AN ASSESSMENT OF OPTIONS FOR MANAGING WATER LEVEL AND WATER QUALITY PROBLEMS AT GULL LAKE

By

Andrew Hay

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Natural Resources Institute
University of Manitoba
Winnipeg, Manitoba, Canada
R3T 2N2

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ABSTRACT

Assessments were made of water quality and water level issues at Gull Lake, in south eastern Manitoba, to provide recommendations to the local cottage owners association for maintaining acceptable standards of water quality. The water level issue was addressed with reference to a proposal by the Gull Lake Ratepayers Association (GLRA) for recharging the lake with groundwater. Although this approach qualifies as an engineering solution to an ecologically based problem it is intended as a part of a broader plan to revive the lake, the success of which ultimately depends on phosphorus containment.

A questionnaire was distributed to lake residents to ascertain user habits and gauge attitudes and awareness of key management issues; and a water balance was devised to enhance hydrological information about the lake. Results of this research were used to evaluate the feasibility of recharging the lake with groundwater from a nearby aquifer.

While conclusions of this study were that recharging the lake could achieve some degree of success more data are required, particularly for groundwater, before feasibility of the project can be confidently stated. Other conclusions were that, with or without implementation of the project, the long-term sustainability of Gull Lake as a viable recreational resource depends on a comprehensive management plan that includes greater public involvement. A program of ongoing research in the basin is recommended and the need for communicating this research to lake users is emphasized.

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Most important was the support of my family and friends who tried to make life easier along the way, particularly my parents whose devoted support made it all possible. Finally, I wish to dedicate this work to my partner Jacqueline who was always there when I needed help. Merci.

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1.0 Introduction

1.1 Background

Some of the problems typically experienced at recreational lakes include degraded water quality, groundwater and well contamination and conflicts between different user groups. Development of lakes for recreation has usually proceeded in accordance with individual property rights, sometimes at the expense of the collective good. Development patterns tend to become established long before any potential adverse impacts will be felt, and solutions to these adverse impacts are more elusive and expensive at later stages of development because of the relatively large number of affected parties. Most problems associated with recreational lakes can ultimately be traced to overdevelopment of lakeshores as they become more heavily utilized. More specifically it is the unplanned and unsustainable nature of development that has created the problems which threaten peoples' enjoyment of these precious resources.

At an elevation of 20-30 metres above the surrounding terrain, Gull Lake has been unaffected by pollution outside the watershed, however the absence of either in-flowing or out-flowing surface streams means that pollutants generated in the watershed will not be as quickly flushed out. Furthermore any prolonged absence of rainfall and reduction in groundwater flow to the lake will tend to exacerbate existing water quality problems. Extensive non-point sources of pollution within the lake's small watershed (approximately four square km.) have, in fact, led to a marked decline in water quality.

Until approximately fifteen years ago Gull Lake had a reputation as a small, spring fed lake with high quality water. Fraser (no date) refers to it as the place beyond the hill with clear spring waters, white sand beaches and surrounding forests of pine and birch. The lake has been a recreational destination for Manitobans since the early part of this century but, despite its popularity, it was not easily accessible by large numbers of people until the 1950's, when improvements in road infrastructure and increasing recreational demands, led to heavy development of the lakeshore.

The capacity of the lake to assimilate the impacts of this intensive use may have been exceeded some time ago and periodic blooms of algae and weeds, apparent since the 1930's, have become more frequent. Early concerns related to fish die offs during the winter but by the late 1960's the emphasis of concerns had shifted to the excessive growth of weeds and swimmer's itch (Beck 1986). In the last several years the quality of water has declined further with accompanying algal blooms and increased turbidity. In a trophic study of the lake Beck (1986) found phosphorous to be the limiting nutrient with approximately 65% of the total phosphorous supply coming from artificial sources. A significant reduction in the rate of eutrophication could therefore be achieved by removing the artificial sources of phosphorus (Beck 1986), which come from the septic fields and outhouses of approximately 285 cottages. Figure 1.1 is a graph showing the accelerated increase in the Manitoba Water Quality Index at Gull Lake since 1984.

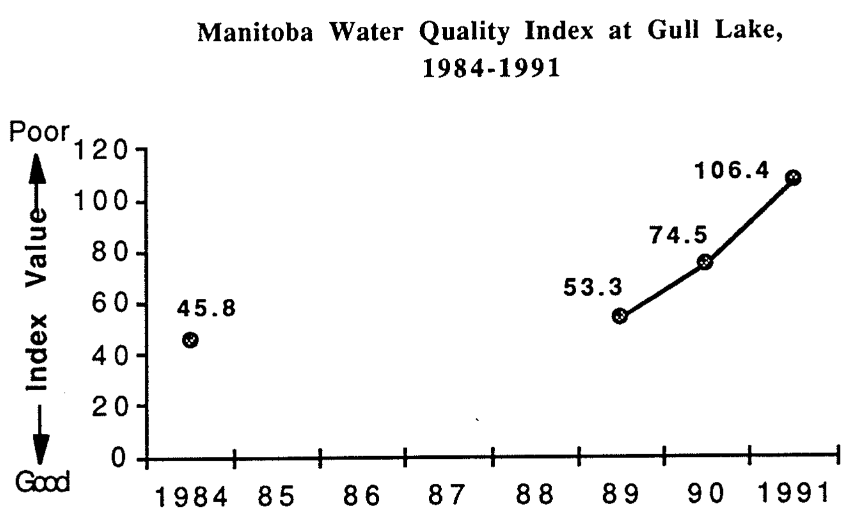

Figure 1.1 Water Quality Index at Gull Lake, 1984-91. Source: Gull Lake - 1990 and 1991 Water Quality Update; Manitoba Environment - Water quality Management Section

Low index numbers represent good water quality and high numbers represent poor water quality, based on a combination of biological and physical variables. Water quality was not monitored from 1985 through 1988 although during that time it rose 7.5 points from 45.8 to 53.3. The visible increase in turbidity since 1989 reported by many lake users is dramatically shown by the index, which doubled from 53.3 to 106.4 in only two seasons.

The deterioration of water quality has been accompanied by a significant decrease in the level of the lake, and the generally drier conditions during the 1980's have likely intensified the water quality problems at Gull Lake by reducing the volume of the lake. In contrast to the 1980's, where drought was a prominent concern, the 1970's were characterized by high water levels which were damaging or threatening to flood private property around the lake. Residents requested the Rural Municipality of St. Clements to lower the level of the lake and prevent future flood occurrences. A drainage ditch was built during 1975 under guidance of the Water Resources Branch. A rock filled weir was added late in 1976 to control flows. The top of the structure was measured to be 253.96 metres A.S.L. (833.2 feet). In August, 1981 the weir was capped with concrete at 253.82 metres (832.75 feet) (Manitoba Water Resources). No cause and effect relationship between the weir and the current water deficit can be demonstrated because there was no thorough documentation or gauging of surface drainage prior to (or after) installation of the weir. The assumption that the surplus water drained from the lake during the late 1970's would have alleviated the current water deficit can neither be proven nor disproved. Other theories have been proposed to try and account for declining water levels; such as, ground water discharge at the north end of the lake, holes or voids in the impermeable layers and gravel pit operations on the west side of the lake. However, intermittent drought conditions since 1980 have ultimately had a major effect the water level of the lake.

The Ratepayers were successful in having a bylaw passed that would require all cottages to be equipped with sewage holding tanks, and in 1989 they began to address the problem of declining water levels. In 1990 they approached the R.M. of St. Clements and the Province of Manitoba for financial assistance, and the Minister of Natural Resources for advice, on raising the water level of Gull Lake by pumping groundwater from an aquifer into the lake.

Figure 1.2 Concrete Weir at north end of Gull Lake. The shallow channel leading to the weir is visible in the foreground. Photograph taken in spring 1991

1.2 Site Description

Gull Lake is a small lake with a surface area of 104 hectares (260 acres), located seventy kilometers (42 miles) northeast of Winnipeg. The basin is thought to have formed 8,000 to 10,000 years ago when a large ice sheet came to rest and melted over a glacial outwash delta (Beck 1990). The lake basin has formed in a shallow depression created by the weight of stagnant ice. Underlying deposits of clay and relatively impermeable till have inhibited the drainage of water from the basin into adjacent sand and gravel deposits. The maximum and average depths of the lake are 5.2 metres and 3.3 metres respectively.

Figure 1.3 Aerial view of the lake, looking northwest across highway 304. Lake Winnipeg is visible in the background. Photograph taken in October, 1991

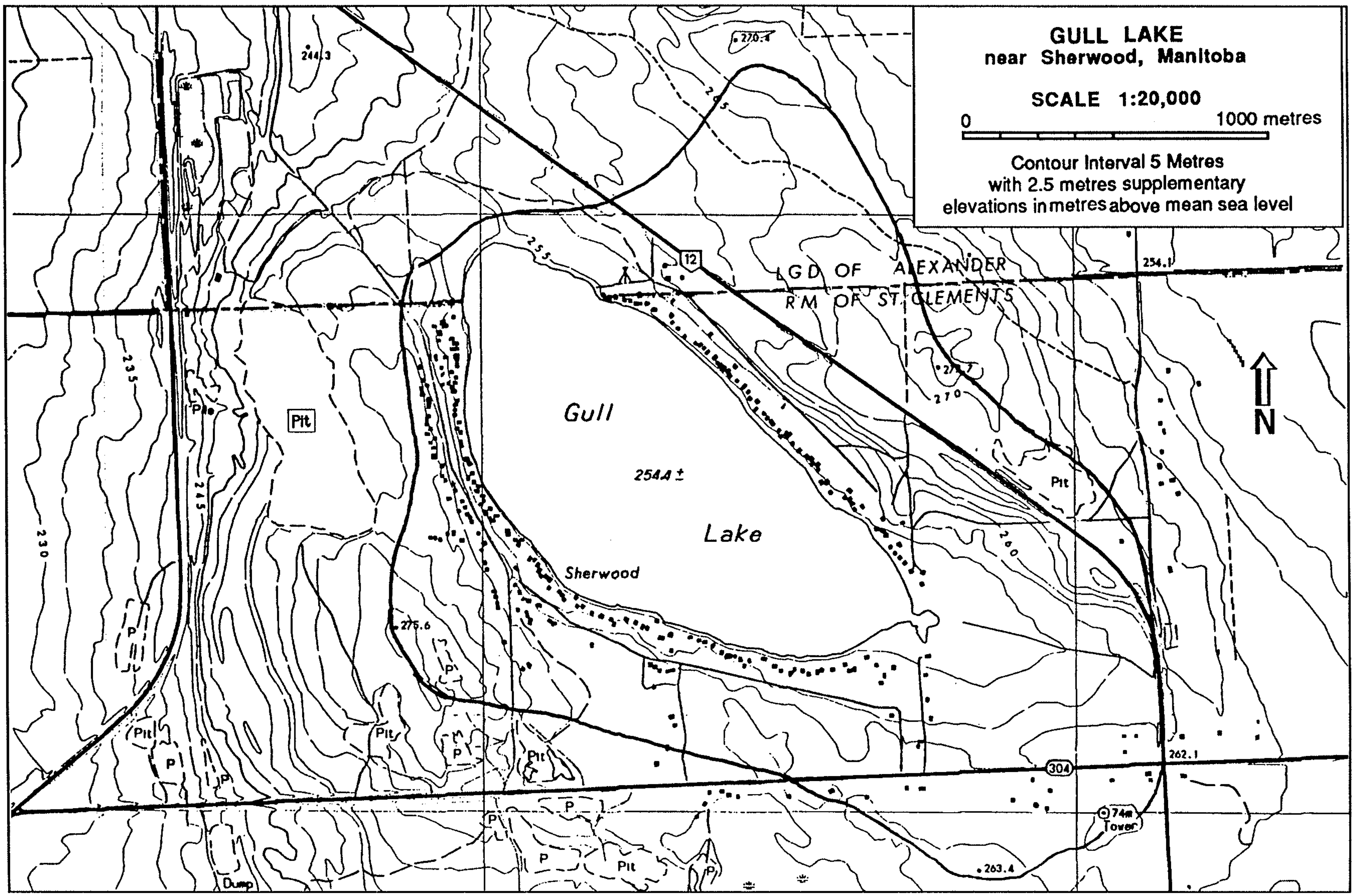

Figure 1.4 Map of Gull Lake showing watershed and topographic contours

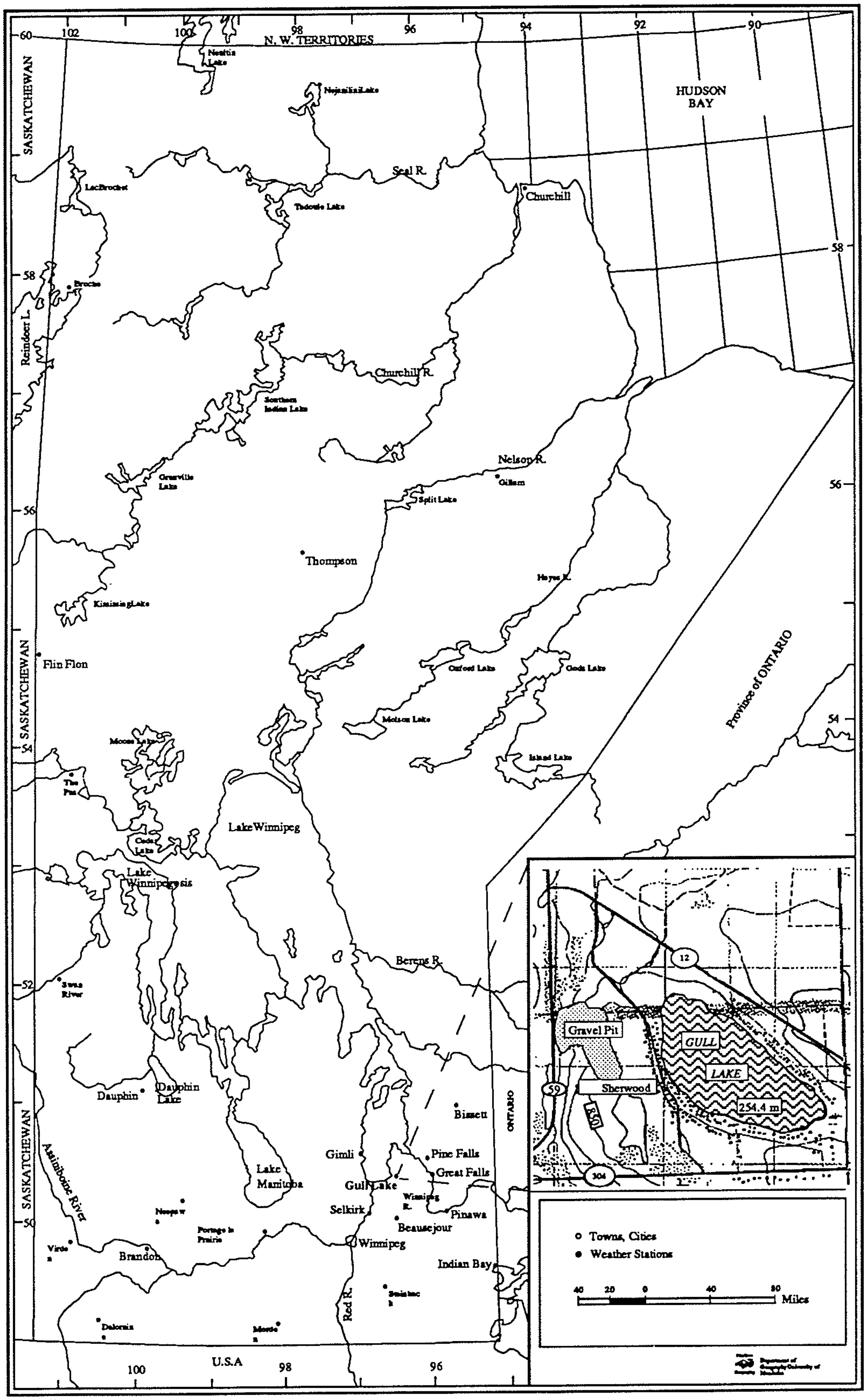

Figure 1.5 Manitoba Provincial Map Locating Gull Lake and nearest weather stations

A circular ridge of 5-18 metres encloses the lake. There are no permanent rivers or streams flowing into the basin, however, water flows out over a weir at the north end of the lake if the level is in excess of 253.82 metres A.S.L. (832.75 feet). The basin is enclosed by two ridges or moraines ranging in elevation from 255 metres at the north end of the lake A.S.L to as high as 275 metres on the east and west sides of the basin.

1.3 Problem Statement

Water quality problems have been reported for Gull Lake since the 1930's (Beck 1990). In 1986 the lake was mesotrophic and bordering on eutrophic (Beck 1986). Ongoing water quality tests suggest the lake has deteriorated further since then, and many lake users have reported noticeable increases in water turbidity. Declining lake levels and degraded water quality are regarded as a crisis situation by cottage owners because of the implications for property values, currently estimated to be $15 million (GLRA pers. comm.), as well as diminished recreational opportunities. The relationship between water level and water quality is a complex one, but it is likely that factors contributing to eutrophication of the lake i.e., poor water quality, would be ameliorated if the volume of water in the lake were increased. The main issue to be addressed was whether the level of the lake could be raised by pumping water into it for extended periods of time.

1.4 Objectives of the Study

The primary objective of this study was to identify and assess alternative courses of action to address water level and water quality problems at Gull Lake.

Specific objectives were:

1.4.1) to examine factors related to the biological and physical processes essential to the life cycle of lakes similar to Gull Lake through a review of relevant literature and professional/expert opinion;

1.4.2) to conduct a survey of cottage owners at Gull Lake to determine their attitudes and perceptions of proposed management initiatives;

1.4.3) to determine the extent of natural fluctuations in water levels;

1.4.4) to calculate a water balance of all measurable inflows and outflows at Gull Lake;

1.4.5) to estimate the potential costs of building and maintaining an aqueduct to recharge Gull Lake during drought conditions; and,

1.4.6) to provide recommendations to the Ratepayers Association for maintaining acceptable standards of water quality and lake levels.

1.5 Methods

The methods used to reach the stated objectives were: a review of literature related to the problem; a questionnaire; informal discussions with cottage owners; a water balance calculation and consultation with professionals and experts from disciplines related to the management of water resources.

Literature Review

The literature review was necessary to define the characteristic biological and physical processes essential for maintaining the health of small prairie lakes over the long run. It also indicated if similar research had been done by others. The literature review involved a library search and personal interviews with professionals and experts in the field. Consultation with agencies and individuals familiar with the area, including many cottage owners, was also invaluable in providing necessary information on the natural history of Gull Lake and other similar lakes.

Questionnaire:

A questionnaire with return postage was delivered to cottage owners and lake users. Its purpose was to collect information about the awareness and acceptability for proposed and potential management options for Gull Lake. Questions were intended to deal with various issues without specific reference to them so that the true level of awareness and knowledge would be more apparent. The questionnaire was able to quantify information, previously lacking, on important issues, such as the level of support and awareness for recent initiatives to restore the lake to a healthy condition and cottage owners' awareness and perceptions of water quality and water level.

Water Balance

Some cottage owners at Gull Lake regard it as crucial to have more water in the lake, but before time and money were committed to a project for raising the level of the lake, it was necessary to assemble some hydrologic data to predict the feasibility and the long-term effects of pumping water into the lake. The water balance provided a more complete picture than previously existed of the relative magnitude of water flows in and out of the basin. The water balance involved calculating, or in some cases estimating the volumes of inflows and outflows such as evaporation, evapotranspiration, precipitation, groundwater flows and surface runoff. Withdrawals from the lake for domestic use were also estimated.

1.6 Importance of the Study

Wherever possible human activities should compliment natural processes so that the health of the lake is ensured, but a trophic study of Gull Lake, completed in 1986 has indicated that these processes are being compromised to a degree that recreational prospects are uncertain. It was recommended by the Minister of Natural Resources and the R M of St. Clements that there should be an assessment of the hydrologic conditions of Gull Lake to explain why the lake level has fallen and to determine if the enhancement measures proposed by the Ratepayers would be effective. Their desire to preserve the lake for future generations to enjoy, and to protect and maintain property values, was the basis for their proposal to artificially recharge the basin. The research in this report was conducted to evaluate the potential impact of implementing that proposal.

1.7 Limitations of the Study

A recent proposal to enhance the long-term water quality and water level of the lake was considered in detail, however certain assessments were beyond the scope of this research and might remain to be addressed. This study did not attempt, nor was it possible, to determine the technical feasibility of pumping groundwater into the lake or whether the aquifers could, in reality, supply a sufficient volume of water to increase the level of the lake. The objectives were to detail the costs of implementing the project and assess its feasibility in terms of:

-the general availability and quality of groundwater,

-potential hydrologic and ecological impacts on the lake,

-retention capacity of the lake basin,

-provincial resource management policy, and

-alternative measures for enhancing water quality.

2.0 Literature Review

2.1 Processes of Lake Formation

Lakes and their basins have been formed in many different ways, from catastrophic events such as landslides, earthquakes, volcanic activity and even meteorites; to more gradual processes such as wind and water erosion, acting selectively on different types of terrain. For many years, scholars have attempted to classify lakes according to their origin, using very different approaches. Davis (1882) adopted a formal classification of the processes which may produce lake basins, grouping them as constructive, destructive or obstructive. Hutchinson (1957) felt this classification tended to "obscure the regional grouping of lakes". The catastrophic origin of lakes during ice ages or periods of intense tectonic, or volcanic activity, implies a localized distribution of lake basin types, so lakes tend to be grouped into lake districts Hutchinson (1957). The concept of lake districts is the most useful means of broadly classifying lakes, and the specific process by which any one lake basin may have been formed, is a means of further distinguishing a basin within a given lake district.

In addition to his classification of lake types, Davis (1882) also emphasized the contrast between the immature landscape with an abundance of lakes, and the relatively lakeless mature landscape. This distinction is important because it calls attention to the impermanence of lakes. Natural environments are continuously changing, although on a human time scale they can remain much the same, if left undisturbed. All lakes are destined to become shallow as their basins are filled in with sediment. Prairie lakes in Manitoba are naturally nutrient enriched because they are situated in productive land so they are likely to evolve more quickly through progressive stages of development. Due to the complexity of interrelationships within ecosystems the human impact on lakes was apparent long before it was understood and could be effectively minimized.

2.1.1 Glaciation

On the North American continent lakes have been formed in vast numbers by glaciation. The immense number of small lakes produced by glacial activity is a quite exceptional phenomenon (Hutchinson 1957). During the Pleistocene glaciations 10,000 years ago, ice sheets of comparable size to what now exist over Greenland and Antarctica blanketed the northern hemisphere. The movement of glaciers across large areas of what is now southern Manitoba, created the present landscape. The action of glaciers in mountainous areas may produce forms quite different to those of ice sheets in regions of more mature and gentle relief (Hutchinson 1957). In either case lakes may be produced but the way in which this happens may be quite different, and the resulting basins may have such diverse forms that throughout their entire histories their character will reflect this difference in origin (Hutchinson 1957).

Gull Lake fits into a category of lakes that have been formed by the melting of ice as glaciers receded from the area. This process is illustrated in figure 2.1. Large deposits of sand and gravel surrounding the lake are believed to be outwash deposits (Charron 1975), which are formed by the fluvial action of melt water from glaciers spreading layers of sorted material across depressions and valleys. (See figure 2.2 for a map of sand and gravel deposits and topographic high points). Large blocks of ice would occasionally become detached from the receding ice sheets and left immobilized while they continued to melt. In cases where outwash material has enveloped or surrounded these icebergs, depressions called kettles have been left behind.

Hutchinson (1957) lists five variations of glacially formed lakes which he refers to as Types 35 through 39. Gull Lake is probably most similar to Type 38; lakes in kettles within the till of continental ice sheets. Till is the most widespread deposit left by glaciation, consisting of unstratified stony blue-grey or brown clay, reaching thicknesses of more than sixty metres (Sparks 1972). The Selkirk map area is distinguished by nine topographic high points (figure 2.2) composed primarily of three till lenses (Charron 1975).

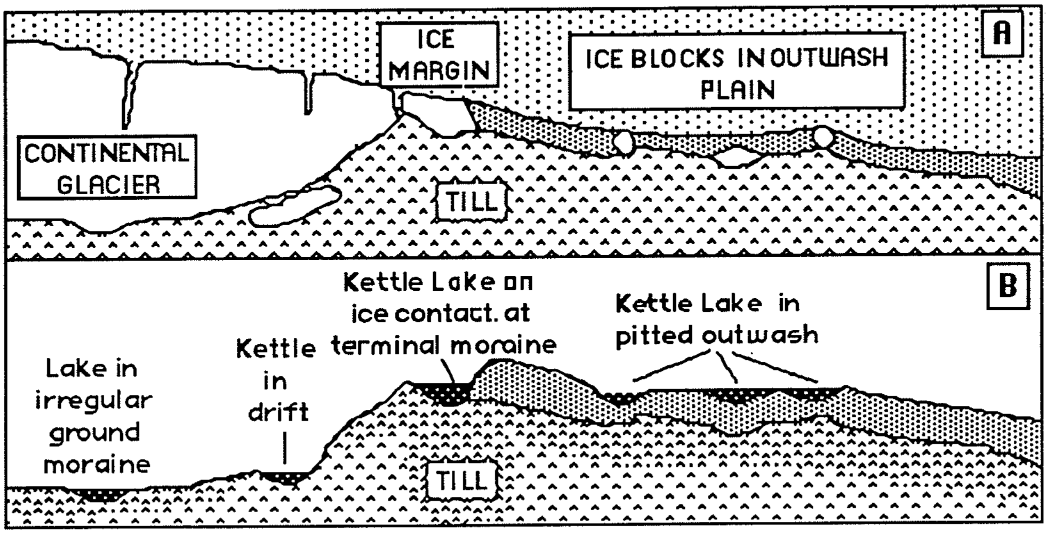

Figure 2.1 Formation of various types of Kettle Lakes.; A, retreating continental ice, with outwash plain containing stagnant ice blocks. B, Lakes formed in outwash and in till by by melting ice blocks, and as irregularity in ground moraine (after Zumberge). (Source: Hutchinson, E. Treatise on Limnology 1957)

The thicknesses of till below the high points are generally in excess of sixty metres. Gull Lake is located on high point number 3 (see figure 2.2, and figure 3.2 for a profile of the basin). The colour and texture of the till is dependent on the terrain through which the ice sheets passed. Deposits of till are normally of minor relief but they may be diversified by kettles (Sparks 1972). Many small lakes occupy kettles with their shape and size extremely variable, ranging from dozens of metres to several kilometres across (Hutchinson 1957). Generally the smaller ones have simple relief and uncomplicated shore line development, having been formed by the action of only one mass of glacial ice (Hutchinson 1957). Gull Lake is probably a simplified kettle lake basin, oval in shape, with a shallow, uniform depth. Sand and gravel around the lake may be the remnants of moraines piled up by the action of glaciers before they melted. Moraines are unstratified deposits of rocky debris caused by the movement of glaciers and, like till, they are composed of unsorted material.

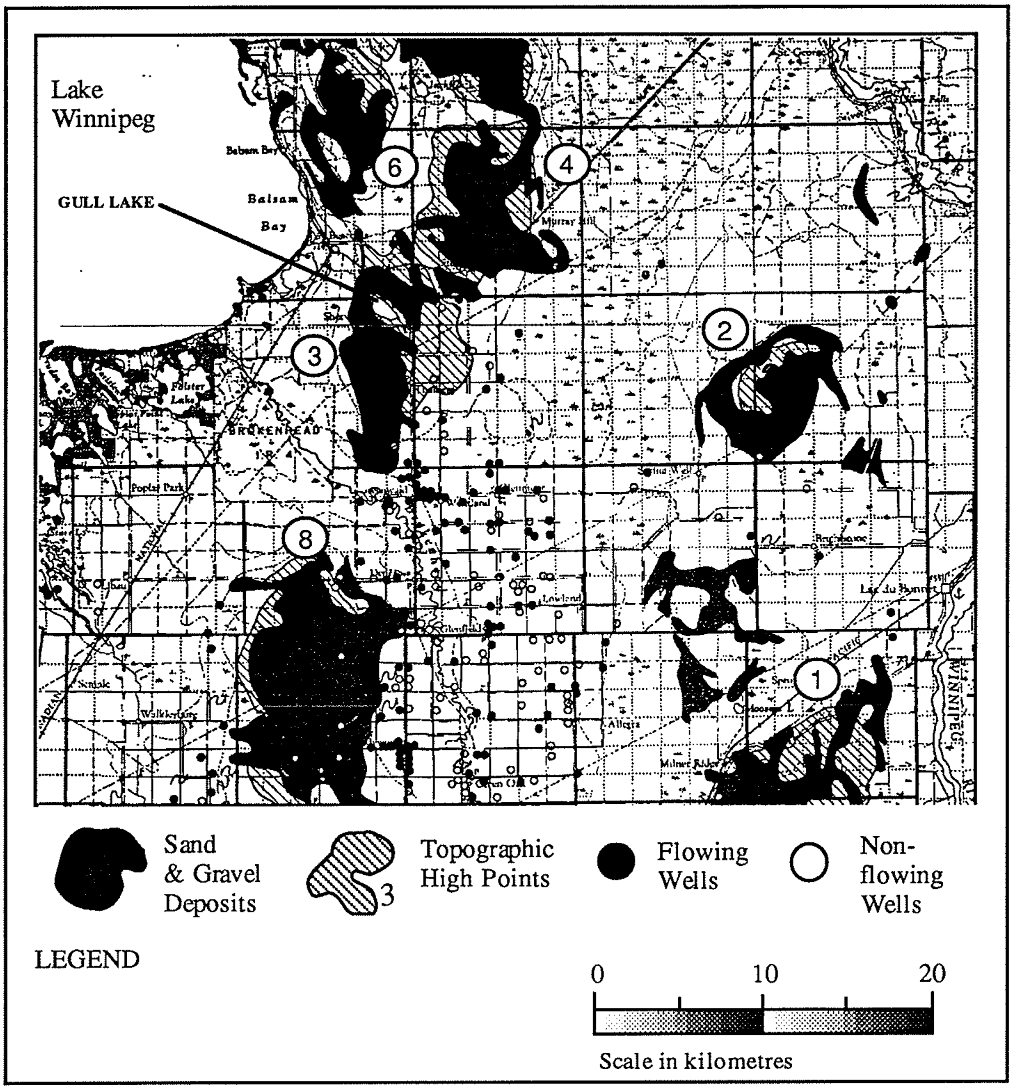

Figure 2.2 Map of sand and gravel deposits; topographic high points; and flowing and non-flowing wells. Source J.E. Charron, A Hydrogeological Study of the Selkirk Area,Manitoba 1975

2.1.2 Lake Basin Types and their Sources of Water

The supply of water for a lake must come from at least one of the following sources: 1) precipitation, 2) rivers or streams, 3) groundwater seepage in through the lake bed, and 4) discrete groundwater springs. The relative importance of these sources for any given lake is variable. It is probable that lakes exist in which nearly all the water enters by just one of these sources (Hutchinson 1957). A major distinction can be made between seepage lakes which are fed by precipitation and groundwater, and drainage lakes which are recharged and discharged primarily by rivers or streams. Lake basins may also be either open or closed with the latter type losing water only to evaporation. Most seepage lakes, in this sense, are almost certainly open basins (Hutchinson 1957), since they are subject to considerable groundwater flux through the lake bed.

Seepage Lakes

Seepage lakes can occur in both open and closed[1] basins, but are generally associated with highly permeable glacial drift soils (Stephenson 1971) that would permit significant shallow subsurface inflow into a basin, subject to topography. Seepage lakes are spring fed or groundwater fed, generally with insignificant direct surface inflow or outflow (Stephenson 1971). Gull Lake is likely an open basin seepage lake. In a typical year it will receive 520 mm. of precipitation, which translates into 615,000 cu.m. of precipitation directly on the lake surface; 1,050,000 cu.m.of precipitation on the watershed of which 430,000 cu.m.becomes runoff to the lake and 620,000 cu.m. is used by vegetation; annual lake evaporation of 600,000 to 750,000 cu.m.; and an apparent net outflow of approximately 800,000 cu.m. per year calculated from the yearly change in lake volume. Net outflow is composed of two major unknown factors in the lake's water budget: seepage inflow and seepage outflow. Total inflows using the figures above are

[1] The word "closed" is used by Stephenson to describe lakes with no in-flowing or out-flowing streams, but which may lose water by seepage; whereas Hutchinson uses the word "closed" to refer to lakes that lose water by evaporation only.

1,045,000 cu.m. (615,000 + 430,000) and total yearly outflows from known sources (lake evaporation) of say 650,000. The difference (1,045,000- 650,000) indicates a surplus of water each year of 395,000 cu.m. which is equivalent to a gain in lake volume of 10% per year. In reality the lake volume has declined by an average of 75,000 cu.m. per year since its peak volume in 1974/75. If the inflows and outflows are estimated correctly the difference between the expected gain in lake volume and the actual loss can only be accounted for by an apparent surplus of seepage out of the lake over seepage into the lake, hereafter referred to as *net outflow*.

This apparent loss of water from the lake suggests that it is an open basin with some portion of the lake basin being naturally permeable. Seepage is probably confined to the upper part of the basin otherwise the lake could not exist as it is, perched on a high point. Unfortunately relatively little is known about the behavior of groundwater which imposes limitations on explaining and predicting changes in lake level. Without actual field measurements the magnitude and influence of subsurface flows remains unknown. Some generalizations are possible based on the literature of other watershed studies where these type of data have been gathered.

2.2 Groundwater Within Lake Environments

Fluctuations of the lake level are a response to the local groundwater table around it, which in turn is connected to a larger regional groundwater table underneath it. Several comments made by Stephenson (1971) are particularly relevant to any discussion of Gull Lake water levels. He states:

> Two areas of concern for any lake type include its quality and quantity, or stage [lake level]. For seepage lakes these aspects have special significance due to the absence of surface-water inflow to such a lake. Thus stage is directly related to water table fluctuations and is not readily manipulated.

Most small lakes not in rock basins are separated from the groundwater by a seal which represents the initial deposition of clay and very fine silt that has settled out of the lake during its early stages of development (Broughton 1941, Hutchinson 1957). This seal not only permits the lake to retain water regardless of seasonal variations in groundwater level, but also results in considerable chemical differences between groundwater and lake water (Hutchinson 1957). There are at least two ways to determine how well the Gull Lake basin is sealed; first, a comparative analysis of lake water and groundwater chemistry to check for differences, and second, charting the elevations and fluctuations over time of the lake relative to the adjacent groundwater. The first alternative has never been done, although it would be relatively easy to incorporate into a water quality monitoring program. The second alternative has been done at one site by the Water Resources Branch using data from the observation well and manually recorded data from a lake level gauge shown in figure 3.1. The level in the observation well and the lake level follow each other closely (see hydrograph in pocket). It is possible that the well is too close to the lake to reflect the true water table. The prevalence of sand and gravel around the lake means it is likely that the lake and the ground water adjacent to it will always tend to be similar. A well located further away from the lake would probably display a different correlation. The diagram in figure 2.3 is adapted from a theoretical example used by Winter (1981b). It depicts a lake and its associated water table. Note that in figure 2.3 only the water table itself is shown, not the land surface. The arrows indicate the direction of water flow as they subside from the mounds in the water table. The point marked with an "S" is a stagnation point where flows of water from opposite directions meet and diverge. The heavy lines represent the interface between different local and regional flow systems.

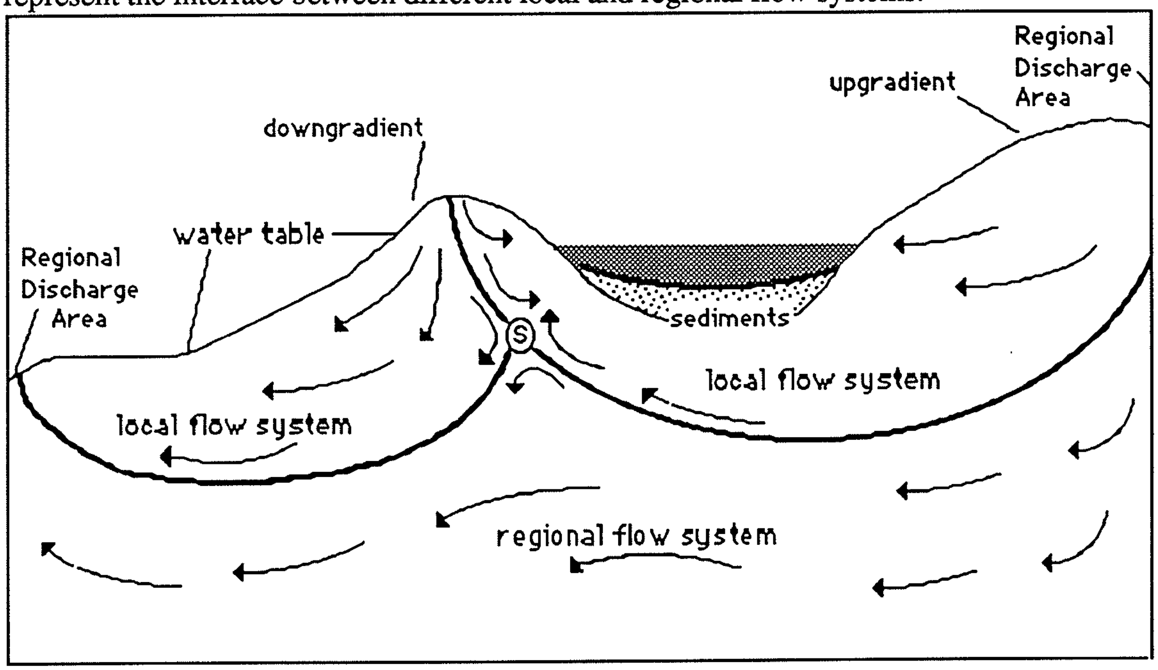

Figure 2.3 Theoretical diagram of local and regional water tables, adapted from a diagram by Winter (1981a)

Sediments below the lake impede the escape of water but seepage could still occur from near shore areas that are more permeable. Winter's original series of diagrams explain that regardless of the permeability of the basin, seepage is more dependent on the groundwater conditions. If the hydraulic pressure under the lake, influenced in part by the water table mounds, is greater than the pressure exerted by the height of the water column in the lake there will be a net gain of water in the lake due to groundwater flows in through the bed.

Where the shore is not significantly elevated above the lake, shallow subsurface water can flow out of the lake. Such a situation exists at the north end of the Gull Lake basin adjacent to the weir where the shoreline relief is low. Water can leave the lake as shallow groundwater through the permeable surface deposits. The lake can be characterized as a seepage lake but during high water years drainage of excess water, at or near the surface, into the forest at the north end gives it some characteristics of a drainage lake type.

