* was found within all of the treatment groups, so it was chosen for this comparison.

Plants in the Effluent sites exhibited higher phosphorus and nitrogen concentrations than in the Inflow and Outflow sites (Table 5.6.3). These findings suggest *Myriophyllum exalbescens* tissue concentrations reflected the amount of available nutrients in each of the treatments. The relative percentage of biomass made up of *Myriophyllum exalbescens* in each treatment suggests that this species may prefer areas which are rich in nitrogen and phosphorus. There was a significant difference ($p = 0.005$) in the phosphorus concentration of *Myriophyllum exalbescens* found among the three treatments. Dunn's pairwise comparison test indicated that significantly different phosphorus concentrations were found with the greatest concentrations in the effluent areas followed by the Inflow and Outflow areas, respectively ($p < 0.05$). Even though the average concentrations were much higher at the Effluent sites, nitrogen and potassium concentrations were not significantly different ($p > 0.05$) in this species across the three treatments. This analysis was based on a small sample size ($n = 3$ to 9), so the analysis does not offer a high level of confidence, but a trend is reflected in the data suggesting that *Myriophyllum exalbescens* prefers nutrient rich sites may be correct. This is consistent with observations by Davis and Brinson, 1980; Freckmann, 1993; and Seddon, 1972; and Best, 1980.

Table 5.6.3. Tissue nitrogen, phosphorus, and potassium concentration for *Myriophyllum exalbescens* in mg/kg.

	Effluent Sites n = 9		Inflow Sites n = 3		Outflow Sites n = 4	
Variable	Average	Median	Average	Median	Average	Median
Nitrogen	14,944	15,100	10,767	9,800	9,850	9,750
Phosphorus	1,753	1,791	843	793	855	827
Potassium	7,263	7,208	4,684	4,226	5,459	4,905
% of Standing Crop	30		12		1	

Composite Species Tissue Analysis

The factor of time of sampling during the growing season and growth stage appears to play an important role in the concentration of nutrients within aquatic plants (Mutzar et al., 1978). Filbin and Barko (1985) found that moderate reductions in the concentration of nitrogen and phosphorus, but not potassium, occurred during late summer. These reductions corresponded to the attainment of peak standing crop and were probably caused by nutrient dilution in vegetation as it matures and as readily available supplies in sediments are depleted. These trends were also displayed in this study. Phosphorus and nitrogen tissue concentrations appeared to follow a slight decline or remained the same during the growing season (Figure 5.6.7). Potassium tissue concentrations followed no apparent trend between the three treatment groups or over time (Figure 5.6.7). Dunn's pairwise multiple comparison analysis indicated that the two Inflow treatments were not statistically different for tissue nitrogen, phosphorus, and potassium, but that these treatments were statistically different from the Outflow treatment ($p < 0.05$)(Table 5.64). This may relate to those additional nutrients which are available for plant uptake associated with groundwater seepage in the Effluent and Inflow treatments.

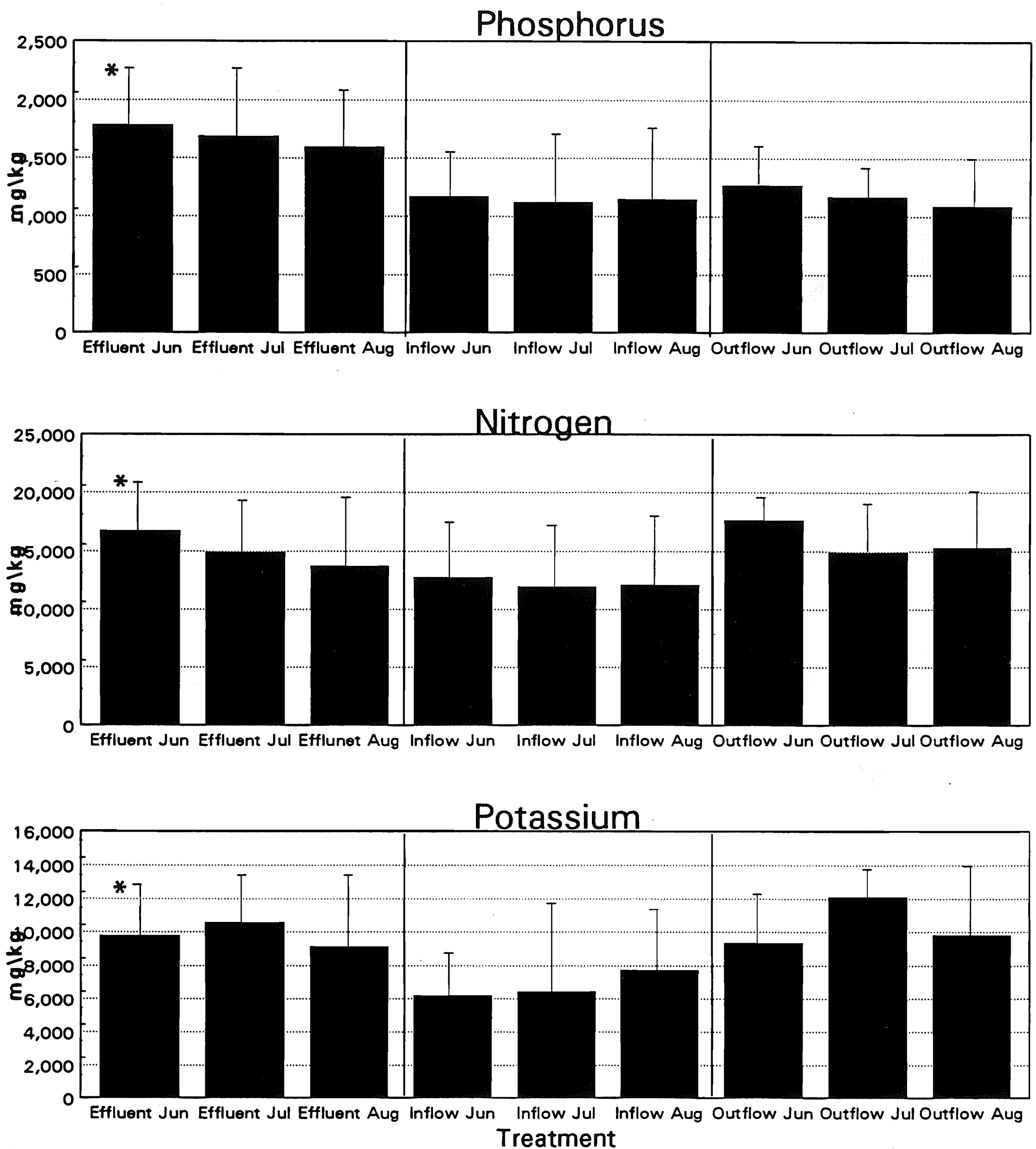
There were no significant differences in tissue nitrogen, phosphorus or potassium found between the three depths at which plants were sampled ($P > 0.05$) (Figure 5.6.8). There is, however, an observable trend showing increased nitrogen concentrations at all sites with increased depth. This correlates to elevated sediment total nitrogen and organic matter with depth.

Table 5.6.4. Mean and Median tissue nitrogen, phosphorus and potassium concentrations (mg/kg) for three treatments based on a composite of all species.

	Mean			Median		
Variable	Effluent	Inflow	Outflow	Effluent	Inflow	Outflow
Nitrogen	15165	12265	15956	16344	11850	17050
Phosphorus	1694	1146	1174	1758	1062	1131
Potassium	9816	6778	10470	9638	5696	10629

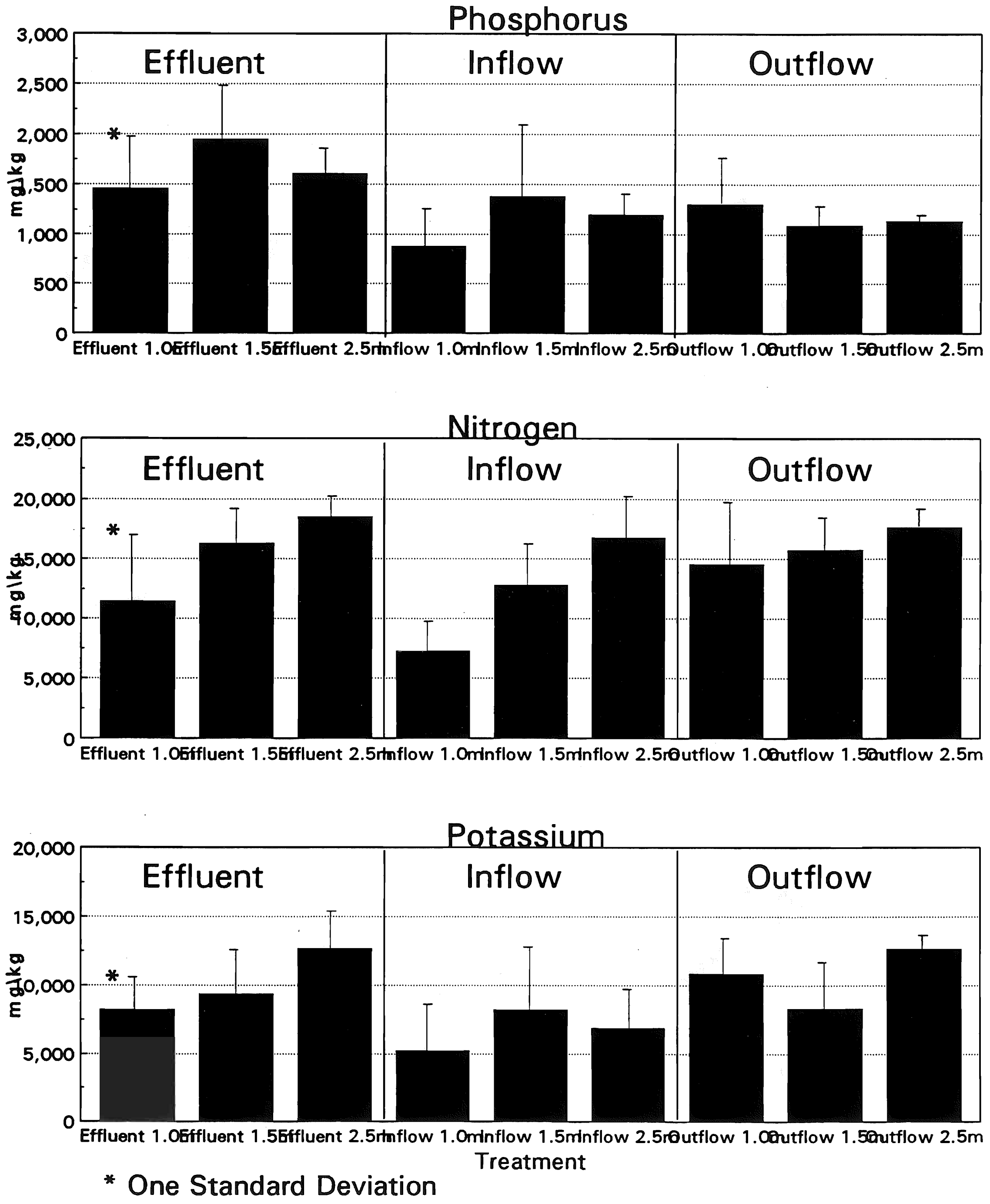
Gerloff and Krumbulz (1966) found that either phosphorus or nitrogen can limit aquatic plant growth. Plants can also store both nutrients in excess of biological needs (Engel, 1990). A critical value of 1.3% was found for tissue nitrogen concentrations and a