2.2.1 The Importance of Groundwater in Water Resource Planning

The evaluation of lakes as they are related to groundwater flow systems is of special concern prior to efficient planning and development of recreational areas (Stephenson 1971). In most cases the quantity of ground water inflow and outflow are unknown and they are assumed to have little significance in the water budget (Crowe, Franklin and Schwartz 1981). Because groundwater flow near lakes has been poorly understood, its discussion in water or nutrient balance studies is often limited (Winter 1971). The implications of subsurface flow in this study remain theoretical due to an absence of actual data for groundwater. The collection of more detailed hydrologic data for the watershed would greatly facilitate the evaluation of future development and enhancement proposals.

The significance of groundwater in most small watersheds tends to be overlooked. Winter (1971) describes the interaction between lakes and groundwater as "the most elusive factor of all". Its role in the water balance is complex and, unlike precipitation and evaporation, is not confined to watershed boundaries. The geology and topography of small drainage basins is often less complicated than large ones, better lending themselves to practical and theoretical studies (Tóth 1963). Nevertheless, attempts to define groundwater are generally made only for large basin watersheds of greater economic interest.

2.2.2 Groundwater Monitoring

Groundwater motion in a given area can not be conceived of as generally known until certain characteristics of the flow system involved are well defined, the most important of which are: the location and extent of recharge and discharge areas, the direction and velocity of flow at any given point in the region, and the depths of the flow systems (Tóth 1963). The importance of consistent, long-term monitoring of groundwater is apparent from the literature. Field observations made while trying to define groundwater flow patterns, can be misleading since the observed phenomenon relating to flow systems may be due to different causes in different situations (Tóth 1963). Winter (1981b) cautions against errors that can result when point data are taken as representative of general conditions. Groundwater recharge is variable in time and space, depending on the thickness and permeability of the unsaturated zone through which infiltrating moves. The complex and transient groundwater flow systems that result, have a significant impact on contiguous surface water (Winter 1983).

Defining Groundwater Flows in Glacial Till Basins

The flow of water within the saturated zone of till areas is extremely variable and the higher the topographic relief, the greater is the importance of the local flow systems Tóth (1963). Greater relief produces greater water table mounds which influence the local flow direction and intensity. In the previous section several authors indicated the uncertainty of ascertaining groundwater/lake level relationships especially Winter (1981b and 1983), who suggests that one observation well adjacent to a lake shore is insufficient for defining groundwater flow adjacent to lakes. Without an adequate knowledge of groundwater, seepage can not be adequately defined and neither can the feasibility of water engineering projects for lake restoration. While little is currently known about Gull Lake the data base could be easily and quickly improved using standard hydrologic observation techniques. Depending on the type of construction, existing wells can be used to monitor groundwater levels on a basin wide scale as part of a program to determine the effect of groundwater on surface water bodies. Piezometer nests can also be easily installed for the same purpose.

Piezometer Nests

A piezometer is a simple device consisting of a transparent tube with a perforated tip that can be installed manually, or by power auger, in shallow parts of lakes or on land. They can be installed at any depth up to at least twenty metres. Once installed it will measure the hydraulic head at that point. The common procedure is to install several piezometers grouped together in nests, each at different depths. Williams and Farvolden (1967) demonstrated with piezometer nests at various sites, in northeastern Illinois, that hydraulic potential does not increase uniformly through till after a precipitation event. Differences in the response of hydraulic potential at different sites after precipitation were attributed to paths of high permeability within glacial till. These paths in the till, called joints, permit water to move peripherally through the till at different rates relative to the surrounding till. This suggests that underground aquifers normally confined by relatively impermeable till may be selectively recharged if they are connected to joints of higher conductivity. The effect of these joints in till would be to enhance the ability of till to transmit water into or out of a lake basin and to increase the variability of the flow through space. The presence of joints below the unsaturated zone would increase the infiltration rate of precipitation (Williams and Farvolden 1967), altering the runoff potential to nearby lakes and affecting the recharge and yield of aquifers.

2.2.3 Groundwater Modelling

Theoretical models to describe groundwater flow were used by Winter (1981b and 1983) to predict the extent of seepage from lakes. The models can be useful as predictive tools if they are applied judiciously to actual watersheds. Winter (1983) concluded that local recharge of groundwater does not always occur where it is commonly assumed to and, for lakes situated in permeable media i.e., sand and gravel deposits, it is conceivable that local recharge could cause a hydraulic head dam (a zone of higher water pressure due to the pressure exerted by a water table mound) that is sufficiently large to prevent seepage from a lake. Seepage would eventually occur in after the mound has dissipated. Winter's (1983) analysis highlights the complications of designing field studies to assess the interaction of lakes and groundwater. Even several wells in the vicinity of a lake (as are commonly relied on) are probably not sufficient to define the interaction (Winter 1983).

Figure 2.4 depicts a lake situated between two high points of land, one higher than the other. The division between regional and local flow systems is shown similar to figure 2.3. Seepage may occur from the left side of the lake bed if the hydraulic pressure at the stagnation point “S” (expressed in metres above sea level) is higher than the lake level. Hydraulic pressure at “S” depends on the amount of precipitation recharging local groundwater, the slope of the hydraulic gradients (not shown) and the slope of the water table near the lake, on the downgradient side of the basin.

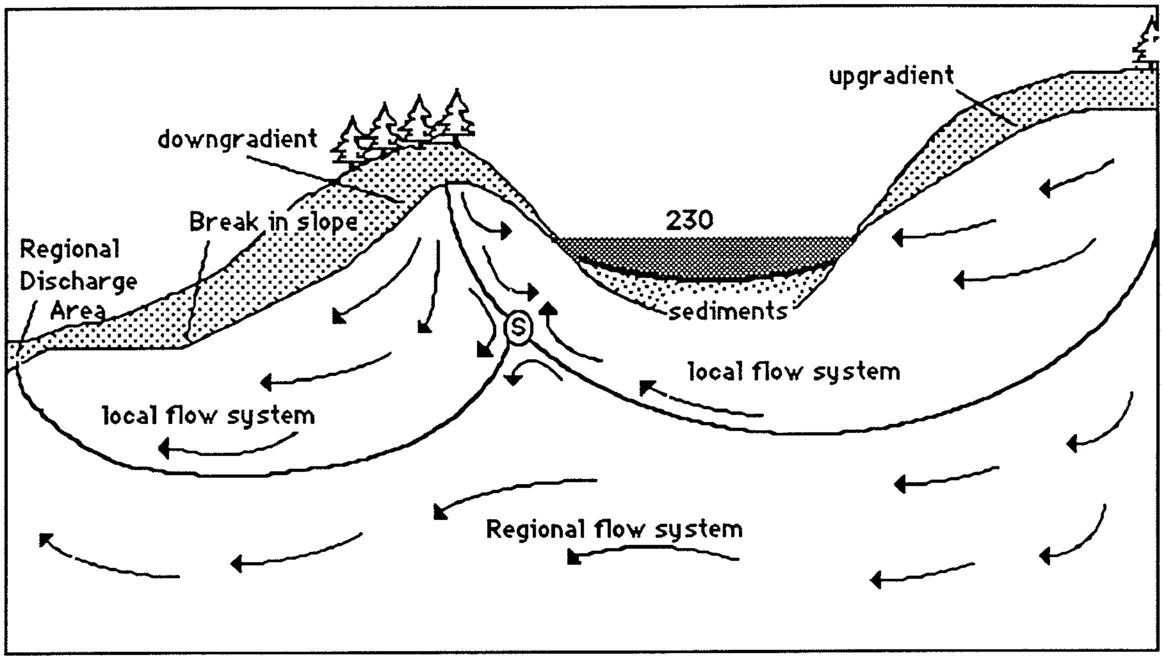

Figure 2.4 Regional and local groundwater flow systems associated with a lake. Adapted from Winter (1981b). Lake level is at 230 metres ASL Shaded upper portion is the unsaturated zone, unshaded lower portion is groundwater.

The identification of all losses of water is critical for accurately defining the water balance of lakes. Precipitation and evaporation components can be estimated within reasonable margins of error but the measurement of groundwater presents problems. Although direct monitoring is preferable, groundwater is often measured indirectly as a residual amount to save time and money. Williams (1968) assessed the flow of groundwater in three small glacial till basins (basin A, B, and E) containing marshes rather than lakes. The area and slope of the basins varied, the largest being approximately two square kilometres. Comparison of hydrographs derived from piezometer nests, precipitation data, and the level of marshes in these basins indicated that the effect of precipitation on the marshes was variable. Williams explained this variability through differentials in hydraulic conductivity of joints in the till and by temporal variation of rainfall. During prolonged dry periods the marshes in two of the basins were discharge areas; that is, they consumed water, either by direct open water evaporation or evapo-transpiration from the aquatic vegetation. During heavy rain these two marshes changed from discharge areas to temporary recharge areas, recharging the groundwater. The marsh in the third basin remained a discharge zone depleting groundwater throughout the season.

Overall conclusions were that depressions in some till basins (containing in this case marshes) behave as groundwater sinks a majority of the time, whereas others are more often recharge areas for groundwater. Precipitation intensity, basin area, and basin slope are significant factors in determining whether till basins change from recharge to discharge areas (Williams 1968). The significance of this research for lakes in till basins is that; like marshes, they can act as either as sinks by consuming groundwater, or recharge areas that replenish groundwater. Whether Gull Lake is primarily a groundwater sink or a recharge area needs to be confirmed.

The remainder of this chapter deals with three major areas on which this study has focused. The first is the water balance, the second is eutrophication, which is the natural aging process that gradually transforms lakes into more enriched and productive ecosystems, and the third area of focus deals with approaches for managing aquatic environments that might be appropriate for Gull Lake.

2.3 The Water Balance

An understanding of the volumes and pattern of flow of water in and around a lake is important Nutrient budgets are of primary importance in lake restoration projects but strictly hydrological information is also required for improved prediction and assessment of rehabilitation techniques. The calculation of a water balance is necessary, not only for an understanding of the hydrology that governs a lake, but for understanding how the transfer of nutrients in a basin is affected by the flow of water. One objective of this study was to define the water balance for Gull Lake.

Small scale research or enhancement work has been undertaken intermittently at least as early as the 1930's. These efforts focused on specific issues such as fish die-offs or the control of swimmers itch. Davidson's (1973) study of management approaches has been the only attempt at devising an integrated basin management plan for the lake and Beck's Trophic Study of Gull Lake (1986), completed with the assistance of cottagers, has been the most comprehensive and intensive study of water quality to date.

Although the Trophic Study (1986) included quantification of the main hydrologic factors affecting the nutrient cycle, this study focused in more detail on the hydrologic processes affecting the lake in order to assess the feasibility of pumping water into the lake. Analysis of the water balance provides new information for management options for restoring the lake to its former condition and provides lake users with a broader information base with which to promote wise and sustainable use of the lake.

Water quality and lake level are directly affected by the hydrologic cycle. By definition it has no beginning or end, but it is convenient to think of precipitation as the primary input to the system. The first step is to define the boundaries of the hydrologic system affecting the lake. The area within the boundaries is the watershed or catchment area (the Gull Lake watershed is shown in figure 1.4). The next step is to define and quantify the distinct components of the water balance. These are described below.

Losses of Water - Evaporation, Transpiration and Interception

On a broad geographic scale there are no losses of water in the hydrologic cycle since water lost by one process is gained through another. For localized areas it is true that for short time periods, losses of water due to evaporation or transpiration may not be offset by precipitation.

2.3.1 Lake Evaporation

Evaporation is one of the ways by which the temperature of a body of water is regulated so that biological processes within that water body can be maintained. It occurs wherever there is a difference in moisture between two adjacent locations such as the lake and the air above it. Evaporation from the lake surface, known as lake evaporation can entail a considerable loss of water from lakes and can easily surpass the volume of precipitation. The three conditions necessary for evaporation from a free water surface are: energy input, a vapour pressure gradient between the lake surface and the atmosphere, and the circulation of air at the water's surface (Dunne and Leopold 1978). Since evaporation depends on solar radiation, its variability is often a function of geographic latitude, season, time of day and cloudiness (Dunne and Leopold 1978).

The morphological characteristics of water bodies, such as volume, depth, and surface area will also affect the rate of evaporation. Solar radiation is initially absorbed by lakes without significant evaporation until the water heats to a temperature at which evaporation will occur more readily. If a lake is deep and cold this process will take longer than in shallow warmer ones. There is little change in net amount of energy received annually by a lake, even though on a monthly basis it can vary widely (Dunne and Leopold 1978). The warming effect of the sun is more rapid in shallow lakes so evaporation would tend to commence sooner in Gull Lake which has an average depth of 3.2 metres.

The rate of evaporation is directly proportional to the difference in vapour pressure between the water surface and the atmosphere directly above, therefore wind blowing across a lake surface will accelerate the rate of evaporation by replacing the humid air and increasing the vapour pressure gradient between the air and the water. It follows that there should be an inverse relationship between evaporation rates and the size of a lake since the exchange of air across small lakes is greater, as is the vapour pressure deficit (Dunne and Leopold 1978).

Measuring Evaporation

The standard technique for measuring evaporation from open water surfaces is by the use of an evaporation pan. There are four types of pans, which produce a range of estimates acceptably close to the actual evaporation rate. Errors in estimating evaporation can be quite high for short time periods, but are within acceptable margins over periods of a month or more. The essential design is a circular galvanized metal tub ten inches to two feet deep and three to six feet wide. They can be floated on a lake, dug into the ground, or mounted above the ground on a palette with air circulating underneath. The change in water level in the pan is measured daily and precipitation is recorded by an adjacent rain gage. The difference in the daily levels, with corrections made for precipitation, is the apparent evaporation from the pan. The rate of evaporation from a pan is greater than for lakes so a coefficient is applied to the pan data to determine the equivalent lake evaporation (these coefficients are based on a complex formula and vary between .6 an .8 according to the type of pan). The class A pan, mounted above ground, is most commonly used because it is more stable than floating pans, has a stable evaporation coefficient, provides more data, does not collect as much dirt and debris and is the easiest to install (Chow 1964). Experimental evidence from many parts of the world indicates that .7 is the appropriate coefficient for class A pans (Ward 1967 b). Class A pan data is measured at six sites in the province and the data are published in various formats. This data can be applied satisfactorily to most lakes especially if they are in close proximity to a weather station.

2.3.2 Interception

A certain percentage of rainfall is evaporated back into the atmosphere from the surface of vegetation and other cover types, never reaching the ground, where it would be used by vegetation, contribute to runoff, or percolate into the groundwater. Interception of rainfall by dense vegetation prevents rain from falling directly on the soil. This dramatically reduces soil erosion but may increase the proportion of rainfall lost to evaporation. A light rainshower falling during warm weather conditions could theoretically be completely intercepted by forest cover resulting in no net contribution to runoff or groundwater. The contribution of rainfall under such conditions is limited to what falls directly on the lake. The volume of water on the wetted surfaces of leaves and branches is called interception storage, and the quantity of this storage depends on the characteristics and density of the vegetation. Interception storage evaporates, during and after a rainfall. Even during rainstorms when the atmosphere is very humid, evaporative losses are appreciable because the total area of wetted leaf surfaces is large (Dunne and Leopold 1978).

Precipitation must also penetrate the leaf litter layer that covers the ground before it can enter the mineral soil below and contribute to soil moisture or ground water. Helvey (1967) has estimated that anywhere from 2.5 percent to 4 percent of gross precipitation is intercepted by the litter layer depending on its organic composition (Dunne and Leopold 1978).

Generally lower atmospheric temperatures in rural areas would result in less evaporation during rainfall events compared with urban areas, although the dense natural canopy of jackpine and birch, covering much of the Gull Lake watershed, could result in greater interception of rainfall, causing a higher evaporation loss.

A knowledge of the species composition and density of vegetation and other cover characteristics is necessary to estimate interception of rainfall. Coefficients applicable to general conditions are also available, where field analysis is not practical, though the inclusion of such detail in the analysis of water related problems at Gull Lake was not feasible.

2.3.3 Evapo-transpiration

The term evapo-transpiration is used to describe the combined evaporative loss of intercepted rainfall and water transpired by vegetation and trees. The two factors are difficult to separate so they are treated as one component and called evapo-transpiration (ET). There is a further distinction between *actual* and *potential* evapo-transpiration. Evapo-transpiration seldom reaches its potential rate in actual field conditions because soil moisture is limited and generally below the capacity of vegetation to use it.

The difference between rainfall and runoff is largely explained by evapo-transpiration (Dunne and Leopold 1978). Once water is withdrawn from the soil by a tree or plant, it is ultimately lost to the atmosphere by evaporation through pores on the leaf surface called stomata. Transpiration is highly dependent on numerous factors such as air temperature, relative humidity, soil moisture, soil porosity, and solar intensity. Over short periods of time these factors are critical in the water balance because, as they fluctuate, they strongly influence the flow of water through the unsaturated zone determining how much reaches the lake. On an annual basis it is fairly accurate to apply the average rate reducing the potential for error.

Actual vs Potential Evapo-transpiration

A standard text book coefficient for ET was used. Tables devised for estimating potential ET allow the researcher to calculate this coefficient based on the biological and physical characteristics of the study area. The coefficient is then applied to precipitation data to determine the consumption of water. ET has been intensively studied but it is inherently difficult to define accurately due to the numerous variables which affect it, so actual rates are seldom practical to calculate. Potential rates were used instead.

2.3.4 Precipitation

Studies which require estimates of precipitation sometimes have access to data recorded within the area of interest, but more often weather stations outside the study area are the only source of data. In either case a method for converting the point data (preferably from several gauging sites) to areal averages must be used. The three common methods of determining areal averages for precipitation are the arithmetic mean, Thiessen polygon method and the isohyetal method (Winter 1981a). Each method produces slightly different, but comparable, results.

Thiessen polygons are often employed because they are easily applied and produce relatively accurate results. The area of interest is divided into polygons each with a weather station at its centre. The watershed is superimposed over the polygon network and the fractions of each polygon covered, are used to compute a weighted average for precipitation. In this way precipitation recorded at the stations with the greatest percentage of their polygons in the watershed, will be weighted more heavily. This technique requires a large enough watershed to span several polygons, and was not suitable for the small Gull Lake watershed of only four square kilometres.

Most preferable is the isohyetal method because it addresses some of the limitations of the Thiessen polygon technique, but it was not readily applicable to the study area either because of the large ungauged area surrounding the lake. The notable absence of stations near the lake makes it impossible to draw accurate isohyets through the region where the lake is located. Apart from a weather station installed in 1991 at Stead, Manitoba (which operates from May to September only), and Grand Beach which operated for only a few months in total, no recording weather stations have ever been located near Gull Lake. In fact the lake is located in the centre of an area 3800 km^2, where no yearly weather observations are recorded.

A simple arithmetical average technique was adopted instead. Data from seven stations nearest the lake was compiled for the period 1972-91, including Beausejour, Gimli, Great Falls, Pinawa, Pine Falls, Selkirk, and Brokenhead (from 1981-84).

Sources of Error in Estimating Precipitation

Several factors affect the accuracy of rain gauge measurements which are important to consider in the interpretation of precipitation data. Rain gauges were being used more than 2000 years ago, but in spite of this, it is still not possible to measure the amount of precipitation falling at a point on the earth's surface to a known degree of accuracy (WMO 1973). The essence of the problem of rainfall measurement is the rapid change in precipitation over both space and time (Burroughs 1990). Actual on-site measurements are always preferable to measurements from weather stations further away because of the extreme areal variability of precipitation. This variability is observable over small or large areas, and even data recorded on-site and extrapolated to an entire watershed, can be in error. The degree of error can be quite high for individual rainfall events but declines substantially for longer periods of time. A network of rain gauges produces the most reliable estimates of precipitation, especially over large areas. After a review of selected literature on the relative accuracy and precision of different types of rain gauges, Winter (1981a) concluded that wind is the major source of variation in rain gauge data. Other sources of variation were attributable to the style of the gauge, its height above the ground, and general exposure. In general, sampling errors (of precipitation data) tend to decrease as the gauge network density is increased and as the duration of precipitation and size of the study area are increased (Winter 1981a).

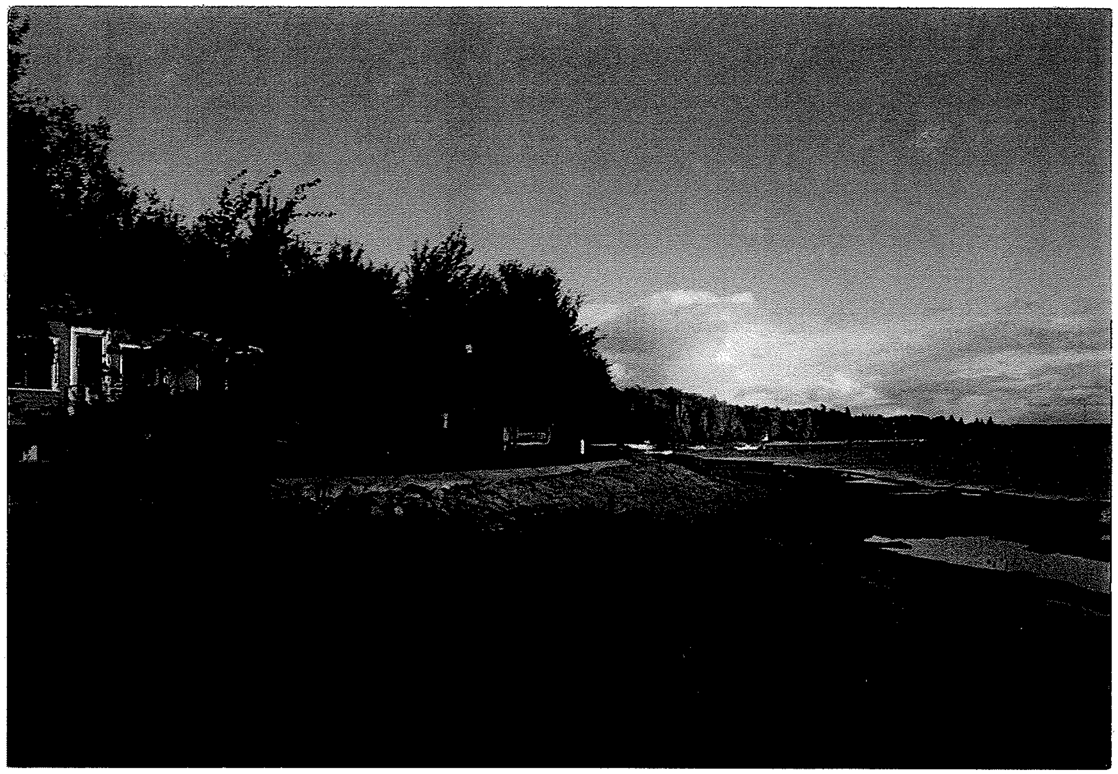

Figure 2.5 "North Shore" of Gull Lake looking south from public access area.; Note vegetation encroachment on beach. A trial installation of an AES rain Gauge is visible as a small white object, in centre of photo. Observation well is 20m to the left of edge of frame. Photo taken September, 1991

2.3.5 <u>The Runoff Cycle;</u>

The runoff cycle described by Hoyt (1942) is comprised of five phases which are influenced by topography, geology, vegetation, land use, and climatic factors. Each phase is a state of being for any given area determining its response to rainfall and runoff.

Phase 1 is the rainless period preceding a rainfall event when groundwater is subsiding at some rate governed by the permeability of the ground. Water infiltrates much faster through sand and gravel than glacial till, and till is more permeable than pure clay. The Gull Lake basin contains layers of all three of these materials but their location, thickness and extent are not precisely known except where deep wells have been drilled.

Phase 2 occurs during the initial period of rain. Some rain falls on the lake itself and contributes directly to its volume, some is intercepted by the forest canopy, some infiltrates the soil directly or is retained in small surface depressions, and some evaporates into the atmosphere or is transpired by vegetation. There is little or no runoff during phase 2 except on bare impervious surfaces.

The occurrence of Phase 3 depends on the duration of the rainfall. It is associated with surface runoff which occurs when the rate of rainfall exceeds the rate of infiltration. When enough rain has infiltrated to fill the zone of aeration (the unsaturated zone above the water table), it can no longer move downwards to be stored as shallow groundwater so it moves laterally in the form of subsurface runoff flowing toward lower elevations and eventually into lakes and rivers. After frost has left the ground there would be a rapid increase in groundwater recharge accompanied by an equivalent decrease in surface runoff. Groundwater adjacent to Gull Lake rises dramatically each spring by as much as 0.6 metres in only a few days.

Phase 4 is reached when all natural storage capacity has been exhausted. The infiltration rate of the rainwater will approach the rate of water movement through the zone of aeration (which is now saturated). If the rain continues to fall the water table will rise until groundwater has been fully recharged; all rain after this point becomes surface runoff. This condition is rarely ever reached but is sometimes observed in flat swampy areas after periods of heavy and prolonged rainfall (Chow 1964).

Phase 5 begins immediately after rainfall has stopped and it ends with the start of phase 1, when groundwater and runoff begin to subside. The latter phases, particularly phase 4, are not always reached. For example, if phase 2 rainfall abruptly ended then the cycle would start again at phase 1 and the volume of rainfall would not have been sufficient to recharge groundwater.

2.4 Case Studies in Lake Research

At a certain stage in the development of natural areas for human use, the need to re-develop or enhance the area to suit the changing needs of users will eventually arise. Before this is done there are usually questions that must be answered. This can be the first realization that more information is needed to make decisions which are intended to improve conditions for human use. It may be permissible to make decisions despite a lack of sufficient information if they are not expected to adversely affect the area or its potential uses. It is not practical to implement intensive studies of every area that is directly or indirectly subjected to human impacts. As an alternative, data generated by studies of hydrology, ecology and meteorology in representative areas can often be applied to areas with no existing data base. The following section outlines examples of some of these areas which are being intensively studied to provide information which can be used predict development impacts in other areas.

Mirror Lake and its Watershed

An extensive and comprehensive study of Mirror Lake, New Hampshire was begun in the early 1980's as an extension of a study on a larger upstream watershed, ongoing since 1955 by the U.S. Forest Service. With reference to Mirror Lake, Likens (1985) commented on the need for comprehensive ecosystem research as follows:

> Attempts to understand or manage environmental problems are usually based on

information pieced together from studies isolated in time, space, or habitat. This approach ignores important functional; linkages which are vital to natural ecosystems. The purpose of the Mirror Lake Study was to evaluate historical and present day linkages between the atmosphere and terrestrial and aquatic components comprising the Mirror Lake watershed-ecosystem (Likens 1985).

Table 2.1 below outlines the type of data that has been gathered since 1955

Table 2.1

Average Annual Hydrologic Budget for Watersheds 1-6 of the Hubbard Brook Experimental Forest During 1956 to 1980 (all numbers in millimetres)

	Precipitation	Streamflow [1]	Evapotrans.
MEAN	1311	821	490.
STD Deviation	42.5	41.4	6.5
% of Total	100	63	37
Range	951-1857	501-1361	414-537

[1] Certain watersheds subjected to experimental treatment are not included in the data after disturbance.
Source (Likens 1985, Table II B-2)

Precipitation is measured in the Hubbard Brook valley, where Mirror Lake is situated, by a series of rain gauges, one for every thirteen hectares of watershed, and two near the lake. The Thiessen polygon method is used to calculate rainfall distribution over each watershed including Mirror Lake. Hydrologic measurements have been recorded for the whole valley by the U.S. Forest Service since 1955. From this record it has been determined that 131.1 cm. of precipitation falls on the experimental watersheds. Precipitation on the Mirror Lake watershed is 1215 mm., of which 821 mm. (63 percent) becomes streamflow and 490 mm. (37 percent) is lost through evapo-transpiration (Likens 1985). The range of variation in the table above is different for each component. Evapo-transpiration is quite stable from year to year while precipitation and streamflow vary more than two-fold. Because annual evapo-transpiration is so constant from year to year, the amount of streamflow is highly and directly correlated with precipitation (Likens 1985). Evapo-transpiration noted at Mirror Lake is probably close to the potential rate having a standard deviation of only 6.5 mm. out of a total of 490 mm. whereas in Manitoba ET is limited to actual rates somewhat less than the potential. Trees and vegetation can only use what is available. If soil moisture is depleted plants will use less water. Soil moisture depletion resulting in stress to crops, is a reality in Manitoba and Saskatchewan. According to Ash (1991) average evaporation during the growing season at Gimli (May 1- Aug. 8-20) since 1972, is 260.4 mm. (26.04 cm.) while the average growing season precipitation is 214.1 mm. (21.41 cm.) indicating that evaporation, on average, exceeded precipitation by 46.3 mm. or 4.63 cm. A similar moisture deficit can be observed in the Gull Lake hydrograph between June through September each year, when there is a gradual but steady decline in lake and groundwater levels. Annual precipitation at Mirror lake is 1311 mm. per year, 2.6 times the amount received annually at Gull Lake. Precipitation in southern Manitoba averages 500 mm. per year.

2.5 Water Quality

Assessments of the causes of lake deterioration and the success of management and restoration projects are based on nutrient budgets (Winter 1981a). The nutrient budget of a lake is fundamental to the interaction between terrestrial and aquatic environments. The watershed and the airshed surrounding a lake deliver nutrients, including phosphorus, nitrogen, and carbon, to aquatic ecosystems according to a balanced nutrient budget. In the long term, nutrients are removed from sites of accumulation within terrestrial systems and transported to less accessible sites in lacustrine or marine sediments (Likens and Bormann 1974). Forests and other areas under natural vegetation would be examples of sites of accumulation. There is a gradual downslope movement, by water, of dissolved nutrients and particulate matter from higher to lower elevations. Lakes retard this downhill movement of detritus by storing matter in the sediment layer as lacustrine deposits. Under natural conditions erosion and deposition of material is kept to a minimum by the biologic structure of the ecosystem and changes in a lake will occur very gradually. Uncontrolled human exploitation of an ecosystem inevitably disrupts the balanced nutrient budget resulting in increased erosion, accelerated eutrophication, and rapid changes to the physical character of the land and water. Successful rehabilitation of damaged lakes addresses these imbalances with measures that restore the balance of nutrients.

2.5.1 Eutrophication

Eutrophication is a term used to describe the progressive enrichment of aquatic environments with nutrients. It is a natural process that is associated with the accumulation of sediments in a lake basin and increased biologic activity (Sze 1986). The process is accelerated by the presence of human activity near a lake which often results in dramatic increases in nutrient discharges directly or indirectly into a lake.

Elevation of the Gull Lake basin above the agricultural plain to the east and south, and the absence of surface streams into the lake eliminates the hazard of non-point sources of pollution. However, a perched lake with a small watershed is more sensitive to pollution from within the watershed because the water exchange rate is slower. The residence time for nutrients within seepage lakes may be greater than comparably sized drainage lakes [that are connected to a network of streams] (Stephenson 1971). Gull Lake probably has a lower tolerance for increased nutrient loads than other small lakes which are fed by surface water i.e., drainage lakes. Lakes, streams, swamps, and marshes embedded within the terrestrial landscape have a variety of linkages for energy and nutrient exchange with the terrestrial ecosystems surrounding them (Likens and Bormann 1974). Disturbances to the natural flux of nutrients can grossly accelerate ecosystem output in the form of algae and weeds. Such disturbances are conveyed by the downhill flow of water which will carry any available excess nutrients. The immediate ecosystem response [to nutrient inputs] is increased photosynthesis, plant growth and algae which leads to increased productivity at all levels of the food chain up to and including fish (Vallentyne 1974). This process may or may not be desirable depending on the intended use of the water body.

2.5.2 The Role of Phosphorus

No other element in fresh water ecosystems has been studied as intensively as phosphorus and its associated ecological impacts. In comparison to the rich natural supply of other major nutritional and structural components of biological systems (carbon, hydrogen, nitrogen, oxygen, sulphur), phosphorus is least abundant and most commonly limits biological productivity (Wetzel 1983).

The effects of eutrophication, in terms of recreation, drinking water supply and aesthetics; are generally unwanted, whereas effects on fish production may or may not be desirable depending on the extent to which fish [such as carp] that thrive under eutrophic conditions are needed as food (Vallentyne 1974). In affluent regions such as North America, where lakes and rivers are appreciated for their recreational potential and aesthetic qualities eutrophication is a problem because it detracts from those qualities.

2.5.3 Trophic States

Eutrophication takes place in nearly all lakes, however the rate at which it occurs varies greatly. Lakes are but a temporary feature of the landscape in geologic terms. Their ultimate fate is to become filled with sediment and replaced by forests or grasslands (Vallentyne 1974). Confusion [over the term eutrophication] occurs because historically it has been applied not only to process, but to describe types of water (Rosenburg and Freedman 1985, 3:239). Three types of water are often named to describe the trophic status of lakes. At one extreme are oligotrophic waters which are often relatively young lakes with deep basins. At the other extreme are eutrophic lakes which are nutrient rich and may support extensive algal growths during the summer (Sze 1986). Waters that are intermediate between oligotrophic and eutrophic are called mesotrophic. There are no clear divisions between these trophic states, in fact, mesotrophy is not always recognized as a distinct trophic state, but rather a convenient term for describing water bodies which are between the two extremes. The extremely slow, almost imperceptible process of natural eutrophication contrasts sharply with the rapid changes in lakes caused by cultural eutrophication. The principal nutrients involved are compounds of phosphorous and nitrogen because they are in short supply which makes them the limiting factors to growth of aquatic plants. The ratios by weight of phosphorous, nitrogen and carbon present in all plants are given by (Vallentyne 1974) as:

1P:7N:40C:100 DRY weight or,

1P:7N:40C:500 FRESH weight

If one of the three elements is in limited supply and all other elements are present in excess of physical needs, the sudden introduction of that element will cause an ecosystem response. For example, phosphorus (with a ratio by weight of 500 fresh algae:1phosphorus) added to a stable ecosystem can theoretically generate 500 times its own weight in living algae, nitrogen 71 times (500:7), and carbon 12 times its weight (500:40) (Wetzel 1983). In a lake such as Gull Lake where phosphorus is limiting the implication of these ratios are that each kilogram of extra phosphorous from external sources, like sewage and greywater, can potentially produce 500 kilograms of algae or other aquatic vegetation. Figure 1.1 shows the sharp increase in the water quality index for the lake due to cultural eutrophication. The external (or artificial) load of phosphorus in Gull Lake was determined by Beck (1986) to be 170.8 kg.per year, based on a current lake volume of 3,200,000 cubic metres. Not all phosphate and nitrogen entering a lake is in a form which can be directly utilized by aquatic vegetation (Beck 1986). The ratios (by mass in milligrams) of nitrogen to phosphorus, required by plankton and algae are given by Beck (1986) as:

plankton	7.24 mg N:1mg P,
and for algae	10.86 mg N:1mg P

Three different ratios for these two elements in Gull Lake were calculated by Beck (1986), one based on the theoretical maximum supply of each element, and two others based on different estimates of the percentage of total N and P which can be utilized by algae and plankton.

1) theoretical maximum supply (Gull Lake)	80.91 N:1 P
2) modification based on Cowan and Lee (1976)	188.79 N:1 P
3) modification based on Hutchinson (1957)	13.64 N:1 P

There is a wide variation in the three ratios but all are above the critical range which indicates that phosphorus is the limiting nutrient. Concentrations of phosphorous and nitrogen compounds are 1000 times higher in sewage than in natural lake water. The human sources can therefore trigger far more explosive algae blooms and macrophyte growth than natural sources can but the two sources are different in one important respect, human induced eutrophication is easily reversible because the source of nutrients can be contained and prevented from entering the ecosystem. The natural phosphorous load for the lake is 92.5 kg.per year while the actual load is estimated by Beck (1986) to be 263.3 kg.per year.

Phosphorous was found to be the limiting nutrient at Gull Lake and with approximately 65 percent of the total phosphorous supply coming from artificial sources a significant reduction in the rate of eutrophication could be achieved by removing this source (Beck 1986). Early attempts to control eutrophication of lakes in Europe and North America had the desired effect, but were ultimately unsuccessful because they treated the symptoms and did not remove the source of nutrients. Using chemicals to control algae growth; one of the symptoms of eutrophication, is only temporarily effective because nutrients remain in the system and will continue to produce algae when the conditions are right.

2.5.4 Environmental Factors

Algae and weed growth depend on more than a nutrient supply to initiate and maintain their growth cycle. Water temperature, depth and visibility, solar radiation, and composition of the lake bed are some factors that must be appropriate before aquatic vegetation can grow.

Thermal Stratification

In response to seasonal temperatures lakes will tend to stratify into layers of different temperature. Deeper lakes develop a thermocline during the spring which is a zone of abrupt temperature change dividing the upper level of the lake (the epilimnion) which is warmed by the sun, from the lower level (the hypolimnion) that remains cold. The decrease in temperature in the thermocline is also associated with a rapid increase in density of the water. Such a density gradient acts as a barrier to the vertical mixing of water (Sze, 1986). Vertical mixing in a lake has important consequences for algae and weed growth. In a stratified lake they are restricted to the epilimnion which limits the availability of nutrients for their growth.

Lake Depth

Opportunities for weed and algae growth are enhanced in shallow lakes because they are not deep enough to thermally stratify in the summer. In the absence of a thermocline the zone of mixing extends to the bottom of a lake providing a greater source of nutrients for plant production. Beck (1986) notes that significant macrophyte growth (bottom rooted weeds) may inhibit wind induced mixing action. This would tend to inhibit algae growth, however, the extent of macrophyte growth may vary each year and between different areas of the lake, so the effect of macrophytes on wind mixing and algae growth is unreliable.

Light Penetration

The production of algae also depends on light for photosynthesis. Each species of aquatic flora have their own optimum light requirements so any given level of light intensity, in addition to nutrient supply, will favour certain plant species. Light decreases exponentially as it penetrates the water column due to its absorption by particulate matter including weeds and algae. Near the surface light is sufficient and nutrients would be the only limiting factor to algae growth. Light intensity may be excessive for some species and there is also a compensation depth where the amount of light is just sufficient for cellular maintenance without the production of new biomass. Above the compensation depth biomass is increased and below it the species cannot survive (Sze 1986).

Oxygen Depletion

Organic material from sewage may severely deplete oxygen in the deep layers of a lake as it decomposes. Additionally, dead cells settling out after algae blooms will also decompose in the hypolimnion and, in lakes with massive summer growths of phytoplankton (algae), the algae may be the principal control on oxygen content of the lake (Sze 1986).

2.6 Methods of Lake Restoration

Effective physical restoration techniques have been devised for reversing the effects of eutrophication where the abatement of phosphorus loading alone, has been insufficient It is presupposed in all cases where these methods have been used, that an effective means of nutrient control has been established and is ongoing. Restoration does not imply the permanent reinstatement of a lake to conditions which may have prevailed during a former phase of its development. It is supposed to restore conditions in a lake such that it becomes an acceptable environment for the purposes for which it was intended. Several of these restoration methods are reviewed in the following section.

2.6.1 Suction-Dredging

Overloading of lakes with nutrients from external (artificial) sources can lead to accelerated eutrophication of lakes. Even if the external loading is reduced to normal levels, internal loading from nutrient rich sediments can prevent recovery (Björk 1988). Conventional remedial measures to reduce nutrient input and slow down or reverse the process of eutrophication are often unrealistic because there are already sufficient nutrients in the system and they will be recycled, keeping the lake in a hypertrophic state (Barica 1981). The exchange of phosphorus between lake sediments and the water column above is complex. Under aerobic (oxygenated) water conditions the exchange of phosphorus is largely unidirectional from the water toward the sediments (Wetzel 1983). Under anaerobic conditions phosphorus can migrate from a depth of 10 cm. in the sediments back into the water above in only two to three months (Wetzel 1983). This is a further nutrient load added to what may be already entering a lake from artificial sources.

Bacterial agents also play a role in this process but the chemical process is the most critical. Oxygen depletion can develop in the hypolimnion after algae blooms and aquatic macrophytes (weeds) have died off and begun to decay. The oxygen content in the hypolimnion (bottom layer) of eutrophic lakes becomes severely depleted during summer stratification. In contrast, an oligotrophic lake experiences oxygen depletion in its epilimnion (upper layer) and retains high dissolved oxygen in the hypolimnion. Oxygen consumption, from the biological oxidation of organic matter in the hypolimnion of eutrophic waters, is not offset by the same oxygen renewal mechanisms (aeration, circulation, and photosynthesis) that occur at the surface of a lake. If wind mixing over the predominantly shallow depths of Gull Lake is sufficient to prevent stratification, then anoxic conditions are not as likely to occur. Potential anoxic conditions are more threatening in winter months when ice cover prevents the entry of oxygen into the lake.

The phosphorus content of lake sediments in combination with oxygen saturation of the water, over the winter will have an effect on the phosphorus concentration of the water and hence the growth of algae. Whether the removal of external artificial phosphorus sources brings the desired results may depend on the conditions at the sediment water interface. It is thus useful to examine alternate strategies of phosphorus reduction which have been necessary elsewhere.

Lake Trummen: An example of Suction-Dredging

Located in South Central Sweden, Lake Trummen had an area of one km^2, a maximum depth before restoration of 1.2 metres, and a theoretical water residence time of four months. Heavy development at this lake in the 1970's resulted in increased pollution by industrial waste water and municipal sewage. Originally an oligotrophic lake, it displayed all the signs of a collapsed ecosystem such as fish-kills, heavy blooms of blue-green algae and repulsive odours. Sewage diversion had been accomplished in 1958, but continuous and intensive internal loading prevented its recovery.and eleven years after the diversion of sewage water quality was no better having a secchi disc transparency of only 10-20 cm. (Björk 1988). A decision was made to re-develop the lake and the land around it to improve its recreational and aesthetic potential. Only suction-dredging is of interest for the removal of soft organic sediments that cause internal nutrient loading (Björk 1988). At Lake Trummen there were 50 cm. of black, loose top sediments on top of the natural layer. The nutrient enriched quality of the pore water in these sediments made it necessary to avoid creating turbulence during suction of the material from the bottom. A custom designed apparatus was built and sediments were pumped out of the lake into settling basins. The high volume of runoff water was treated with aluminum sulfate to precipitate the phosphorous before it was returned to the lake. The suction-dredging period lasted nine summer months during 1970-71 during which time 600,000 cu.m. of water-sediment mixture were pumped out of the lake. The sediment was sold for use in various applications as a fertile soil supplement (Björk 1988).

The removal of sediments resulted in an immediate and permanent decline of nutrient concentrations and phytoplankton [algae] biomass so that winter oxygen deficiencies and massive algae blooms no longer occurred (Björk 1988). From 1976-79 an intense culling program of selected fish species was carried out leaving populations of predatory species, like pike and perch, intact. The fish management program was not maintained and results of this aspect of the restoration were undetermined.

2.6.2 Dilution/Flushing

The exchange rate of water in lakes reflects on their trophic status and has implications on water quality (Kudelska 1989). Poor water quality in a lake is often mistakenly assumed to be the result of a long water residence time, but a study of several hundred lakes in Poland by Kudelska (1989) found that lakes with greater water exchange rates had inferior water quality to lakes with longer water residence times, as long as the latter had not been subject to non-point sources of pollution. Results of Kudelska's study are an indication that an increasing the hydraulic load to a lake does not guarantee improvements in water quality unless the water source is of high quality. Pollution and nutrient loading from tributaries was determined to be the cause of poor water quality in these lakes despite the faster flushing time. Dillon (1975) found a more complicated relationship between the hydraulic load and water quality. Two lakes in northwestern Ontario, one with a phosphorus loading rate twenty times higher than the other, had virtually identical phosphorus concentrations which he attributed to the difference in the flushing rates of each lake. His explanation that greater flushing rates tend to reduce nutrient concentrations even though the P loading rate in the flush water is high, contradicts Kudelska's conclusions. Other factors such as phosphorus retention coefficients, not analyzed by Kudelska, probably explain the different findings of the two studies.

Dilution and flushing are two distinct effects resulting from diverting water into a lake basin. The effect of dilution is primarily to reduce the growth rate of algal biomass and the effect of flushing is to increase its physical loss rate (U.S. EPA 1981). The physical loss of biomass will only occur if the lake has an outlet which will physically transport it out of the watershed.

Dilution of large bodies of water requires large volumes of water; such that, where this has been practiced, rivers have been diverted to supply the water. This is obviously not practical in most situations even where it is technically possible. Another source of water was used at Green Lake, Washington (104 ha, mean depth 3.8m); a lake smaller and shallower than Gull Lake. Long-term dilution at a low rate was attempted using the Seattle domestic water supply (U.S.EPA 1981). Over a 13 year period the average water exchange rate was increased from .88 times per year to 2.4 times per year. A striking improvement in both chlorophyll a, P, and secchi disc visibility resulted.

2.7 Management Priorities

Environmental protection and management is only practical when it re-establishes conditions in a lake that are suitable either to its current level of development or, more ideally, to a realistically determined socially optimal level of development. If the socially optimal level of development has already been exceeded and environmental degradation has occurred, it should logically be the choice of public and private stakeholders and interest groups to decide what type of restoration is appropriate. Restoration schemes devised by experts, regardless of how ecologically sound they are, are not likely to succeed without the support of the people who will be affected.

Initially only the affected public may be aware that a problem exists and in these cases some degree of public involvement is inevitable, but regardless of who initiates an inquiry into an environmental matter, public participation should be the basis for discussions leading to a proposed solution. An active participation not only increases general public awareness of environmental affairs, but can contribute significantly to the elaboration of the design and implementation of environmental policies and protection measures (Åkerman 1990). There is also an opportunity for "experts" to learn from the public. On the local watershed level, participation in planning allows for local knowledge and concerns about the watershed to be articulated (Pinkerton 1991). Some of the key factors that are essential for devising and implementing an effective management plan are outlined by Pinkerton (1991). They include consensus building among interested parties to identify problems and find solutions; a focus on the solutions rather than on who is causing the problem; careful selection of a committee or joint management board that represents all interest groups; access to appropriate technical and educational resources; promotion of community involvement and volunteer programs; the development of a specific set of strategies to address the problems and recommendations that lead to an action plan.

2.7.1 Recent Approaches to Lake Management

The need for integrated environmental management has become increasingly apparent in western Canada and provinces are taking steps to mitigate past damage and prevent further degradation of their natural resources. The Alberta Lake Management Society (ALMS) was officially founded in 1991 in response to a need and a desire to preserve lakes and reservoirs. It was formed by a collection of interest groups and individuals concerned with the management and restoration of lakes. Workshops were held to bring together cottage owner associations, public and private sector groups involved with water resources, municipalities, resort owners, and concerned citizens. The ALMS also became the first Canadian chapter of the North American Lake Management society (NALMS), a vast resource network providing technical support to its members in the form of magazines, journals, video and slide presentations, conferences, workshops, funding and other resources. The ALMS provides a link between individual cottage owners and their associations, who may have little or no experience in lake management issues, and large public and private sector agencies specializing in environmental management.

Another example of how a joint committee can organize and administer a comprehensive management plan at Gull Lake, can be seen on a much larger scale in the Dauphin Lake basin in western Manitoba. The Dauphin Lake Advisory Board formed in November, 1989 at the request of the Minister of Natural Resources for the purpose of halting the rapid deterioration of the lake and its extensive watershed. Representatives for an advisory board were sought from fifty nine agencies, interest groups, and local levels of government so that basin residents could play a decision making role in the program (DLAB 1992).

There is a need to ensure that subsequent developments for Gull Lake conform to a sustainable use of the resource. Choosing a course of action which most effectively mitigates past damage is more difficult and expensive than preventing its occurrence in the first place, but the management infrastructure required to do either is much the same. Mobilizing public support and involvement at Gull Lake is a manageable prospect since the lake is small and the number of individuals is limited. For reasons noted above, public involvement in the planning and execution phases of a long-term management plan to restore and protect the lake, are essential to its success.

3.0 Methods

3.1 Questionnaire

The aim of the questionnaire was to find out more about the attitudes, perceptions and awareness of residents at Gull Lake about management issues. It was divided into 3 parts:

Part A dealt with the attributes of respondents and their property. Questions related to the age and type of cottage, ownership status, patterns of use, intensity of use and other factors related to the consumption and use of water.

Part B dealt with the behavior patterns of respondents, with the objective of finding out what kinds of recreational activities they are involved in while at the lake.

Part C dealt with water quality, water level and lake management issues and how these are perceived by respondents.

In Part A respondents were asked to check the most appropriate answer from a list of choices. Question format in the latter two parts was different. Respondents were asked to rank alternatives or express their level of agreement with specific statements using a five point Likert Scale. A blank questionnaire appears in appendix A.

Sample Size

The entire population of cottages was sampled. Questionnaires were hand delivered, one to each cottage, which could be filled out by any member of the household. Cottages or trailers that had obviously been vacant for some time, did not receive questionnaires. These amounted to approximately 5 percent of the total number of habitations. The period of distribution was concentrated over three weekends in August. Approximately 265 questionnaires were handed out. Postage paid envelopes were included so respondents could complete and return the questionnaires at their convenience.

The identity of respondents was not solicited in the questionnaire to guarantee anonymity to the respondents, and because no follow up interviews were planned. People were asked to state their general location relative to the lake so that results could be stratified by location. The main intent was to see if there were differences in between on-lake and off-lake respondents. The sample of trailer owners was not expected to be large enough to draw any statistical inferences between that group and property owners.

3.2 Water Balance

This section outlines the techniques used to calculate a water balance for Gull Lake. All flows of water entering and exiting the lake basin for the period 1972-91 were considered. The intent was to determine if their had been any trends or changes in the hydrologic regime of the lake that would account for declining water levels and enable more informed assessment of initiatives for the enhancement of the lake.

3.2.1 The Water Balance Equation

The water balance of any hydrological system for a given time period is expressed by the following equation:

Equation 3.0 INFLOW = OUTFLOW + CHANGE IN STORAGE

This is the simplest form of the water balance equation. Each term must be separated into its sub-components for its application to specific case studies. Equation 3.0 thus becomes:

Equation 3.1 $$I_{surf} + I_{sub} + P = O_{surf} + O_{sub} + E_0 + (V_2 - V_1)$$

where:

$I_{surf} + I_{sub}$ = volume of inflows from surface and subsurface streams and ground water

P = volume of precipitation onto watershed area

O_{surf}, O_{sub} = volume of surface and subsurface outflows to streams and groundwater

E_0 = volume of water evaporated from watershed area

V_1, V_2 = volume of lake at beginning and end of measurement period so that: $(V_2 - V_1)$ = change in storage

Few lakes provide conditions that minimize errors in estimating the parameters in the equation above (Dunne and Leopold 1978). Some lakes with small drainage basins and no inflow or outlet may have a very simple water balance (Chow 1964). For Gull Lake the two terms I_{surf} and O_{surf} were eliminated from the equation since surface inflow is negligible and there has been no surface outflow from the lake since June 1979. Determining the inflow from groundwater is complex and there were no provisions for doing so in this study so the term I_{sub} was deleted from the equation on the basis of two assumptions: A) that I_{sub} is roughly constant on an annual basis and therefore produces no net change in lake volume, and B) the magnitude of I_{sub} is minimal in comparison to precipitation volume. Assumption A is commonly adopted for water balance studies where I_{sub} cannot actually be measured, whereas assumption B is a potential source of error because there is no actual data to suggest how dependent the lake is on groundwater flows. The majority of water reaches the lake by shallow subsurface runoff due to rainfall and snow melt. and the lake is assumed to be dependent primarily on local groundwater recharge, which in turn is dependent on precipitation. Equation 3.2 is the water balance equation amended for Gull Lake.

Equation 3.2 $$P = O_{sub} + E_0 + (V_2 - V_1)$$

3.2.2 Gull Lake Water Balance

Precipitation (P) and evaporation (E_0) are often the largest components in the water balance of prairie lakes, especially when there is no surface drainage. Data for these components have not been recorded in the vicinity of Gull Lake but estimates were obtained using data recorded at the nearest weather stations. Each component was converted from linear amounts to volumetric equivalents in cubic metres. The method of conversion is explained in the sections below.

Lake level (V_2-V_1)

Both monthly and annual periods were considered. V_2 represents the lake level at the end of some period of interest and V_1 is the level at the beginning of the same period, thus (V_2-V_1) is the change observed in lake level for any given period. Lake level data were converted from metres above sea level to volumetric equivalents based on the bathymetric survey of the lake bottom used by Beck (1986). The area of the lake is first determined with a planimeter (a device that calculates the area of irregular shapes by tracing their circumference). The total volume of the lake is then calculated by summing the volumes of each successive one metre depth contour. Gull Lake is approximately five metres deep so the total water volume is the sum of the volume of each of the five stratum. The volume of each stratum is found using the following formula:

$$\text{Volume} = \frac{H}{3}\left(A1 + A2 + \sqrt{A1\ A2}\right)$$

where H is the vertical depth or thickness of the stratum in metres; A1 is the area of the upper surface of the stratum in square metres, and A2 = the area of the lower surface of the stratum whose volume is to be determined. Volumes of precipitation were added and evaporation subtracted from a base lake volume used by Beck (1986) to arrive at the *expected* monthly and annual lake volumes found in appendix E and table 4.2.

Precipitation (P)

The mean monthly and annual amounts of precipitation were calculated from records of the seven weather stations nearest to the lake. Precipitation recorded on-site is always preferable and more accurate than applying data recorded at other sites nearby. As explained in section 2.3.4; precipitation is extremely variable over time and space. The potential for error in applying precipitation data to ungauged sites i.e., Gull Lake, is acknowledged, especially for short periods of time, but over monthly and annual time periods this error is minimized and data becomes more representative of precipitation at ungauged sites in reasonable proximity to the area of measurement. Precipitation data used in the water balance is displayed in tables D-3 and D-4 in appendix D. Snowfall measurements in winter months are expressed as water equivalents. Several stations (Beausejour, Brokenhead, and Selkirk) have incomplete records but where available, the data was used for calculating monthly and annual means. The annual mean of all seven stations in table D-2 is the sum of the values in that column and is *not* an average of all the annual totals for each station. The table is arranged from July 1 through June 30 of each year to correspond to the water balance period.

Volumetric equivalents of precipitation in cubic metres were calculated for each month of the the 19 year period using Equation 3.3 below.

Equation 3.3 $$(P)Volume = (P)Depth \times Area$$

where (P)Volume is the volume of precipitation in cubic metres; (P)Depth is the precipitation depth in metres; and Area is the area of the watershed in square metres, including lake (calculated to be 3,932,000 square metres or 3.932 square kilometres)

<u>Surface and Subsurface Inflows</u> (Isub and I surf)

Surface and subsurface runoff are normally treated separately in a water balance calculation but for this study they were estimated together because the surface runoff component is relatively small. Surface runoff only occurs during heavy or sustained rainfall events. (see section 2.3.5 for an explanation of factors affecting inflows from runoff).

The Sandilands-Woodridge group of soils dominate the area. These are dry sand or gravelly soils with low water holding capacity and are classified as dominantly rapidly drained. The southern portion of the watershed is characterized by the Carrick-St. Labre group of soils which are dominantly well to imperfectly drained with highly variable texture of surface deposits (Smith and Ehrlich 1967). Davidson (1973) includes a thorough discussion of drainage and surface deposits around Gull Lake.

Measurement of the area contributing to runoff (the watershed area) was done using planimetry. Surface stratigraphy was examined with an auger in the forested areas on the east side of highway 12 to confirm the supposed permeability of the surface deposits. The volume of combined surface and subsurface runoff was estimated to be 30 percent of the incoming precipitation. In other words 70 percent was assumed to be consumed by evapotranspiration. Calculation of this runoff coefficient is detailed below.

Calculation of the Runoff Coefficient

Using techniques described by Gray (1970), a runoff coefficient (C) of .3 was estimated for the Gull Lake basin. The coefficient C represents a volumetric coefficient or ratio of the total volume of runoff to rainfall (Gray 1970). The magnitude of this coefficient varies with factors such as (a) nature of the land surface, (b) its slope, (c) surface storage, (d) degree of saturation prior to rainfall, and (e) rainfall intensity Gray (1970). Table 3.1 shows the average consumptive factors associated with different types of terrain. The runoff coefficient (C) is obtained by selecting one value from each group (topography, soil, and cover) that best approximates the watershed being studied then their sum is subtracted from unity. The topography of the watershed at Gull Lake is predominantly hilly, soils are sandy and cover is woodland. The values of C for the Gull Lake watershed thus becomes:

$$C = 1-(.10 + .40 + .20) = .30$$

Table 3.1

Deductions from Unity to Obtain the Runoff Coefficient for Agricultural Areas

Type of Area	
TOPOGRAPHY	
Flat land with average slope of 1 -3 ft per mile	.30
Rolling land with average slope 15 - 20 ft. per mile	.20
Hilly land with average slope of 150 - 250 ft. per mile	.10
SOIL	
Tight impervious clay	.10
Medium combinations of clay and loam	.20
Open sandy loam	.40
COVER	
Cultivated lands	.10
Woodland	.20

Source: Gray 1970, Table VIII.2 (After Bernard, 1935)

Subsurface Outflows (O_{sub})

The predominance of till, which is a semi permeable material, underneath the lake is a factor that will influence subsurface outflow (seepage) and inflow in the lake basin. Seepage through lake beds is transient and speculation that seepage is greater at the north end of the lake are supported by the literature discussed in section 2.0, results of the water balance (outlined in section 4.2), and by a stratigraphy assessment (section 3.2.4).

Surface outflows (O_{surf})

This component was not significant in the Gull Lake water balance because there has been no surface outflow from the lake since June, 1979. The volume of outflow prior to the weir construction is unknown and no gauge was installed subsequently, so the annual volume of surface outflow between July 1972 and June 1979 could only be estimated roughly by comparing the annual outflows in column 9 (after evaporative losses are deducted) with the annual inflow from precipitation (column 4).

Evaporation (E_0)

Evaporation is a relatively significant portion of the hydrologic cycle of prairie lakes and is roughly equal to summer rainfall. Soil moisture deficits on the prairies are common in agricultural areas so it is logical to expect corresponding deficits for lakes in those regions. The effect of rising topography around the lake, close proximity to Lake Winnipeg, and extensive forest cover could theoretically produce a wetter microclimate around Gull Lake than the lowlying agricultural areas east and south of the basin, though this effect has not been documented. This would help to overcome moisture deficits caused by excessive evaporation. Pan data derived from areas with similar attributes to Gull Lake such as proximity to water bodies and forest cover was used. Two components of evaporation were estimated. Lake evaporation (EL) and evapo-transpiration (ET).

Lake Evaporation

Meteorological conditions have never been monitored at the lake so the only practical approach to estimating evaporation at Gull Lake was to assume that it is similar to the calculated pan evaporation at Bissett, Gimli and Indian Bay. Pan data calculated at Bissett from 1972-84 was used and data from Gimli for 1985-91 completed the record. Readings from Indian Bay were used where data was missing in the records of the other two stations. The data are published in the Monthly Record for Western Canada. (See appendix D, Summary of Pan Data).

Evapo-transpiration

The difference between rainfall and runoff is largely explained by evapo-transpiration (Dunne and Leopold 1978). Rainfall and runoff were estimated using separate procedures mentioned above, so evapo-transpiration was assigned the residual amount since field measurements are complex, uncertain, and were not practical for this study. In general it was assumed that, if precipitation is known and that if runoff is 30 percent of precipitation (from table 3.1), then evapo-transpiration must be 70 percent. This component is negligible in the winter months and does not intensify until after spring runoff continuing until the growing season has ended. May through September precipitation volumes in column 4 of the table in appendix E were multiplied by .7 to arrive at a figure for evapo-transpiration (column 5, appendix E). The volume of precipitation falling directly on the lake was not included in this calculation .

3.2.3 Calculation of the Water Balance

Data for each of the components in the water balance were assembled in tabular form using Microsoft Excel. Lake volumes (converted from levels) for the beginning and end of each monthly and annual period were used to calculate the change in lake volume for that period (V2 -V1). Precipitation was added and lake evaporation and evapo-transpiration were subtracted from the initial volumes of the monthly and annual periods, to determine *expected* month end and year end volumes of the lake. The difference between the *expected* and *actual* volumes was attributed to the following, in order of decreasing magnitude: subsurface outflow, surface outflow (up till June 1979), residual error of estimation, and domestic water consumption. Actual lake volumes were derived from actual lake elevations. Figure 3.1 shows the lake level recording gauge which is used to measure actual lake elevation. The results of all monthly calculations are assembled in appendix E and table 4.2 is an annual summary.

Explanation of Tables in Appendix E

Column 1 simply indicates the month for which each row of data applies.

Column 2 displays the year and the calculated lake volume where data were available. The summer months (June 1 till September 1). Spring and fall season readings are incomplete.

Column 3 lists the depth of precipitation in metres. Winter precipitation is converted to water equivalents by the Atmospheric Environment Service (AES) by multiplying snow depth by one tenth.

Column 4 lists the estimated volume of precipitation that fell each month, calculated from the mean of seven weather stations around the lake. A table showing the geographic position of these weather stations is provided in appendix D.

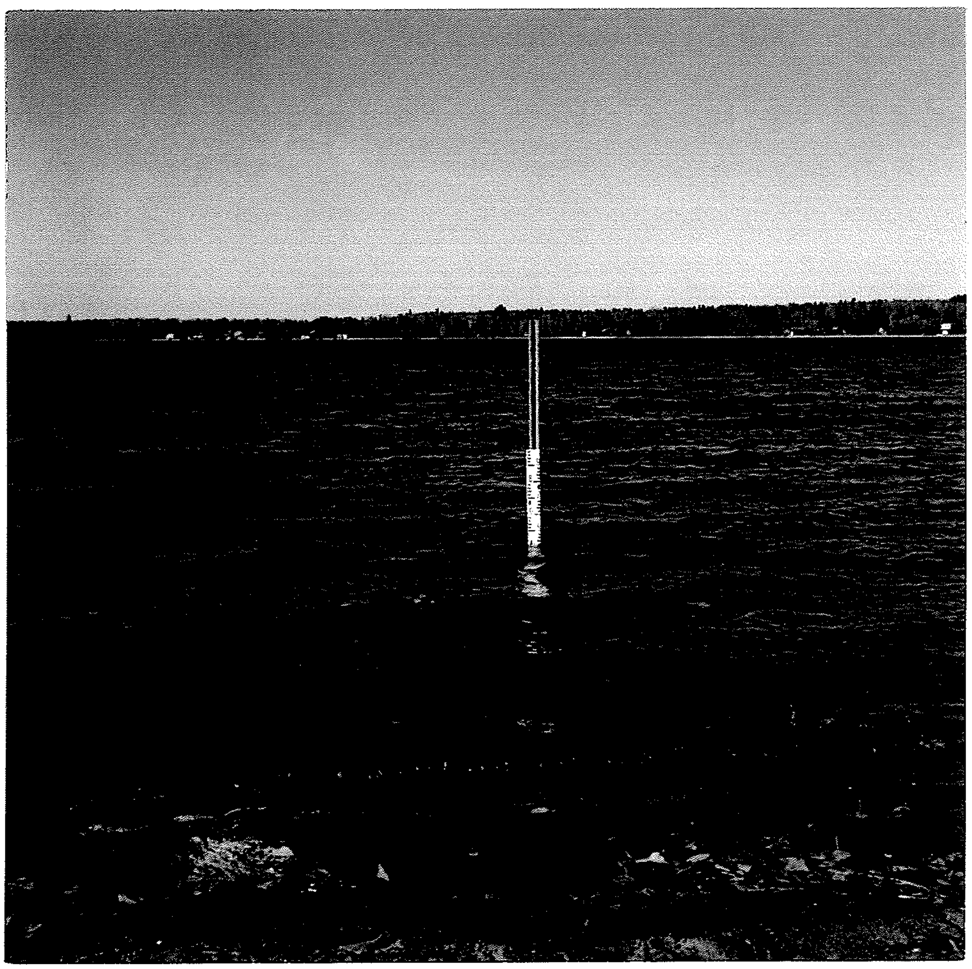

Figure 3.1 Lake level recording gauge positioned on southwest side of lake since spring 1991, view faces east/northeast. Former location was near public access area on north shore. Photograph taken Oct. 1991

Column 5 displays calculated lake evaporation values extracted from the Monthly Record and converted to cubic metres of water using the same formula as for precipitation.

Column 6 contains the calculated *potential* evapo-transpiration from the watershed around the lake, in cubic metres for the months in which it is applicable.

Column 7 shows the lake volume expected at the end of each month and is calculated by adding the net increase or decrease of water in the basin (calculated from the other columns) to the volume at the beginning of the month:

Expected volume = (Column 2) + (Column 4) - (Column 5) - (Column 6)

Column 8 shows the actual lake volume and,

Column 9 is the difference between the expected and actual lake volumes and represents net apparent outflow from the lake. The uniformly negative values in column 9 are a measure of water loss from the lake, other than evaporation and evapo-transpiration, which are already deducted. The magnitude of the loss in column 9 is subject to errors of estimating evaporation, precipitation, evapo-transpiration and runoff. These relationships are discussed further in sections 4.0 and 5.0.

3.2.4 Additional Data Sources

Studies involving a water balance often involve several field seasons which enables researchers to make actual measurements of many of the components in the water balance equation. Due to the time constraints of one field season and limited resources, the collection of new data was not feasible for this study. Constructing a water balance for this study involved compiling data from various sources (AES, WRB, Monthly Record, Fisheries Branch and Questionnaire results).

Three other avenues of investigation were followed to qualify the results obtained: 1) A review of related literature pertaining to small basin watersheds 2) a documentation of deep basin stratigraphy and surface stratigraphy of the marsh and forest area at the north end of the lake, and 3) an estimation of the domestic consumption of water by lake users. The review of the literature appears in section 2.0, the assessment of deep and shallow stratigraphy and domestic water consumption are explained below.

Deep Basin Stratigraphy

Documentation of stratigraphy was done to provide additional information for evaluating the residual values in column 9 of table 4.2 and column 10 of appendix E.

Two factors which have an effect on how much water can be retained by the lake are the lake basin seal and the permeability of the till beneath the lake basin. Lake beds are typically covered by fine sediments and clays which have settled to the bottom to form an impermeable layer but they are confined to the deeper parts of the lake. Near shore areas are more permeable and can permit an exchange between the lake and groundwater. The profile of the lake in figure 3.2 is a general representation of the basin stratigraphy and should not be interpreted literally. Sand and gravel aquifers that surround the lake are depicted, extending from the edges of the lake and down the slopes away from the basin as well as into deeper strata beneath the lake. The scale of the diagram is insufficient to show lake sediments, but the major stratigraphic layers extending to bedrock are identified.

Details about the general profile of the basin shown in figure 3.2, were documented using the drillers' reports from deep wells drilled in the area. Wells were selected to form a continuous line along the south shore which would represent a broken profile of that part of the basin. A similar profile for the north shore was not possible because fewer deep wells have been installed there. Stratigraphy in other parts of the basin was assumed to be similar in overall composition although the stratigraphy of glacial drift is variable enough to

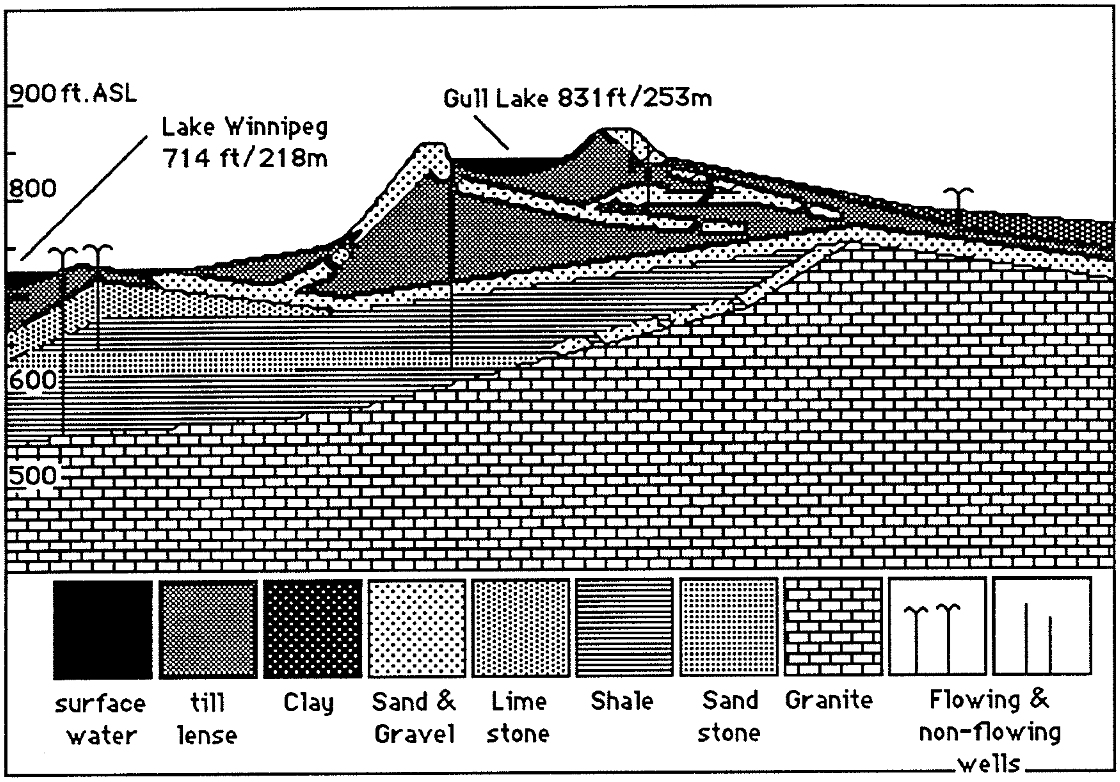

Figure 3.2 Cross section of Gull Lake basin showing stratigraphic layers. Source: Charron, J.E. (1975) Hydrological Study of the Selkirk Area, Manitoba)

create localized drainage characteristics not found in adjacent areas. In the absence of comprehensive quantitative and qualitative data relating to the strata under the lake, only general conclusions about drainage characteristics of the lake were possible.

Surface Stratigraphy Assessment

In response to concerns that water could be escaping from the lake through low areas or holes in the impermeable layers beneath the lake, a series of test holes were augered in the area adjacent to the weir. The objective was to determine if deposits of sand or gravel were conducting subsurface water out of the lake. A total of nine holes were drilled to an average depth of 1.5 metres.

Domestic Water Consumption

Population density at Gull Lake was estimated with information from the questionnaire. Per capita water consumption was estimated by adapting per capita consumption rates for the City of Winnipeg based on user patterns at Gull Lake. Water consumption by sprinklers was also was estimated. The two uses of water were combined into an annual total domestic consumption figure which could be deducted from net outflow in the water balance, if significant enough to influence the results.

Per capita indoor residential water consumption in Winnipeg is estimated to be 270 litres per day or 60 imperial gallons (Sacher, personal communication 1991). U.S. indoor residential use of water averages eighty gallons (67 imperial gallons) per person per day (Woodwell 1989). This consumption is equivalent to 304 litres. Since these two estimates are roughly the same, the Winnipeg estimate was considered a reliable basis for estimating the rate of water consumption at Gull Lake.

The following assumptions were made:

1) There are approximately 285 cottages in general use at the lake,

2) Per capita water consumption at Gull Lake is 40 percent of the rate assessed for Winnipeg due to such factors as water efficient toilets, fewer bathtubs per capita and fewer dishwashers and washing machines.

3) There are and estimated 800 people at the lake on each summer weekend. (this figure was arrived at by using the results of Question 4 of the Questionnaire)

4) Pumps and sprinklers operate at a rate of two gallons per minute.

Data compiled from the results of part 1 of the questionnaire were used to estimate water consumption patterns. Personal water consumption was estimated separately from consumption of water by sprinklers for watering lawns and gardens. Consumption during the week was not included in the calculation because the majority of people tend to use the lake on weekends. If water consumption at cottages is 40 percent of urban use then use at Gull Lake would be approximately 108 litres per day per person. The number of person days spent at Gull Lake was estimated and multiplied by 108 litres per day, to arrive at the yearly domestic consumption. The number of cottages using sprinklers was estimated and the sprinklers were assumed to operate six hours per day, two days per week and sixteen weeks per year. Results of both calculations are presented in section 4.2.5.

3.2.5 Summary

The water balance procedure was used to define the hydrologic regime of Gull Lake. The relevant components of the water balance equation were identified and estimated. The area of the watershed and lake surface were calculated with planimetry and volumetric equivalents of all components in the water balance equation were determined. Precipitation was estimated by averaging the data from up to seven weather recording stations closest to the lake. Calculated lake evaporation from the Monthly Record was applied to the area. A runoff coefficient was estimated and applied to precipitation volumes to determine potential evapo-transpiration, and the remainder was assumed to be runoff to the lake. Subsurface and surface inflows were treated as a single component and assumed to be fed entirely by precipitation. Results of the water balance were discussed in the light of the literature review; assessments of basin stratigraphy and surface stratigraphy; and domestic water consumption.

4.0 Results

4.1 Questionnaire Results

Approximately 260 questionnaires were distributed and 179 completed questionnaires were returned, for a response rate of 68.8 percent. A total of 160 were distributed to on-lake residents, ninety to off-lake residents and ten to trailers and campers.

4.1.1 Part A - Types of Cottages and User Patterns

Each question from the original questionnaire is identified below with its associated "Item" numbers. The Item numbers and the frequencies for each are listed in appendix C.

Question 1 (Item 1,2)

Question 1 was split into two sections to facilitate analysis. The first section indicated whether the respondent owned property, rented, had a trailer, or lived year-round at Gull Lake. The second section indicated their location relative to the lake i.e., whether they were on the north shore, south shore, or located off-lake.

Section I Results:

86.0%	Property owner/Member of family that owns property	
2.2%	Renting a cottage	
2.8%	Have a trailer	
8.4%	Year round resident	
0.0%	Other	n=179

All respondents described their status at the lake, of which 94.4 percent of the respondents were property owners (86 percent seasonal and 8.4 percent year-round). Nearly all respondents were the actual property owners. Only a handful of respondents were junior family members and were included in the property owners group.

Section 2 Results are shown in table 4.1 below.

Table 4.1

Location of Respondents

Area delivered to:	number delivered	No.of responses	response rate by area	% of actual responses
North shore, (on-lake)	58	52	89.7%	34.2%
South shore, (on-lake)	102	80	78.4%	52.6%
Off-lake	72	20	27.8%	13.2%
unspecified location	28	-	-	
Totals	260	152		100 0%

The highest response rate on an area basis was 89.7 percent for north shore residents along Sherwood Street and Luining's lane with fifty two out of fifty six questionnaires distributed to that area, being returned. The second highest response rate was 78.4 percent for south shore residents along Arnhold and John Street where eighty out of 102 questionnaires distributed, were returned. Twenty of seventy two questionnaires distributed to off-lake locations were returned for a response rate from that group of 27.8 percent. Approximately twenty eight questionnaires were distributed to unrecorded locations around the lake, so it was not possible to determine percentage response rates of these by area. Of the 179 questionnaires returned, twenty seven respondents did not specify their location.

Question 2 (Item 3)

Property owners were asked how many years they have owned a cottage or have been coming to Gull Lake. Some people merely stated the total number of years as property owners while most chose to include time spent at the lake before purchasing their own property. The categories were divided into ten year increments for analysis.

10.5% 1-10 years
18.0% 11-20 years

21.5%	21-30 years	
40.1%	31-50 years	
9.9%	More than 50 years	n=172

It is apparent from the data that most respondents who own property at Gull Lake are long-time residents. Over 70 percent of respondents have spent more than twenty years at the lake, while 50 percent have spent more than fifty years there.

Question 3 (Item 4)

Determining the average age of cottages at Gull Lake was intended to give some information about how modern facilities are for the average cottage at Gull Lake. People were asked to indicate the specific year their cottage was built and the analysis divided the responses into decades shown below.

13.4%	Built in the 1980's	
17.1%	Built in the 1970's	
15.9%	Built in the 1960's	
24.4%	Built in the 1950's	
29.3%	Built in the 1940's or earlier	n=164

Question 4 (Item 5)

The intensity of cottage use on weekends was of interest for estimating the size of population and its potential impacts on the lake. Weekend use was focused on, since it is heaviest time of use. Responses were grouped into ranges for presentation of the results.

61.0%	Up to 4 people	
29.7%	4-6 people	
8.7%	7-8 people	
0.6%	Did not state	n=172

Question 5 (Item 6)

Another measure of intensity of use was sought by asking how many months of the year respondents keep their cottages open. More than 64 percent use their cottage during summer months only and 15 percent extend their use into the spring and fall months. Year-round use is 20.2 percent including full-time residents as well as weekend users.

7.5%	Up to 3 months	
57.2%	4-6 months	
15.0%	7-8 months	
20.2%	12 months	n=173

<u>Question</u> 6 (Item 7)

This was an enquiry about cottage fixtures that are related to the consumption of water. Respondents were asked to check any of four items that they used in their cottage, including: automatic dishwashers, washing machines, bathtubs, showers and "Other". The categories were grouped together for analysis as shown below.