Figure 5.6.7. Monthly composite plant tissue phosphorus, nitrogen and potassium concentrations (mg/kg) for three treatments during June, July and August 1993.



* One Standard Deviation

Figure 5.6.8. Composite plant tissue phosphorus, nitrogen and potassium concentrations (mg/kg) for three treatments and three lake depths.



critical value of 0.13% for phosphorus was found by Gerloff and Krumbulz (1966). The critical values from Gerloff's study related to the minimum concentration of a nutrient required for a plant to obtain maximum growth potential, and they suggested that the critical values found for nitrogen and phosphorus for *Valisneria americana* could be extrapolated to other species. In the Legend Lake study high biomass values were found both above and below Gerloff's critical values suggesting that neither nitrogen or phosphorus alone is limiting plant growth in the Inflow treatments, but that phosphorus may be limiting growth in the Outflow sites (Figure 5.6.9 and Figure 5.6.10).

Nutrient uptake by individual species from the same site and depth can be quite variable as suggested by Gerloff (1975). For example, nitrogen concentrations for *Myriophyllum exalbescens* and the multi-species composite sample were twice as high as the concentrations found in *Zosterella dubia*. Analysis of Table 5.6.5 confirms that individual aquatic plant species have the capability to extract available nutrients at different amounts based on individual needs. It was found that the means for each of the three treatment groups were well above the critical values for both nitrogen and phosphorus in the plant tissue. But, it did appear that there was even more luxury uptake of phosphorus in the Effluent treatment sites than the other two treatments (Figure 5.6.8) (Table 5.6.5).

Figure 5.6.9. Tissue biomass versus tissue nitrogen concentration (%) for three lake depths during June, July and August 1993.

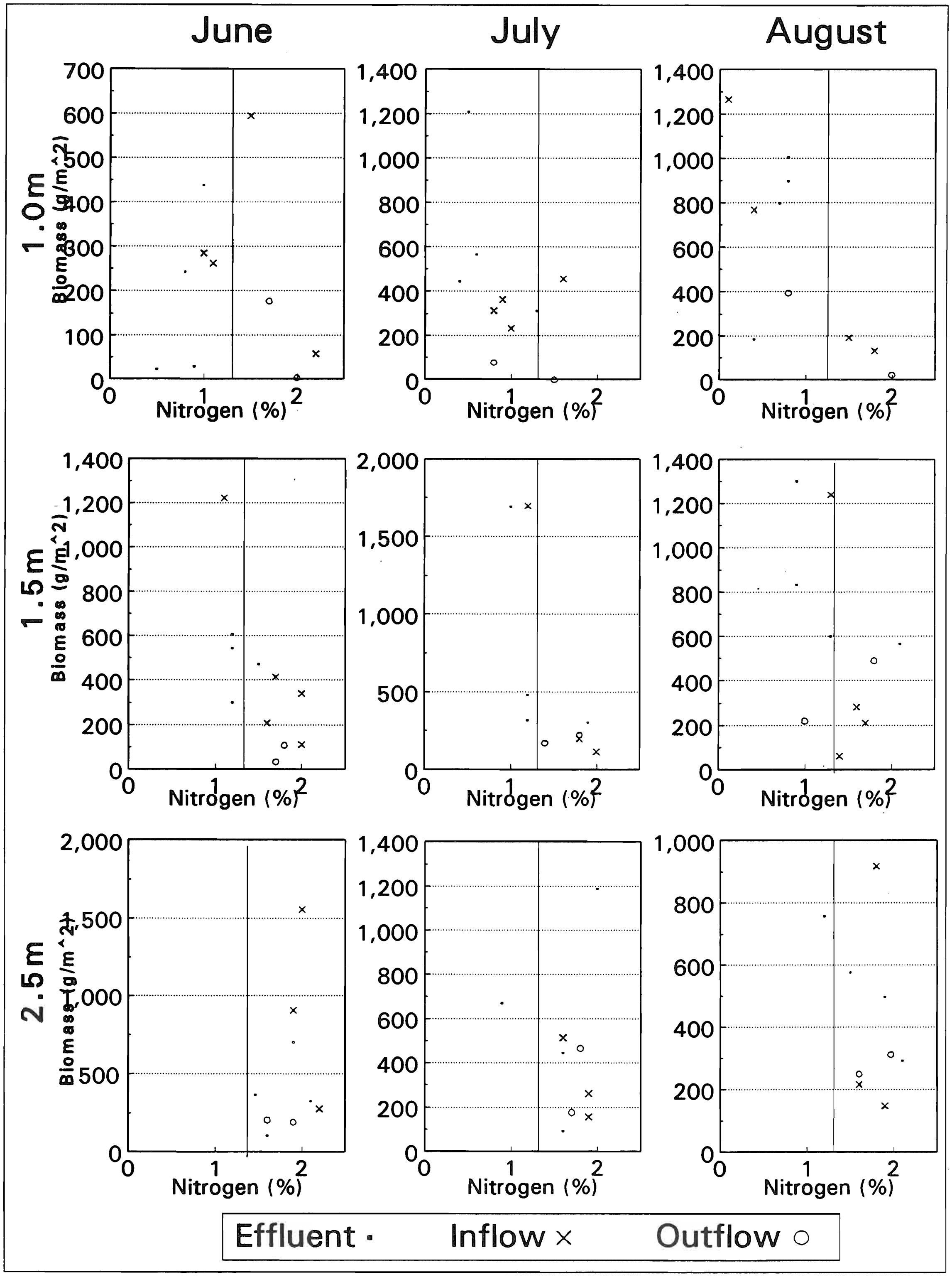


Figure 5.6.10. Tissue biomass versus tissue phosphorus concentration (%) for three lake depths during June, July and August 1993.