21.8%	Dishwasher and/or washing machine	
19.6%	Bathtub	
58.6%	Other or no answer given	n=74

<u>Questions 7 and 8</u> (Items 8 and 9)

These focussed on the user patterns for drinking water and general purpose water. Of the 161 people who answered this question, 42.2 percent use shallow wells for general purposes, 44.1 percent use lake water and 13.7 percent have deep wells for general use. The results for question 7, general water source were:

42.2%	Shallow well	
13.7%	Deep well	
44.1%	Lake water	n=161

There was an obvious preference for bottled water instead lake or well water. Most people (66.9 percent) bring drinking water either from their permanent residence or from the spring at Beaconia, north of Gull Lake. Nearly 3 percent use filtration to make their general water source drinkable and 30.6 percent the respondents use the same water source for general purposes and drinking, without treatment. The latter group are likely people with deep wells or shallow wells with better than average quality water. Results for question 8:

30.6%	Same as above	
2.9%	Same as above with filtration	
66.9%	Bring water from somewhere else	n=170

Question 9 (Item 10)

Waste water disposal, in terms of grey water rather than sewage, was the focus of question 9. Most respondents answered this question, with 44.6 percent indicating they drain all grey water into a field. This would include kitchen and bathroom waste water other than toilet sources. A significant percentage (37.5 percent) indicated they contain all grey water.

Results of Question 9:

17.9%	Some but not all of the grey water goes into a field	
44.6%	All of the grey water goes into a field	
37.5%	All of the grey water goes into holding tank	n=168

4.1.2 Part B - General Habits of Lake Users:

Information was gathered concerning the activities and habits of lake users which would have potentially adverse direct or indirect impacts on the lake.

Question 10 - Chemical use and Lawn Watering (Items 11-14)

The use of chemicals in the maintenance of private property was surveyed by asking respondents if they used any of three chemicals; fertilizers, herbicides, and pesticides. The extent of lawn or garden watering was also analyzed. Pesticides were used least often of the three with 8.9 percent of 169 respondents indicating they "occasionally" used them. The word "occasionally" was not defined either in the question or by respondents. Herbicides and fertilizers were used by 10.1 percent and 13.6 percent of respondents respectively. 54.4 percent of respondents used sprinklers to water their lawn or garden.

Question 11 - Recreational Activities: (Items 15-19)

Six specific activities were listed on the questionnaire for people to rank, in order from highest to lowest frequency, the ones they take part in. Many respondents merely checked off the activities they do without ranking them in order of preference, so the data does not accurately express the relative frequency of each activity. Related activities were grouped in the tabulation of results to suit the computer software analysis format . Swimming was the most popular activity with 89.2 percent of the respondents indicating they swam in the lake. 63.6 percent of the respondents said they engage in non-water related leisure activities, listing such things as bird watching, walking or hiking, craft making and various individual and team oriented sports. 58.5 percent pursue non-motorized water sports activities such as canoeing, sailing, sailboarding and paddleboating; while 44.3 percent took part in water skiing and/or powerboating. 23.3 percent of the respondents listed "Other" activities. The percentages shown are not mutually exclusive and in many cases some people participated in all the activities listed.

Question 12 - Regulation of Controversial Activities: (Items 20-26)

Respondents were asked how strongly they felt regulation was needed for certain activities or customs that are often identified as detrimental to lake ecosystems. 76.6 percent strongly agreed that shampooing in the lake should be regulated, with many adding extra emphasis that complete prohibition is more appropriate. 76.5 percent identified "Other" activities they are concerned about and 63.4 percent of those mentioned motor boats as their primary concern in question 12(g). At the other extreme was watering of trees, plants and lawns for which only 17.8 percent of the respondents expressed strong agreement for regulation. Watering was the most evenly distributed between the five degrees of concern among the seven possible categories provided. Fertilizers, herbicides and pesticides (Items 23, 24, 25) all elicited strong agreement for regulation in over 50 percent of the respondents. Fifty one respondents mentioned other activities for 12(g). These are displayed in the chart below.

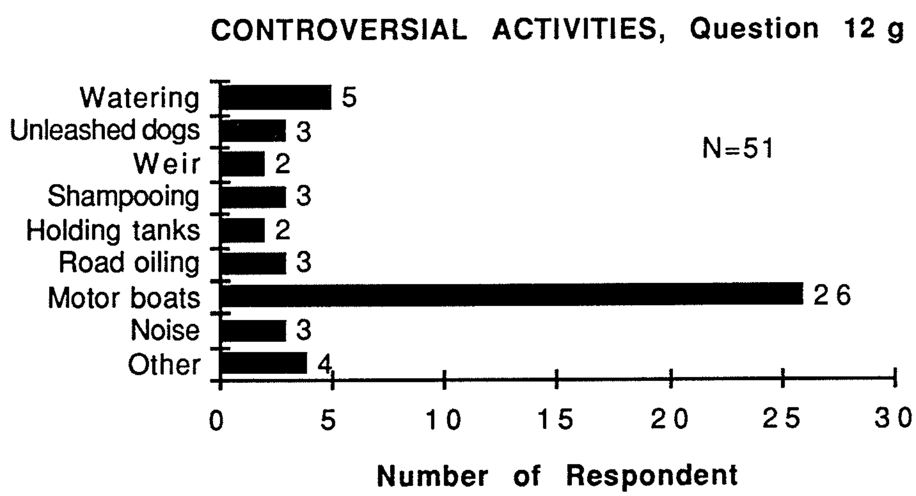

Figure 4.1 Controversial activities noted by questionnaire respondents in question 12(g).

Motor boats was the a concern for 51 percent of the fifty one respondents to question 12(g), followed by watering of lawns and gardens mentioned by five people. The "Other" category included concerns such as day users and lake shore development.

4.1.3 Part C - Water Quality, Management Options, Information Sources

Question 13: Well Water Quality (Item 27)

Respondents were divided as to how they rate their well water quality but the highest percentage of people rated their well water as "very good". This figure includes people who had a deep well installed on their property because of poor quality or yield with their shallow well. In contrast 22.1 percent rated their well water as "poor".

Question 14 and 15: Changes in Lake Water Quality and Lake Level (Items 28 and 29)

Worsening water quality is perhaps the most unequivocal issue at Gull Lake according to the results of the questionnaire. The focus of many respondents' written comments was water quality. 91.5 percent of respondents felt that lake water quality was somewhat worse or much worse over the last several years, while only 7 percent felt that it had not changed and 1.2 percent felt it had improved somewhat. A similar consensus was apparent from the results of question 15. 77.6 percent of respondents thought the lake had gone down significantly and a further 13.2 percent thought the level had gone down somewhat. Approximately 6 percent felt the lake had gone up but several of these respondents made that comment in reference to a dramatic 25 cm rise in water levels witnessed at the end of June and beginning of July.

Question 16: Selected Issues Relating to Water Quality: (Items 30-36)

At least 65 percent of the respondents expressed strong agreement that six of seven water quality issues listed in question 16 are a problem at Gull Lake. 50.3 percent "strongly agreed" that Swimmers' itch was a problem for but more respondents were neutral on this issue than for the other items listed. Again, as with question 12, respondents were most often in strong agreement that the "Other" or open category which they specified, was a problem. The results of 16(g) are listed in the chart below. Thirty three respondents listed more than a dozen other issues that they felt were a problem at Gull Lake. The main categories and the frequencies with which they were mentioned are displayed in the chart below. Motorboats was mentioned thirteen times, more than any of the other issues. There were six issues related to water quality mentioned which included sewage disposal, aeration, leeches and water odour. Single mentions of miscellaneous issues are shown in the "Other" category, including property values, education and awareness, unleashed dogs, the bulletin board, funding of provincial parks and bank erosion.

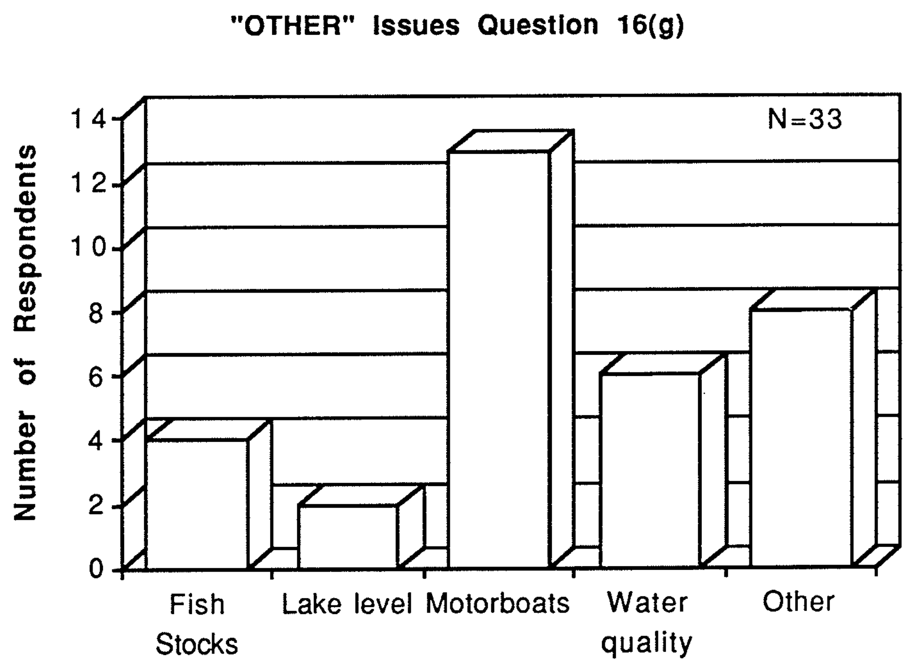

Figure 4.2 Frequency of selected "Other" Issues noted by questionnaire respondents in question 16(g)

<u>Question</u> 17: Management Options for Gull Lake (Items 37-42)

There was considerable variance among respondents on the subject of water conservation. 41.6 percent "strongly agreed" and 27.3 percent said they "agree" with water conservation as a management option for the lake. The opinions expressed about the other options suggested were more extreme, particularly the suggestion that everything is normal and there is no problem. 80.1 percent strongly disagreed with that statement. 84.3 percent either strongly disagreed or disagreed with the suggestion that nature would solve any problems with the lake. There was also a lot of qualified support for an enhancement project with 66.3 percent strongly agreeing and 23.7 in agreement.

Question 18 Enhancement of the Lake:

This was a qualitative question that had to be analyzed manually so there are no item numbers in appendix C for question 18. Respondents were asked to write their reasons for favouring or opposing an enhancement project. The majority of people did this, some submitting entire typed or hand written pages to explain their position. Figure 4.3 displays the frequency of issues cited by respondents relating to the enhancement project mentioned in question 18.

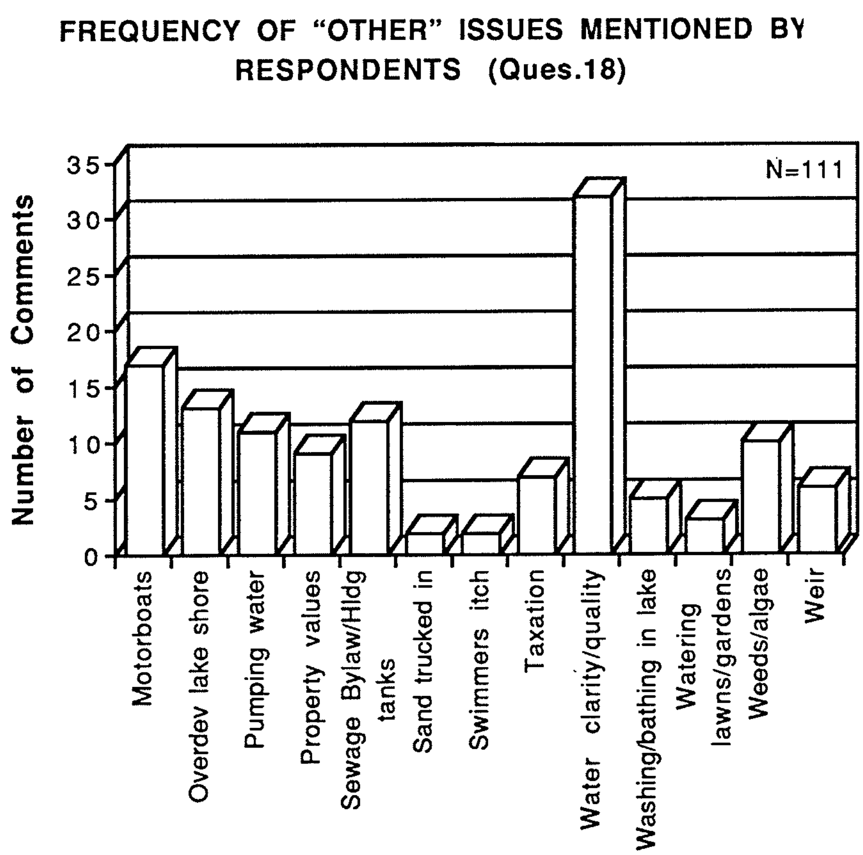

Figure 4.3 Issues mentioned by questionnaire respondents in question 18.

There were 111 people who chose to express their views in question 18. There is no "Item" for question 18 in appendix C because it required a qualitative answer which could not be analyzed by the computer. Selected comments by respondents to question 18 were, however, transcribed and are included in appendix B.

Question 19: Information Sources about Gull Lake (Items 43-46)

The predominant sources of information were annual meetings, mentioned by 66.1 percent and word-of-mouth by 66.3 percent of the respondents, most citing both sources. Government publications were only mentioned by 15.5 percent and newspapers by 11.4 percent of respondents. The trophic study, bulletin board, Ratepayer newsletters and personal observation were drawn out of the "Other" category and the frequencies for these are included in figure 4.4 below.

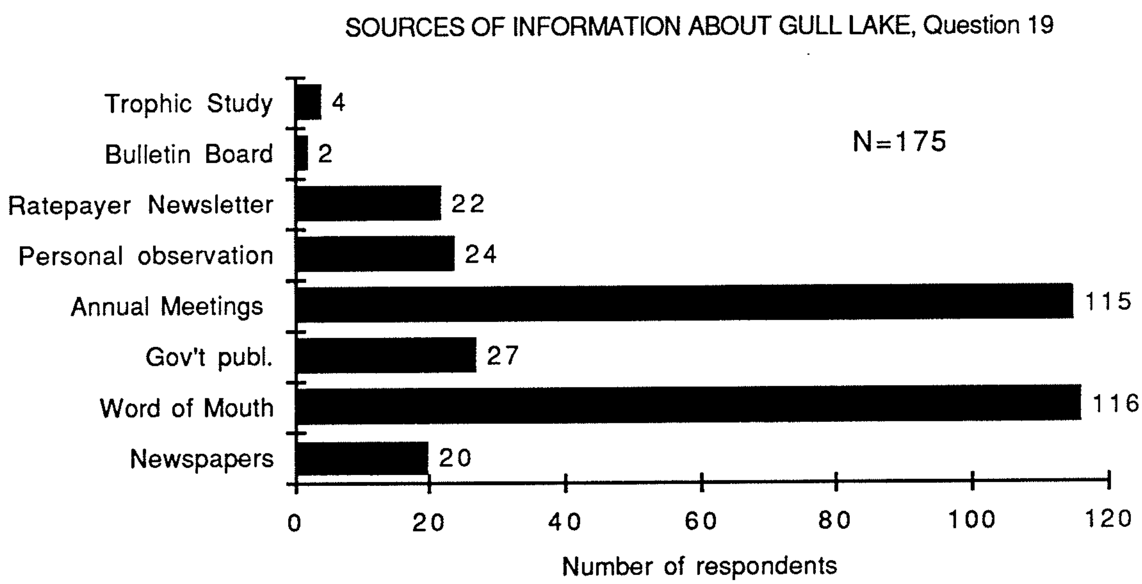

Figure 4.4 Sources of information about Gull Lake used by respondents

Question 20: Age of Respondents (Item 47)

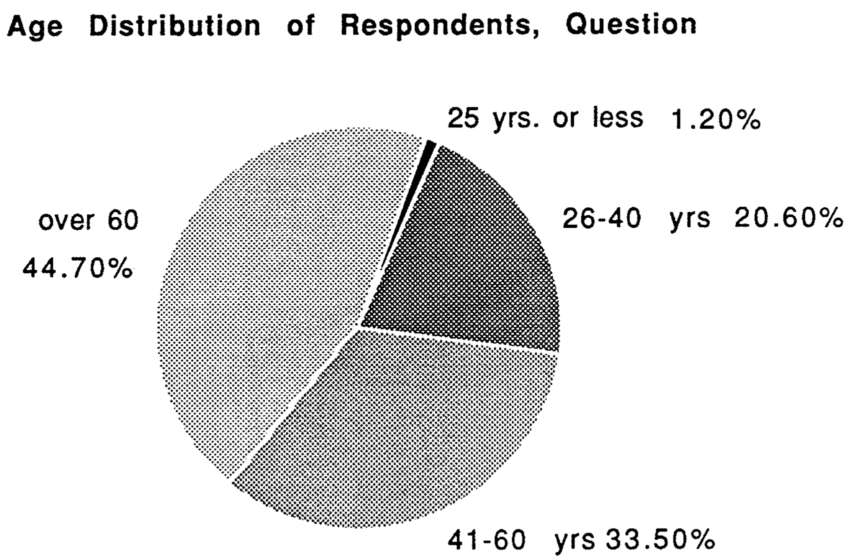

Figure 4.5 Age distribution of survey respondents

Question 21: Sex Distribution of Respondents (Items 48)

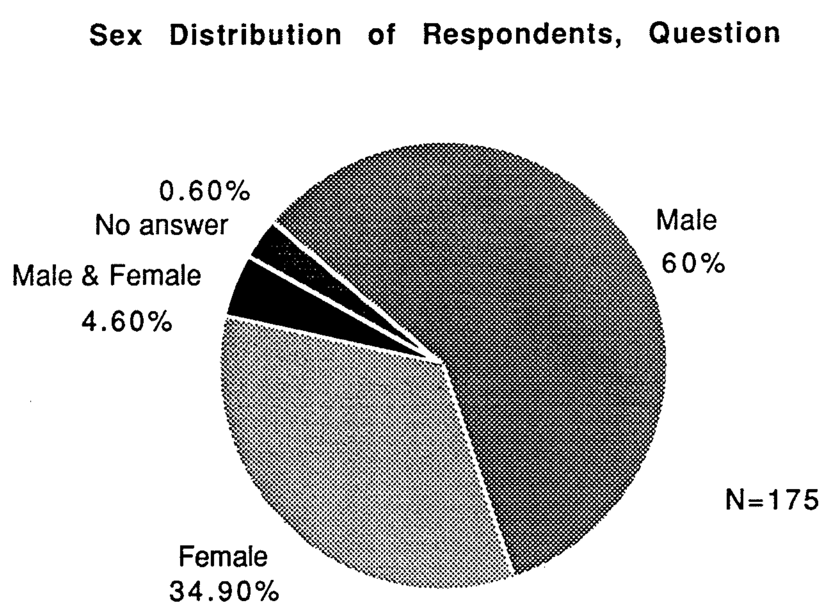

Figure 4.6 Sex distribution of survey respondents

4.2 Water Balance

All components of the water balance were tracked on a monthly basis except for months where water level readings of the lake were not available. The water balance period was calculated for July 1 till June 30 of each year. Table 4.2 is a one page annual summary of appendix E. It lists the annual totals for each component of the water balance for each year from 1972 - 91.

4.2.1 Explanation of Table 4.2

The numbers in table 4.2 are an annual summary of the monthly water balance in appendix E which was explained in section 3.2.3.

Column 1 lists the months, starting with July

Column 2 lists the volume of the lake in cubic metres on July 1st of each year.

Column 3 shows the depth of precipitation each month, from which the volumes are calculated.

Column 4 lists the monthly volume of precipitation falling over the entire basin, including the lake surface.

Column 5 shows the calculated volumes of lake evaporation.

Column 6 displays potential evapo-transpiration which is 70 percent of the precipitation that fell during the 5 month growing season. For example rainfall during July, August, September, May and June of each period were multiplyed by 70 percent.

Column 7 Shows the lake volume in cubic metres, expected at year end. It is arrived at by adding the row amounts for columns 2 and 4, then subtracting the amounts in columns 5 and 6.

Column 8 lists the actual measured lake volume on June 30th each year.

Column 9 is the difference between columns 7 and 8. The number in column 9 is the residual amount of water after all other losses have been identified.

Figures in column 9 range from from a low of -346,146 cubic metres in 1977/78 to a maximum of -1,311,837 cubic metres in 1976/77. The mean outflow for the 19 year is -796,315. The largest value -1,311,837 for 1975/76 corresponds to artificial drainage of the lake through the channel excavation.

Table 4.2 Annual Water Balance - Gull Lake 1972-91

1	2	3	4	5	6	7	8	9
YEAR Jul 1-	Lake vol. July 1	Precip.	Precip.	Lake evap	Potential Evapotrans	Exp. vol. -June 30	actual vol. -June 30	Net Outflow (#8)-(#7)
Jun30	(cu.m.)	(m)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)
1972-73	4,253,800	.5833	2,293,391	582,537	838,234	5,126,420	4,155,167	-971,253
1973-74	4,155,167	.6932	2,725,793	715,965	809,591	5,355,405	4,438,003	-917,402
1974-75	4,438,003	.5123	2,014,298	476,323	710,335	5,265,643	4,537,961	-727,682
1975-76	4,537,961	.5623	2,211,029	584,659	724,400	5,439,932	4,128,095	-1,311,837
1976-77	4,128,095	.4061	1,596,720	704,362	591,555	4,428,898	3,787,140	-641,758
1977-78	3,787,140	.5764	2,266,562	753,853	833,559	4,466,290	4,120,144	-346,146
1978-79	4,120,144	.5265	2,070,244	562,400	626,267	5,001,721	4,147,784	-853,937
1979-80	4,147,784	.3828	1,504,973	677,248	423,677	4,551,832	3,893,345	-658,487
1980-81	3,893,345	.4811	1,891,711	534,931	676,297	4,573,829	3,795,848	-777,981
1981-82	3,795,848	.4394	1,727,845	592,170	538,058	4,393,466	3,637,808	-755,658
1982-83	3,637,808	.5947	2,338,177	606,140	851,320	4,518,525	3,905,651	-612,874
1983-84	3,905,651	.4288	1,686,028	695,118	560,843	4,335,718	3,621,300	-714,418
1984-85	3,621,300	.5072	1,994,376	610,887	515,098	4,489,691	3,501,653	-988,048
1985-86	3,501,653	.5521	2,170,818	612,238	626,781	4,433,452	3,648,183	-785,269
1986-87	3,648,183	.4576	1,799,283	604,957	641,006	4,201,503	3,450,539	-750,964
1987-88	3,450,539	.4776	1,878,022	618,522	674,113	4,035,925	3,225,822	-810,103
1988-89	3,225,822	.6049	2,378,421	651,666	841,734	4,110,843	3,342,251	-768,592
1989-90	3,342,251	.5894	2,317,521	657,822	743,506	4,258,444	3,269,175	-998,142
1990-91	3,269,175	.5074	1,994,900	617,000	640,557	4,006,518	3,258,195	-748,323
19yr. total		9.8830	38,860,112	11,858,798	12,866,930			-15,129,989
19yr. mean	3,834,719	.5202	2,045,269	624,147	677,207	4,578,634	3,782,319	-796,315
						mean net outflow		780,000

4.2.2 <u>Results of Table 4.2</u>

<u>Precipitation</u> (column 3 and 4)

Mean annual precipitation for the 19 year period is .5202m which is equivalent to 2,045,269cu.m. The range in precipitation is .3828m in 1979/80 (1,504,973 cu.m.) to .6932m. in 1973/74 (2,725,793 cu.m.). Precipitation data from seven stations was used in table 4.2 but the difference from using one station is not dramatic. The volume of precipitation at one station can differ in a given year from the mean of seven stations but the 19 year total for all the components is virtually identical. The drawback to using single station data is that some months are missing. None of the seven stations have 19 years of uninterrupted data. For example, Pine Falls; the most complete of the seven, has nineteen months since 1972 where no data were recorded. During 1990/91 four of twelve months are missing, including June, the wettest month of the year. In cases these the mean precipitation from the other stations must be substituted defeating the purpose of using single station data, were it attempted. For the sake of contrast between single and multiple station data sets, table D-2 in appendix D, shows the annual water balance calculated with precipitation data from Pine Falls instead of the seven station mean. Table D-3 in appendix D is a monthly precipitation summary of all seven stations from 1972-91, and table D-4 is an annual summary of precipitation of the seven stations for their entire period of record. The extreme variation in precipitation noted in section 3.2.2 is evident in tables D-3 and D-4, emphasizing the need for caution when applying the data to unguaged sites like Gull Lake. Table D-3 indicates that the least amount of precipitation falling in any one year with a complete record, from July 1 to June 30th of the following year, is 317.6mm. (Great Falls 1979-80), while the greatest was 781.6mm. (Beausejour 1972-73). Table D-4 shows some even more dramatic extremes.

<u>Evaporation</u> (column 4)

Evaporation is a significant factor in the water balance from May through September. It should be included in the calculations for a minimum of those five months. Ten year averages were used to fill in gaps in the evaporation record for months with missing evaporation records; so the data in column 5 are a combination of actual and mean values. Calculated pan evaporation has not yet been published for 1990 and 91 so evaporation in the final year is based entirely on averages.

Mean annual lake evaporation since 1972 has been 624,147cu.m. which is equivalent to 527.2mm of water depth, or 7mm more than the mean annual depth of precipitation, 520.2mm. The importance of runoff and groundwater recharge for maintaining the lake volume is evident from this observation.

Evapo-transpiration (column 6)

The data in column 6 are potentially the most prone to error for two main reasons. First, the data are estimates of potential evapo-transpiration loss, rather than an estimate of the actual rate of water consumption. Potential rates are seldom attained in reality because precipitation is often in short supply. Second the method of calculating the runoff coefficient is a general model and is not specifically designed for Gull Lake.

Net outflow (column 9)

One objective of the water balance was to determine seepage. To do this, domestic water consumption and surface outflows through the weir had to be separated from column 9. Domestic consumption was assessed and determined to be an insignificant component in the water balance, and remains in column 9 (the calculation appears at the end of this chapter). There is no existing data with which to determine surface outflow, so years during which surface outflows occurred (July 1972 -June 1979), were omitted from the calculation of the mean net outflow figure at the bottom of the column. The 19 year mean is also provided but the two do not differ substantially.

Net outflow is also subject to the cumulative error from the data in the other columns, but there was no means of actually determining the magnitude of this error. The numerous factors which make it difficult to accurately estimate evapo-transpiration are explained above, and in section 2.3.3. The error associated with estimating precipitation and lake evaporation is assumed to be small relative to the potential error in column 6; evapo-transpiration.

4.2.3 Results of Basin Stratigraphy Assessment

Figure 4.7 confirms Charron's description of the till lenses, although their vertical depth is much greater at Gull Lake than the 75 or 100 foot depths he refers to. This is because the basin is situated on one of nine topographic high points in the Selkirk map area; some of which are shown in figure 2.2 (page 15). The till lense under the lake is roughly two hundred feet thick interspersed with sand, gravel, boulders or various combinations of these. Different grades of sand, gravel, till and clay described in appendix F are not differentiated in figure 4.7 which is intended as a general survey of stratigraphy. Some variations within one type of strata, such as till are indicated with division lines such as the different grades of till noted in the profile of Well 2 between 22 feet and 216 feet; grey till and boulders were found from 22-87 feet, grey till with layers of soft clay between 87-163 feet and more homogeneous grey till between 163-216 feet. The legend of figure 4.7 labels them all as till, but dividing lines are used to show it is not actually homogeneous. Figure 3.2 illustrates a profile of the entire basin, while figure 4.7 is a sequential profile of the basin along the south shore, running from south to north. An areal view of this profile is shown in figure 4.8 which indicates the positions of the deep wells shown in figure 4.7.

Eight of ten wells indicate layers of sand or gravel to depths of 5-50 feet (1.5-15 metres). The topographic map indicates surface elevations around the wells to be 255-265m ASL. The majority of the wells are west of Arnhold street and are above 260m ASL. Well 6 and Well 10 do not indicate any significant permeable surface deposits, while Well 3 and Well 9 show the deepest occurrence of sand and gravel. The permeable surface deposits in the latter two wells probably extend below lake level. The log in appendix F for Well 8 describes thirty feet of sand or sandy till near the surface so a diagonal division was used in figure 4.7 to show the separation of this layer from the deeper ones. Deeper layers of sand or gravel between 190 and 260 feet below the surface, shown in figure 3.2, are also apparent in figure 4.5 for all the wells except well 10 which was only drilled to a depth of forty feet. Hole 7 indicates sandstone in figure 4.7 but more specifically the drillers log (appendix F) indicated silica sand or sandstone over red granite bedrock. This was the deepest of the 10 wells shown and the position of the bedrock at 270 feet

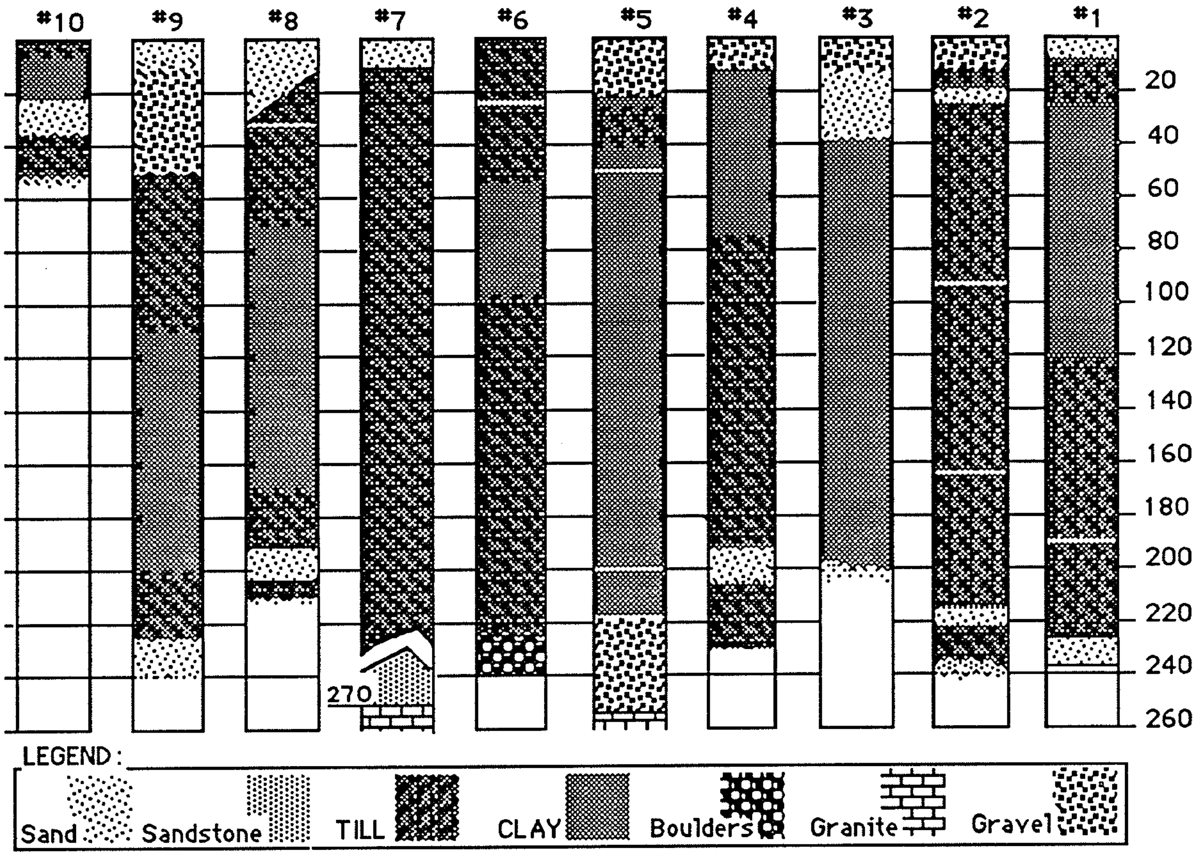

Figure 4.7 Diagram of basin stratigraphy. Information from selected deep wells drilled along south shore of Gull Lake. (figure 4.6 shows well locations in the basin)

corresponds closely with a profile of the same location in figure 3.2. The vertical line near the centre of figure 3.2 is roughly the same position as hole 7 in figure 4.7. The major difference between figure 3.2 and figure 4.7 is the presence of shale indicated in 3.2 by Charron but not mentioned in any of the drillers' reports shown in figure 4.7.

4.2.4 Results of Surface Stratigraphy Assessment

The issue of whether water seeps out of the lake at the north end has never been investigated so surficial investigation was undertaken to assess this possibility. Till or clay was found in 8 of 9 holes augered near the edge of the lake around the weir. The general composition of ground material consisted of an upper horizon of humous, soil or silt approximately 25 cm in depth, followed by successive layers of sand and gravel of variable texture approximately 50 -70 cm thick. Various densities of clay of till were found at depths of 75 -100 cm below ground level. In some holes this impermeable layer was gravelly and in others it was a fine sandy texture. Several of the holes filled with water at rates which were consistent with their proximity to the edge of the lake. Holes 1 and 2 filled too rapidly to excavate with the manual auger and the gas powered auger was used instead. Clay was at a similar depth in holes 1 and 2. Hole 7, directly in front of the channel leading to the weir, also filled with water but took a matter of hours to do so. The water was probably seeping from the sides of the hole but the slow rate made it difficult to confirm this. Holes 3, 4, 5, 6, 8, and 9 were all dry but were farther from the lake edge. In all other respects they were similar to the water filled holes. Hole 4 was different from the others being located in the forest adjacent to the channel. No impermeable material was discovered in hole 4 but it was assumed to be present at a greater depth. Technical difficulties prevented deeper excavation to find it. The ground elevation was higher at this site. Figure 4.7 shows test hole 9 and the typical horizons found in all the test holes. The dark upper layer is soil, followed by a layer of greyish brown sand. The smaller diameter opening at the base of the photo is approximately 50-60 cm deep with till at the bottom and till and gravel above that. Figure 4.11 shows a photo of the general area of surface stratigraphy assessment.

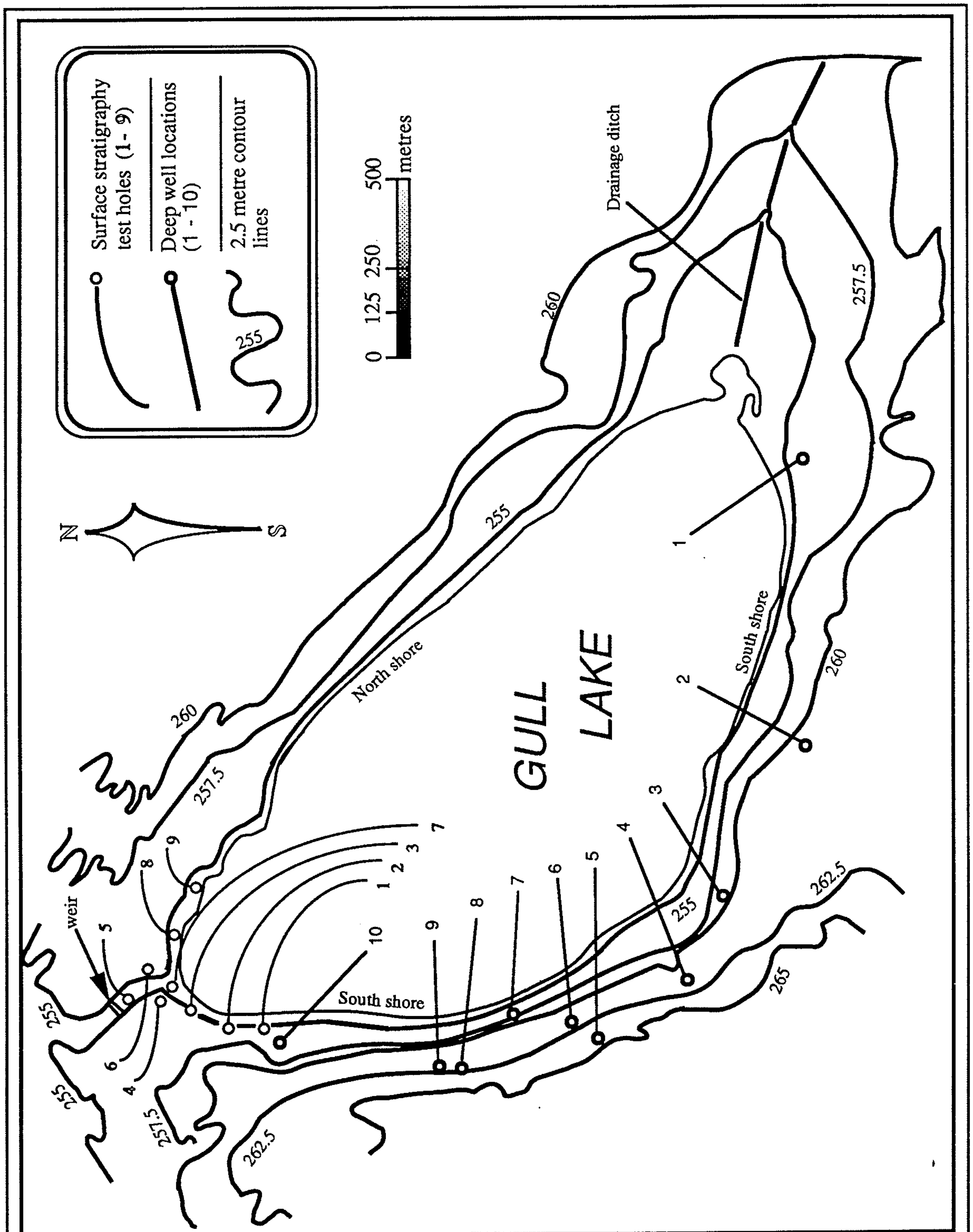

Figure 4.8 Map of deep well locations illustrated in figure 4.7; and locations of surface stratigraphy test holes

Figure 4.9 Photo of test hole number 9, in surface stratigraphy assessment, located approximately 50 m east of the channel leading to the weir and 10-15 m from lake shore. Decayed aquatic vegetation is visible around rim indicating the former position of shoreline.

Figure 4.10 General area of surface investigation. Note exposed rocks and receding shore line. Weir is not visible but is located in forest section 2 inches from left edge of photo. Photo taken October 1991

4.2.5 Domestic Water Consumption

Personal consumption of water was estimated for the summer season of June, July, and August. Use during the other nine months of the year was assumed to be negligible. Consumption by lawn and garden sprinklers for the same period was also estimated. Both uses of water were estimated for weekends only because the number of users on weekdays is relatively small. Per capita consumption of water at cottages was assumed to be approximately 40 percent of urban consumption:

270 litres/day/person x 40% =108 litres/day/person.