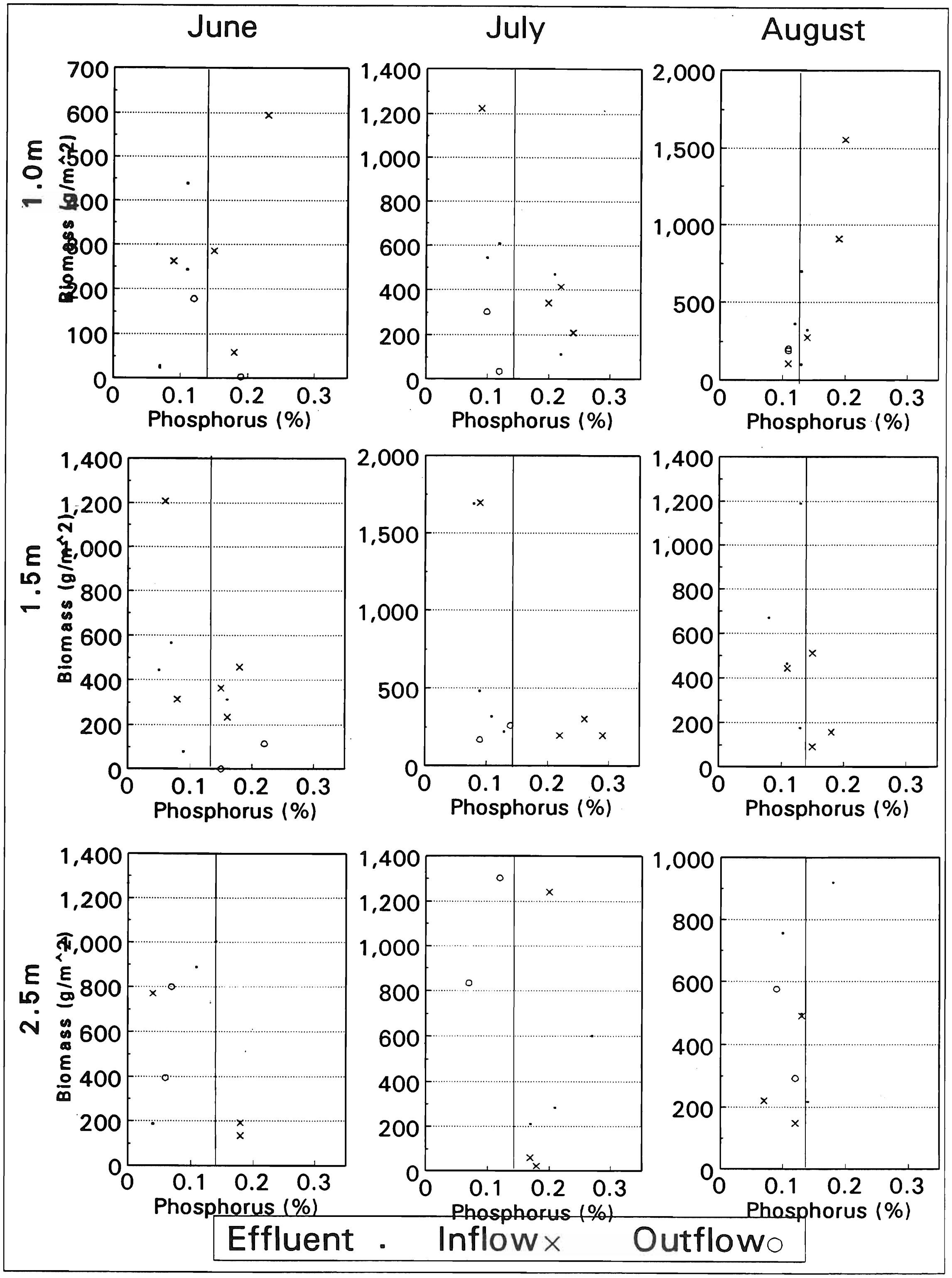


Table 5.6.5. Comparison of tissue nutrient concentrations (mg/kg) for *Myriophyllum exalbescens, Zosterella dubia* and a multi-species composite sample for June, July and August 1993 at the Tallmoon 13 site.

	June			July			August		
	Comp	*Myr.ex.*	*Zos.du*	*Comp*	*Myr.ex.*	*Zos.du.*	*Comp*	*Myr.ex*	*Zos.du.*
Biomass g/m^2	484	41	70	190	43	2	1201	20	45
N	15800	14300	7900	9600	12100	9600	10300	8300	5500
P	2400	2000	1500	1530	1791	1716	1568	1116	1238
N/P Ratio	6.6	7.1	5.3	6.3	6.7	5.6	6.6	7.4	4.4
K	12100	6300	6400	10348	7208	10759	9152	4354	8284
Ca	41400	65900	16700	19553	43830	25524	41449	45489	15921
Mg	3200	3200	1800	2242	3420	2611	3661	3022	2052
S	4500	4700	3300	2720	3854	3545	3187	2532	2426
Zn	39.86	39.27	27.18	24.6	31.84	29.33	20.12	18.31	18.66
B	24.34	26.98	20.41	17.44	21.84	15.31	14.98	13.01	7.365
Mn	395.9	344.4	175.4	303.3	480.3	323.7	461.6	330.8	232.3
Fe	5786	6150	6807	3497	4989	5920	4354	4600	5815
Cu	10.42	11.92	8.43	6.229	8.067	8.236	9.083	8.563	8.495
Al	2794	3047	2691	2060	3394	3328	2827	3189	2962
Na	3796	4162	2831	1729	3771	4227	1193	2016	2939

Interactions Among Variables

Groundwater/Seepage Water Relationship

Total and soluble reactive phosphorus and available nitrogen within the seepage meters (Figure 5.6.11) did not correlate well with values found in the groundwater samples (Table 5.6.6). This poor correlation between well and seepage concentrations (Table 5.6.6) was also observed on Lake Mendota. Brock et al., (1982) suggested that phosphorus and ammonia may be derived from the lake sediments rather than from the surrounding land. Sediment cores from Lake Mendota contained a considerable amount of organic P and N. These researchers suggested that the groundwater which passes through these sediments into the lake as seepage can transport these nutrients back into the system.

Table 5.6.6. Spearman correlation coefficients (r) for groundwater and seepage water nitrogen and phosphorus concentrations. (None significant at 0.05 level)

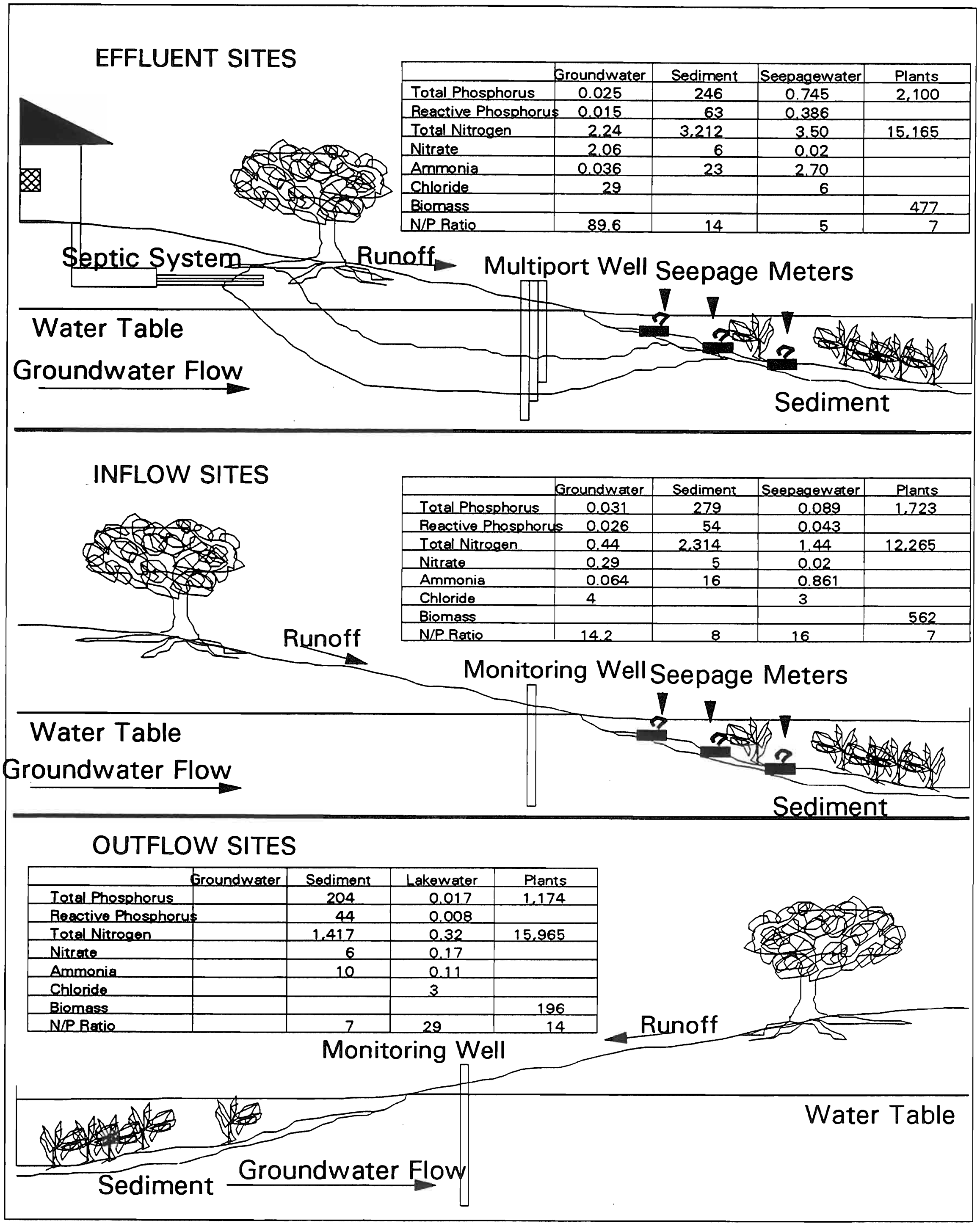
	Effluent Sites	Inflow Sites	All Sites
Total Phosphorus	r = -0.05	0.45	0.30
Soluble Reactive Phosphorus	r = -0.269	-0.10	-0.18
Total Nitrogen	r = 0.25	0.11	0.14
Ammonia	r = -0.007	0.19	0.005
Nitrate	r = 0.27	-0.143	-0.013

We can summarize from looking at the seepage meter, groundwater, and sediment data that the amount of phosphorus observed in seepage meters was not completely related to groundwater (Figure 5.6.11). Seepage meter total phosphorus and total nitrogen values were greater than those values found in the wells. This would agree with the results found in the above mentioned Lake Mendota study.

Nitrate-N concentrations in Legend Lake water, on average, were at or below detection limits and NH_4^+ comprised 99% of the soluble nitrogen for seepage water. This may be a result of biological uptake of NO_3 and decomposition of organic matter and the subsequent release of NH_4^+ as the groundwater passes through the lake sediments with a certain amount being released as nitrogen gas (N_2) by denitrification.

These additional nutrients in the seepage may also be related to some form of human activities other than septic systems such as lawn fertilization, phosphorus detergents associated with two cycle outboard motor oil, leaf litter, and lake bathing. These activities can enrich sediments which in time could impact seepage chemistry.

Figure 5.6.11. Summary diagram and table of nutrients (mg/l) in groundwater, sediment, seepage, plant tissue, and plant biomass for three treatments.



EFFLUENT SITES

	Groundwater	Sediment	Seepagewater	Plants
Total Phosphorus	0.025	246	0.745	2,100
Reactive Phosphorus	0.015	63	0.386	
Total Nitrogen	2.24	3,212	3.50	15,165
Nitrate	2.06	6	0.02	
Ammonia	0.036	23	2.70	
Chloride	29		6	
Biomass				477
N/P Ratio	89.6	14	5	7

INFLOW SITES

	Groundwater	Sediment	Seepagewater	Plants
Total Phosphorus	0.031	279	0.089	1,723
Reactive Phosphorus	0.026	54	0.043	
Total Nitrogen	0.44	2,314	1.44	12,265
Nitrate	0.29	5	0.02	
Ammonia	0.064	16	0.861	
Chloride	4		3	
Biomass				562
N/P Ratio	14.2	8	16	7

OUTFLOW SITES

	Groundwater	Sediment	Lakewater	Plants
Total Phosphorus		204	0.017	1,174
Reactive Phosphorus		44	0.008	
Total Nitrogen		1,417	0.32	15,965
Nitrate		6	0.17	
Ammonia		10	0.11	
Chloride			3	
Biomass				196
N/P Ratio		7	29	14

Sediment Chemistry/Seepage Water Interrelationship

The data presented in Table 5.6.7 shows a statistically significant relationship between total phosphorus in lake sediment and seepage water at the effluent sites. A similar relationship was found for total nitrogen. Available nitrogen and phosphorus in sediments at the Effluent sites were useful as a predictor of amounts found in seepage meters, but were not significant at 0.05 level. The higher amounts of total phosphorus and total nitrogen found in Effluent site sediments did result in higher concentrations in water entering the lakes, as indicated by the seepage meters.

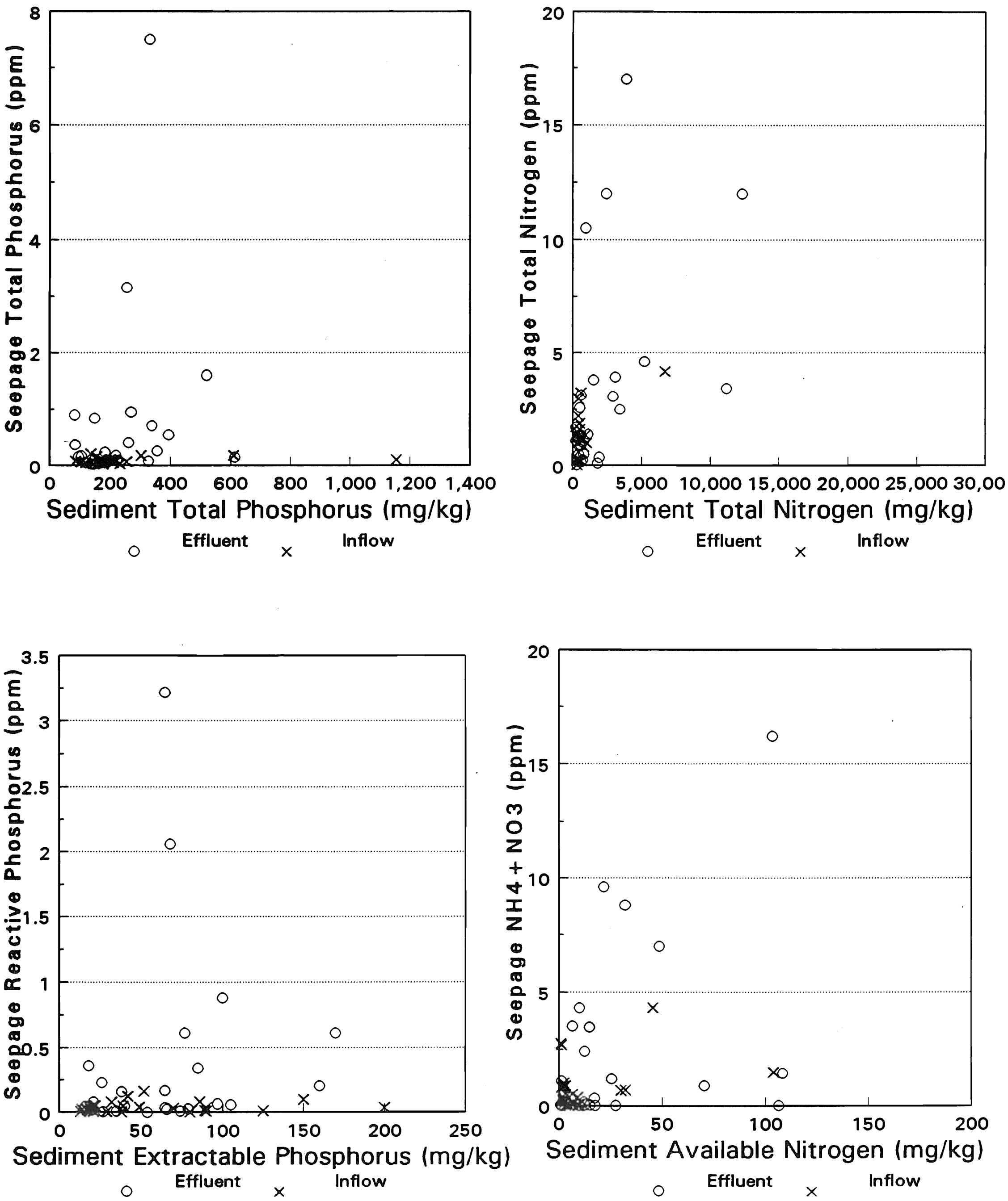
These data suggest that extractable phosphorus analysis on sediment samples is better correlated to plant uptake while total phosphorus content of sediment correlated better to sediment release into overlying water. Sediment total nitrogen was a better estimate of both plant tissue and seepage nitrogen concentrations. These results suggest that both total and available nutrients in sediments need to be analyzed to characterize nutrient availability and release.

Table 5.6.7. Spearman correlation coefficients between sediment and seepage available and total nitrogen and phosphorus concentrations.

	Effluent	Inflow	Outflow
Soluble Reactive Phosphorus	0.324	0.172	**
Available Nitrogen (NH_4+NO_3)	0.284	-0.096	**
Total Phosphorus	**0.392**	0.171	**
Total Nitrogen	**0.574**	0.282	**

Bold values are statistically significant based on sample size and $\propto$ = 0.05.
** Seepage meters were not installed at the Outflow sites.

Figure 5.6.12. Seepage meter total and soluble reactive phosphorus and nitrogen concentrations plotted against sediment total and extractable phosphorus and nitrogen for three treatments.



Sediment Chemistry/Macrophyte Chemistry Interrelationships

Correlation analysis between tissue phosphorus and nitrogen concentrations and sediment phosphorus and nitrogen suggests that there are some significant relationships (Tables 5.6.7 and 5.6.8)(Figures 5.6.13 and 5.6.14). These data suggest that extractable phosphorus found in sediment samples is better correlated to plant uptake while total phosphorus content of sediment correlated better to sediment release into overlying water. Sediment total nitrogen was a better estimate of both plant tissue and seepage nitrogen concentrations than was sediment available nitrogen. These results suggest that both Total and available nitrogen in sediments need to be analyzed to characterize nutrient availability and release. Available nitrogen concentrations in the sediments may not truly represent the amount of nitrogen available to plants over the whole growing season, due to continued decomposition of organic matter. The total nitrogen concentrations in the sediments may better reflect the available forms of nitrogen. The differences in plant species composition between the three treatments may also influence the concentration of nitrogen and phosphorus in the tissue as suggested by Gerloff, 1975.

Table 5.6.8. Spearman correlation coefficient (r) for tissue phosphorus to sediment extractable and total phosphorus.

	Effluent	Inflow	Outflow	All Sites
Extractable Phosphorus	**0.523**	0.228	**0.659**	**0.395**
Total Phosphorus	0.294	0.178	**0.674**	**0.311**

Bolded values are statistically significant based on sample size and $\propto$ = 0.05.

Table 5.6.9. Spearman correlation coefficient (r) for tissue nitrogen to sediment available and total nitrogen.

	Effluent	Inflow	Outflow	All Sites
Available Nitrogen	0.214	0.132	0.361	**0.289**
Total Nitrogen	**0.662**	**0.440**	0.366	**0.625**

Bolded values are statistically significant based on sample size and ∝ = 0.05.

Figure 5.6.13. Sediment extractable phosphorus versus tissue phosphorus for three treatments.

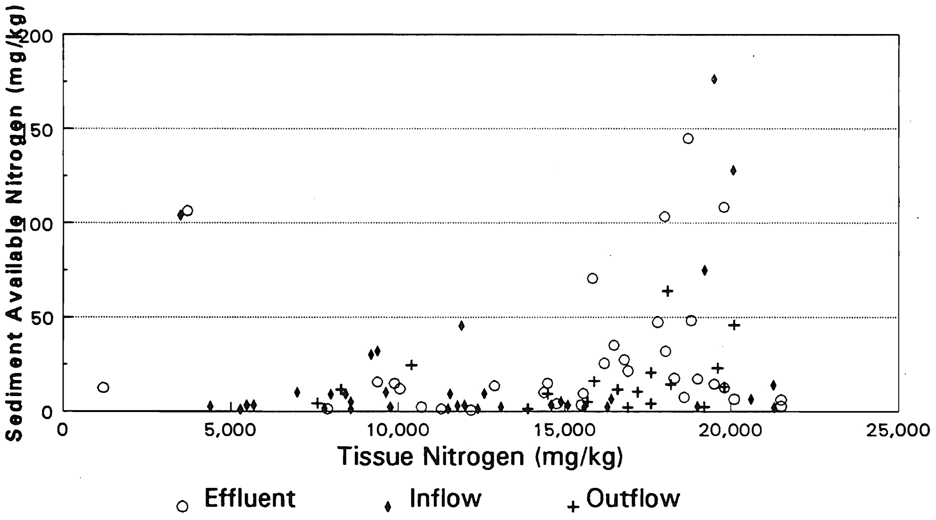
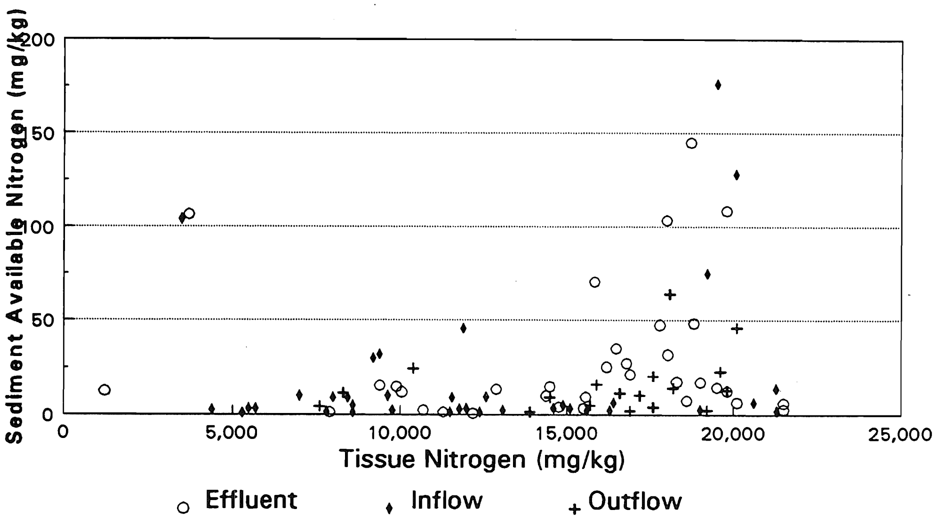