The number of people at the lake on weekends was estimated using data from the results of question 4 of the questionnaire. Using the median number of users in each category listed in question 4 (up to 4 people = 2; 4-6 people = 5; and 7-8 people = 7.5) each category was multiplied by the percentage that category represented of the total. Assuming 285 cottages around the lake the result is:

285 x 61.0% x {2 People} = 347 People
285 x 29.7% x {5 People} = 423 People
285 x 8.7% x {7.5 People} = 186 People

(347 + 423 + 186) = 956 People present at the lake on weekends.

A more conservative figure of 800 was adopted instead of 956 people since it did not seem likely that over 900 people visit the lake every weekend. Total human water consumption for the summer season was calculated as follows:

Personal Consumption:

Total seasonal consumption:

= (per capita use)x(no.of persons)x(no.days/wk)x(no.of wks)

= (108 litres)x(800 people)x(2 days/wk.)x(12wks)

= 2,073,600 litres

= 2,074 cubic metres

Lawn and Garden Consumption:

The other major use of water from the lake is the use of sprinklers on lawns and gardens. Questionnaire results indicated that over 50 percent of lake users water their property to some extent. This extent was arbitrarily set at 2 days per week on weekends, for 6 hours per day, for a duration of 12 weeks at a rate of 2 G.P.M. The total consumption is calculated below.

A) Total seasonal consumption per sprinkler:

= (pump rate)x(no.minutes/day)x(no.days/wk)x(no.wkends)

= (2 GPM) x (360 minutes) x (2 days) x (12 weekends)

= 17,280 gallons/sprinkler

= 78.5 cubic metres

B) Total seasonal consumption for all sprinklers:

= (17,280 gallons/sprinkler) x (no.cottages using sprinklers)

= (17,280 gal.) x (285 x 50%)

= (2,462,000 imperial gallons)

= 11,000 cubic metres

Total human consumption, the sum of indoor and outdoor water consumption as noted above is approximately 13,000 cubic metres. The annual total of the consumptive uses outlined is approximately 13,000 cu. m./year which is roughly equivalent to the volume of lake evaporation during a typical summer weekend. This statistic, although crude, should alleviate any concerns about the impact of water withdrawals on the lake for non-essential purposes. The small value for human consumption relative to the net outflow in column 9 suggests that even if it were much higher it is not a significant component of the water balance.

5.0 Discussion

5.1 Questionnaire

Question 1: Response Rates

A relatively high response rate to the questionnaire of 68.8 percent indicated that there is a considerable degree of interest in the management of Gull Lake. The good response may have been due to personal contact and the numerous conversations that took place between the researcher and potential respondents during distribution. Much background information about the lake was gathered during this time. Response rates for the north shore were particularly high (89.7 percent) and the response from the south shore was also very good (78.4 percent). The rate of returns for off-lake residents was quite low (27.8 percent). To some extent this could be expected since this group of people are more isolated from the lake and would tend to be less aware or concerned about specific issues regarding the lake. Another reason for the lower response rate of the off-lake group could be that fewer contacts were made during distribution of the questionnaire to off-lake properties. Twenty seven of the 179 respondents did not specify their location which may have skewed the percentage response rates by area.

Question 2: Resident Tenure

A notable result of the questionnaire was the long period of time that respondents have spent at Gull Lake in many cases since they were children. 50 percent of respondents have been at Gull Lake, in some capacity, for more than thirty years. The long tenure of many lake users probably accounts for the high degree of concern for the health of the lake.

Questions 3-5: Age of Cottages and Intensity of Use

The majority of housing on the lake is of 1950's or earlier vintage and many of the more modern structures are renovations of older cottages. Fewer than 10 percent of respondents reported more than six people using their cottage on weekends. Apparently this is enough to prompt complaints of loud noise and late night parties by some residents. A more immediate concern for the lake is the potential impact of these extra residents on water quality. One cottage owner reported seeing lineups outside outhouses during a weekend party. This is certain to occur in some instances even where a cottage has a holding tank. With total containment of sewage the recovery time of the lake is expected to be fourteen years. Infractions of the bylaw will extend this period, so the temptation to ignore or even oppose the new regulations should be resisted.

Questions 6-9: Amenities

Questions in Part A were designed to gauge the volume of water consumption by lake users, but in view of the marginal impact domestic use has on the total water balance, the main concern for lake users should be *how* they are using the water, rather than *how much* they are using. The quality of water going into greywater fields is the critical issue where domestic water consumption is concerned. The impact of dishwashers which require detergents with heavy phosphate content is the most probable risk. In fact, neither liquid dishwashing detergents nor automatic dishwasher detergents are restricted by Canadian law as to their phosphate content or the labelling of such ingredients. Phosphate content of powdered automatic dishwashing detergents in Canada ranges from 18 to 31 percent (Canadian Green Consumer Guide 1989). Over 52.7 percent of respondents use dishwashers and/or washing machines while 63 percent drain some or all of their greywater into a field. These figures indicate the potential for appreciable levels of phosphates to drain into greywater fields and eventually reach the lake. Although phosphate-free soaps of all kinds are available it is unknown how many people make use of them on a routine basis.

Question 10: Use of Chemicals

Another dimension of the water quality issue is the use of chemical fertilizers, herbicides and pesticides. The application of these substances to lawns and gardens is an inherently risky and uncertain process. Detailed information on these activities was not solicited in the questionnaire so only general comments are possible. In many cases these products are used for the wrong reasons or do not accomplish the intended task. However effective they may be, numerous alternative products and methods of maintaining a garden or lawn are available if individuals are prepared to investigate. Synthetic chemical agents are becomingly increasingly recognized as potentially hazardous substances, in any concentration, and not as effective over the long run at controlling pests or weeds or encouraging healthy growth. The confined hydrology of the Gull Lake basin suggests that chemical use should be avoided.

Question 11: Recreational Activities

There is a wide range of activities taking place at Gull Lake. Most notable from the results of this section of the questionnaire were the conflicts between non-motorized activities like swimming or canoeing and the recreational use of motorboats. Some individuals favour a complete ban of motorboats while others are opposed only to the larger boats. Considerable information was gathered about attitudes concerning recreation from written comments appended to the questionnaire. Although more than 44 percent of the respondents waterski at the lake, this activity appears to generate the most controversy. Reasons for opposition to water skiing include noise, water pollution, increased water turbidity and safety concerns. Figures 4.1, 4.2 and 4.3 all indicate this relationship. Elsewhere, measures have been taken to restrict certain recreational activities that generate unresolvable conflicts, or have been deemed detrimental to a lake (small lakes in particular). This is for the overall benefit of the lake and its users.

Question 12: Regulation of Controversial Activities

Shampooing in the lake elicited the strongest call for regulation of the items listed in question 12; perhaps because it is more visible to bystanders and is generally known to be harmful to sensitive aquatic environments. People at Gull Lake are sensitized to the negative impacts of phosphorous; for example, opposition to the use of chemicals was over

50 percent but more than 76 percent of respondents opposed shampooing. There is probably less awareness of the chemical use that goes on, or the environmental implications associated with it, than with shampooing but the long-term negative impacts of chemical use is probably more serious and requires more attention.

Questions 13-16: Water Quality

Virtually all respondents felt that water quality has worsened noticeably, but a significant range of opinion exists on how this situation could be improved. Highly visible changes in environmental quality, reflected in such factors as poor water quality, are the main reason for the wide range of concerns about the health of the lake. Changes in water quality are an obvious warning sign to lake users that something is wrong; while the implications of changing water levels are less clear cut and open to misinterpretation. These environmental factors (water quality and water level) are not mutually exclusive in terms of their cause and effect. Although low water levels may receive more attention than warranted when water quality is happens to be poor, the decline in both the quality and the quantity of water at Gull Lake is (and should be) a clear indication to people that there are problems which must be dealt with. Water quality testing has borne this out and underlined the need for a change in the customs and habits of most lake users to solve these problems.

Question 17: Management Options for the Lake

Responses to management options suggested in question 17 displayed a noticeable pattern. Water conservation policies, as such, were not endorsed by the majority of people, although the principle was accepted by most. Water conservation can probably be considered a dead issue relative to water quality since domestic water consumption was shown to be negligible relative to the lake's water balance (see Domestic Water Consumption in section 4.2.5).

More emphatic responses were recorded for the second half of question 17. The issues of whether 1) a "nature fix", 2) that everything is "normal" and 3) that natural processes are enough to repair the lake, all elicited strong disagreement. 84.3 percent felt that a nature fix is not realistic, and over 90 percent did not agree that that everything is normal, or that natural processes are enough to save the lake. These statistics are an indication that people are generally prepared to do what is required to restore the lake. Comments written by people also show that they are anxious to know what needs to be done.

Question 18: Lake Restoration and Enhancement

The issue of an enhancement project was presented for respondents to comment on. Specific reference was not made to the proposal to pump water into the lake because it was felt that nobody would be philosophically opposed to any restoration project. Asking such a question would be like asking if they were in favour of good water quality. In retrospect providing several restoration alternatives to choose from would have given respondents the opportunity to answer this question more objectively. Despite this, many people did make reference to the water pumping proposal, indicating their awareness and general support for it. Some stated that they were worried about the condition of the lake and they would support *any* initiative aimed at restoring it; others were more pessimistic and felt it was "too late" to return the lake to its former pristine condition.

Question 19: Public Information Sources

The overwhelming majority of respondents rely on the annual public meetings or the Ratepayer newsletters for news about the lake but many do not have a regular information source except what they pick up in day to day contact with others at the lake. This outlines the need for an improved information network that will keep people informed about environmental issues and progress. Detailed scientific research has been done at Gull Lake by the Environment Department, yet it appears that few people have read the reports. Only four people mentioned the Trophic Study of Gull Lake in question 19, even though it specifically deals with water quality and eutrophication; the most widely held concerns of the cottage owners. If people are provided with more access to this kind of information in a form that they can understand, acceptance and compliance for measures such as holding tanks will improve.

Questions 20-21: Age and Sex of Respondents

The majority of questionnaires were personally delivered to property owners which likely explains why less than 2 percent of the respondents were under the age of twenty five. The lengthy tenure of lake users noted in question 2 is echoed in question 20, where nearly 45 percent of the respondents were more than sixty years old. When this group is combined with the 40-60 year old group, they comprise over 78 percent of all respondents. The mature make-up of the survey population (as opposed to the entire population) at the lake is no doubt an important consideration for the discussion of the results. The questionnaire was distributed to property owners, as a result opinions of young lake users are not well represented. One possible objective of further surveys could be to address this deficiency.

The sex ratio of respondents was more even, in fact if the female group of respondents is combined with the joint group i.e., male and female collaborative responses, the sex ratio becomes 60 percent male to 40 percent female. Cross tabulations of the differences in responses between each group were not attempted but would make an interesting sociological analysis of the perception of environmental quality between sexes.

5.2 Water Balance

Factors Affecting Net Outflow (column 9)

Net outflow in column 9, table 4.2 is a residual figure because it was not measured directly. The values are uniformly negative because they represent a net loss of water from the lake including surface outflow (1970's only), domestic water consumption, and residual error from estimating precipitation, evaporation, evapo-transpiration, area of the watershed, and lake volumes. Annual domestic water consumption was estimated and can be deducted from column 9 but residual error in column 9 is difficult to determine unless outflow from the lake is verified by measurement. Error in column 9 would be minimized if the other components such as, runoff characteristics, precipitation, and evaporation were measured on-site.

It is important to note that column 9 is *net* outflow not *total* outflow. It is the volume by which losses by seepage exceed gains by seepage . Outflow is not a measure of the decrease in lake volume, it is a volume of water lost, that is unexplained by evaporation and evapo-transpiration and therefore must be attributable to other components of the hydrologic cycle i.e., recharge to groundwater or surface outflows. Therefore, even though there is a mean outflow of 796,000 cu.m. per year, lake volume can remain steady because there are compensating inflows from precipitation and groundwater to offset that loss. The tables in appendix E show how lake volume can increase during months and years with large outflow, presumably due to the recharge sources mentioned above.

Domestic Consumption

Domestic consumption represents less than 2 percent of the mean outflow in column 9, so it has little effect on the natural flow of water. The actual volume of water used may be underestimated by the calculations in section 4.2.5. It was only calculated for the summer months, and there are permanent residents near the lake as well as cottagers who go there every weekend. However, even a more liberal assessment of water consumption would not likely account for more than 20,000 cu m. of water, and domestic use of water is not entirely consumptive either. Some water returns to groundwater and the lake through septic fields or as surface drainage from sprinklers.

Precipitation

Net outflow from the lake is fairly constant each year with a mean of 796,315 and a standard deviation of only 195,000. Only 1977-78 (at 346,146 cu.m.), has a net outflow less than 600,000 cu.m. This lack of deviation from the mean may be due in part to the effect of using mean precipitation data from seven stations. Single station precipitation data tends to have a wider range of fluctuation causing greater fluctuations in net outflow, which do not reflect reality. Mean values do not reflect reality for specific sites either, but at least they minimize extremes. It is possible that monthly data from one station close to the lake is more applicable than a mean of seven stations from a much larger area, but none of the seven available stations are close enough to be representative of the study area. A summary of mean precipitation by decade for the period of record of six stations nearest to Gull Lake is shown below in table 5.1. Brokenhead was omitted because it was in commission for less than five years.

Table 5.1

Summary of Mean Precipitation by Decade for Six Weather Stations Nearest to Gull Lake (1916-1990)

	Beausjr.	Gimli	Grt Falls	Pinawa	Pine Fls	Selkirk	MEANS
Start date	(1960-)	(1944-)	(1922-)	(1915-)	(1959-)	(1963-)	
1910's				505.5			505.7
1920's			417.5	407.3			412.4
1930's			426.3	305.9			366.1
1940's		508.0	552.5	357.0			472.5
1950's		551.3	470.4		460.9		494.2
1960's	530.8	542.2	457.7	570.1	534.7	563.1	533.1
1970's	527.3	538.3	468.5	581.0	566.2	464.3	524.3
1980's		552.6	469.5	524.7	497.2	485.2	505.8

All figures in millimetres. Source: Atmospheric Environment Service. Years with incomplete records are not included in calculation of means. The mean precipitation for the 19 year period of all seven weather stations (as noted in Table 4.2) was 520.2 mm.

The thirty year period from 1920-1950 shows substantially lower precipitation but only two of the six stations were operating during that period, so the mean for those decades might not be indicative of actual conditions. (A yearly summary of table 5.1 is provided in appendix D, table D-4). Between successive decades precipitation is fairly stable. From 1960 it has remained above five hundred mm. although it declined gradually each decade since then. Precipitation at specific stations can vary from the seven station mean by 120 mm. or more (note Pine Falls in 1971) but it is more often within twenty to thirty mm. of the mean. This general conformity of single station data to the average indicates that the mean is a reliable indicator of actual precipitation, at least over periods longer than a year, and particularly over the full 19 year period.

Lower outflow is an indication of reduced seepage, increased inflow, or both. Seepage has never been monitored, but annual changes in inflow, which are heavily influenced by precipitation, can be estimated using climatological records for the 19 year period.

Fluctuations in inflow will roughly correspond to the volume of precipitation received each year. Less precipitation will result in less inflow and ultimately less outflow from the basin, assuming there is a lag time between rainfall and its effect on groundwater. Table 5.2 shows the deviation in annual precipitation from the 19 year mean, and the corresponding changes observed in lake volume. Columns 1, 2, and 6 are taken from table 4.2, while column 3, 4, and 5 are added to show the relative variation in precipitation each year and the corresponding change in actual lake volume.

Table 5.2

Deviation of Annual Precipitation from the 19 year mean 1972-91

1	2	3	4	5	6
YEAR	Prec.(cu.m.)	dev.above	dev.below	Actual chg.	Actual vol.
Jul 1-		mean	mean	in lake vol.	-June 30
1972-73	2,293,391	248,122		-98,633	4,155,167
1973-74	2,725,793	680,524		282,836	4,438,003
1974-75	2,014,298		-30,971	99,958	4,537,961
1975-76	2,211,029	165,760		-409,866	4,128,095
1976-77	1,596,720		-448,549	-340,955	3,787,140
1977-78	2,266,562	221,293		333,004	4,120,144
1978-79	2,070,244	24,975		27,640	4,147,784
1979-80	1,504,973		-540,296	-254,439	3,893,345
1980-81	1,891,711		-153,558	-97,497	3,795,848
1981-82	1,727,845		-317,424	-158,040	3,637,808
1982-83	2,338,177	292,908		267,843	3,905,651
1983-84	1,686,028		-359,242	-284,351	3,621,300
1984-85	1,994,376		-50,893	-119,647	3,501,653
1985-86	2,170,818	125,549		146,530	3,648,183
1986-87	1,799,283		-245,986	-197,644	3,450,539
1987-88	1,878,022		-167,248	-224,717	3,225,822
1988-89	2,378,421	333,152		116,429	3,342,251
1989-90	2,317,521	272,252		-73,076	3,269,175
1990-91	1,994,900		-50,369	-10,980	3,258,195
19 yr total	38,860,112	2,364,535	-2,364,535	-995,605	
19 yr mean	2,045,269			-52,400	3,782,319

(All figures in cubic metres)

In most years where precipitation is above the mean there is an associated increase in lake volume, except for 1972/73, 75/76 and 89/90. There was a net decrease in lake volume during most years with below average precipitation, except in 1974/75. The average annual depth of precipitation from 1972 through 1991 from table 4.2 was 520.2 mm. Table 5.1 shows the mean precipitation by decade has declined gradually since 1960. The average for 1960's was 533.1 mm., the 1970's 524.3 mm. and the 1980's 505.8 mm. Reduced precipitation over the last thirty years is consistent with the gradual decline in lake level observable in the hydrograph. More complete weather records would be required to establish a link between rainfall and lake level, and there are undoubtedly numerous other related factors that would have to be considered to determine why the lake level has continued to decrease. Ideally a long-term precipitation mean would provide a more valid bench mark to compare with annual means observed during the water balance period. Table 5.2 was devised for this purpose but the precipitation mean (520.2 mm.), for calculating the annual moisture deficits (or surpluses), was based only on the 19 year period because historical weather records before 1960, near Gull Lake are not extensive. The only weather stations recording precipitation prior to 1964 were Pinawa (since 1915), Great Falls (since 1922), and Gimli (since 1944) and the records of these stations during this period are also incomplete, making it difficult to determine what the "normal" precipitation is. See appendix D, table D-4 for yearly precipitation at the seven stations since 1916.

5.2.1 Basin Stratigraphy Assessment

Gull Lake is perched over one of three extensive till lenses in the Selkirk map area (Charron 1975). These till lenses are considered semi-permeable, long-term recharge areas with slow infiltration rates (Charron 1975). This is the essential characteristic of till which has allowed water to collect in the basin that encloses Gull Lake. The lake is potentially far from sealed, as is often assumed. The presence of 1) joints in till described by Williams, and Farvolden (1967), 2) the occurrence of sand and gravel at various depths below the lake noted in drillers' reports, and 3) the groundwater models described by Winter (1981 and 1983), all indicate that seepage from the lake to groundwater is possibly a significant component of the water balance. Figure 3.2. is a profile of the till lens underneath Gull Lake.

5.2.2 <u>Surface Stratigraphy Assessment</u>

The purpose of this investigation was to find out if there were any areas at the north end of the lake where semi-permeable layers (till), or impermeable layers (clay), are interrupted by deposits of permeable material such as sand and gravel. This would indicate whether there are opportunities for water to escape from the lake. Results showed that finely textured sandy till, rather than pure clay, was apparent in eight of nine holes augered along the shore on either side of the weir. This is a relatively impermeable barrier which would permit only minimal downward water seepage. Lateral seepage is more likely in this area via the deposits of sand and gravel which lie on top of the of the till. Figure 4.8, shows the location of the holes and the surrounding topography.

The appearance of water in some of these holes is significant because the level of the water table was found to be at, or near, the level of the lake. Precise measurement of the two levels would conclusively indicate whether this area is a discharge or recharge zone for the lake at any given point in time. Observations made at the site indicated that the two water levels were at roughly the same elevation, however, it was subsequently realized that instrumentation could be used to determine the exact ground level and water level elevations at each test hole. Knowledge of these relative elevations could indicate whether water was seeping out of the lake. A higher lake level would suggest discharge to groundwater. This would have been useful information for interpreting net outflow in the water balance, but it would have only amounted to data at that one point in time i.e., October 1991. Continuous monitoring of groundwater levels would be necessary to assess the long-term relationship between groundwater and the lake. This has been done on the north shore at the observation well since 1972.

The direction of flow around test hole 7 is of particular interest because it is in front of the weir and the stratigraphy at this site may have been disrupted during installation of the weir. Ground elevations are lowest near the weir, than for any other section of the lake shore, making it a natural drainage area for surface and subsurface water when the lake is very high, and by subsurface water when the lake level is lower than the weir. The channel itself would convey surface water only during high water years but results of the water balance indicate that subsurface flows continue to discharge from the lake regardless of the lake level. There was apparent disturbance of sedimentary deposits close to the weir. These deposits normally restrict seepage out of the lake by sealing the permeable layers underneath. If water ever rises to the level of the weir again, seepage might be more substantial than formerly, due to the disturbance to the sediments created by the artificial channel. The topographical map shows the ground relief in this area to be little more than one metre above the present lake level. Various proportions of sand, gravel, and till are present to a depth of at least one metre, as noted in the test holes described earlier in this section. This tends to confirm evidence in the water balance that lateral drainage out of the lake is occurring even at the low water levels currently being experienced. This is the primary area where seepage can leave the local flow system and flow to the regional groundwater system where it is no longer available to the lake The magnitude of these flows can be seen in column 9 of Table 4.2. Mean annual net outflow for the 19 year period is 796,315 cu.m., and has remained fairly steady during that time with only two exceptional years (1975/76, 1977/78). During the first seven years (1972-79) net outflow includes an undetermined amount of surface outflow due to very high water levels at the time. This will inflate the seepage values associated with that time period, but how much remains undetermined without knowing the volume of surface flow that actually occured[1].

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[1] Net outflow (seepage) from 1979 onwards (*after* the lake had receded from the weir) was estimated to adjust for the unknown influence of surface outflow prior to that time. The result was annual mean seepage of 780,000cu. m. equivalent to 89 percent of mean net outflow shown in table 4.2.

5.2.3 General Discussion

Due to uncertainty regarding the size of the local groundwater table and its relationship with the regional water table, only general conclusions from the water balance are possible. Subsurface outflow apparently occurs at any lake level and is probably due to a lack of precipitation. The lack of moisture would cause the groundwater mounds around the lake to subside (see figures 2.3 and 2.4). If the water table mounds fall below lake level seepage from the lake would occur where the lake bed is not well sealed. During wet conditions the reverse situation would occur. If rainfall is regular enough to maintain the water table mounds above the level of the lake, there would be net inflow to the lake. A given amount of rainfall elevates the groundwater table quickly because much of the water infiltrating the ground is displaced by sand and gravel. The lake level responds more gradually to rainfall as can be seen by the more gradual curve in the hydrograph. Except for the sharp spikes in the groundwater hydrograph there is usually less than a six inch difference between the lake and the groundwater levels; at the observation well site. During the 1970's groundwater was higher than the lake but during the 1980's it was more often below the lake level. The close association between the two levels is consistent with the steady net outflow noted in column 9 of table 4.2.

Water flowing out of the lake would either remain with the local groundwater, or it could discharge to regional groundwater at which point it is effectively lost. The latter would most likely occur around the weir where the lake is not confined by the till. Discharge from other areas of the lake would be confined to the local groundwater by till except where there may be joints in the till, or sand and gravel deposits illustrated in figure 4.7. With the exception of the area around the weir, the lake and the local groundwater table are generally confined by till. Ground conditions and surface elevations indicate that the weir area could discharge enough water to the regional water table to account for a significant percentage of yearly net outflow. The results in table 4.2 indicate that net outflow including seepage has been relatively steady for the entire 19 year period. Stable seepage and outflow rates can be explained if one or more of the following statements are assumed to be true.

1) The lake is not outside its natural range of fluctuation so subsurface outflow has not subsided i.e., net ouflow continues.

2) The estimation of certain components in the water balance do not accurately reflect the true situation, and there are additional volumes of groundwater recharge and discharge not accounted for.

3) The lake is effectively confined by the till basin, but it is in variable states of recharge and discharge, depending on the relative elevations of groundwater and lake level.

A lake can be directly related to a groundwater flow system or it can be, to any degree, independent of it. Not all lakes are so directly related to a flow system, some are perched above regional water tables, while others are progressively sealed by sedimentation processes and their relation to flow systems is thus continually changing (Stephenson 1971). A steady annual net outflow despite the wide range in lake level since 1972, suggests that the lake is directly related to the groundwater flow system, but groundwater has never been adequately monitored so the interaction of regional and local systems and how they influence the lake can not be confirmed. There is an exchange of water between the lake and local groundwater which no doubt varies around the basin, according to contours of till, sand, and gravel, but the issue of concern to the project feasibility is the movement of water from local to regional groundwater systems and the potential loss of that water. The water balance determines the volume of outflow but it does not indicate whether it is flowing to regional or local groundwater. The stratigraphy assessment suggests there is a connection between local and regional groundwater that is limited mainly to the north end of the lake. This could only be confirmed with more detailed assessment of stratigraphy and groundwater flux.

The Effect of the Gravel Pit,West of the Lake

Davidson (1973) mentions a hydrological assessment of the gravel pit which had been done in 1972, to determine if excavations for sand and gravel were having any impact on the lake. The assessment found no cause for concern, however since that time more gravel has been removed from the pit, making it deeper and wider, and the potential threat to the lake has remained a persistent issue. If only gravel is removed from the area, there should be no appreciable effect on groundwater recharge (MacInnes 1991 and Rutulis 1991 personal communications). If till is removed there could potentially be an impact on groundwater flows, and on the lake. Figures 5.4 and 5.5 are recent photgraphs of the gravel pit. It has been twenty years since the last assessment and in view of the estimated $15 million in property values, it may be advisable to commission another.

The General Effect of Water Balance Components on the Lake

The recharge of lake volume is primarily dependent on the depth of precipitation which falls on the watershed. Of the volume of precipitation falling on the entire watershed area (including the lake), 30 percent falls on the lake's surface and 70 percent falls on the land around the lake. the process of evapo-transpiration consumes 70 percent of what falls on the land and lake evaporation consumes the equivalent of 100 percent of what falls directly on the lake, leaving a net surplus of 20 percent to increase the lake volume. The actual source of this theoretical 20 percent surplus is certain to vary widely according to weather conditions and deep and shallow groundwater flows. If the time period of interest is generally rainy and average temperatures are lower, then evaporative losses would be reduced and a greater percentage of total summer precipitation would contribute to the lake volume. The reverse would occur when weather conditions are dry for an extended period. The influence of temperature and the frequency of rainfall are not directly factored into the water balance, but lake evaporation data are derived from real weather observations, so variations in column 5 of table 4.2, do to some extent reflect actual moisture surpluses or

Figure 5.4 Aerial view of the south shore of Gull Lake illustrating the close proximity of the gravel pit, west of the lake. Note the high cottage density. Photograph taken August, 1991; courtesy of Stan Malec.

Figure 5.5 Interior of gravel pit, showing several ponds excavated in clayey till. The ponds are approximately 400 metres west of the lakeshore at an undetermined elevation below the lake level. View is northwest; with Lake Winnipeg visible and Highway 59 obscured by trees in background. Photo: fall,1991

deficits resulting from changing weather conditions. The water balance is divided into annual periods for the convenience of discussion, but factors that cause the water balance to fluctuate overlap those time periods. The effect of weather conditions during one period will influence the next period, for example, a year of heavy precipitation will not produce a significant increase in lake volume if an exceptionally dry year preceded, because much of the rain will be consumed to replenish groundwater. This variability is illustrated in table 5.2 where extreme deviations in precipitation do not produce an equivalent change in lake volume.

Conclusions about the lake have been drawn from the data compiled in table 4.2 but more detailed analysis of net outflow would involve more complete monitoring of actual ground water levels at multiple locations, as well as more consistent lake level readings spanning the entire open water season. Where this has been done for other lakes, the procedure has involved a network of observation wells, including those which may have already been installed for domestic purposes [see Stephenson (1971), Winter (1983) and Shaw (1990)]. Once a flow system is mapped, numerous applications can be made toward the solution of problems relating to the use of either surface water or groundwater (Stephenson 1971).

5.3 Gull Lake Enhancement Project

The construction of a crude drainage channel in late 1975 was followed shortly after by the installation of a weir to control the flow of water out of the lake. Since that time the water level in the lake has dropped 1.232 metres (48.5 inches) from its maximum recorded high of 254.307 metres ASL in June, 1974 to 253.075 metres ASL in June, 1990.

Accompanying the steady decline in lake level there has been an increase in problems associated with water quality. People are very concerned about the declining water level and numerous issues related to water quality, in fact, 85-90 percent of the questionnaire respondents agreed that water level, algae growth, weed growth, water clarity, water pollution, and "Other" issues are significant problems at the lake.

The unanimity of concern about these issues has created a sense of urgency for initiatives to aid the lake. The potential of the water pumping initiative to alleviate problems associated with water quality and water level has made it a focus of attention for revival of the lake. The water to be pumped into the lake may be obtainable from an existing well in the gravel pit, or if this source is not reliable then another would have to be found and a new well drilled. The Ratepayers' have proposed to artificially recharge the volume of the lake with water from one of the aquifers east of highway 59. A 6-8 inch pipeline would transfer water from the well to the lake with the objective of maintaining an optimum lake level and diluting the concentration of nutrients now present in the lake.

Advantages of a Regulated Lake Level

i) Gull Lake has been stocked with hundreds of thousands of fish since the 1930's but the Fisheries Branch has decided that stocking the lake is not currently feasible because conditions in the lake are poor. Higher water levels will create more favourable conditions for fish by reducing the incidence of winter kills.

ii) Relatively pure water from an aquifer will tend to improve the overall water quality of the lake. Approximately 350,000 cu. m. of water could theoretically be pumped into the lake during a six month period. This is equivalent to nearly 10 percent of the current lake volume. The actual elevation of the water level that could be achieved is difficult to predict accurately because of factors such as seepage.

iii) The flow of water can be turned on whenever it is required and turned off when the lake level is within an acceptable range. Subsequent periods of low water levels can be prevented from occurring by resuming the flow of water.

iv) The proposal to pump water into the lake is regarded by the Ratepayers as one aspect of a more comprehensive management approach for the enhancement of the lake. As such, it is viewed as a form of insurance which will tend to improve and maintain water quality and water levels, or at least prevent further deterioration. The benefits associated with pumping will in theory occur relatively sooner after project implementation than those of other enhancement measures which could be undertaken.

v) Improved water quality and easy access to the lake results in greater recreational potential which, in turn, enhances property values for owners and secures a reliable tax base for the municipality.

vi) Introducing a purer water source to the lake would tend to slow the ageing process caused by nutrient loading and restore the aesthetic qualities of the water for lake users.

Disadvantages of Regulated Levels

Although the pumping initiative is acknowledged to be only one part of a more comprehensive enhancement measure, it could be perceived by some individuals as a solution for all the water quality problems. As such it could promote a false sense of security and a lack of support for other necessary enhancement measures.

5.3.1 Project Description

The proposal for pumping water into the lake is tentative since availability of a sufficient water supply is not yet guaranteed. The costs of the heavy equipment and materials, and safety considerations, are outlined. Water would either be pumped from an existing well in the gravel quarry (shown in figure 5.1) or a new well would be drilled to obtain water from another site. The information in section 5.3.2 was compiled by the Environmental Concerns Committee at Gull Lake. Costs are subject to change since this information was compiled in June, 1991. The guarantee of an adequate supply of water and the access to it are not yet secured. These issues are discussed in section 5.3.5. A map of the project area is shown in figure 5.2

5.3.2 Project Costs

The following costs pertain to the existing well and pump already in use in the gravel pit.

6 inch pipe at $3.25/ft. X 3500 ft	11,375.00
Used stock from Alberta shipped to Gull Lake	200.00
Subtotal	11,575.00
Taxes	1,736.00
Total	13,311.00

Pipe Installation:

6" butterfly valves	$120.00 ea.	2 units	$240.00
6" flanges	$20.00 ea.	8 units	$160.00
Welding	$40.00/hr.	50 hrs	$2,000.00
Backhoe	$35.00/hr.	50 hrs	$1,750.00
Leveling of site	$60.00/hr.	8 hrs	$480.00
Total			$4,630.00

Miscellaneous:

Backhoe to unload	2 hrs	$70.00
Backhoe to place pipe	10 hrs	$350.00
Backhoe for trenching & filling	10 hrs	$350.00
Chain link enclosure (installed)	4'x3'x20'	$716.34
Problem expenses		$1,000.00
Total		$1,486.34

Equipment:

Figures below relate to the fifty horsepower motor already installed at the retention pond adjacent to the well.

Monarch Pump (serial#20555 A 3045; total pressure of 65 P.S.I.)

	3500 ft.
Change in elevation between contours 775-850 ft	75 ft.
Pressure loss due to lift	32 P.S.I.
Pressure loss over distance (6 P.S.I./100ftX3500 ft)	21 P.S.I.
Remaining pressure at lake end (65-32-21) P.S.I.	12 P.S.I.

Safety Considerations:

-Chain link enclosure would keep people away from outlet in lake.

-Water flow would end shortly after meeting resistance in the lake.

-Pipe would be buried in public areas.

5.3.3 Costs for Drilling a New Well

The following costs would apply if the existing well and pump are inadequate and a new well has to be drilled and a new pump installed.

Test Well		
5 inch well @ $15.00/foot X (150 feet)	2,250.00	
2 Screens @ $850.00 each	1,700.00	
Pump test (up to 6 hours) @ $65.00/hour	390.00	
TOTAL	$ 4,340.00	
		4,340.00
Final Well		
8 inch well @ $28.00/foot X (150 feet)	4,200.00	
2 Screens @ $1326.00 each	2,652.00	
Pump test (up to 6 hours) @ $65.00/hour	390.00	
Subtotal	$ 7,242.00	
		7,242.00
Equipment Costs		
Pump: 30 H.P., 220 volt, 4 stage	4,337.00	
Pipe:		
6 inch pipe (used) 2500 feet @ $3.25/foot	8,125.00	
Subtotal	$ 12,462.00	
		12,462.00

NOTE - If used pipe is not available, new pipe at $7.00/foot would be substituted. 2500 feet X $ 7.00/foot = 17,500.00
Cost difference: (17,500.00 - 8,125.00) = $ 9,250.00

Pipe Installation		
Welding: 50 hours @ $40.00/hour	$ 2,000.00	
Backhoe: to assist Welder $35.00/hour	$ 1,750.00	
Level site: 8 hours @ $60.00/hour	$ 480.00	
Subtotal	$ 4,230.00	
		4,230.00

Miscellaneous:

Backhoe		
-to unload 2 hours @ $35.00/hour	70.00	
-to place pipe 10 hours @ $35.00/hour	350.00	
-for trenching/filling 10 hours @ $35.00/hour	350.00	
Other Miscellaneous costs	1000.00	
Subtotal	$ 2490.00	2490.00
Total Startup costs		$ 30,764.00

Hydro Electric Costs

These costs are only roughly calculated because the actual power consumption of the electric motor is not known. Power consumption was roughly estimated with the formula below for ten and thirty horsepower loads. The ten horsepower load is associated with smaller pipe diameter, and a pumping rate of approximately 150 GPM for twelve months of the year.

Horse Power x Hours x Days/month= Kwh's/month

10 H.P. x 24 hrs x 30 = 7,200 Kwh/month

7,200 Kwh/month x 12 Months = 86,400 Kwh/year

30 H.P. x 24 hrs x 30 = 21,600 Kwh/month

21,600 Kwh/month x 6 Months = 129,600 Kwh/season

Estimated Monthly Hydro Charges	30 HP	10 HP
Connection Charge	?	?
Basic Monthly Charge	20.01	20.01
First 1090 Kwh's @ $0.06512/Kwh	70.98	70.98
Next 10,000 Kwh's @ $0.04923/Kwh	492.30	300.80
Next 7,500 Kwh's @ $0.03277/Kwh	245.78	-
Next 3,010 Kwh's @ $0.01982/Kwh	59.66	-
TOTAL	$ 888.73	391.79

5.3.5 Project Feasibility

Background

A Hydrologic Study of the Selkirk Area by Charron (1975) which surveyed groundwater resources using an extensive inventory of drilled and dug wells, was used to outline groundwater quality and its direction of flow around the lake. A volume of water sufficient for recharging the lake is not identified by Charron around the till areas. Mainly shallow groundwater resources were studied by Charron with a supply suitable only for domestic use, especially in the till areas where infiltration is slow.

The most relevant information for evaluating a water supply for the enhancement project would be deep wells drilled through the till lens to bedrock. Currently there is no thorough documentation of deep wells near the lake which can be used to reliably predict water availability other than for low volume domestic use. Ultimately, tests will have to be done on existing wells, or on new ones, to determine how much water is available for the project.

The following section assesses the feasibility of using groundwater from this area to recharge Gull Lake. The results of this assessment do not in any way confirm the presence of water. This would be done during the licensing phase of the project. Actual site conditions could differ in terms of water quantity, and location of a well.

The two main objectives of the enhancement project are,

-to elevate the water level of the lake to improve recreation and enjoyment, and

-retard the rate of eutrophication by reducing the concentration of nutrients in the water.

Therefore, feasibility of the project and its ability to enhance the water quality and water level of the lake will depend on:

1) **Groundwater availability** - Without a sufficient volume of water the project

would not be worth undertaking, therefore groundwater availability, in large amounts, is critical to the success of the project.

2) **Permeability of the lake basin -** Seepage out of the lake is a factor in the success of the enhancement project.

3) **Groundwater quality** - Groundwater is generally of higher quality than surface water, but this has yet to be confirmed.

4) **Dilution of the lake** - The ability of groundwater to dilute nutrient concentrations in the lake will indicate the potential for improving water quality.

These four areas of concern are addressed in more detail below.

1) Groundwater Availability

The proposed volume of water to be pumped from the aquifer to the lake is 300 imperial gallons per minute (IGPM or GPM) continuously from May 1 through October 31 each year till a more desirable water level is reached. The immediate question which needs to be answered is whether 300 GPM can be withdrawn continuously from an aquifer without depleting it. This question cannot be answered for certain until a well is located and tested but the literature gives some general indications of groundwater availability. For the purposes of addressing these four issues, the volume is assumed to be 300 GPM even though in reality it could be less.

Sustainable Yield of Aquifers

Gull Lake is situated on one of nine topographical high points in the Selkirk area. These high points, some of which are illustrated in figure 2.2, consist of till, sand, and gravel and are recharge zones for groundwater as opposed to the groundwater discharge zones characteristic of the clay plain south and east of the lake. Groundwater aquifers within these high points are described by Charron (1974) as confined aquifers with a direction of flow radiating outwards in all directions. Shallow sand and gravel aquifers are common along the north and west shores of Gull Lake and in many other parts of the Selkirk district, but they yield only a domestic supply of water. The extensive sand and gravel deposits just west of Gull Lake (the enhancement project area) are dry because they are separated from the lake by a barrier of till (Rutulis 1978). Shallow groundwater water is more accessible on the east side of Lake Winnipeg but yields are considerably lower than on the west side. As a result it is likely that yields approaching 300 GPM near Gull Lake will only be found close to bedrock.

The proximity of high yield aquifers close to the lake is crucial to the feasibility of the project. Till yields relatively little water and groundwater availability around the lake is rated from 1 to 5 GPM. Wells in the sand and gravel outwash deposits yield on average 10 GPM (Charron 1974). As one moves away from the highpoints the supply of groundwater increases. Zones yielding 5-50 and 50-500 GPM are found in successive concentric zones further away from high points, but these zones are outside the feasible range of a pipeline leading to the lake. The lower elevation of these zones would also necessitate heavier and more expensive pumping equipment.

The most feasible solution appears to be the installation of a deep well through the till overburden to the bedrock where the yield is considerably larger. Data from existing deep wells indicates that bedrock aquifers could supply the required flow, though none of the drillers' reports provide documentation of a pump test in the 300 GPM range. If the existing well in the gravel pit can not be used, success of the project would depend on whether a new well site near the lake could be found.

The essential characteristic determining water yield for deep wells appears to be the bedrock composition. The sandstone of the Winnipeg Formation has yielded 500 GPM in the Town of Selkirk, while the limestone and dolomite rock of the Red River formation yields much less water. Rutulis (1978) states that:

> Based on an estimated recharge for the entire Selkirk area the total potential yield of the aquifers in the [Selkirk] district is about 24,000 acre feet per year [29.6 million cu.m.] or a sustained pumping rate of 12,000 GPM; this will supply some 20,000 private residences and an additional sustained withdrawal of 6,000 GPM for other uses.

The overall abundance of water is apparent from this assessment but the abundance of water in specific locations i.e., the gravel pit at Gull Lake, is a different matter. Foster and Sewell (1981) point out that the popular view of the "superabundance" of water is exaggerated. They say: "Much of the water is in the wrong place or is available at inappropriate times" and remaining undeveloped resources can only be developed at escalating costs. Aquifers in the gravel pit west of Gull Lake have *not* been intensively developed but the abundance of water in that area, and its accessibility remains to be seen.

2) <u>Permeability of the Lake Basin</u>

In a further attempt to predict the effect of pumping water on seepage rates, net outflow from the water balance was plotted against lake volume and a linear regression line was fitted to the data. The equation of the line of least squares through the scatter of data points defines the relationship between x and y, in this case outflow and lake volume. If there is a relationship between the independent variable (lake volume) and the dependent variable (outflow) then the equation could be used to predict outflow at the desired lake level and hence how much water pumped into the lake would be lost to outflow.

Results of the regression are shown in figure 5.6 and 5.7. Figure 5.6 plots monthly outflow against corresponding lake volumes observed at the end of each month. Each point on the graphs represents an outflow reading (read from the vertical Y-axis) and the actual lake volume for that month (read form the horizontal X-axis). The values on the X-axis range from 3-5 million cubic metres which spans the range of lake volumes experienced at Gull Lake. Seepage ranges from -287,000 to +64,000 cubic metres. There are only six months with net inflow (values above zero) indicating inflows of water such as rainfall and runoff for that particular month were in excess of outflows like evaporation and seepage. Figure 5.7 is the same arrangement of data, except that the values used are annual instead of monthly. The most notable difference between figure 5.6 and 5.7 is that on an annual basis there are no years with net inflow to the lake, hence all the data points fall below the zero point on the Y-axis.

The slope of the straight line running through the scatter of points is the calculated by the least squares equation:

$$y = \beta_0 + \beta_1 x + e$$

where y = seepage; β_0 = the y-intercept; β_1 = the slope of the line; x = lake volume; and e = random error.

The least squares equations for the regression lines in figure 5.6, with values derived from the data sets, are inset on the graphs. The equation for figure 5.6 is:

$$y = -1.426 \times 10^{4} - 2.417 \times 10^{-2} X$$

If we know either the x or y value the other can be calculated using the formula. For example, if we want to predict the net outflow (y) expected at a lake volume of 3,200,000 cu.m., then that value for x (say 3,200,000) is inserted into the equation producing a value for y of -91,604 cu.m per month. In reality the monthly net outflow occurring at a lake volume of 3,200,000 cu.m. could be drastically different depending on the weather and groundwater conditions. This is why the data points are scattered around the line instead of lying along it. The regression equation and the line of least squares are only capable of predicting the average net outflow values based on the 19 year set of data. A regression line can be calculated for any set of data regardless of any existing correlation.

From a statistical point of view the wide scatter of points around the line indicates there is no causal relationship or correlation between x (lake volume) and y (net outflow). Therefore seepage or net outflow can not be predicted by lake volume alone unless other factors are considered as well.

Monthly Net Outflow vs. Lake Volume, Gull Lake (at Sherwood) 1972-91

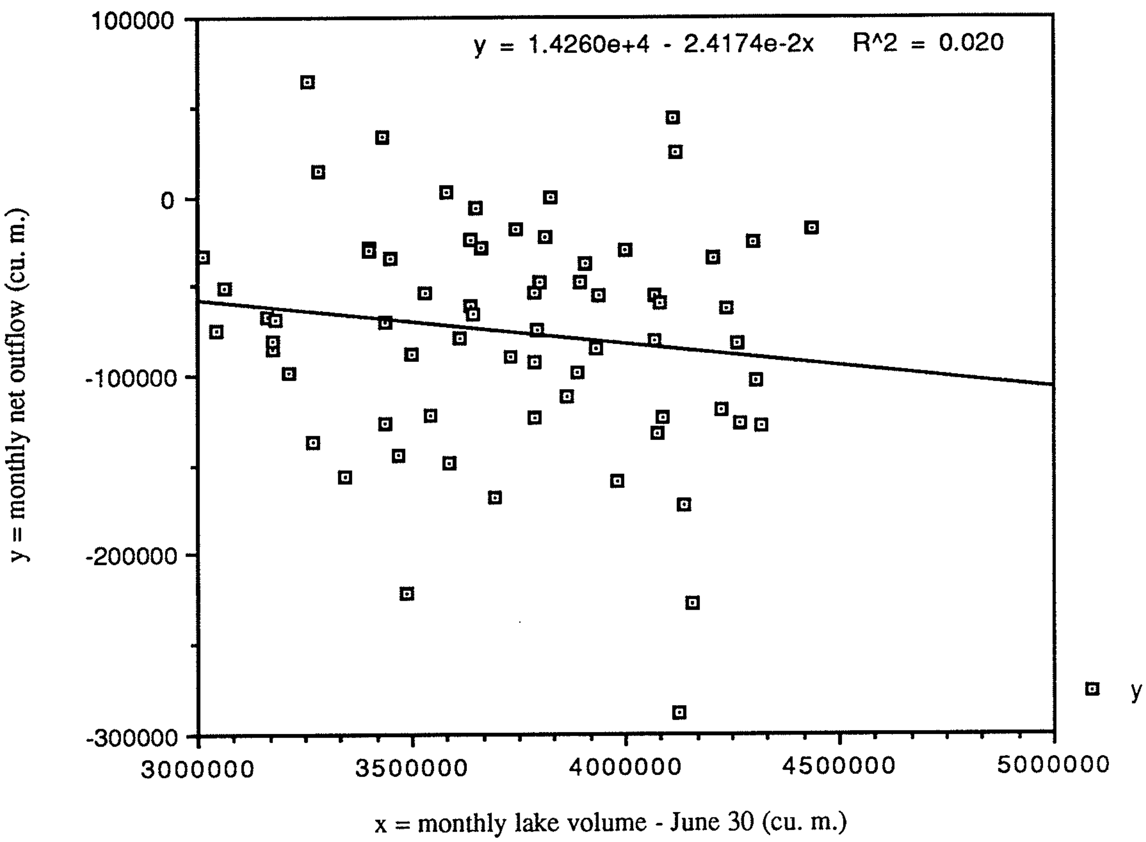

Figure 5.6 Regression correlation of monthly net outflow vs. lake volume plotted from data in column 2 and column 10 of the water balance in appendix E

The correlation is better in figure 5.7 but there is still a significant amount of variation in net outflow at any given lake volume. The regression line predicts an annual net outflow of over -800,000 cu.m. at the present lake volume of 3.2 million cu.m., but the range in actual net outflow at this volume has been -750,000 to -1,000,000 cu.m. At a lake volume of 4.1 million cu.m. the range in net outflow was -346,000 to -1,312,000 cu.m. The latter figure is influenced heavily by the weir installation while the former is not as easily explained and is probably due to variation in several components of the water balance.

Annual Net Outflow vs. Lake Volume, Gull Lake (at Sherwood) 1972-91

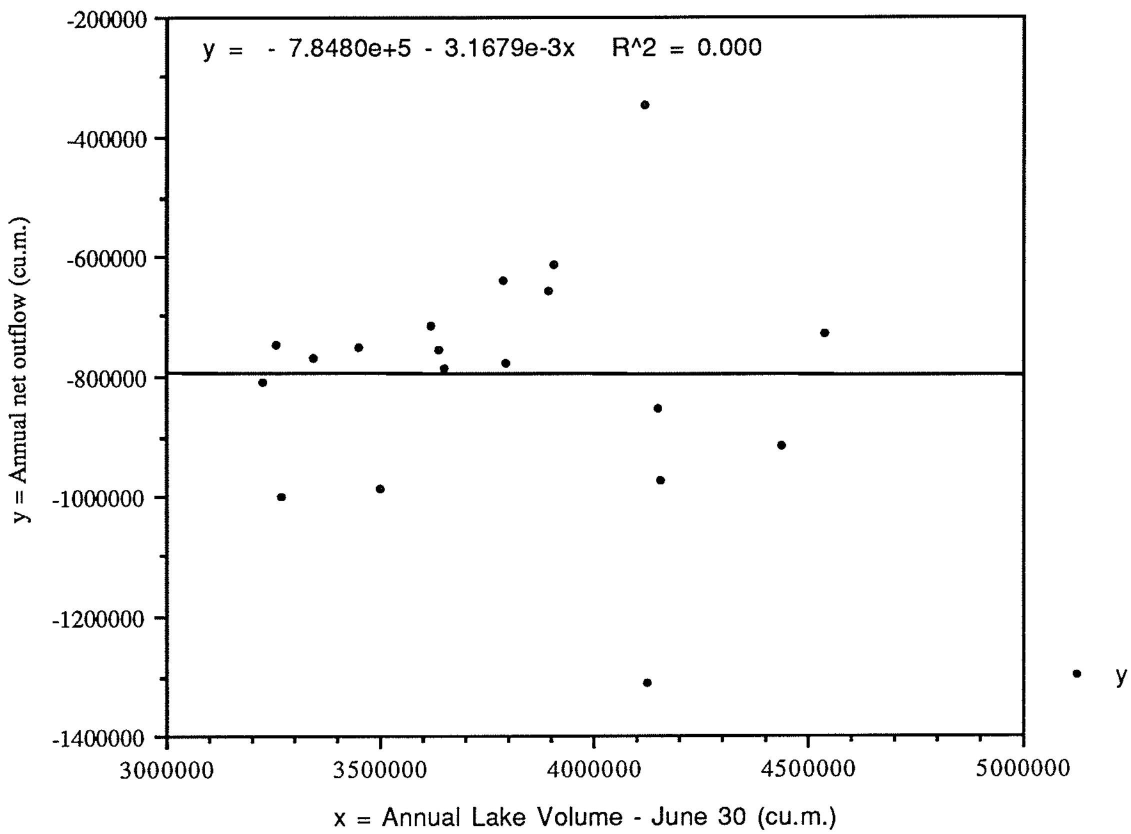

Figure 5.7 Regression correlation of annual net outflow vs. lake volume plotted from data in column 9 and column 2 of table 4.2

Linear regression is most useful as a predictive tool when there is high degree of correlation between the x and y values. Lake volume, which is the x value, is not a good predictor of net outflow because, as noted above, there are other factors which influence the magnitude of net outflow and for which we have no measurements.

The results of the linear regression analysis show that net outflow can not be reliably predicted from the available data. This is because environmental factors such as prevailing soil moisture conditions, frequency and intensity of precipitation, and groundwater movement all influence seepage, and are not accounted for by the water balance. Data for these components is required for an adequate assessment of the effect of net outflow on the feasibility of the enhancement project.

In the absence of a method for reliably predicting outflow or seepage it is still informative to determine the relative effect of artificial recharge on the yearly deficit or surplus of water in the basin. From column 4 of table 5.2 it is evident that any of the deficits in precipitation could be overcome by pumping 350,000 cu.m. of additional water into the basin. Only 1975/76 had a deficit greater than 350,000 cu.m.; when the lake volume decreased by 409,866 cu.m.

The difference between the precipitation deficit in column 4 and the corresponding decrease in lake volume in column 5, confirms there are factors other than precipitation which influence lake volume. Factors such as stratigraphy and infiltration rates can produce a lasting effect on discharge and recharge rates in the basin.

Summary of Basin Permeability

There are numerous factors that affect net outflow which relate to weather conditions as well as surface deposits and their permeability. Since no data have been gathered on these factors a change in the volume of outflow from the lake in response to artificial recharge can not be predicted. Artificial recharge after June would probably have a smaller impact than prior to that time because there is a natural and persistent drawdown in both lake and groundwater levels between the end of June, which is statistically the wettest month, and October each year. There is a general deficit of moisture from July onward although there are many exceptions to this condition. It is notable that during only one other summer season between 1972 and the present, has there been an net increase in lake level [2].

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[2] During the same period in 1977 the lake rose 11.5 cm. Both 1977 and 1991 were years with heavy precipitation. The average change in lake level over the summer period since 1972 has been -15.6 cm, (a drop in level). The maximum drop was in 1974, 29.3 cm; other summer seasons with declines in lake level in excess of 20 cm include: 1975, 76, 79, 81, 83, 84, and 89.

Artificial recharge would tend to minimize, but not necessarily reverse declining lake levels during dry periods and produce larger increases during months with a moisture surplus.

3) Groundwater Quality

The concentration of total dissolved solids was measured in ninety four groundwater samples taken in the Selkirk map area. Tests on the samples were also done to detect the presence of six major ions; including calcium, magnesium, sodium, chloride, sulfate, and bicarbonate. Seven of the ninety four samples taken from wells within a few kilometres of Gull Lake ranged from 300 to 400 parts per million (PPM) of total dissolved solids (TDS). TDS exceeded 1000 PPM in a small, confined area directly east of the lake along the shore of Lake Winnipeg. All seven samples from the vicinity of Gull Lake had low average TDS. In every case the aquifers are confined and are from both unconsolidated [till] and bedrock aquifers (Charron 1974). The flow of water radiates outward from the hill areas moving from the lake toward the project area in the gravel pit and eventually towards Lake Winnipeg.

The quality of the groundwater from all the aquifers near the lake was good, indicating a low risk of contamination to groundwater or the lake (such as saline intrusion or other dissolved solids) due to large withdrawals from an aquifer.

4) Dilution of Nutrient Concentrations in the Lake

Water Residence Time

Water residence time is a measure of the length of time required for a lake or reservoir to completely flush itself and is an indication of how long nutrient enriched water resides in the basin before being flushed out. With the addition of 300 GPM of relatively clean water from an aquifer, the residence time will be decreased and nutrients will be displaced more quickly.

Average and current water residence times were calculated as shown in formulas 1 and 2 below. The mean annual outflow for the years since 1979 was used in formula 1 to exclude the effect of the weir installation, although the resulting figure (791,044 cu. m.) is not significantly lower than the 19 year mean of 796,315.

Formula 1:

Average Residence Time = (Mean Annual Lake Volume/Mean Annual Outflow)

= (3,514,200 cu.m./791,044 cu.m.)

= 4.44 years

Formula 2

Current Residence Time = Lake Volume (1991)/Outflow(1991)

= 3,250,000 cu.m./748,000 cu.m.

= 4.34 years

Both times are slightly shorter than the 4.93 years calculated in the Trophic Study (1986).

Increased Flushing of Nutrients

Pumping water into the lake will change the annual outflow from the lake but there is no way to predict what that change will be. Without knowing how outflow will be affected a new residence time can not be calculated. However for the purposes of determining the expected change in dilution of nutrients, an artificial residence time was calculated by treating the water pumped into the lake as an addition to outflow. This may be considered acceptable since all water pumped into the lake regardless of how it affects outflow, will help to dilute the existing nutrient concentration in the lake. Wind across the lake surface would effectively mix the new water with existing water in the basin and the dilution effect would not be compromised by greater net outflow resulting from a higher water level.

For the purposes of assessing dilution only, the residence time formula was used combining outflow from the water balance with additional inflow from pumping. Formula 3 calculates the artificial water residence time assuming 350,000 cu.m. of water can be pumped into the lake and formula 4 calculates the proportional change in nutrient dilution:

Formula 3

Artificial residence time = Lake volume/(outflow + water volume pumped)

= 3,250,000 cu.m./(748,000 cu.m.+ 350,000 cu.m.)

= 2.96 years

Phosphorous supply in the lake was shown by Beck (1986) to be the limiting factor in growth of aquatic macrophytes and algae, therefore dilution of phosphorus concentrations in the lake are the focus of this discussion.

The change in phosphorus dilution will be proportional to the difference between actual residence time and artificial residence time according to formula 4.

Formula 4 $P_1/P_2 = Rt_1/Rt_2$

where: P_1 = current phosphorus load, P_2 = projected phosphorus load with dilution, Rt_1 = actual residence time, and Rt_2 = artificial residence time

Rt_1 and Rt_2 have been calculated in formula 2 and formula 3. The phosphorus loads P_1 and P_2 are taken from the Trophic Study (Table 1, step 16 and 31) and converted from milligrams to kilograms.

$$\text{P natural} + \text{P artificial} = \text{Total P load/year}$$

$$92.5 \text{ Kg} + 170.8 \text{ Kg} = 263.3 \text{ Kg/year}$$

using formula 4:

$$\frac{263.3}{P_2} = \frac{4.34}{2.96}$$

$$P_2 = 263.3 \text{ X } 2.96/4.34$$

$$P_2 = 179.58 \text{ kg/year}$$

The difference between the current P load which is 263.3 kg/year and the projected P load calculated by formula 4 is approximately 84 kg. The addition of a high quality water source to the lake could potentially reduce the phosphorous concentration by approximately 84 Kg. or by 32 percent over the residence time period.

The change in the residence time calculated above is theoretical and the actual change could be different. The effect of additional water in the basin on net outflow is unknown.

Summary of Dilution of Nutrient Concentrations

The calculations above are approximations but they show that pumping water can aid the revival of the lake. Artificial recharge of the lake is a restoration technique that can produce immediate results. If 300 GPM can be withdrawn from an aquifer on a sustained basis then the project can improve that level and the quality of the lake. All calculations were based on 350,000 cu.m. per year which is equivalent to 300 GPM for six months. If the aquifer can not sustain this volume the benefits to the lake will be reduced but not lost. The success of the dilution and flushing aspect of the project might depend on the degree of nutrient recycling from lake sediments which have prevented the recovery of some heavily polluted lakes. If Gull Lake sediments are storing high levels of phosphorous then recharging the lake with fresh water might raise the water level without a significant improvement in water quality.

5.4 Water Resource Policy and its Implications for Restoring Gull Lake

Apart from the site specific technical and environmental considerations that have already been addressed, there are uncertainties inherent in the licensing phase of the project. The supply of water on the prairies is limited and its allocation among competing uses has always been a serious issue. Growing demand for both surface and groundwater and the increasing abuses it is subjected to by industry and increased population densities, has brought water to the forefront of political attention.

The province of Manitoba now has a sustainable development policy relating to the allocation and use of water resources. Like many other provinces it is realizing that current practices and access to water have already exceeded the sustainable use of the resource in some cases and it is in the process of re-examining water policies. The current order of priorities for water use is being reviewed by the province but is not likely to change. It is also apt to be more rigidly enforced than formerly, due to increased pressure from competing users and a greater scarcity of ground and surface water. In Manitoba the water use priorities are listed in the Water Rights Act (W80) in descending priority of purpose:

1) Domestic
2) Municipal
3) Agricultural
4) Industrial
5) Irrigation
6) Other

The use of water for recreational purposes, such as the enhancement project for Gull Lake, falls into the lowest priority category. Although the much of the water withdrawn by the project, would return to groundwater after it has passed through the lake basin, the project would be scrutinized for its potential impact on existing groundwater availability and groundwater quality for existing users.

Access to water in the gravel pit, whether it is an existing well or a new one will depend on the potential infringement of existing water users. Priority within any classification of water use is based on a "first in time, first in right" system. First in time is established by the date of application not the date of the licence.

The other aspect of water allocation relevant to the project is the system of reservations which is used to preserve water supplies for future uses. The reservation for a specific purpose judged to be the greatest advantage of the residents of the province, is one specific type of reservation that, if exercised, would jeopardize the supply of water for Gull Lake.

Examples of Problems with Water Allocation

There are numerous examples of groundwater which has been impacted adversely by over allocation and which has made jurisdictions cautious over new proposals to use water.

Loni Beach, Winnipeg

Free flowing wells on the shore of lake Winnipeg have been the focus of concern until recently, when the Department of Natural Resources recommended that they be capped. This goes against the wishes of residents who naturally have come to expect the access to free flowing water in abundance and high quality, but who do not have any legal right to it.

Red Deer Alberta

Residents there are demanding tougher restrictions on housing densities and the number of wells which can be drilled in new subdivisions, due to degraded water quality and depletion of existing wells. There are also concerns about deep wells which have transected several confined aquifers and caused them to drain and dry out existing wells in the area.

Manitoba

The Assiniboine Delta Aquifer, west of Winnipeg has been the subject of considerable attention regarding its allocation. A dispute between different users has reached the point where municipalities have been denied access to water even for high priority domestic purposes.

These cases are illustrated to describe the current context in which the Gull Lake proposal will be examined. Fortunately there are fewer competing users of water in the area where the project has been proposed, however there have been concerns expressed by some individuals about how the project would affect their water supply. These concerns may be taken seriously by the province or the municipality.

5.4.1 Concerns Relating to Enhancement

In the long run Gull Lake can only be maintained in a healthy condition if the impacts of human use are diminished. The potential drawback of this project is that it could serve to perpetuate the unsustainable level of development around the lake. Pumping water can be a partial solution for the problems at Gull Lake but only if other enhancement measures are implemented in conjunction with it. Therefore it is important to view the water pumping initiative as part of a broader scheme for reviving the lake.

There is anecdotal evidence to suggest that during the 1930's and 1950's the lake level has been as low or even lower than it is now. The factor that makes the current situation different from these former low water cycles is the increased intensity of development around the lake. The fact that more severe problems are now being experienced indicates that the sustainable level of use of Gull Lake has been exceeded and this is the ultimate problem which needs to be addressed. In the short-term the population around the lake will not change and long-term changes will not be easily accomplished. The pumping initiative has been favoured in part because it can alleviate stresses on the lake now and in the long-term, but if initiatives in other areas of management are not also addressed, the future of the lake would be questionable. Ultimately a way must be found to significantly reduce the impact of the current level of use and/or reduce the intensity of use by cottagers.

5.4.2 Alternative Measures for Enhancement

If the overall objective of enhancing the lake is to raise the level then there are no alternatives or substitutes for the proposed project. There are alternatives as to how the project is executed, for example by altering the volume of water that is pumped or the duration of pumping. The greatest uncertainty associated with the project is the supply of water. There might not be a well that can sustain 300 GPM, or the flow might have to be reduced for technical reasons. These considerations along with the uncertainty of the licensing process suggest the need for appropriate alternatives as a backup.

Alternative One

If water supply becomes a problem it may be practical instead to pump a smaller volume of water that is easily sustainable. Advantages to this alternative would include:

- lower start up costs,
- lower maintenance costs,
- option to pump year-round to make up for reduced volume per unit of time,
- winter pumping which would tend to alleviate or prevent anoxic conditions and fish-kills

Alternative Two

Although relatively pure groundwater is preferable to surface water, it is probably easier to obtain a water rights licence for surface water. Provincial policy is likely to be more tolerant of low priority or non-essential uses of surface water, than it is for groundwater. Surface water is less accessible and therefore more expensive to pump and it may be of inferior quality relative to groundwater.

Alternative Three

An alternative to pumping fresh water into the lake would be to enhance the natural capacity of the lake to recharge itself. The reversal or modification of past land use changes could produce greater runoff delivery to the lake. For example, it is possible that less water is reaching the lake as a result of alterations due to road construction. The reconnection of small sections of watershed which have been isolated by construction of highway 12 and

304 offers some potential to increase the natural groundwater supply to the lake. Further research is needed to determine the feasibility of this option.

Alternative Four

If insufficient volumes of water are available to implement the project as it was conceived, then the diminished enhancement potential can be made up for by enhancement of another factor of water quality. A program of aeration either in conjunction with pumping water, or as a separate initiative, would be one example. Aeration only addresses one of the symptoms of poor water quality but it would be easier to implement and maintain than pumping water.

5.5 The Need for Further Research

The process of research into the various social and environmental aspects of water level and water quality problems at Gull Lake has indicated the need for further research. More information is necessary to complement existing and proposed initiatives for enhancing the lake. Some major areas where information is lacking are:

Groundwater/Lake Level Relationship

A more precise and consistent monitoring of the lake level would be useful in establishing its relationship to the ground water table. This would be particularly useful in defining water flows at the north end around the weir. The results of this study have raised questions that need clarifying. Much information can be gathered from existing wells, particularly deep wells, if the ground elevation and the static water level are known. The wells are there but the data is lacking.

More complete hydrological information would permit more accurate interpretation of the water balance and more technically accurate assessment of the pumping proposal either before or after it has been implemented.

Drainage Basin Research

There are significant opportunities for ongoing research which could be done by students at a reasonable cost, and for which there would be opportunities for funding. A fuller compliment of limnological parameters should be calculated i.e., water temperature, depth readings etc. Some of this work is currently being done but it relates mostly to water chemistry. If water is to be pumped into the lake it would be advisable to institute more comprehensive monitoring to identify changes in the lake that result from the project.

Meteorological monitoring is also crucial to gain a better understanding of the natural processes that affect the lake. For example, a means of estimating evaporation, rainfall, and evapo-transpiration over the watershed could be implemented. These parameters are highly site specific, and this information is almost completely lacking. Their definition is central in the estimation of the water balance of any lake and would be of considerable use in the assessment of pumping water into the lake.

6.0 Summary, Conclusions and Recommendations

6.1 Summary

In November, 1990 the Gull Lake Ratepayers Association approached the Rural Municipality of St. Clements to secure financial assistance for a feasibility study relating to a proposal to elevate the water level in Gull Lake. The Municipality in turn approached the Department of Natural Resources for similar assistance and eventually an agreement between the three parties established that the Natural Resources Institute would conduct applied research related to this matter, resulting in this report.

The primary objective of this study was to assess approaches for managing water level and water quality problems, and to provide recommendations to the aforementioned parties for improving and maintaining the water level and acceptable water quality standards at Gull Lake.

A questionnaire was distributed to lake residents to ascertain user habits and gauge attitudes and awareness relating to key management issues; a water balance for the basin was done to determine possible causes and potential remedies for the gradual decline in level of the lake; literature relating to these two areas was examined to establish the parameters for sustainable use of the lake; and an evaluations were made relating to specific strategies for restoring declining water levels in the lake.

Several conclusions follow:

6.2 Conclusions

1) The primary conclusion drawn from this research was that there are at least three management strategies. They are:

i) to maintain current initiatives for improving water quality through reductions in nutrient loading,

ii) to reduce nutrient loading further through options such as sediment removal and/or pumping water into the lake to dilute and flush excess nutrients, or,

iii) to adopt a fully integrated management strategy for the lake, including the initiatives mentioned above, that aims to restore water quality through the recruitment of direct public support and involvement in a wider range of restoration measures.

Other conclusions drawn from the research are:

2) The situation at Gull Lake is a classic example of the common property resource dilemma where people have traditionally used the resource without consideration of the cumulative effect of their actions which have had a detrimental effect on the lake.

3) Intensive recreational use and cottage development has far exceeded the sustainable capacity of the lake, placing the ecosystem under stress. The growing deficit of water at Gull Lake, and many other Manitoba lakes, through the 1980's is ultimately caused by a prolonged drought cycle which has worsened this stressed condition.

4) Over a long-term horizon the future of shallow prairie lakes appears less certain in the context of global atmospheric change including warmer average temperatures and shifting precipitation patterns. The decade of the 1980's has been the warmest on record and shortages of water may become more common over the prairies in the years to come.

5) Lake users are very concerned about the condition of Gull Lake and would like to be a part of initiatives for its rehabilitation. More specifically results of the questionnaire indicate that:

i) The majority of users believe that the lake is experiencing problems that nature alone cannot correct and they support in principle an integrated management and enhancement plan which will assist and accelerate the lake's recovery.

ii) Lake users recognize that water quality problems can only be remedied through collective action, but in many cases they are not sure what course of action is appropriate. They are uncertain about their fellow residents' willingness to act individually for the collective well-being of the lake.

iii) Water level and water quality are two issues which are most often cited as serious problems. The concerns expressed on these issues relate to such topics as algae, weed growth, water clarity, holding tanks and overdevelopment of the lakeshore.

Conclusions Relating to Water Level

6) Recent and historic fluctuations of the level in Gull Lake are normal for the prairie region except for the sudden change in lake volume coinciding with the weir installation during 1975/76.

The water balance and the other related assessments indicate:

i) There has been no appreciable escape of water from the lake which can not be accounted for by natural hydrologic and meteorologic processes, or land use changes in the basin.

ii) Climatological data and anecdotal evidence suggest that water levels during the 1930's were lower than they are now but this extreme is no longer acceptable or practical for the current intensity of use.

iii) Acceptance of the past decision to restrict the peak level of the lake may necessitate further intervention to prevent it from falling too low during dry weather cycles.

iv) Installation of the weir in 1975 escalated the onset of low water levels in the lake, while reduced inflows from precipitation and possibly increased outflows from evaporation have also been responsible for the current water deficit.

v) Stratigraphy assessments support the notion that the low-lying area at the north end of the basin is a natural subsurface discharge zone for the lake and stratigraphic profiles indicate the possibility of discharge along the south shore.

vi) Seepage is the most crucial factor determining the feasibility of the enhancement project, but the connection between local and regional groundwater is not yet defined adequately enough to accurately predict its impact on the project.

vii) Increases in lake level via artificial recharge could be dramatic if groundwater mounds on either side of the lake are also recharged by precipitation. Success in raising the water level over periods when precipitation is minimal will depend on how completely the basin is confined by till.

viii) Further or more specific conclusions about the feasibility of recharging the lake are constrained by a lack of site specific data and it is not possible to determine how much of the gradual loss of water in the lake, between 1976-1991 is due to reduced recharge and/or greater discharge.

ix) The feasibility of artificially recharging the lake cannot be accurately determined until more information is acquired relating to groundwater and seepage. Two options for acquiring this information are:

A) implementation of a systematic groundwater monitoring program prior to the enhancement project, to determine the retention capacity of the basin, or

B) implementation of the enhancement project on an experimental basis in conjunction with comprehensive monitoring of ground and surface water to determine its precise effect on the water level in the lake.

Conclusions Relating to Water Quality

7) Sewage containment is crucial to the long-term success of improving water quality, and careful management of greywater disposal by cottagers and residents will enhance this improvement.

8) A management strategy comprised of integrated environmental, and social components is required for enhancing and maintaining the ecological integrity of the lake.

9) The proposed enhancement project to recharge the lake with water from a nearby aquifer would improve water quality by decreasing water residence time and, depending on the quality of the water supply, by diluting the nutrient concentration of the lake water.

10) The degree to which artificially recharging the lake will improve water quality depends on two factors: 1) sewage and greywater containment and 2) the natural effect of nutrient recycling from lake sediments to the water column.

11) There are inherent dangers associated with pumping large volumes of water from an aquifer, with notable examples in Manitoba and the rest of Canada, therefore groundwater pumping must be carefully monitored to ensure there is no intrusion of dissolved solids within the aquifer causing irreparable harm to both the lake and groundwater. If it is used wisely groundwater could be a beneficial, and perhaps necessary, component of a

management plan for maintaining water quality in the lake.

6.3 Recommendations

6.3.1 Recommendations to Cottage Owners

1) The impact of human activities on the lake should be assessed on a collective basis rather than an individual basis and the mitigation of these impacts should be a priority of cottage owners and lake users. Cottage owners should try to be generally aware of the ways in which the maintenance of their property can have adverse or beneficial effects on the lake.

There are at least seven specific recommendations related to how this can be done.

i) Cottagers should willingly have their holding tanks inspected as often as necessary to ensure proper functioning and adherence to the related bylaw.

ii) Cottages still using septic fields to dispose of greywater should either consider diverting greywater to their holding tank or, if this is not possible, use phosphate-free detergents and prevent the escape of excessive suspended solids into septic fields.

iii) Cottage owners should avoid making physical changes to their landscape such as tree clearing, excavations, and the use of fill materials which can lead to increased erosion and deposition of material in the lake.

iv) Cottage owners should try to preserve and encourage the growth of naturally occurring trees flowers and shrubs on their property since this will reduce erosion, protect property and the lake and reduce the need for fertilizers and other chemicals which are harmful to the lake.

v) Wherever possible the use of fertilizers, pesticides and herbicides should be discontinued. If these products are deemed necessary, cottage owners should consider switching to organic and natural versions.

vi) The burning of leaves or debris close to the lake or on slopes which would allow the ash to eventually wash into the lake, should be avoided.

6.3.2 Recommendations to Rural Municipality

1) Many of the problems associated with managing the lake in a sustainable fashion have been exaggerated by the gradual overdevelopment of cottage lots around the lake. It is in the best interests of all parties that the population at Gull Lake is reduced. It is therefore recommended that some way be found to reduce the incidence of multiple dwellings on single lots, that is satisfactory to both property owners and the Municipality. Any future proposals to develop back lots along John and Arnhold Streets should be discouraged or carefully controlled.

2) A meeting of cottage owners and the municipality should be held to discuss more effective ways of implementing the sewage containment bylaw and to address issues connected to the proposed project for artificially recharging the lake.

3) Alternatives to the practice of oiling roads around Gull Lake should be found and the most feasible ones adopted, since this practice appears to be socially unacceptable and potentially harmful to the lake.

4) More thorough and rigorous inspections of holding tanks should be made by a qualified officer of the municipality, to ensure complete compliance with the sewage containment bylaw.

5) The Municipality should draft a Water Allocation Policy and consider other pertinent environmental policies which may be necessary to assist it in dealing with current and future proposals at Gull Lake and in its other wards.

6) An environmental impact assessment of the gravel pit operation west of the lake should be undertaken to ensure that the lake will not be affected by further excavations of sand, gravel or clay. This assessment may, in fact, be long overdue as the last one was completed nearly twenty years ago.

6.3.3 Recommendations to Gull Lake Ratepayers

1) Although 300 GPM withdrawn from an aquifer, if realized, would be enough to overcome most deficits in precipitation, the impact of changes in seepage and groundwater flows is unknown, therefore it is recommended that this water be pumped into the lake on an experimental basis until more detailed assessment of seepage can be completed.

An experimental approach is also recommended because of the potential dangers associated with using large volumes of groundwater. The enhancement project can only be recommended if there is a provision for regular monitoring to ensure that standards of water quality are maintained and contamination of either the aquifer or the lake does not occur and/or depletion of groundwater.

2) It is advisable that at least one public meeting be held to inform people about the enhancement project and to address any specific or related concerns that individuals or interest groups may have pertaining to it.

3) An integrated management strategy, comprised of the following components, should be implemented to address general environmental issues around the lake:

i) A mandate of maintaining environmental quality through sustainable development of the basin to prevent potentially adverse environmental impacts and enhance environmental qualities degraded by past activities.

ii) The formation of a joint management board, comprised of stakeholders, to implement and manage a sustainable development plan for the Gull Lake Basin.

iii) The implementation of monitoring programs for hydrologic and meteorologic factors affecting the lake basin, in addition to the monitoring of water quality of groundwater if it is used to recharge the lake.

iv) Maintenance of the trophic study of the lake which already monitors water quality of the lake itself.

iv) An education and awareness campaign relating to specific issues of concern to the cottagers, as well as issues which are critical to the successful implementation of the management plan put forth by the joint management board.

Other recommendations are:

4) The GLRA should capitalize further on their prominent position as a source of information for the public. The Environmental Concerns Committee, should also establish an interactive exchange of information between people at the lake and agencies with experience in the area of lake management.

5) The GLRA should consider affiliating itself with a larger lake management agency such as the North American Lake Management Society, as a way of accessing a larger body of experience related to the restoration and management of lakes.

6) Assessments should be made by the joint management board to identify areas in the watershed that could be reclaimed or enhanced as recharge zones for the water table around the lake, in case access to groundwater is delayed or the sustainable rate of withdrawal is less than expected.

7) The water engineering approach to lake restoration, while it may prove to be successful and even necessary, should not diminish the importance of the other management strategies which are recommended here.

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Appendix A

Gull Lake Questionnaire

GULL LAKE SURVEY

A Survey Associated with a Masters
Practicum Entitled:

An Assessment of Management Alternatives
for Addressing Water Level and Water Quality
Problems at Gull Lake

Submitted by Andrew Hay
in partial fulfillment
of the requirements
for the degree:
Master of Natural Resources Management

August, 1991

Natural Resources Institute
University of Manitoba
177 Dysart Road
Winnipeg, Manitoba
R3T 2N2

PURPOSE OF THE QUESTIONNAIRE

This questionnaire is designed to determine how people make use of Gull Lake and how they feel about various issues relating to the lake. The questionnaire is part of a larger study by a University of Manitoba Student who is investigating the physical processes of Gull Lake.

Gull Lake is an important recreational resource for many people and the R.M. of St. Clements, the Minister of Natural Resources and the Gull Lake Ratepayers Association would like to make sure that it continues to be an attractive destination for lake users in the future.