Figure 5.6.14. Sediment available nitrogen versus tissue nitrogen for three treatments.



Seepage Chemistry/Macrophyte Chemistry Interrelationships

Correlation analysis determined that a number of relationships exist between plant and seepage water nutrients. Effluent site analysis suggested that both reactive and total phosphorus were significantly related to the concentration of phosphorus in plant tissue (Table 5.6.10 and 18). This same trend was found for available and total nitrogen concentrations in the seepage to tissue nitrogen concentrations. In both the phosphorus and nitrogen analysis, no correlation was detected between seepage water and plant tissue concentrations in the Inflow treatments. This is consistent with the lack of correlations between nutrient concentrations in sediments, seepage water, or plants for Inflow sites. This may relate to the differences in species assemblages between the two treatments and the higher nutrient concentrations found in the sediment and seepage at the Effluent sites.

Table 5.6.10. Spearman correlation coefficient (r) for tissue phosphorus to seepage reactive soluble and total phosphorus.

	Effluent	Inflow	Outflow
Soluble Reactive Phosphorus	**0.505**	0.290	**
Total Phosphorus	**0.324**	0.098	**

Bolded values are statistically significant based on sample size and ∝ = 0.05.
** These sites did not have seepage meters

Table 5.6.11. Spearman correlation coefficient (r) for tissue nitrogen to seepage available and total nitrogen.

	Effluent	Inflow	Outflow
Soluble Nitrogen	**0.426**	-0.198	**
Total Nitrogen	**0.498**	0.108	**

Bolded values are statistically significant based on sample size and ∝ = 0.05.
** These sites did not have seepage meters

Macrophyte Biomass and Species Diversity Relationships with Groundwater, Sediment Characteristics, and Seepage Water Chemistry

Correlation analysis was performed on the data to determine the strength of the relationships between groundwater, sediment, seepage water, and tissue chemistry to plant biomass and species diversity.

Results do not indicate any strong relationship between groundwater nitrogen and phosphorus and plant biomass or number of species (Tables 5.6.12 and 5.6.13). Any correlation found would be coincidental since groundwater undergoes chemical changes as it passes through the lake sediments as discussed in earlier sections.

Spence (1967) stated that factors such as rate of organic sediment accumulation and particle size of substrate can influence the location of macrophyte species and biomass within a lake. This did not hold true for this study. Sediment particle size was not uniform within the treatment groups and did not correlate to the number of plant species or biomass (Tables 5.6.12 and 5.6.13).

Organic matter content of the sediments has often been associated with increased nutrient levels allowing for increased plant growth. Organic matter did not show any correlation to number of species or plant biomass in this study. Barko (1983) found that high concentrations (>24 %) of organic matter in sediments inhibited Eurasian water milfoil growth. This was thought to be related to the low redox potentials, accumulation of organic acids, low pH, increased metal availability, and the evolution of growth inhibiting gases (methane and sulfides) found in these high organic matter sediments. These factors overshadowed the improved fertility provided by the organic matter addition. Similar processes may be occurring at Legend Lake. High organic matter sediment was found only at greater depths where other factors may limit plant growth and prevent a direct relationship to organic matter from occurring.

Correlation of available nitrogen and phosphorus concentrations in the sediment to plant biomass and the number of species found within each treatment and all the treatment data analyzed as one group showed few statistical relationships (Tables 5.6.12 and 5.6.13, Figures 5.6.15 and 5.6.16). Sediment extractable phosphorus to biomass shared a significant negative correlation ($p < 0.05$) in both of the groundwater Inflow treatments, while it was not significant for the Outflow sites or the All site data set. Sediment available nitrogen to biomass showed a significant positive relationship in the Inflow treatment only (Figure 5.6.15). These inconsistencies in correlation may be related to the aquatic plant species composition of each treatment group. Sediment available potassium concentrations for Outflow sites significantly correlated to biomass, while the other two treatments did not (Table 5.6.12).

Sediment extractable phosphorus correlated to the number of species found within the Effluent treatment, but not within any of the other data sets. Available nitrogen was not significantly correlated to number of species present (Table 5.6.13). Sediment available potassium was significantly correlated to numbers of species for the Inflow and All site data sets, but not to the Effluent or Outflow data.

Figure 5.6.21 to 5.6.24 show an increase in species numbers with an increase in nitrogen and phosphorus content of sediment; six to eight species per plot with higher species numbers associated with higher nutrient concentrations. These data suggest the most nutrient rich sediment will have few species present with less diversity than some sites with lower nutrient concentrations. Sites with very few species (<5) tended to occur on sites with low nutrient supply. The lack of any strong correlations would suggest that sediment nutrients are not the sole source of nutrients for the aquatic macrophytes of Legend Lake and that neither nitrogen nor phosphorus alone are the limiting factor for biomass or number of species.

Seepage characteristics were also tested to see if they correlated to plant biomass and the number of species present within each treatment group. Seepage discharge (Q) was found to negatively correlate with macrophyte biomass, but not the number of species within each of the treatment groups. The scatter shown in Figure 5.6.19 suggests that there is no pattern to the relationship. The significantly higher biomass for both Inflow treatments compared to the Outflow site does suggest that (Q) may have some influence on biomass accumulation in lakes as suggested by Lillie and Barko, 1990 (Tables 5.6.12 and 5.6.13).

Those characteristics measured during the course of this project did not appear to clearly identify factors that limit plant growth or the occurrence of species. It is obvious that different factors are important at Inflow versus Outflow sites, and between Effluent

Table 5.6.12. Spearman correlation coefficients (r) for aquatic macrophyte biomass data versus nutrient sources, sediment texture and plant nutrient concentrations.

	TREATMENTS			
Variable	**Effluent Sites**	**Inflow Sites**	**Outflow Sites**	**All Sites**
Groundwater R. Phosphorus	-0.246	0.114	----	0.080
Groundwater NH4+NO3	0.194	0.136	----	0.007
%Silt + %Clay	0.076	0.228	-0.282	-0.043
%Organic Matter	-0.211	0.140	-0.087	-0.128
Sediment Ext. Phosphorus	**-0.407**	**-0.440**	-0.118	-0.315
Sediment Av. Nitrogen	-0.002	**0.553**	0.402	0.098
Sediment Av. Potassium	-0.199	0.113	**0.504**	0.011
Seepage Discharge (Q)	-0.352	-0.319	----	**-0.327**
Seepage R. Phosphorus	-0.191	-0.118	----	-0.185
Seepage Av. Nitrogen	-0.148	**-0.416**	----	-0.209
Tissue Phosphorus	-0.173	-0.085	-0.374	-0.175
Tissue Nitrogen	**-0.394**	-0.142	-0.021	-0.277
Tissue Nitrogen	-0.216	0.105	-0.204	-0.220

Those bolded values are statistically significant based on sample size and an ∝ = 0.05.

and Inflow sites. Other factors such as temperature, light, turbulence, boating activity, and land use practices may have an equal or greater influence on the aquatic plant biomass and species occurrence.

Table 5.6.13. Spearman correlation coefficients (r) for aquatic macrophyte species richness data versus nutrient sources and sediment texture and plant nutrient concentrations.

	TREATMENTS			
Variable	**Effluent Sites**	**Inflow Sites**	**Outflow Sites**	**All Sites**
Groundwater R. Phosphorus	**0.399**	-0.183	----	0.037
Groundwater NH4+NO3	-0.182	**0.501**	----	**0.303**
%Silt + %Clay	0.098	0.205	-0.109	-0.042
%Organic Matter	0.125	0.219	-0.126	0.043
Sediment Av. Phosphorus	**0.332**	-0.243	-0.106	0.119
Sediment Av. Nitrogen	0.136	0.254	-0.270	0.150
Sediment Av. Potassium	0.226	**0.430**	0.711	**0.276**
Seepage Discharge (Q)	-0.375	-0.260	----	-0.221
Seepage R. Phosphorus	0.283	-0.023	----	**0.345**
Seepage Av. Nitrogen	0.167	-0.162	0.160	0.067
Tissue Phosphorus	**0.382**	0.264	0.164	**0.408**
Tissue Nitrogen	0.170	0.181	0.189	0.078
Tissue Potassium	0.299	0.054	0.021	0.049

Those bolded values are statistically significant based on sample size and $\alpha = 0.05$.

Figure 5.6.15. Sediment available nitrogen concentration (mg/kg) versus aquatic macrophyte biomass (g/m^2) for three treatments.

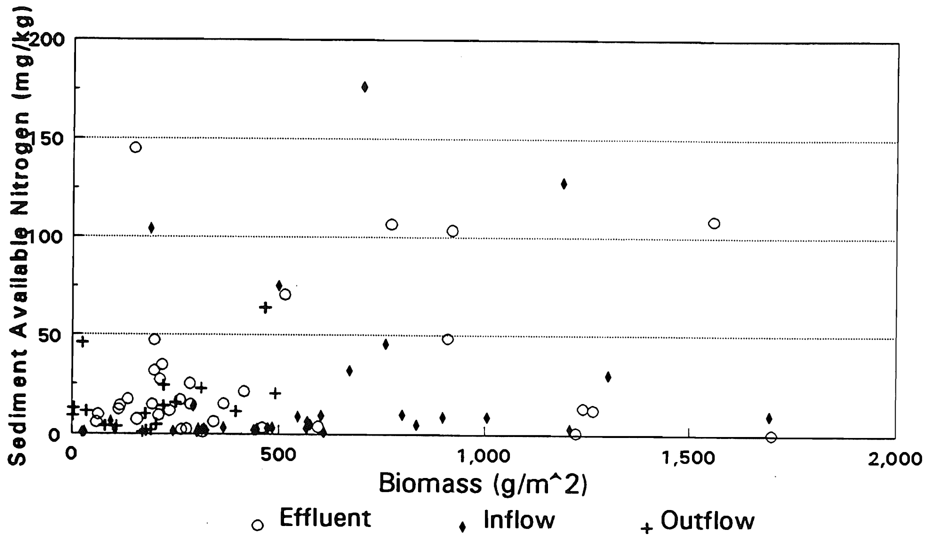


Figure 5.6.16. Sediment extractable phosphorus concentration (mg/kg) versus aquatic macrophyte biomass (g/m^2) for three treatments.

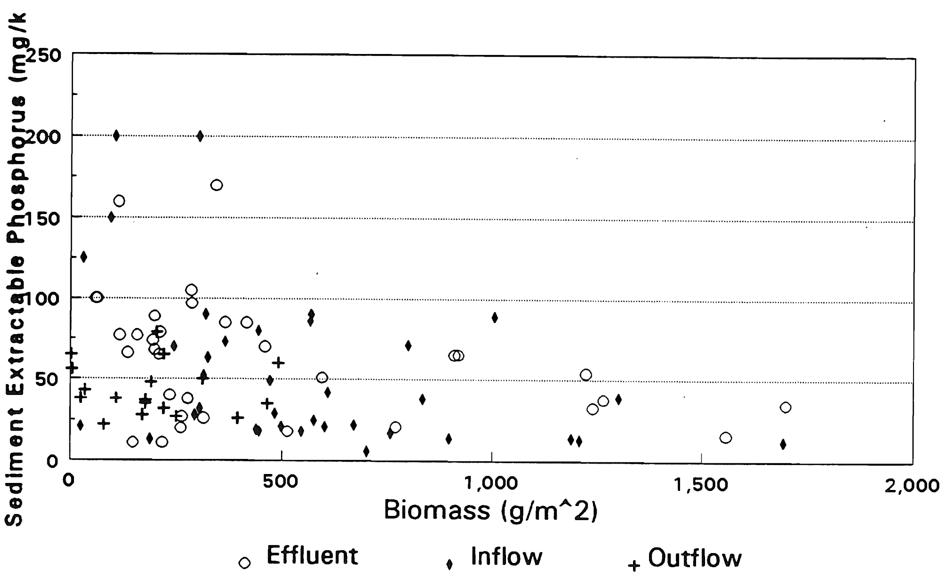


Figure 5.6.17. Sediment available potassium concentration (mg/kg) versus aquatic macrophyte biomass (g/m^2) for three treatments.

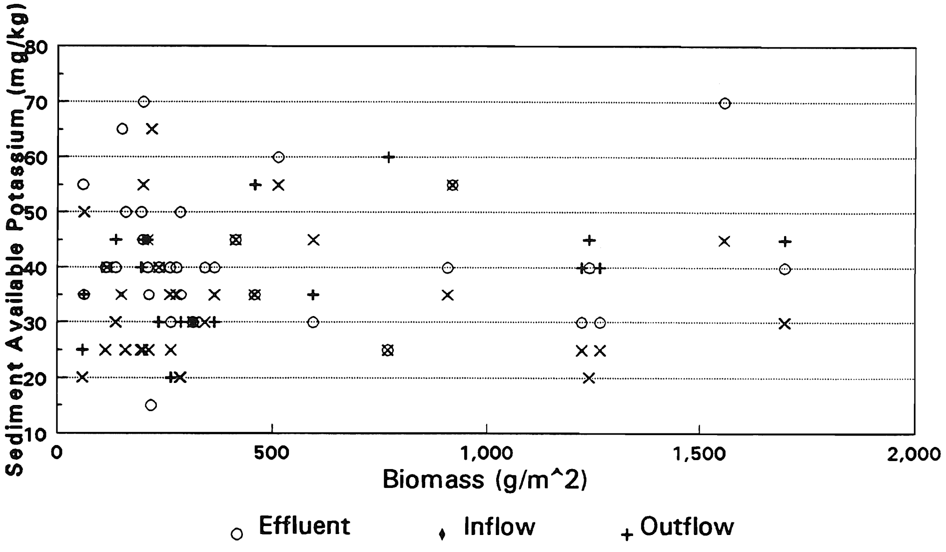


Figure 5.6.18. Tissue nitrogen concentration (mg/kg) versus aquatic macrophyte biomass (g/m^2) for three treatments.

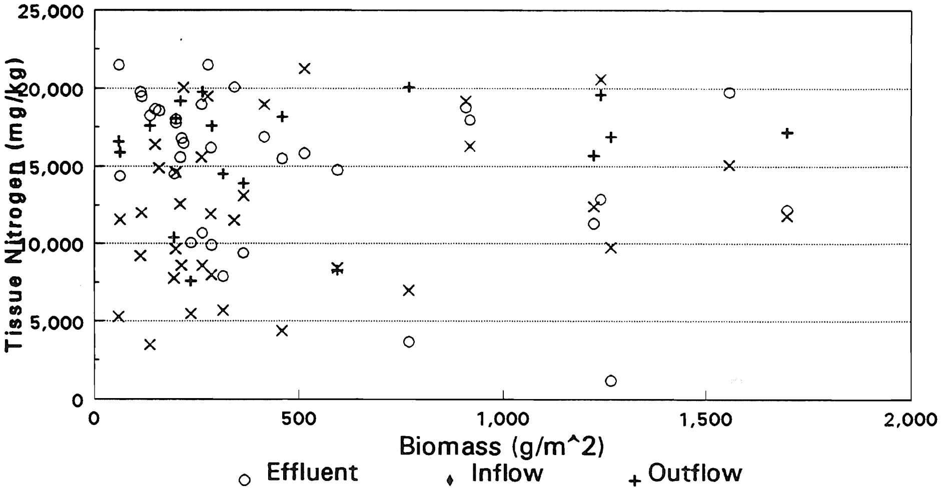


Figure 5.6.19. Seepage discharge (l/m^2/day) versus aquatic macrophyte biomass (g/m^2)for three treatments.

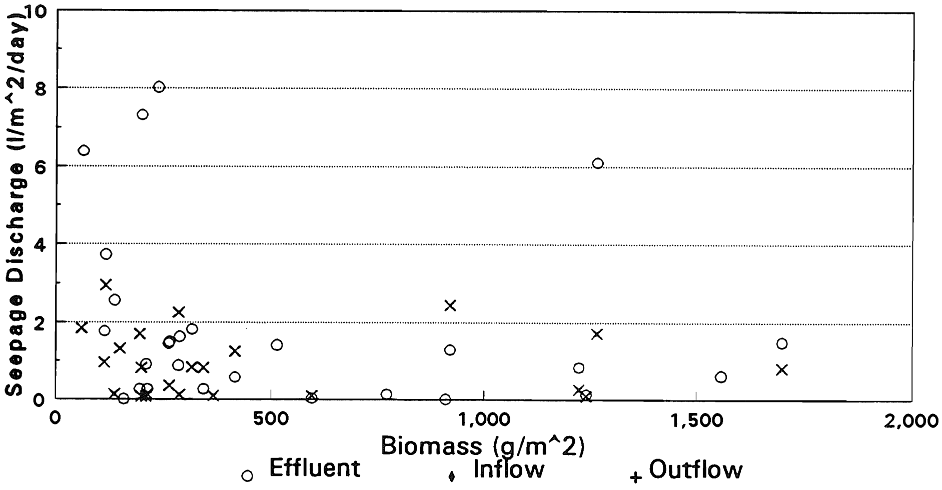


Figure 5.6.20. Seepage available nitrogen (NH_4 + NO_3) concentration (mg/l) versus aquatic macrophyte biomass (g/m^2) for three treatments.