WHY IT IS IMPORTANT TO FILL OUT THIS QUESTIONNAIRE

Your opinions are important and will have an effect on the outcome of this study. In order that the results truly represent the thinking of people at Gull Lake it is important that you complete the questionnaire and return it as soon as possible in the postage paid envelope. It takes only a few minutes and the results will help to determine the best way of managing Gull Lake for everyone's benefit.

FUNDING AND COORDINATION OF THE STUDY

Funding for the Gull Lake Study is being provided equally by the Minister of Natural Resources and the Rural Municipality of St. Clements.

The Gull Lake Study is being conducted by a student from the Natural Resources Institute at the University of Manitoba. Completion of the study fulfills part of this student's requirements for a Masters Degree in Natural Resources Management.

CONFIDENTIALITY OF THE QUESTIONNAIRE

The results of this questionnaire are completely confidential and only the graduate student and his academic committee have access to the results. Some questions ask you for general personal information but the questionnaire does not ask you to identify yourself.and it is not the intention nor the desire of the student or the University to determine the identity of respondents.

WHAT TO DO WHEN YOU HAVE FINISHED THE QUESTIONNAIRE

When you have answered all the questions please return this questionnaire promptly to the address listed below. A postage paid envelope is supplied for your convenience.

Completed questionnaires must be returned by August 31st, 1991
addressed to the attention of:

Andrew Hay
Natural Resources Institute
University of Manitoba
177 Dysart Road
Winnipeg, Manitoba
R3T 2N2

If you would like more information on the Gull Lake study you can contact Andrew Hay at
or the Gull Lake Ratepayers Association Executive.

Appendix A

INSTRUCTIONS:

Simply place a check mark in the box next to the answer that you feel is most suitable. Some of the questions require a YES or NO answer while others offer a range of choices for you to choose from. If none of the choices are suitable for you or if you don't have the information being requested then you can leave it blank. If you need more room to write out an answer use the back of the page.

Part A: Types of Cottages and User Patterns

1) Which category best describes you?

[ ] Property owner at Gull Lake
[ ] Member of a family that owns property on Gull Lake
[ ] Renting a cottage for all or part of the season
[ ] Year round resident

If one of the above where are you located?

[ ] North shore
[ ] South shore
[ ] Off-lake

If NOT one of the above, check one below:

[ ] Visiting friends or relatives at Gull Lake
[ ] Have a trailer in the camp ground
[ ] Member or guest of the Canadian Polish Athletic Club
[ ] Other, please specify below (example day or weekend user)

____

Please note, if you or your family DO NOT own a cottage or if you are NOT renting a cottage at Gull Lake go to Question 11

2) For how many years have you owned a cottage or have you been coming to Gull Lake?

number of years: _____

3) Approximately when was your cottage built?

Year: 19___

4) On average how many people make use of your cottage on weekends?

Number of persons: _____

5) How many months of the year do you keep your cottage open?

Number of months: ____

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6) Is your cottage equipped with any of the following?
   [ ] Automatic dishwasher
   [ ] Washing machine
   [ ] Bathtub
   [ ] Shower

7) What is the source of your water for general purposes?
   [ ] Shallow well
   [ ] Deep well
   [ ] Lake water

8) What is the source of your Drinking Water?
   [ ] Same as above
   [ ] Same as above with filtration
   [ ] Bring water from somewhere else (example: from Winnipeg)

9) Do you discharge some or all of your gray water into a gray water field?
   [ ] Some but not all of the gray water goes into a field
   (please explain)________________________________
   [ ] All of the gray water goes into a field
   [ ] All of the gray water goes into a holding tank

Part B: General Habits of Lake Users

10) Which of the following do you use in the maintenance of your property at Gull Lake?
   [ ] Fertilizers
   [ ] Herbicides
   [ ] Pesticides
   [ ] Lawn or garden sprinklers

11) Rank as many of the following activities that apply to you while you are at Gull Lake? (starting with 1 for those you do most often up to 8 for least often)
   ____ swimming
   ____ power boating
   ____ sailing
   ____ sailboarding
   ____ canoeing
   ____ water-skiing
   ____ non-water related leisure activities ____ Other (specify)

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12) Do you agree that the following activities should be regulated at Gull Lake? (SA=strongly agree; A= agree; N=neutral; D=disagree; SD=strongly disagree)

		SA	A	N	D	SD
a)	Shampooing in the lake	[ ]	[ ]	[ ]	[ ]	[ ]
b)	Watering trees, plants or lawns	[ ]	[ ]	[ ]	[ ]	[ ]
c)	Washing cars or boats	[ ]	[ ]	[ ]	[ ]	[ ]
d)	Using fertilizers	[ ]	[ ]	[ ]	[ ]	[ ]
e)	Using herbicides	[ ]	[ ]	[ ]	[ ]	[ ]
f)	Using pesticides	[ ]	[ ]	[ ]	[ ]	[ ]
g)	Other ________	[ ]	[ ]	[ ]	[ ]	[ ]

Part C: Water Quality and Water Level

13) How would you rate the quality of **Well Water** that you use at Gull Lake?

[ ] Very good
[ ] Moderately good
[ ] Satisfactory
[ ] Less than satisfactory
[ ] Poor

14) Have you noticed any significant changes in **Lake Water quality** over the last several years?

[ ] Water quality is much better
[ ] Water quality has improved somewhat
[ ] Water quality is about the same
[ ] Water quality has worsened somewhat
[ ] Water quality is much worse

15) Have you noticed any significant changes in **Lake Levels** over the last few years?

[ ] Level has gone up significantly
[ ] Level has gone up somewhat
[ ] Level is about the same
[ ] Level has gone down somewhat
[ ] Level has gone down significantly

16) How much do you agree that the following issues are a problem at Gull Lake? (SA=strongly agree; A= agree; N=neutral; D=disagree; SD=strongly disagree)

		SA	A	N	D	SD
a)	Water depth	[ ]	[ ]	[ ]	[ ]	[ ]
b)	Algae growth	[ ]	[ ]	[ ]	[ ]	[ ]
c)	Weed growth	[ ]	[ ]	[ ]	[ ]	[ ]
d)	Water clarity	[ ]	[ ]	[ ]	[ ]	[ ]
e)	"Swimmers itch"	[ ]	[ ]	[ ]	[ ]	[ ]
f)	Pollution of the water	[ ]	[ ]	[ ]	[ ]	[ ]
g)	Other (please specify)	[ ]	[ ]	[ ]	[ ]	[ ]

17) How much do you agree with the following as potential management options for Gull Lake? (SA=strongly agree; A= agree; N=neutral; D=disagree; SD=strongly disagree)

		SA	A	N	D	SD
a)	A water conservation program should be implemented	[ ]	[ ]	[ ]	[ ]	[ ]
b)	A water pollution control program should be implemented	[ ]	[ ]	[ ]	[ ]	[ ]
c)	Water conservation and pollution control should be implemented	[ ]	[ ]	[ ]	[ ]	[ ]
d)	Nature will fix any problems with the lake	[ ]	[ ]	[ ]	[ ]	[ ]
e)	Everything is normal, there is no problem	[ ]	[ ]	[ ]	[ ]	[ ]
f)	Natural processes are not enough and an enhancement project of some kind is needed to ensure the health of Gull Lake,	[ ]	[ ]	[ ]	[ ]	[ ]

18) Briefly explain why you would Oppose or Favour an enhancement project for Gull Lake. (please use the back of the page)

____

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19) What is your main source of information about Gull Lake?

(check any that apply)
[ ] Newspapers
[ ] Word of Mouth
[ ] Government publications or brochures
[ ] Annual meetings at Gull Lake
[ ] Other, (please specify)________________________________

20) What year were you born?

Year: 19___

21) What is your sex?

[ ] Female

[ ] Male

Thank-you for taking the time to fill out this questionnaire. Please make sure you have answered all the questions that apply to you. If you would like to make any comments about the questionnaire or about some of the issues mentioned, please do so in the space below.

Appendix B

Selected Questionnaire Comments

General Comments

I believe this lake needs help and soon! (#16)

The lake is dying and so are property values.

Drain the lake and have a football field. (#0)

Some people are still washing their hair in the lake. (#138)

In my honest opinion we are too late, this lake is doomed like his namesake in Sask. which is a big dry hole. This lake has been studied for 20 years with no improvement to date.(#47)

The lake is overdeveloped, a moratorium should be placed on more development until the lake recovers. (#32)

Ice fishers leave their debris behind to sink with the ice. I Have also seen people rake up piles of leaves, wait for the ice and then take them out onto the lake.(#111)

The itch has posed a great problem for every one who swims in Gull Lake. Couldn't something be put in the lake to stop this? (#149)

Am concerned about the future of the lake for ourselves and our children's children. (#162)

When I first came here to Gull Lake the water level was high and the water was beautifully clear. (#16)

Please explain if the gravel pit affects the water level; through the ratepayers association. (#23)

I believe that the gravel pit has spoiled our lake. (#22)

The water level is so low, we have atleast 20m more beach than twenty years ago. (#90)

I'm told this has literally no bearing on lake level. (re watering trees, plants, lawns) (#120)

Collective Action

Apathy is a problem at Gull Lake, too many people let the lake get like it is before doing anything about it. (verbal comment)

Every step must be taken to keep lake water as pure as possible to make certain future generations will enjoy the benefits we had in the past. (#101)

Any steps taken should be a result of consensus of atleast 66% of lakefront property owners. (#149)

The horrendous apathy of the cottage owners at Gull Lake is absolutely appalling. (#147)

The lake has been thoroughly neglected in the past 15-20 years. (#164)

I strongly support any action which would completely ban motorized water craft; hair, body, laundry, and car washing in the lake; and the trucking in of sand for beaches. (#4)

Ecosystem Awareness:

I'm skeptical that enough people can be persuaded to work with nature to help the lake recover. (verbal comment)

Perhaps a good idea would be to put perch and jack back in the lake. These fish seem to be natural to our lake and trying to put trout, or any other species in, is a waste of time and money. (#33)

You can't fool around with nature. In the last four years we have had drought, so the lake is down, leave it alone. (#131)

People who are bringing truckloads of sand for their beaches every year are hugely speeding up this aging process. (#4)

The lake water level was on a 7 year cycle....We never had such long periods of drought before 1970 as we experienced the last few years (#101)

In 1954 to in the 60's the lake level was a lot lower than it has ever been. The old timers have said that the lake levels go up and down in 40 year cycles. (#111)

Its our feeling that nature, not man, is closing it (the lake) down the fastest with drought, low snow. Nature is here 365 days, us only 8 weeks per year. (#137)

There is little or no phosphates or nitrates present in the water which means sewage has not been entering the lake. Algae growth has come directly in growth in size and volume of boats. (#158)

Enhancement project:

There is no way they can get enough water from the gravel pit to fill Gull Lake, they (B.A. Materials) don't have enough for their own use. (#3)

Pumping from an alternate source, to raise and maintain the water level, is the only possible solution. (#92)

Many people fear that any enhancement project will further increase our uneven tax burden. (#2)

Property owners should be made to pay for these enhancements by taxation. (#67)

We feel that as long as the pollution entering the lake is controlled nature will do the rest. (#17)

Let nature take its course. (#8)

One enhancement project that didn't work was putting rainbow trout in the lake. All that did was bring in a bunch of outside people (to fish) that didn't care about the lake. (#6)

Pumping water from an aquifer is very expensive and would be a waste of time and money. (#33)

I am in favour of and enhancement project because it is the cottagers and the overbuilding of cottages that have caused the problem in the first place. The water quality will never improve naturally, it will require human intervention. (#34)

Would agree to an enhancement program if it is proven that the conditions that exist are a direct result of the cottage users over a period of years. (#48)

Favour enhancement: Need to improve the quality of water by use of deep wells or some other matter of raising the water level. Fish should be put into the lake each year and a check made to see how they are developing. (#49)

What is needed now is some concrete hydrological information about the water quality and geology of Gull lake that will enable us to determine what this enhancement project should include. (#54)

Constant vigilance is needed to prevent total disaster and if rainfall persists below average we might need to explore further the feasibility of adding water and increasing aeration, perhaps year-round. (#64)

Too much restriction of activities will decrease enjoyment in the area. An enhancement project would or could supplement natural processes and still permit maximum enjoyment. (#97)

Although water levels may be cyclical over the years, measures still could be taken to increase the levels. (#103)

While the efforts of council on behalf of the lake are appreciated, it appears that council gets carried away in its zeal to protect the lake and moves too hastily to solve what historical studies might show are not problems at all. (#110)

Far too often I have heard long time residents of Gull Lake remark that what we are going through is cyclical and the lake will return to a healthy condition in due time. This I do not support...

I feel an increase in the level of the water in the lake would help the quality of water. (#119)

I feel any enhancement program should be coupled with an enforcement program. It will unfortunate indeed if its (the lake) life cycle is shortened by our own stupidity and selfish behavior. (#120)

An enhancement project is needed for Gull Lake to bring the level of the lake back up atleast 2 feet so some sort of fish can survive in the winter months. (#134)

I am prepared to do whatever it takes to protect my investment. (#135)

We believe raising its level is a hot idea to ensure its life for our children. If the government defaults we are going to suggest we do it, after all its our lake not a park. (#137)

We favour a three prong approach to a water enhancement project. 1) Attempt to replace the water that was negligently drained through the drainage ditch built in 1984. 2) harvest the weeds in a manner similar to weed farming presently being attempted by the City of Winnipeg in various man-made ponds throughout Winnipeg. 3) vacuum suction the weed bed areas of the lake to eliminate the soil the weeds grow in. (#147)

The level of the lake should be increased by pumping if we continue to have dry years.

(#148)

If the water level was raised we feel it would reduce the algae. (#149)

We are in favour of any program that would enhance and improve the quality of water in Gull Lake. (#150)

If what is meant by an enhancement program is pumping, then the only known available quantity of water would be Lake Winnipeg. (#161)

In favour of an enhancement project so we have some control of water level and quality. (#162)

The lake level must be elevated by two/three feet by artificial means. (#169)

We have just come through several years of drought and low snow fall. Rains in late June, early July of 1991 brought the lake level up substantially (I estimate (9-10").

Definitely not too much in favour of water levels being raised artificially; nature usually has a way of taking care of its own. (#174)

I think the pumping option may have gone on the back burner since this summer's rain has demonstrated what could recharge the lake.

We need to get the water level up so fish will not die over winter; also plough the lake and oxygenate it through the winter. (#175)

Education and Awareness:

People (day users) will throw things into the lake and abuse it. (#6)

I have been a summer user of the lake all my life and my parents before me since 1932. Over the years we have noticed with concern the declining water quality. However we, as most people, feel somewhat helpless in improving the situation.- I feel that most people maintain the attitude that this situation will go away. However, that is not reasonable. (#27)

...Somewhere between 50-98% of humans haven't a clue as to something being wrong, what needs to be done about it, the consequences etc.and even if they did they, for the most part, feel the problems being exaggerated, applies only to others, is beyond hope and too costly to cure. For the foregoing reasons I support an "enforced" enhancement program.(#80)

While most cottagers are concerned about the lake, there needs to be more of a concerted effort where everyone is doing their share towards environmental issues. (#103)

The situation (water quality etc.) may not change if just left up to individuals. (#103)

People are washing their boats, their dogs, themselves, barbecue grills and even baby diapers; and who knows what soaps they are using? (#69)

Motor Boats:

Restrict the use of high powered motorboats. The lake is too small and shallow. Some of the motorboats churn up the water causing all sorts of problems.(#87)

Current leisure water activities should not be hampered in any way (#149)

Theres too many power boats on the lake, they stir up the bottom and increase evaporation (verbal comment)

On summer weekends the boat traffic is too heavy. This is a potentially dangerous situation. Non-motorized water sports ie. canoeing, kyaking, rowing, pedaling should be substituted for water-skiing etc. This proposal may eventually see a decrease in the number of people using the lake which could enhance water quality. (#90)

We believe the large number of power boats contribute to the lake problem and feel that this should somehow be regulated. (#21)

Another thing which helps to destroy the water clarity, warm the water and speed up weed growth, is motor boats. (#4)

I would particularly like to see restrictions on motor boats on such a small lake...the water quality seems to improve during the week when big boats are not on the lake. (#103)

I believe the algae growth in the lake is caused by the motor boats stirring up the silt from the lake bottom. (#158)

Holding tanks:

I don't see how my outhouse can pollute the lake when my well water is still fit to drink. (verbal comment)

It was overheard that one individual intends to use it (a septic field) once the present holding tank requirements blow over. (#87)

I also feel that grey water should be contained in holding tanks, as new generations of cottage owners rely on modern conveniences such as dishwashers and washing machines. (#132)

I strongly favour an enhancement project but only after every cottager has been made to put in a holding tank for sewage, and it is enforced. There are half-dozen cottagers on our side of the lake (south shore) who have no intention of putting in a holding tank. (#117)

The need for controls exists at Gull Lake and its urgency is of the utmost. (#135)

Approximately 50% of the north shore is breaking this law. I know of one person who has an old fuel oil tank in the ground for over 20 years. He pumps his on the grass, says "it makes the grass greener" (signed pissed off) (#151)

I understand all kinds of people punch holes in the bottom of their holding tank so it won't fill up and all kinds of people still have functioning septic fields. (#175)

Many are not complying with this by-law....The main building installs a holding tank while the satellite buildings continue to use unvaulted out houses. (#172)

Appendix C

Results of IBM Data Analysis of Questionnaire

Appendix C

The original 21 questions in the questionnaire were broken down into 48 "items" for analysis of the results. All questions which originally had several parts were divided into as many parts for analysis. For example question 16 had parts a) through g) so it is became 7 items (items 30 through 36) for the data analysis. The frequencies of responses for the 48 items follow the list below and the key for the frequencies is at the end of appendix C

"Item" Identification List

1 Habitation status of respondent
2 Location, relative to lake
3 Years at Gull Lake
4 Age of cottage
5 Number of users on weekends
6 Number months cottage open
7 Dishwasher/washer, bathtub
8 General water source
9 Drinking water source
10 Grey water disposal
11 Fertilizers
12 Herbicides
13 Pesticides
14 Garden Sprinklers
15 Swimming
16 Waterski/power boat
17 Non-motorized activities
18 Non-water related activities
19 Other activities
20 Shampooing
21 Watering gardens
22 Washing cars/boats
23 Regulate fertilizers
24 Regulate herbicides
25 Regulate pesticides
26 Regulate "other" activities
27 Well water quality
28 Lake water quality
29 Lake level changes
30 Water depth a problem
31 Algae a problem
32 Weed growth a problem
33 Water clarity a problem
34 Swimmers itch a problem
35 Water pollution a problem
36 "other" problems perceived
37 Conservation program
38 Pollution program
39 Conserv.& Poll.program
40 Nature fix
41 There is no Problem
42 Enhancement proj. needed
43 Newspapers
44 Word of mouth
45 Government publications
46 Annual meetings
47 Age of respondent
48 Sex of respondent

Appendix C

Frequencies for 48 Item Questionnaire Analysis

Item No.	value	cases	percent	accumulated	mean	variance	std.dev	median	mode	missing cases
1	5	1	0.6	100.0	1.37	1.03	1.01	1.08	1	0
	4	15	8.4	99.4						
	3	5	2.8	91.1						
	2	4	2.2	88.3						
	1	154	86.0	86.0						
Total		179	100.0							
2	3	20	13.2	100.0	1.79	0.43	0.66	1.8	2	27
	2	80	52.6	86.8						
	1	52	34.2	34.2						
Total		152	100.0							
3	5	17	9.9	100.0	3.21	1.35	1.16	3.5	4	7
	4	69	40.1	90.1						
	3	37	21.5	50.0						
	2	31	18.0	28.5						
	1	18	10.5	10.5						
Total		172	100							
4	5	48	29.3	100.0	3.39	1.97	1.4	3.65	5	15
	4	40	24.4	70.7						
	3	26	15.9	46.3						
	2	28	17.1	30.5						
	1	22	13.4	13.4						
Total		164	100.0							
5	4	1	0.6	100.0	1.49	0.46	0.68	1.32	1	7
	3	15	8.7	99.4						
	2	51	29.7	90.7						
	1	105	61	61.0						
Total		172	100							
6	4	35	20.2	100.0	2.48	0.8	0.9	2.24	2	6
	3	26	15.0	79.8						
	2	99	57.2	64.7						
	1	13	7.5	7.5						
Total		173	100.0							
7	2	35	47.3	100.0	1.47	0.25	0.5	1.45	1	105
	1	39	52.7	52.0						
Total		74	100.0							
8	3	71	44.1	100.0	2.02	0.86	0.93	2.07	3	18
	2	22	13.7	55.9						
	1	68	42.2	42.2						
Total		161	100.0							

Appendix C

Item No.	value	cases	percent	accumulated	mean	variance	std.dev.	median	mode	missing cases
9	3	113	66.5	100.0	2.36	0.84	0.92	2.75	3	9
	2	5	2.9	33.5						
	1	52	30.6	30.6						
Total		170	100.0							
10	3	63	37.5	100.0	2.2	0.51	0.72	2.22	2	11
	2	75	44.6	62.5						
	1	30	17.9	17.9						
Total		168	100.0							
11	2	146	86.4	100.0	1.86	0.12	0.34	1.92	2	10
	1	23	13.6	13.6						
Total		169	100.0							
12	2	152	89.9	100.0	1.9	0.09	0.3	1.94	2	10
	1	17	10.1	10.1						
Total		169	100.0							
13	2	154	91.1	100.0	1.91	0.08	0.28	1.95	2	10
	1	15	8.9	8.9						
Total		169	100.0							
14	2	77	45.6	100.0	1.46	0.25	0.5	1.42	1	10
	1	92	54.4	54.4						
Total		169	100.0							
15	2	19	10.8	100.0	1.11	0.1	0.31	1.06	1	3
	1	157	89.2	89.2						
Total		176	100.0							
16	2	98	55.7	100.0	1.56	0.25	0.5	1.6	2	3
	1	78	44.3	44.3						
Total		176	100.0							
17	2	73	41.5	100.0	1.41	0.24	0.49	1.35	1	3
	1	103	58.5	58.5						
Total			100.0							
18	2	64	36.4	100.0	1.36	0.23	0.48	1.29	1	3
	1	112	63.6	63.6						
Total		176	100.0							
19	2	132	76.7	10.0	1.77	0.18	0.42	1.85	2	7
	1	40	23.3	23.3						
Total		172	100.0							

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Item No.	value	cases	percent	accumulated	mean	variance	std.dev.	median	mode	missing cases
20	5	25	14.0	100.0	1.7	2	1.41	1.15	1	1
	4	2	1.1	86.0						
	3	3	1.7	84.8						
	2	12	6.7	83.1						
	1	136	76.6	76.4						
Total		178	10.0							
21	5	33	19.0	100.0	3.07	1.77	1.33	3.1	3	5
	4	31	17.8	81.0						
	3	57	32.8	63.2						
	2	22	12.6	30.5						
	1	31	17.8	17.8						
Total		104	100.0							
22	5	25	14.4	100.0	2.35	2.19	1.48	1.87	1	5
	4	16	9.2	85.6						
	3	34	19.5	75.4						
	2	19	10.9	56.9						
	1	80	46.0	46.0						
Total		174	100.0							
23	5	17	9.7	100.0	2.03	1.81	1.35	1.42	1	4
	4	10	5.7	90.3						
	3	29	16.6	84.6						
	2	24	13.7	68.0						
	1	95	54.3	54.3						
Total		175	100.0							
24	5	20	11.4	100.0	2.01	2.02	1.42	1.35	1	3
	4	13	7.4	88.6						
	3	20	11.4	81.3						
	2	19	10.8	69.9						
	1	104	59.1	59.1						
Total		176	100.0							
25	5	18	10.5	100.0	2.07	1.87	1.37	1.46	1	7
	4	11	6.4	89.5						
	3	26	15.1	83.1						
	2	27	15.7	68.0						
	1	90	52.3	52.3						
Total		172	100.0							
26	5	2	3.9	100.0	1.49	1.03	1.02	1.15	1	128
	4	1	2.0	96.1						
	3	5	9.8	94.1						
	2	4	7.8	84.3						
	1	39	76.5	76.5						
Total		51	100.0							

Item No.	value	cases	percent	accumulated	mean	variance	std.dev.	median	mode	missing cases
27	5	29	22.1	100.0	2.86	2.36	1.54	2.83	1	48
	4	21	16.0	77.9						
	3	23	17.6	61.8						
	2	19	14.5	44.3						
	1	39	29.8	29.8						
Total		131	100.0							
28	5	115	66.9	100.0	4.58	0.45	0.67	4.75	5	7
	4	43	25.0	33.1						
	3	12	7.0	8.1						
	2	2	1.2	1.2						
	1	0	0.0	0.0						
Total		172	100.0							
29	5	135	77.6	100.0	4.6	0.83	0.91	4.86	5	5
	4	23	13.2	22.4						
	3	6	3.4	9.2						
	2	5	2.9	5.7						
	1	5	2.9	2.9						
Total		174	100.0							
30	5	5	3	100.0	1.6	0.92	0.96	1.27	1	11
	4	3	1.8	97.0						
	3	18	10.7	95.2						
	2	33	19.6	84.5						
	1	109	64.9	64.9						
Total		168	100							
31	5	6	3.5	100.0	1.47	0.83	0.91	1.2	1	8
	4	1	0.6	96.5						
	3	11	6.4	95.9						
	2	31	18.1	89.5						
	1	122	713.0	71.3						
Total		171	100.0							
32	5	5	2.9	100.0	1.49	0.8	0.89	1.24	1	7
	4	2	1.2	97.1						
	3	11	6.4	95.9						
	2	37	21.5	89.5						
	1	117	68.0	68.0						
Total		172	100.0							
33	5	4	2.4	100.0	1.48	0.73	0.85	1.25	1	15
	4	2	1.2	97.6						
	3	9	5.5	96.3						
	2	39	23.8	90.9						
	1	110	67.1	67.1						
Total		164	100.0							

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Item No.	value	cases	percent	accumulated	mean	variance	std.dev.	median	mode	missing cases
34	5	6	3.6	100.0	1.89	1.19	1.09	1.49	1	12
	4	7	4.2	96.4						
	3	34	20.4	92.2						
	2	36	21.6	71.9						
	1	84	50.3	50.3						
Total		167	100.0							
35	5	4	2.5	100.0	1.55	0.9	0.95	1.24	1	17
	4	5	3.1	97.5						
	3	14	8.6	94.4						
	2	30	18.5	9.4						
	1	109	67.3	85.8						
Total		162	100.0	67.3						
36	5	0	0.0	100.0	1.24	0.37	0.6	1.09	1	146
	4	0	0.0	100.0						
	3	3	9.1	100.0						
	2	2	6.1	90.9						
	1	28	84.8	84.8						
Total		33	100.0							
37	5	6	3.7	100.0	2.04	1.25	1.12	1.81	1	18
	4	12	7.5	96.3						
	3	32	19.9	88.8						
	2	44	27.3	68.9						
	1	67	41.6	41.6						
Total		161	100.0							
38	5	2	1.2	100.0	1.43	0.63	0.79	1.22	1	16
	4	5	3.1	98.8						
	3	4	2.5	95.7						
	2	39	23.9	93.3						
	1	113	69.3	69.3						
Total		163	100.0							
39	5	8	5.3	100.0	1.82	1.28	1.13	1.44	1	29
	4	8	5.3	94.7						
	3	13	8.7	89.3						
	2	41	27.3	80.7						
	1	80	53.3	53.3						
Total		150	100.0							
40	5	99	62.3	100.0	4.38	0.9	0.95	4.7	5	20
	4	35	22.0	37.7						
	3	14	8.8	15.7						
	2	9	5.7	6.9						
	1	2	1.3	1.3						
Total		159	100.0							

Appendix C

Item No.	value	cases	percent	accumulated	mean	variance	std.dev.	median	mode	missing cases
41	5	125	80.1	100.0	4.69	0.52	0.72	4.88	5	23
	4	19	12.2	19.9						
	3	9	5.8	7.7						
	2	1	0.6	1.9						
	1	2	1.3	1.3						
Total		156	100.0							
42	5	2	1.2	100.0	1.49	0.69	0.83	1.25	1	10
	4	5	3.0	98.8						
	3	10	5.9	95.8						
	2	40	23.7	89.9						
	1	112	66.3	66.3						
Total		169	100.0							
43	2	155	88.6	100.0	1.89	0.1	0.32	1.94	2	4
	1	20	11.4	11.4						
Total		175	100.0							
44	2	59	33.7	100.0	1.34	0.22	0.47	1.25	1	4
	1	116	66.3	66.3						
Total		175	100.0							
45	2	147	84.5	100.0	1.84	0.13	0.36	1.91	2	5
	1	27	15.5	15.5						
Total		174	100.0							
46	2	59	33.9	100.0	1.34	0.24	0.49	1.26	1	5
	1	115	66.1	66.1						
Total		174	100							
47	4	76	44.7	100.0	3.22	0.65	0.81	3.34	4	9
	3	57	33.5	55.3						
	2	35	20.6	21.8						
	1	2	1.2	1.2						
Total		170	100.0							
48	3	8	5.1	100.0	1.46	0.41	0.64	1.33	1	5
	2	61	34.9	94.9						
	1	105	60.0	60.0						
Total		174	100.0							

1 Habitation status, respondent
1 property owner
2 renting
3 Trailer or campground
4 year-round resident
5 other

2 Location relative to lake
1 north shore
2 south shore
3 off-lake

3 Years at Gull Lake
1 less than 10 yrs
2 11-20 yrs
3 21-30 yrs
4 31-50 yrs
5 more than 50 yrs

4 Age of cottage
1 1980's
2 1970's
3 1960's
4 1950's
5 1940's or earlier

5 Number of users on weekends
1 up to 4 persons
2 5 to 7 persons
3 8 or more persons

6 Number months cottage open
1 3 or less
2 4-6
3 7-8
4 all year

7 Dishwasher/washer, bathtub
1 dishwasher&/or washing mach.
2 bathtub

8 General water source
1 shallow well
2 deep well
3 lake water

9 Drinking water source
1 same as above
2 same as above w/filtration
3 bring water in

10 Grey water disposal
1 some but not all
2 all grey water goes to field
3 all grey water to holding tank

11 Fertilizers
1 yes
2 no

12 Herbicides
1 yes
2 no

13 Pesticides
1 yes
2 no

14 Garden Sprinklers
1 yes
2 no

15 Swimming in Gull Lake
1 yes
2 no

16 Waterski/power boat
1 yes
2 no

17 Non-motorized activities
1 yes
2 no

18 Non-water related activities
1 yes
2 no

19 Other activities
1 yes
2 no

20 Shampooing
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

21 Watering gardens
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

22 Washing cars/boats
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

23 Regulate fertilizers
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

24 Regulate herbicides
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

25 Regulate pesticides
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

26 Regulate "other" activities
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

27 Well water quality
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

28 Lake water quality
1 w.q. much better
2 w.q. improved somewhat
3 w.q. about the same
4 w.q. worsened somewhat
5 w.q. much worse

29 Lake level changes
1 level up significantly
2 level up somewhat
3 level about the same
4 level down somewhat
5 level down significantly

30 Water depth a problem
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

31 Algae a problem
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

32 Weed growth a problem
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

33 Water clarity a problem
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

34 Swimmers itch a problem
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

35 Water pollution a problem
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

36 "Other" problems perceived
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

37 Conservation program
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

38 Pollution program
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

39 Conserv.& Poll.program
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

40 Nature fix
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

41 There is no problem
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

42 Enhancement proj. needed
1 strongly agree
2 agree
3 neutral
4 disagree
5 strongly disagree

43 Newspapers
1 yes
2 no

44 Word of mouth
1 yes
2 no

45 Government publications
1 yes
2 no

46 Annual meetings
1 yes
2 no

47 Age of respondent
1 25 yrs or less
2 26-40 yrs
3 41-60 yrs
4 over 60 yrs

48 Sex of respondent
1 male
2 female
3 joint effort

Appendix D

Monthly and Annual Precipitation Summaries

and

Water Balances

Table D-2 Annual Water Balance at Gull Lake using Pine Falls Precipitation Records

1	2	3	4	5	6	7	8	9
Year	Lake volume	Precipitation		Lake evap	Potential evapotrans	Expected volume	Actual volume	Net Outflow
Jul 1-	July 1	**Pine Falls**				-Jun 30	-Jun 30	(#8)-(#7)
Jun 30	(cu.m.)	(metres)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)
1972-73	4,253,800	.6324	2,486,597	582,537	838,234	5,319,626	4,155,167	-1,164,459
1973-74	4,155,167	.6945	2,730,774	715,965	809,591	5,360,385	4,438,003	-922,382
1974-75	4,438,003	.5335	2,097,722	476,323	710,335	5,349,067	4,537,961	-811,106
1975-76	4,537,961	.5833	2,293,536	584,659	724,400	5,522,438	4,128,095	-1,394,343
1976-77	4,128,095	.4341	1,706,881	704,362	591,555	4,539,059	3,787,140	-751,919
1977-78	3,787,140	.6129	2,409,923	753,853	833,559	4,609,651	4,120,144	-489,507
1978-79	4,120,144	.5908	2,323,026	562,400	626,267	5,254,503	4,147,784	-1,106,719
1979-80	4,147,784	.3754	1,476,073	677,248	423,677	4,522,932	3,893,345	-629,587
1980-81	3,893,345	.5108	2,008,466	534,931	676,297	4,690,583	3,795,848	-894,735
1981-82	3,795,848	.4168	1,638,858	592,170	538,058	4,304,478	3,637,808	-666,670
1982-83	3,637,808	.6401	2,516,873	606,140	851,320	4,697,221	3,905,651	-791,570
1983-84	3,905,651	.4449	1,749,347	695,118	560,843	4,399,037	3,621,300	-777,737
1984-85	3,621,300	.4942	1,943,194	610,887	515,098	4,438,509	3,501,653	-936,856
1985-86	3,501,653	.5181	2,037,169	612,238	626,781	4,299,803	3,648,183	-651,620
1986-87	3,648,183	.4359	1,713,959	604,957	641,006	4,116,179	3,450,539	-665,640
1987-88	3,450,539	.3918	1,540,558	618,522	674,113	3,698,462	3,225,822	-472,640
1988-89	3,225,822	.5933	2,332,856	651,666	841,734	4,065,278	3,342,251	-723,027
1989-90	3,342,251	.4901	1,927,073	657,822	743,506	3,867,996	3,269,175	-598,821
1990-91	3,269,175	.4963	1,951,452	617,000	640,557	3,963,070	3,258,195	-704,875
Totals		9.8892	38,884,334	11,858,798	12,866,931			-15,154,210
19 year mean	3,834,719	.5205	2,046,544	624,147	677,207	4,579,909	3,782,319	-797,590
							mean seepage since 1979	-709,481

Table D-3 Monthly Precipitation at Seven Stations Near Gull Lake

1972/73	Beausjour	Brokenhd.	Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	54.9		51.8	67.8	34.0	98.6	52.3	59.9
AUG	169.9		45.0	73.4	105.9	71.1	84.6	91.7
SEP	54.6		74.4	71.4	71.6	78.0	42.7	65.5
OCT	51.3		21.1	30.5	49.0	32.0	23.4	34.6
NOV	26.9		14.0	38.9	25.1	29.5	8.6	23.8
DEC	47.2		36.1	40.6	34.0	47.0	22.4	37.9
JAN	2.8		1.8	1.3	2.5	1.3	1.3	1.8
FEB	4.6		12.2	1.3	13.7	14.0	5.8	8.6
MAR	3.6		12.7	6.4	8.6	7.6		7.8
APR	32.8		38.9	30.2	33.8	35.6	31.0	33.7
MAY	84.8		29.5	23.9	23.1	14.5	45.5	36.9
JUN	248.2		169.4	119.1	215.9	203.2	131.3	181.2
total	**781.6**		**506.9**	**504.8**	**617.2**	**632.4**	**448.9**	**583.3**

1973/74	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	74.9		40.6	37.6	97.5	68.1	59.9	63.1
AUG	98.6		148.8	110.0	92.7	117.9	66.0	105.7
SEP	111.8		118.1	58.7	148.3	104.1	72.6	102.3
OCT	70.1		76.7	66.0	77.5	71.6	52.3	69.0
NOV	42.4		60.2	59.7	43.4	58.4	42.7	51.1
DEC	13.5		25.9	58.6	21.3	21.6	11.2	25.4
JAN	29.7		40.9	25.9	49.8	43.2	29.2	36.5
FEB	14.5		10.7	10.2	13.2	10.2	7.4	11.0
MAR	15.7		26.4	39.4	25.9	25.4	11.4	24.0
APR	57.4		63.0	36.1	79.2	47.2	53.1	56.0
MAY	94.0		83.1	157.2	139.4	95.0	133.3	117.0
JUN	26.4		30.2	56.1	25.9	31.8	22.6	32.2
total	**649.0**		**724.6**	**715.5**	**814.1**	**694.5**	**561.7**	**693.2**

1974/75	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	30.7		25.7	77.0	37.1	45.5	22.4	39.7
AUG	101.1		86.4	93.0	106.7	104.1	84.3	95.9
SEP	42.2		85.3	54.1	69.3	81.8	61.7	65.7
OCT	3.3		6.1	5.8	9.9	13.5	4.8	7.2
NOV	7.4		9.7	16.0	19.6	20.3	6.1	13.2
DEC	9.1		6.6	5.1	8.6	10.9	8.4	8.1
JAN	33.3		49.3	36.1	41.4	40.6	46.0	41.1
FEB	23.4		19.1	14.0	22.6	15.2	10.4	17.5
MAR	38.1		28.7	16.0	38.1	20.3	26.2	27.9
APR	19.3		36.3	27.7	31.2	23.1	34.0	28.6
MAY	56.4		37.3	48.0	70.1	46.7	44.7	50.5
JUN	69.9		87.6	117.6	192.5	111.5	121.4	116.8
total	**434.2**		**478.1**	**510.4**	**647.1**	**533.5**	**470.4**	**512.3**

Table D-3 Monthly Precipitation at Seven Stations Near Gull Lake

1975/76	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	4.3		63.2	26.4	30.0	27.9	20.6	28.7
AUG	112.8		119.1	108.2	110.2	154.4	141.2	124.3
SEP	49.8		50.3	36.3	60.2	56.6	31.8	47.5
OCT	27.9		38.6	20.3	32.5	49.0	35.8	34.0
NOV	21.1		14.7	8.9	17.5	16.3	15.2	15.6
DEC	8.4		21.3	8.1	25.1	26.2	17.3	17.7
JAN	35.8		21.6	53.3	33.5	29.2	21.8	32.5
FEB	24.1		24.1	9.4	24.6	16.0	6.6	17.5
MAR	31.0		39.9	35.6	27.2	27.9	23.6	30.9
APR	43.2		40.4	30.2	40.4	43.9	30.5	38.1
MAY	7.6		8.9	7.4	15.2	9.7	11.7	10.1
JUN	234.2		125.5	154.9	172.2	126.2	179.1	165.4
total	**600.2**		**567.6**	**499.0**	**588.6**	**583.3**	**535.2**	**562.3**