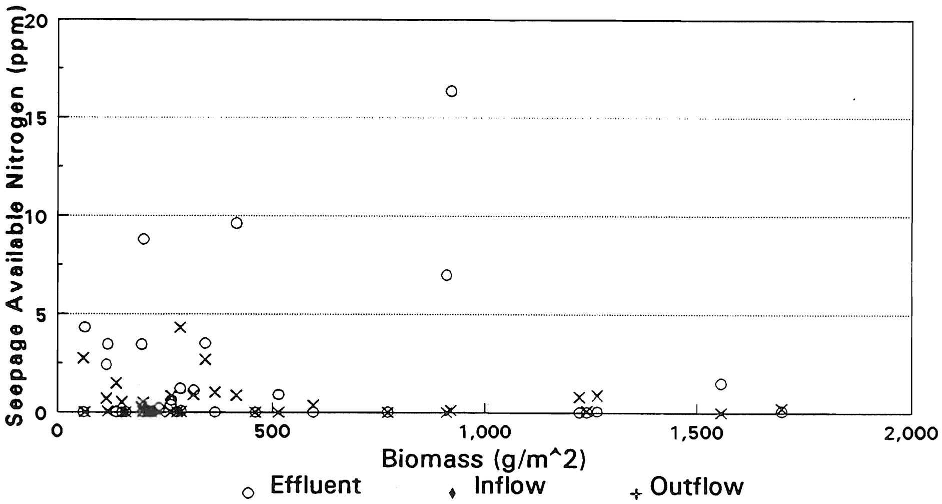


Figure 5.6.21. Sediment available nitrogen concentration (mg/kg) versus number of aquatic macrophyte species present for three treatments.

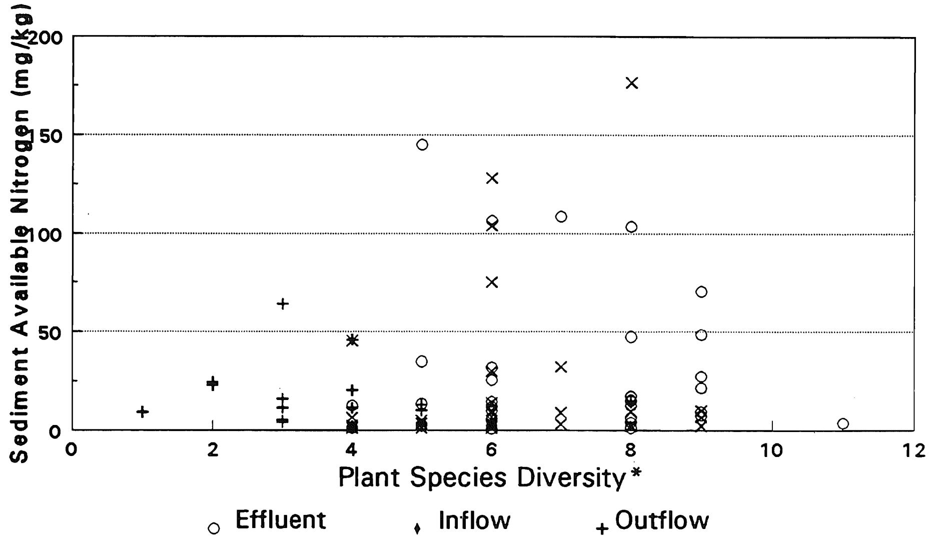
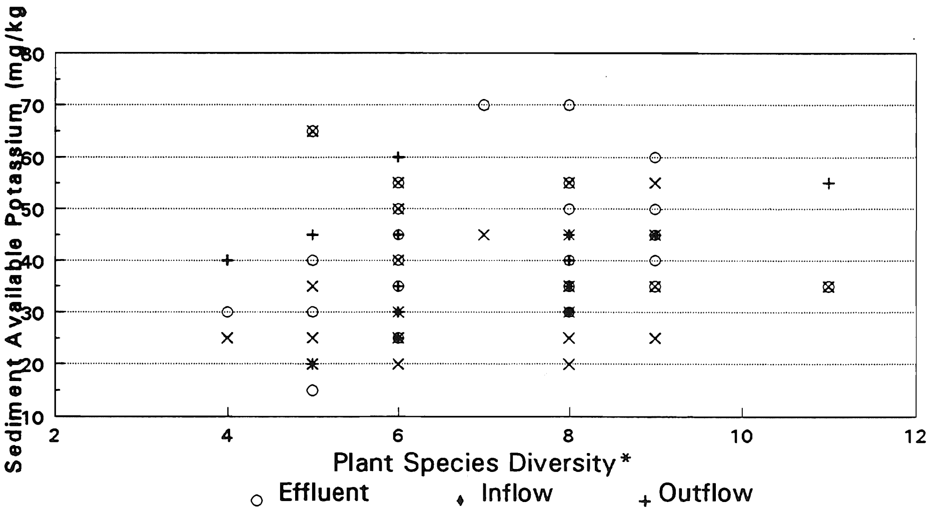


Figure 5.6.22. Sediment available potassium concentration (mg/kg) versus number of aquatic macrophyte species present for three treatments.



* Number species per sample plot

Figure 5.6.23. Tissue phosphorus concentration (mg/kg) versus number of aquatic macrophyte species present for three treatments.

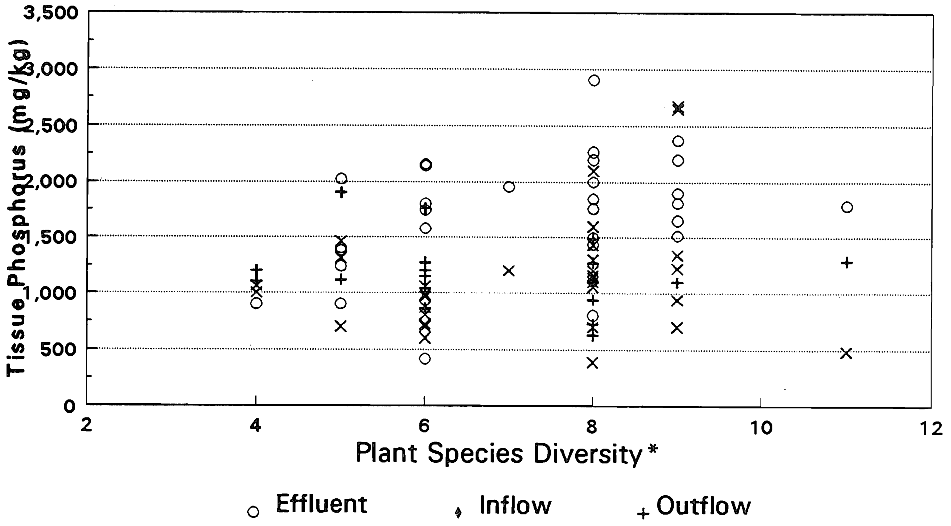
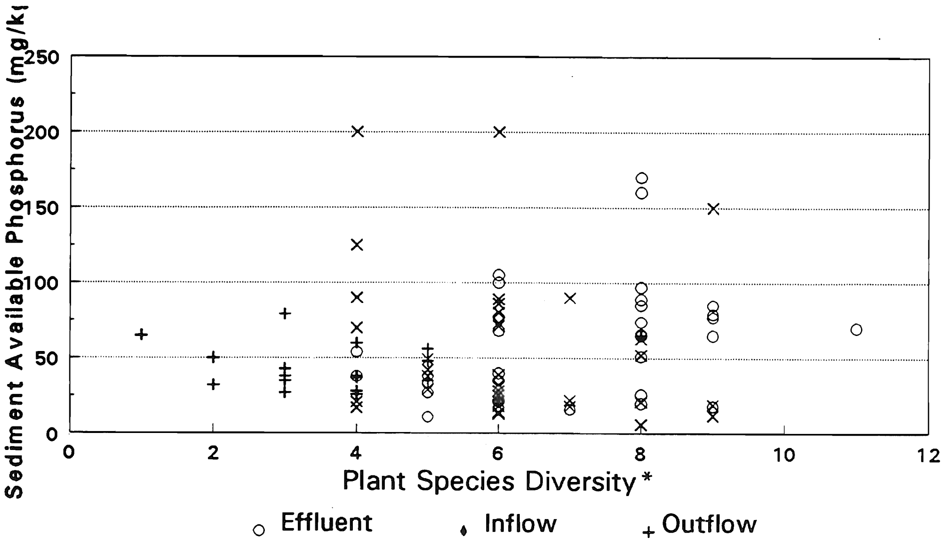


Figure 5.6.24. Sediment extractable phosphorus concentration (mg/kg) versus number of aquatic macrophyte species present for three treatments.



* Number of species per sample plot

Nitrogen-Phosphorus Transfer from Septic Systems to Lake

The movement of chloride relative to nitrogen from septic systems to the lake was investigated by sampling the septic system, near lake monitoring wells, and seepage water. Chloride is considered a conservative chemical which does not undergo the biological transformation that nitrogen does, making the nitrogen:chloride ratios useful to determine changes occurring in nitrogen discharged by septic systems.

The amount of nitrate relative to chloride in wastewater as compared to the groundwater (wells) near the lake indicated a loss of nitrogen relative to chloride between the septic tank and the lake shore as indicated by the increasing Clan ratios between the septic tank and lake shore monitoring wells (Table 5.6.14). Decreases in the ratio between wells and seepage meters indicate an enrichment of nitrogen relative to chloride as groundwater passes through the lake sediments.

One hypothesis for the lack of nitrogen and phosphorus between the septic system and lake shore groundwater may be the uptake of plume nutrients by terrestrial trees and shrubs located near the drainage field and the lake shore. The possibility does exist that the root systems of these plants may remove nutrients from within or under the drainage field or from the capillary fringe near the surface of the water table. This uptake and transport by vegetative matter to the lake sediments would help explain the higher values of nitrogen and phosphorus in sediment and seepage water associated with Effluent sites. The results reported within this study for groundwater may underestimate the concentrations of available nutrients transported by groundwater at non-wooded sites. However, these results may be typical of wooded lake shore property.

Currently, the phosphorus in the groundwater appears to be related to natural mineral processes, but groundwater transported phosphorus may become greater as the septic systems age and the soil adsorptive capacity of the soil becomes saturated.

Nutrient uptake by trees and shrubs could continually enrich sediments as leaf matter enters the lake.

Table 5.6.14. Site chloride to total nitrogen ratio for septic tank, groundwater, and seepage meters at 3 sites around Legend Lake.

	Lake Depth	Average Seepage meter Clan	Average Lakeshore Well Clan	Septic Tank Clan (Collected 10/1/93)
TM7	1.0 m	3.9	38	4.28
	1.5 m	0.86		
	2.5 m	0.25		
TM13	1.0 m	12.1	36	0.89
	1.5 m	2.2		
	2.5 m	0.67		
TM16	1.0 m	0.45	32	0.79
	1.5 m	0.41		
	2.5 m	1.1		

6.0 SUMMARY CONCLUSIONS

Oxygen Depletion

Severe to moderate dissolved oxygen depletion occurs in four of the eight lake basins of Legend Lake. All eight basins show less than 1 mg/l throughout their hypolimnetic stratum in mid-summer. Two of the basins (C and D) also show less than 1 mg/l throughout their metalimnetic mid-depth stratum in mid-summer. Winter oxygen depletion extends to within two meters of the surface in four of the lake basins (Basins A, B, C, and E). This depletion occurs in spite of chlorophyll *a* values that indicate an oligotrophic lake. Lake basins that are nearer the eastern dam outlet have lower concentrations of nutrients, and therefore algae and aquatic plants, and do not experience severe winter oxygen depletion. Therefore, there is an apparent water quality gradient of better conditions in the lake basins nearer the eastern dam. The eastern lake basins also have less buried organic soil and benefit from nutrient removal by lake basins closer to the stream inlets. It appears that the organic matter content of lake sediment, along with the quantity of aquatic plants and algae, largely determine the oxygen conditions of the different lake basins.

Natural Control of Nutrients

Stratification in the deep parts of lake basins, a continuing supply of iron from the watershed, and marl deposition combine to trap phosphorus in the sediments. Not all Legend Lake basins have the same extent of these processes occurring and, therefore, vary widely in their capacity to remove phosphorus and other nutrients from the water column. There could be some algae bloom problems for some of the shallower, longer retention time lake basins in the future unless watershed phosphorus inputs are controlled at their source.

Aquatic Plant Studies in Wah-toh-sah/Skice (A and B) Basins

The abundance of aquatic macrophytes has been considered a problem in Legend Lake since development. Average plant biomass in the groundwater Inflow sites (500 g/m^2) was found to be statistically greater than the biomass found in groundwater Outflow sites (196 g/m^2) for basins A and B. This difference was also perceived to be significant by the lake residents. Differences occurred in the number of species found and occurrence of several species between groundwater Inflow sites with and without septic system effluent and groundwater Outflow sites. The two groundwater inflow groups displayed the greatest number of species. The physiological growth characteristics of those species assemblages found between the two inflow treatments gave the appearance of a much bigger difference. Several species having fall growth found and a preference for enriched sites were found in greater abundance in the Effluent sites. Effluent sites also exhibited higher sediment, seepage, and plant tissue phosphorus and nitrogen concentrations than did the other Inflow and the Outflow sites.

Project Conclusions/Recommendations

1. All lake basins have good overall water clarity due to relatively low amounts of algae. Maximum levels of algae occur in late summer or fall following mixing.

2. Oxygen depletion is frequently seen during winter in several lake basins and in the lower depths of most lake basins in the summer. Severe winter depletion occurs in basins A (Wah-toh-sah), B (Skice), C (Spring), and E (Little Blacksmith).

3. Aquatic plants occur in fairly high abundance in some lake areas; however, species diversity is good and there is no occurrence of major problem species.

4. Lake shore human activity, including septic systems and probably lawn fertilizer, is contributing nutrients to the lake. Some of this can be reduced by residents.

5. Most of the south shore of the lake has water flowing from the lake to groundwater which is moving to the south away from the lake. Most of the north shore has groundwater flow towards the lake.

6. The direct impact of septic system effluent on nutrient inflow was less than we expected, but will increase over time as more year round development occurs and soils become saturated with phosphorus. Current impacts appear to relate to nitrogen as well as phosphorus in the vicinity of developed lots along the groundwater inflow end of the lake.

Homeowner/Residents Survey Conclusions

This survey of residents owning property near Legend Lake has shown the variety of perceptions, aesthetic values, and lake uses of the people living on and around Legend Lake. The Legend Lake housing development was about one-third (948) of the potential (2800) at the time of this survey. Human impacts will increase as the population increases, so the design and implementation of a management plan for the lake area is desirable while impacts are minimal.

1. There are 728,390 person-use-days annually at Legend Lake. The predominant recreational activities and uses of Legend Lake by people surveyed are; boating (91%), swimming (89%), fishing (86%), aesthetic appreciation (56%), and picnicking (27%).

2. The boat types owned and operated by Legend Lake survey respondents were fishing boats (23%), pontoon boats (19%), ski boats (18%), canoes (16%), and paddle boats (10%).

3. We estimate 63,000 gallons of gasoline are used on Legend Lake annually (50 gallons of marine gas/acre of lake surface/year). Gasoline consumption for Menominee Tribal Members was only 2.9% of the gasoline reported being used by all the survey respondents. Gas use varied with the sub-populations primarily due to the types of boats used by each group.

4. Sixty-one percent of the respondents rated the water quality of Legend Lake as excellent or very good, and no one felt the lake had poor water quality. The top three water quality problems were identified as weeds (54%), algae/scum (20%), and litter (13%).

5. The five top rated reasons contributing to a decline in water quality were heavy recreational use, development pressures, septic tank use, soil erosion, and fertilizer use.

6. Fertilizer use was reported by 14% of the respondents. The closest distance to the lake for fertilizer application was most frequently reported between 20 and 100 feet (46%), followed by 6-20 feet (21%), and less than 5 feet (13%). Pesticide use was reported by 12 % of the respondents.

7. Fishing quality was rated as average or fair by 74%. Thirty-eight percent of the respondents felt the quality of fishing has decreased since they have fished at Legend Lake, while 6.6% felt the fishing quality had improved.

8. The factors rated as the highest contributions to a decline in fishing were development pressures, heavy recreation, fertilizer use, and septic tank use. The top three descriptions of the way fishing has changed were fewer and/or smaller game fish (26%), more and/or smaller pan fish (17%), and fewer northern pike (8.3%).

Management Options/Recommendations

A. *Aquatic Plants*

1. Continue harvesting for transportation corridors, aesthetics, and benefit to oxygen conditions, but develop a plant management plan to optimize recreational interests with minimal impact to fish, wildlife, and the entire ecosystem.
2. Maintain records of tonnage of plants removed from each area of each lake.
3. Weed harvesting in late summer and fall to remove some of the biomass of plants that will decompose and use up oxygen over winter could improve winter oxygen levels in some lake basins. Use of herbicides would actually result in more oxygen consumption as the organic biomass remains in the water or adds to the sediment organic matter.
4. Weed removal over time can also help reduce nutrient levels in lake sediments. This would need to be done with the impact on fish considered in the plant management plan recommended above.

B. *Control of Nutrient Inputs*

1. Minimize the use of fertilizer on lake shore property. Permit phosphorus use only when soil tests indicate a need and prohibit all fertilizer use within 20 feet of the lake shore.
2. Encourage residents to use non phosphate detergents for all purposes, including dish washing as well as clothes washing. Laundry conditioners/softeners that are often high in phosphorus should also be avoided.
3. By raking and composting, minimize the amount of leaves entering the lake from lake shore property, as they add to the amount of sediment organic matter and nutrient levels.
4. Do not wash pets, hair, or other items in the lake.
5. Prevent leakage and spillage and minimize the use of outboard gas and oil.

C. *Septic System Management and Future Planning*

Minimizing the present and future impact of septic systems on groundwater, and subsequently surface water, can be done by:

1. Minimizing the amount of phosphorus and nitrogen containing compounds used in the home. These detergents, laundry conditioners, and water conditioners contain phosphorus. Ammonia products contain nitrogen, as does most organic refuse, therefore garbage disposals should not be used.

2. Maximize setback distances from the lake for new or replacement drainfields, especially in the north shore area where groundwater flows towards the lake. Setback of 200-250 feet could be considered a minimum.

3. Consider requiring systems that incorporate nitrogen and phosphorus removal for new or replacement systems. These types of systems are being considered for requirements in the revised state septic system code. Nutrient removal systems serving groups of homes may in the future be more cost effective than larger sewer projects or each home maintaining separate systems.

4. Pumping septic tanks every two to three years helps prevent existing drainfields from plugging up, which could result in the surfacing of wastewater and its flow to the lake.

5. Maintaining tree and shrub vegetation between the drainfields and the lake shore may help intercept nutrients moving toward the lake from septic systems.

6. Consider establishment of a sanitary district especially for areas where groundwater flows toward the lake. Investigate the use of cluster type treatment systems for groups of homes in environmentally sensitive areas.

Other Considerations

D. *Oxygen Conditions - Aeration*

Improved oxygen in summer could increase the amount of water available for fish and potentially allow for two storied fishery in some of the deeper lake basins. Hypolimnion (bottom layer) aeration would be most useful in the summer for basins A, C, and D. This could also reduce nutrient concentrations and algae during fall turnover. Winter aeration would aid fish survival and growth in basins B, C, and E and help prevent nutrient release and transport from sediments to surface water during spring turnover.

E. *Sediment Removal/Dredging*

1. Removal of the highly organic sediment in some lake basins could reduce sediment oxygen consumption and aquatic plant growth. Dredging to remove sediment is very expensive and it is often difficult to find a place to safely dispose of the dredge spoil. This option, while possible in limited areas, may be more expensive than the benefits could justify.

2. Sediment disposed of on land during lake construction is currently causing water quality problems in limited areas. The amount of land where this occurred should be identified and possible remediation of these sites should be evaluated.

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APPENDIX

Copies of Appendices are available upon request.