1976/77	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	63.8		17.5	28.2	65.3	31.0	13.2	36.5
AUG	57.2		26.9	22.9	37.8	41.1	28.2	35.7
SEP	6.9		5.6	10.7	7.6	9.1	5.1	7.5
OCT	2.3		5.3	1.3	8.9	21.8	6.1	7.6
NOV	8.6		5.1	1.3	4.8	10.2	1.5	5.3
DEC			22.4	10.4	24.9	20.3	26.7	20.9
JAN			14.6	14.0	23.3	17.4	8.5	15.6
FEB	39.9		42.3	21.4	32.0	36.8	29.6	33.7
MAR	8.7		12.4		13.7	3.8	6.4	9.0
APR	1.2		4.6	18.6	10.0	6.3	1.4	7.0
MAY	79.7		105.9	101.6	114.4	103.7	120.3	104.3
JUN	125.0		136.8	109.6	115.7	132.6	118.8	123.1
total	**393.3**		**399.4**	**340.0**	**458.4**	**434.1**	**365.8**	**406.1**

1977/78	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	40.3		97.5	60.1	81.0	92.0	122.4	82.2
AUG	102.9		46.9	94.0	128.3	103.8	84.9	93.5
SEP	99.5		156.5	73.8	148.5	123.8	132.9	122.5
OCT	10.8		15.5	14.5	12.6	20.9	16.0	15.1
NOV	50.2		39.2	19.1	58.9	46.9	28.3	40.4
DEC			30.5	12.6	29.2	16.8	15.2	20.9
JAN			20.2	10.2	17.5	12.2	10.6	14.1
FEB	25.2		12.8	2.5	11.3	8.9	10.5	11.9
MAR	13.2		22.6	25.4	27.6	29.5	10.2	21.4
APR	10.4		41.6	16.8	21.4	12.7	17.3	20.0
MAY			87.4	90.2	113.0	104.4	87.2	96.4
JUN	42.1		52.6	17.4	48.4	41.0	26.6	38.0
total	**394.6**		**623.3**	**436.6**	**697.7**	**612.9**	**562.1**	**576.4**

Appendix D

Table D-3 Monthly Precipitation at Seven Stations Near Gull Lake

1978/79	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	77.0		116.3	111.1	100.4	136.2	138.3	113.2
AUG	21.6		42.2	18.0	21.2	12.2	26.7	23.7
SEP	47.6		50.8	39.1	40.2	60.9	41.4	46.7
OCT	23.3		12.5	9.7	23.5	29.3	2.3	16.8
NOV	61.4		40.8	20.8	38.1		30.8	38.4
DEC	21.7		30.9	25.5	33.3	30.6	22.2	27.4
JAN			10.1	7.5	11.3	6.3		8.8
FEB			25.8		29.4	11.5		22.2
MAR			61.9	40.7	49.7	35.0	30.4	43.5
APR			52.9	34.5	53.8	36.3		44.4
MAY	81.4		120.5	100.6	108.9	154.0	88.6	109.0
JUN	21.8		41.2	17.9	37.4	40.1	36.7	32.5
total	**355.8**		**605.9**	**425.4**	**547.2**	**552.4**	**417.4**	**526.5**

1979/80	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	29.3		81.0	29.9	15.7	26.2	28.2	35.1
AUG	51.9		56.7	76.8	85.2	71.2	63.2	67.5
SEP	26.9		53.3	41.1	35.2		30.5	37.4
OCT			22.3	18.2	50.3	40.3	19.4	30.1
NOV	37.4		30.1	32.3	24.9	15.3		28.0
DEC			38.2	15.4	27.7	34.0		28.8
JAN	42.5		38.0	20.2	39.7	31.0		34.3
FEB			29.9	23.0	25.4	25.0		25.8
MAR	18.5		15.1	7.0	15.5	11.0		13.4
APR	5.5		1.1	1.5	4.3	2.0	0.0	2.4
MAY	30.2		20.7	11.1	24.4	21.7	29.9	23.0
JUN	61.4		61.0	41.1	76.3	60.3	41.6	57.0
total	**303.6**		**447.4**	**317.6**	**424.6**	**338.0**	**212.8**	**382.8**

1980/81	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	16.3		40.8	50.0	40.9	38.0	14.9	33.5
AUG	75.6		88.9	51.9	86.6	96.9	77.4	79.6
SEP	79.2		96.6	108.4	111.1	106.3	103.0	100.8
OCT	45.2		60.7	37.4	38.1	39.5	37.4	43.1
NOV	27.9		25.9	12.5	21.9	15.5		20.7
DEC	10.5		16.0	12.9	17.1	16.0		14.5
JAN	27.7		8.9	10.5	18.0	15.5		16.1
FEB	3.0		3.0	0.0	1.6	4.5		2.4
MAR	11.4		20.1	14.7	23.0	18.6		17.6
APR	21.4		13.3	7.7	20.3	15.8		15.7
MAY	41.4		38.3	21.2	37.4	31.2		33.9
JUN	95.6		94.3	98.0	135.7	113.0	83.3	103.3
total	**455.2**		**506.8**	**425.2**	**551.7**	**510.8**	**316.0**	**481.1**

Table D-3 Monthly Precipitation at Seven Stations Near Gull Lake

1981/82	Beausjour	Brokenhd.	Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	25.0		44.5	54.5	18.1	34.5	23.4	33.3
AUG	52.6		148.2	86.3	103.2	80.8	85.3	92.7
SEP	87.4	63.8	84.8	61.9	99.5	67.6	62.8	75.4
OCT	58.7	55.8	73.9	41.0	47.4	56.0		55.5
NOV	2.3	4.0	3.5		13.2	2.0		5.0
DEC	9.7	8.0	10.9		12.9			10.4
JAN		19.2	31.0	10.0	28.5	17.0		21.1
FEB		9.8	10.0	9.5	12.7	14.5		11.3
MAR		13.4	48.5		42.4			34.8
APR		12.6	19.7	37.0	27.3	15.6	20.5	22.1
MAY		25.0	27.5	32.0	25.0	49.4	24.4	30.6
JUN			46.2	38.4	70.2	34.2		47.3
total	**235.7**	**211.6**	**548.7**	**370.6**	**500.4**	**371.6**	**216.4**	**439.4**

1982/83	Beausjour	Brokenhd.	Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL			222.4	153.4	139.8	212.5		182.0
AUG			54.8		88.1	51.7		64.9
SEP			51.6	30.9	39.6	57.5		44.9
OCT			53.2	45.4	53.9	49.6		50.5
NOV			7.9	12.1	15.2	2.5	5.7	8.7
DEC			37.7	31.4	33.8			34.3
JAN			19.6	21.0	21.9	14.0		14.2
FEB	15.0		17.0	10.0	16.1	10.5		13.7
MAR	43.6		46.6		69.2		38.5	26.9
APR	2.2		4.8	0.0	7.9	7.2		4.4
MAY	26.5		28.0	28.8	21.3	45.4	22.2	28.7
JUN	103.4		173.8	131.0	75.5	128.0	116.5	121.4
total	**190.7**		**717.4**	**464.0**	**582.3**	**578.9**	**182.9**	**594.7**

1983/84	Beausjour	Brokenhd.	Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	77.0		26.8	28.6	58.3	34.3	46.7	45.3
AUG	32.9		9.4	10.9	28.5	25.6	40.2	24.6
SEP	64.4		40.2	55.6	51.5	53.7	25.9	48.6
OCT	23.0		53.8	31.4	29.6	62.6	41.1	40.3
NOV	33.5		44.0		27.7	19.0		11.7
DEC	5.2	7.7	11.0	3.0	11.4		8.8	3.9
JAN		15.6	18.4	17.5	14.8	22.0	18.2	17.8
FEB	6.4		11.0	16.0	21.3	11.5	0.6	11.1
MAR	11.5	7.0	16.2	10.0	15.0	11.0	10.0	11.5
APR	45.0	46.1	64.2	32.3	42.5	30.0	30.4	41.5
MAY	45.2	65.0	33.8	38.1	40.2	36.1	35.2	41.9
JUN	130.2		103.6	152.0	124.3	139.1	135.2	130.7
total	**474.3**	**141.4**	**432.4**	**395.4**	**465.1**	**444.9**	**392.3**	**428.8**

Table D-3 Monthly Precipitation at Seven Stations Near Gull Lake

1984/85	Beausjour	Brokenhd.	Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	48.3		32.6		80.7	74.3	47.6	56.7
AUG	19.9	15.1	18.2	19.3	10.9	15.0	24.3	17.5
SEP	68.0	53.0	84.6	59.9	39.7	57.6	73.8	62.4
OCT	99.6	110.0	131.8	109.3	121.5	77.8	101.8	107.4
NOV			36.4	26.5	23.3			28.7
DEC	39.9		22.0		31.4	16.0		27.3
JAN	34.0		19.8	7.7	17.0	24.5		20.6
FEB			17.0	17.5	18.5	27.0		20.0
MAR	15.4		9.2		12.7	3.0		10.1
APR	27.5		17.8	29.2	30.6	28.8	20.5	25.7
MAY	39.3		43.6	48.4	62.2	60.4	72.1	54.3
JUN	68.0		103.3	73.6	65.7	81.1	66.8	76.4
total	**459.9**	**178.1**	**536.3**	**391.4**	**514.2**	**465.5**	**406.9**	**507.2**

1985/86	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	48.6		40.9	26.6	43.6	26.3	49.6	39.3
AUG	170.4		144.6	125.4	97.5	140.2	231.4	151.6
SEP	41.6		54.3	51.0	59.6	65.1	58.8	55.1
OCT	69.8		46.2	20.3	61.7	54.6	21.0	45.6
NOV	39.9		50.0	53.5	46.6	26.0	50.0	44.3
DEC	15.5		15.1	29.5	17.1	15.0		18.4
JAN	8.8		13.4	29.8	9.9	7.0	15.0	14.0
FEB	27.5		16.0	38.0	18.9	23.0	14.0	22.9
MAR	15.7		36.0		31.3	26.4	12.0	24.3
APR	84.9		56.5	25.1	89.9	44.0	60.5	60.2
MAY	21.5		34.4	37.0	17.7	33.6	17.9	27.0
JUN			41.3	98.5	94.5	56.9	42.1	66.7
total	**544.2**		**548.7**	**534.7**	**588.3**	**518.1**	**572.3**	**569.3**

1986/87	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	96.5		63.6	46.4	99.6	78.9	95.4	80.1
AUG			49.2	92.2	22.0	52.3	28.9	48.9
SEP	115.3		58.2	8.8	90.3	98.9	98.1	78.3
OCT	14.2		12.8	53.0	14.4	9.4	14.8	19.8
NOV	59.5		54.3	6.2	55.9	63.8		47.9
DEC	3.0		11.6		9.4	7.0	0.0	6.2
JAN	10.5		4.0	23.0	7.6	7.0		10.4
FEB			46.6	0.8	38.0	23.5		27.2
MAR	7.2		17.0	2.0	13.9	1.0	5.0	7.7
APR	2.0		2.2	94.4	1.6	0.6	1.8	17.1
MAY	58.9		33.5	72.7	66.9	51.1	52.3	55.9
JUN	42.1		47.2	96.8	34.6	42.4	75.4	56.4
total	**409.2**		**400.2**	**496.3**	**454.2**	**435.9**	**371.7**	**455.9**

Appendix D

Table D-3 Monthly Precipitation at Seven Stations Near Gull Lake

1987/88	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL			127.5	36.9	129.2	43.7	191.7	105.8
AUG	87.6		91.8		79.7	71.5	91.9	84.5
SEP	16.3		29.4	30.2	7.7	9.8	30.4	20.6
OCT	33.8		40.6	17.7	29.3	4.2		25.1
NOV	11.4		10.8	11.5	15.5		15.6	13.0
DEC	18.0		23.8		20.3	21.0		20.8
JAN	9.0		15.6	4.0	16.8		0.0	9.1
FEB			14.8		10.3	20.0	0.0	11.3
MAR			37.8	27.0	42.2			35.7
APR	7.2		9.0		4.4	10.4	0.0	6.2
MAY	38.0		29.6	46.7	53.2	43.4	41.9	42.1
JUN	64.3		51.0	131.2	93.1	117.9	37.2	82.5
total	**285.6**		**481.7**	**305.2**	**501.7**	**341.9**	**408.7**	**456.6**

1988/89	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	114.2		86.2	137.3	134.6	94.6	127.9	115.8
AUG	33.2		23.8	51.3	36.8	88.9	22.3	42.7
SEP	67.9		61.2	72.0	75.7	100.7	60.9	73.1
OCT	42.7		22.0	24.5	37.5		12.7	27.9
NOV	20.0		25.0		29.1	18.5		23.2
DEC	39.5		25.4		42.3	25.5		33.2
JAN	50.8		33.2	46.0		30.0		40.0
FEB			8.1	5.5		11.0		8.2
MAR			22.4	13.5				18.0
APR			21.0	11.0		17.6		16.5
MAY			73.1	61.3		73.1	55.4	65.7
JUN			203.4	150.6		85.2		146.4
total	**368.3**		**604.8**	**573.0**	**356.0**	**545.1**	**279.2**	**610.6**

1989/90	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL			54.1	61.4		73.1	49.7	59.6
AUG			50.3	55.7		103.2	105.2	78.6
SEP			10.1	9.5		9.1	21.0	12.4
OCT	38.4		29.3	38.2		14.0	25.1	29.0
NOV	22.6		25.9	6.0		3.0		14.4
DEC	19.0		17.7	10.0				15.6
JAN	36.7		38.7					37.7
FEB	23.0		9.4			6.0		12.8
MAR	36.1		44.8			0.0		27.0
APR	19.9		43.1	26.1		3.0		23.0
MAY	30.2		55.9			50.8	30.2	41.8
JUN	169.4		188.9	240.3		155.6	178.1	186.5
total	**395.3**		**568.2**	**447.2**	**0.0**	**417.8**	**409.3**	**538.3**

Appendix D

Table D-3 Monthly Precipitation at Seven Stations Near Gull Lake

1990/91	Beausjour		Gimli	Grt Falls	Pinawa	Pine Falls	Selkirk	mean
JUL	40.0		101.3	62.1		78.3	37.4	63.8
AUG	22.4		20.8	52.0		48.5	18.7	32.5
SEP	13.2		40.2	55.1		37.0	34.2	35.9
OCT	8.0		5.2	7.6			5.2	6.5
NOV	20.4		26.0	43.5				30.0
DEC	21.0		23.3	13.0		11.0		17.1
JAN	17.5		14.9	19.0		23.0		18.6
FEB	19.5		6.4	8.0		4.0		9.5
MAR	40.0		43.9			43.0		42.3
APR	60.8		31.0				61.1	51.0
MAY	72.6		66.9	35.5		23.9	83.9	56.6
JUN	141.4		94.2				184.6	140.1
total	**476.8**		**474.1**	**295.8**	**0.0**	**268.7**	**425.1**	**503.8**

Table D-4 Annual Precipitation Summary at Six Stations Near Gull Lake

	Beausjour	Gimli	Great Falls	Pinawa	Pine Falls	Selkirk	Means
	(1960-)	(1944-)	(1922-)	(1915-)	(1959-)	(1963-)	
1915							
1916				666.7			
1917				476.2			
1918				523.7			
1919				528.3			
1920				332.6			
mean				**505.7**			**505.7**
1921				563.4			
1922				608.9			
1923				432.4			
1924				293.0			
1925			430.6	347.5			
1926				388.2			
1927			417.8	305.1			
1928				413.0			
1929				301.5			
1930				419.5			
mean			**417.5**	**407.3**			**412.4**
	Beausjour	Gimli	Great Falls	Pinawa	Pine Falls	Selkirk	Means
1931				274.7			
1932				336.4			
1933				312.3			
1934				320.3			
1935				388.6			
1936			328.9	261.6			
1937			450.7	343.3			
1938							
1939			434.5	269.7			
1940			355.7	267.4			
mean			**426.3**	**305.9**			**366.1**
1941			536.2	402.9			
1942			573.2				
1943			496.7	366.1			
1944			632.1	360.0			
1945			539.0	327.8			
1946			496.4	324.5			
1947		452.6		344.5			
1948		385.7	443.4	271.7			**366.9**
1949		615.1	660.2				
1950		537.2	641.8	393.2			**524.1**
mean		**508.0**	**552.5**	**357.0**			**472.5**

Table D-4 Annual Precipitation Summary at Six Stations Near Gull Lake

	Beausjour	Gimli	Great Falls	Pinawa	Pine Falls	Selkirk	Means
1951		376.5	344.6				
1952		385.7	361.9				
1953		504.0	517.5				
1954		679.9	555.4				
1955		616.2	731.7				
1956		570.3	434.8				
1957		490.3	307.4				
1958		687.2	470.6				
1959		577.6	595.4				
1960		625.8	384.7		462.8		**491.1**
mean		**551.3**	**470.4**		**460.9**		**494.2**

	Beausjour	Gimli	Great Falls	Pinawa	Pine Falls	Selkirk	Means
61		416.8	276.0				
62		783.9	493.5				
63		517.6					
64	624.2	527.6	573.0	601.7	508.3		**567.0**
65	551.2	582.4	578.0	676.4	676.1	576.1	**606.7**
66	393.6	515.0	452.4	516.8	528.9		**481.3**
67	431.6	452.6	356.8	399.0	458.9	391.5	**415.1**
68	598.2	617.2	514.3	676.6	654.6	724.0	**630.8**
69	434.6	487.2	424.6	496.5	435.6	467.7	**457.7**
70	582.8	520.1	461.5	629.1	569.6	690.0	**575.5**
mean	**530.8**	**542.2**	**457.7**	**570.1**	**534.7**	**563.1**	**533.1**

	Beausjour	Gimli	Great Falls	Pinawa	Pine Falls	Selkirk	Means
71	475.9	506.8	504.8	520.1	656.3		**532.8**
72	615.5	403.4	454.7	498.6	515.0	378.6	**477.6**
73	788.1	734.8	572.8	778.3	717.9		**718.4**
74	431.5	474.1	575.4	584.6	528.9	444.7	**506.5**
75	464.7	645.4	467.6	671.4	587.8	544.6	**563.6**
76	535.6	343.2	365.6	462.4	386.4	354.1	**407.9**
77	573.8	702.7	539.3	767.6	704.8	684.7	**662.2**
78		530.7	386.7	495.9	477.9	424.1	**463.1**
79		594.0	437.0	529.5	470.2		**507.7**
80	438.6	494.7	377.0	501.3	463.2		**455.0**
mean	**527.3**	**538.3**	**468.5**	**581.0**	**566.2**	**464.3**	**524.3**

81	436.2	543.7		530.3	439.5		**487.4**
82	503.3	610.5		576.5	504.5		**548.7**
83	440.9	475.0		418.9	400.3		**433.8**
84		572.8	480.9	565.6	490.4		**527.4**
85	590.0	561.8	482.7	532.8	552.0		**543.9**
86		447.3	435.0	553.8	501.2	398.7	**467.2**
87			386.0	444.3	275.8		**368.7**
88			494.0	576.0	523.5		**531.2**
89			469.5	506.8	419.3		**465.2**
90	440.3						
mean		**552.6**	**469.5**	**524.7**	**497.2**	**485.2**	**505.8**

Appendix D

Summary of Pan Data, 1972-89

1972	Month	Bissett	Indian B	Gimli	Mean
	May		126.0	115.1	120.5
	June	150.1	157.2	150.6	152.7
	July	127.8	130.8	137.2	131.9
	August	109.7	112.5	117.1	113.1
	Sept	67.3	102.9		85.1
	October				
Totals		454.9	629.4	519.9	534.8

1973	Month	Bissett	Indian B	Gimli	Mean
	May			113.8	
	June	98.3		112.3	105.3
	July	130.3		132.3	131.3
	August	105.7		125.7	115.7
	Sept	69.1		79.2	74.2
	October		40.4	47.2	
Totals		403.4		610.6	507.0

1974	Month	Bissett	Indian B	Gimli	Mean
	May		90.9		90.9
	June	150.1	151.4	153.4	151.6
	July	144.0	158.5	151.1	151.2
	August	96.8	90.2	102.4	96.4
	Sept	45.7		66.0	55.9
	October				
Totals		436.6	491.0	472.9	466.9

1975	Month	Bissett	Indian B	Gimli	Mean
	May				
	June	115.8		109.0	112.4
	July	156.2		152.9	154.6
	August	93.0		101.3	97.2
	Sept	72.6		65.0	68.8
	October				
Totals		437.6		428.2	432.9

1976	Month	Bissett	Indian B	Gimli	Mean
	May		137.2		137.2
	June				
	July	154.2		146.6	150.4
	August	135.4		125.0	130.2
	Sept	76.2		82.8	79.5
	October				
Totals		365.8	137.2	354.3	285.8

1977	Month	Bissett	Indian B	Gimli	Mean
	May			109.5	109.5
	June	119.6		109.7	114.7
	July	161.8		137.4	149.6
	August	93.5		87.1	90.3
	Sept	100.3		57.9	79.1
	October			51.3	51.3
Totals		475.2		553.0	514.1

1978	Month	Bissett	Indian B	Gimli	Mean
	May			114.6	114.6
	June	115.2		114.1	114.7
	July	112.1		123.2	117.7
	August	92.5		106.1	99.3
	Sept	84.9		68.5	76.7
	October			16.9	16.9
Totals		404.7		543.4	474.1

1979	Month	Bissett	Indian B	Gimli	Mean
	May			58.6	58.6
	June				
	July				
	August	93.8		94.0	93.9
	Sept	55.5		62.5	59.0
	October			29.6	
Totals		149.3		244.7	

Appendix D

1980	Month	Bissett	Indian B	Gimli	Mean
	May		130.2	125.0	127.6
	June	116.2	114.1	119.7	116.7
	July	133.6	119.1	115.6	122.8
	August	87.2	83.4	89.1	86.6
	Sept				
	October				
Totals		337.0	446.8	449.4	411.1

1981	Month	Bissett	Indian B	Gimli	Mean
	May			58.8	58.8
	June	99.1		109.9	104.5
	July	142.8		142.2	142.5
	August	95.4		96.5	96.0
	Sept	63.0		71.5	67.3
	October			23.1	23.1
Totals		400.3		502.0	451.2

1982	Month	Bissett	Indian B	Gimli	Mean
	May			57.6	57.6
	June				
	July	119.1			119.1
	August	96.1			96.1
	Sept			71.2	71.2
	October				
Totals		215.2		128.8	

1983	Month	Bissett	Indian B	Gimli	Mean
	May				
	June	107.3		108.4	107.9
	July	134.7		128.8	131.8
	August	139.0		135.2	137.1
	Sept	73.1		71.7	72.4
	October				
Totals		454.1		444.1	449.1

1984	Month	Bissett	Indian B	Gimli	Mean
	May		99.4		
	June	116.4	110.3	124.8	117.2
	July	125.9	119.3	129.5	124.9
	August	114.1	129.6	126.6	123.4
	Sept	54.9	47.4	80.2	60.8
	October				
Totals		411.3	506.0	461.1	459.5

1985	Month	Bissett	Indian B	Gimli	Mean
	May				
	June		102.8	104.8	103.8
	July		129.3	123.1	126.2
	August		77.4	83.7	80.6
	Sept			58.9	58.9
	October				
Totals			309.5	370.5	340.0

1986	Month	Indian B	Gimli	Mean
	May	105.9		105.9
	June	121.1	105.8	113.5
	July	111.2	112.4	111.8
	August	99.1	109.1	104.1
	Sept	48.4	55.9	52.2
	October			
Totals		485.7	383.2	434.4

1987	Month	Indian B	Gimli	Mean
	May			
	June	134.0	156.4	145.2
	July	104.1	115.2	109.7
	August	97.3	142.1	119.7
	Sept	60.1	70.6	65.4
	October			
Totals		395.5	484.3	439.9

1988	Month	Indian B	Gimli	Mean
	May	106.6		106.6
	June	154.4	165.3	159.9
	July	160.0	146.2	153.1
	August	100.8	124.2	112.5
	Sept	56.6	83.0	69.8
	October			
Totals		578.4	518.7	548.6

1989	Month	Indian B	Gimli	Mean
	May	103.7		103.7
	June	105.5	137.0	121.3
	July	130.7	137.0	133.9
	August	114.1	107.6	110.9
	Sept	66.3	74.8	70.6
	October			
Totals		520.3	456.4	488.4

Appendix D

Weather Station Locations

	Latitude	Longitude	Altitude(M)	Period of Record
Beasejour	50 03 N	96 31 W		1960-
Bissett	51 02 N	95 40 W	258	1933-52; 1968-92
Gimli	50 37 N	96 59 W	223	1944-
Great Falls	50 28 N	96 00 W	249	1922-
Indian Bay	49 37 N	95 12 W	327	
Pine Falls	50 34 N	96 13 W	231	1959-
Selkirk	50 09 N	96 53 W	225	1963-

Appendix E

Monthly Water Balance, 1972-1991

Appendix E Gull Lake Monthly Water Balance 1972-1991

1	2	3	4	5	6	7	8	9	10
month	1972/73 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	4,253,800	.0599	235,527	129,918	115,408	4,244,001	4,208,554	-35,447	
AUG.	4,208,554	.0917	360,368	79,695	176,580	4,312,647	4,140,590	-172,057	
SEPT.	4,140,590	.0655	257,349	121,798	126,101	4,150,040	4,069,218	-80,822	
OCT.	4,069,218	.0346	135,851						
NOV.		.0238	93,713						
DEC.		.0379	148,957						
JAN.	1973	.0018	7,209						
FEB.		.0086	33,815						
MAR.		.0078	30,591						
APR.		.0337	132,574						
MAY		.0369	145,025	134,739	71,062		4,135,100		
JUNE	4,135,100	.1812	712,413	116,387	349,082	4,382,043	4,155,167	-226,876	
	Annual totals	**.5833**	2,293,391	582,537	838,234	5,126,420			-971,253
month	1973/74 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	4,155,167	.0631	248,109	154,275	121,574	4,127,428	4,071,301	-56,127	
AUG.	4,071,301	.1057	415,481	138,646	203,586	4,144,550	4,084,364	-60,186	
SEPT.	4,084,364	.1023	402,113	81,814	197,035	4,207,627	4,075,276	-132,350	
OCT.	4,075,276	.0690	271,439	55,885		4,290,831			
NOV.		.0511	201,056						
DEC.		.0254	99,676						
JAN.	1974	.0365	143,321						
FEB.		.0110	43,383						
MAR.		.0240	94,499						
APR.		.0560	220,192						
MAY		.1170	460,044	107,626	225,422		4,569,690		
JUNE	4,569,690	.0322	126,479	177,718	61,975	4,456,476	4,438,003	-18,473	
	Annual totals	**.6932**	2,725,793	715,965	809,591	5,355,405			-917,402

Appendix E Gull Lake Monthly Water Balance 1972-1991									
1	2	3	4	5	6	7	8	9	10
month	1974/75 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	4,438,003	.0397	156,231	170,496	76,553	4,347,185	4,265,159	-82,026	
AUG.	4,265,159	.0959	377,210	114,611	184,833	4,342,925	4,223,320	-119,604	
SEPT.	4,223,320	.0657	258,463	54,109	126,647	4,301,028	4,237,330	-63,698	
OCT.	4,237,330	.0072	28,441			4,265,771			
NOV.		.0132	51,837						
DEC.		.0081	31,915						
JAN.	1975	.0411	161,671						
FEB.		.0175	68,613						
MAR.		.0279	109,703						
APR.		.0286	112,455						
MAY		.0505	198,697		97,362				
JUNE		.1168	459,061	137,107	224,940		4,537,961		
	Annual totals	**.5123**	2,014,298	476,323	710,335	5,265,643			-727,682
month	1975/76 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	4,537,961	.0287	112,979	184,941	55,360	4,410,640	4,307,755	-102,885	
AUG.	4,307,755	.1243	488,813	110,112	239,518	4,446,937	4,318,924	-128,013	
SEPT.	4,318,924	.0475	186,770	85,958	91,517	4,328,218	4,302,075	-26,143	
OCT.	4,302,075	.0340	133,754	38,243		4,397,586	4,271,406	-126,179	
NOV.	4,271,406	.0156	61,405			4,332,811			
DEC.		.0177	69,727						
JAN.	1976	.0325	127,921						
FEB.		.0175	68,679						
MAR.		.0309	121,368						
APR.		.0381	149,809						
MAY		.0101	39,648	165,405	19,427		4,083,985		
JUNE	4,083,985	.1654	650,156		318,577	4,415,565	4,128,095	-287,469	
	Annual totals	**.5623**	2,211,029	584,659	724,400	5,439,931			-1,311,836

Appendix E Gull Lake Monthly Water Balance 1972-1991

1	2	3	4	5	6	7	8	9	10
month	1976/77 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	4,128,095	.0365	143,518	182,573	70,324	4,018,717	3,934,048	-84,669	
AUG.	3,934,048	.0357	140,307	160,314	68,750	3,845,291	3,797,552	-47,739	
SEPT.	3,797,552	.0075	29,490	90,221	14,450	3,722,371			
OCT.		.0076	29,949						
NOV.		.0053	20,643						
DEC.		.0209	82,336						
JAN.	1977	.0156	61,182						
FEB.		.0337	132,377						
MAR.		.0090	35,388						
APR.		.0070	27,590						
MAY		.1043	409,977	129,648	200,889		3,735,268		
JUNE	3,735,268	.1231	483,964	141,606	237,142	3,840,483	3,787,140	-53,343	
	Annual totals	**.4061**	1,596,720	704,362	591,555	4,428,898			-641,758
month	1977/78 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,787,140	.0822	323,276	191,571	158,405	3,760,439	3,741,894	-18,546	
AUG.	3,741,894	.0935	367,511	110,704	180,080	3,818,620	3,728,452	-90,168	
SEPT.	3,728,452	.1225	481,670	118,755	236,018	3,855,349			
OCT.		.0151	59,177	60,739					
NOV.		.0404	158,984						
DEC.		.0209	82,022						
JAN.	1978	.0141	55,598						
FEB.		.0119	46,660						
MAR.		.0214	84,210						
APR.		.0200	78,771						
MAY		.0964	379,202	135,686	185,809		4,155,546		
JUNE	4,155,546	.0380	149,482	136,397	73,246	4,095,385	4,120,144	24,759	
	Annual totals	**.5764**	2,266,562	753,853	833,559	4,466,290			-346,146

Appendix E Gull Lake Monthly Water Balance 1972-1991

1	2	3	4	5	6	7	8	9	10
month	1978/79 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	4,120,144	.1132	445,168	132,726	218,132	4,214,453	4,090,232	-124,221	
AUG.	4,090,232	.0237	92,992	109,520	45,566	4,028,138	3,997,650	-30,488	
SEPT.	3,997,650	.0467	183,493	100,522	89,912	3,990,710	3,935,180	-55,530	
OCT.	3,935,180	.0168	65,927	20,010		3,981,097			
NOV.		.0384	150,910						
DEC.		.0274	107,606						
JAN.	1979	.0088	34,602						
FEB.		.0222	87,421						
MAR.		.0435	171,199						
APR.		.0444	174,483						
MAY		.1090	428,588	69,382	210,008				
JUNE		.0325	127,856	130,240	62,649		4,147,784		
	Annual totals	**.5265**	2,070,244	562,400	626,267	5,001,721			-853,937
month	1979/80 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	4,147,784	.0351	137,817	148,000	67,530	4,070,070	4,113,518	43,448	
AUG.	4,113,518	.0675	265,410	111,059	130,051	4,137,818	3,978,158	-159,660	
SEPT.	3,978,158	.0374	147,057	65,712	72,058	3,987,445	3,889,559	-97,886	
OCT.	3,889,559	.0301	118,353	35,046		3,972,866	3,860,594	-112,272	
NOV.	3,860,594	.0280	110,096			3,970,690			
DEC.		.0288	113,340						
JAN.	1980	.0343	134,789						
FEB.		.0258	101,544						
MAR.		.0134	52,767						
APR.		.0024	9,437	31,850					
MAY		.0230	90,436	148,000	44,314		3,964,906		
JUNE	3,964,906	.0570	223,927	137,581	109,724	3,941,528	3,893,345	-48,183	
	Annual totals	**.3828**	1,504,973	677,248	423,677	4,551,832			-658,487

Appendix E Gull Lake Monthly Water Balance 1972-1991

1	2	3	4	5	6	7	8	9	10
month	1980/81 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,893,345	.0335	131,656	134,502	64,512	3,825,988	3,825,760	-0,228	
AUG.	3,825,760	.0796	312,791	103,245	153,267	3,882,038	3,789,033	-93,005	
SEPT.	3,789,033	.1008	396,215	78,736	194,145	3,912,366	3,788,654	-123,712	
OCT.	3,788,654	.0431	169,273	31,494		3,926,432			
NOV.		.0207	81,550						
DEC.		.0145	57,014						
JAN.	1981	.0161	63,384						
FEB.		.0024	9,515						
MAR.		.0176	69,046						
APR.		.0157	61,732						
MAY		.0339	133,295	69,619	65,314		3,781,460		
JUNE	3,781,460	.1033	406,241	117,334	199,058	3,871,309	3,795,848	-75,461	
	Annual totals	**.4811**	1,891,711	534,931	676,297	4,573,829			-777,980
month	1981/82 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,795,848	.0333	131,067	169,075	64,223	3,693,617	3,664,843	-28,774	
AUG.	3,664,843	.0927	364,627	112,954	178,667	3,737,849	3,588,738	-149,111	
SEPT.	3,588,738	.0754	296,473	74,592	145,272	3,665,347	3,543,303	-122,045	
OCT.	3,543,303	.0555	218,095	27,350		3,734,047			
NOV.		.0050	19,660						
DEC.		.0104	40,795						
JAN.	1982	.0211	83,122						
FEB.		.0113	44,432						
MAR.		.0348	136,703						
APR.		.0221	86,963						
MAY		.0306	120,123	68,198	58,860		3,708,006		
JUNE	3,708,006	.0473	185,787	140,000	91,036	3,662,758	3,637,808	-24,949	
	Annual totals	**.4394**	1,727,845	592,170	538,058	4,393,466			-755,658

Appendix E Gull Lake Monthly Water Balance 1972-1991									
1	2	3	4	5	6	7	8	9	10
month	1982/83 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,637,808	.1820	715,722	141,014	350,704	3,861,812	3,694,186	-167,626	
AUG.	3,694,186	.0649	255,056	113,782	124,977	3,710,482	3,644,397	-66,086	
SEPT.	3,644,397	.0449	176,547	84,301	86,508	3,650,135			
OCT.		.0505	198,664	29,000					
NOV.		.0087	34,130						
DEC.		.0343	134,868						
JAN.	1983	.0142	55,933						
FEB.		.0137	53,947						
MAR.		.0269	105,869						
APR.		.0044	17,379						
MAY		.0287	112,848	111,000	55,296		3,827,653		
JUNE	3,827,653	.1214	477,214	127,043	233,835	3,943,989	3,905,651	-38,338	
	Annual totals	**.5947**	2,338,177	606,140	851,320	4,518,525			-612,874
month	1983/84 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,905,651	.0453	178,054	159,485	87,246	3,836,973	3,814,022	-22,951	
AUG.	3,814,022	.0246	96,662	164,576	47,364	3,698,744	3,636,824	-61,920	
SEPT.	3,636,824	.0486	190,899	86,550	93,540	3,647,632			
OCT.		.0403	158,263	29,000					
NOV.		.0117	45,906						
DEC.		.0039	15,204						
JAN.	1984	.0178	69,793						
FEB.		.0111	43,776						
MAR.		.0115	45,330						
APR.		.0415	163,178						
MAY		.0419	164,919	117,690	80,810				
JUNE		.1307	514,043	137,818	251,881		3,621,300		
	Annual totals	**.4288**	1,686,028	695,118	560,843	4,335,717			-714,417

Appendix E Gull Lake Monthly Water Balance 1972-1991

1	2	3	4	5	6	7	8	9	10
month	1984/85	Precip.	Precipitation	Lake evap.	Pot.evapotr	Exp. lake vol.	Actual lk.vol.	(A-E) vol.	Annual
	Lake Volume	(m.)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)	(month end)	(monthly)	Gain/Loss
JULY	3,621,300	.0567	222,944	149,066	109,243	3,585,936	3,531,944	-53,992	
AUG.	3,531,944	.0175	68,922	135,094	33,772	3,432,000	3,401,317	-30,683	
SEPT.	3,401,317	.0624	245,244	65,002	120,170	3,461,390			
OCT.		.1074	422,297	29,000					
NOV.		.0287	112,979						
DEC.		.0273	107,442						
JAN.	1985	.0206	80,999						
FEB.		.0200	78,640						
MAR.		.0101	39,615						
APR.		.0257	101,183						
MAY		.0543	213,639	111,000	104,683		3,558,637		
JUNE	3,558,637	.0764	300,470	121,715	147,230	3,590,162	3,501,653	-88,508	
	Annual totals	**.5072**	1,994,376	610,877	515,098	4,489,701			-988,048
month	1985/86	Precip.	Precipitation	Lake evap.	Pot.evapotr	Exp. lake vol.	Actual lk.vol.	(A-E) vol.	Annual
	Lake Volume	(m.)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)	(month end)	(monthly)	Gain/Loss
JULY	3,501,653	.0393	154,397	153,091	75,654	3,427,305	3,399,045	-28,259	
AUG.	3,399,045	.1516	596,026	91,642	292,053	3,611,377	3,467,198	-144,178	
SEPT.	3,467,198	.0551	216,522	69,738	106,096	3,507,887			
OCT.		.0456	179,299	29,000					
NOV.		.0443	174,319						
DEC.		.0184	72,506						
JAN.	1986	.0090	35,388						
FEB.		.0215	84,538						
MAR.		.0319	125,431						
APR.		.0560	220,192						
MAY		.0250	98,300	125,386	48,167		3,689,643		
JUNE	3,689,643	.0544	213,901	143,382	104,811	3,655,350	3,648,183	-7,167	
	Annual totals	**.5521**	2,170,818	612,238	626,781	4,433,452			-785,269

Appendix E Gull Lake Monthly Water Balance 1972-1991									
1	2	3	4	5	6	7	8	9	10
month	1986/87 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,648,183	.0888	349,162	131,661	171,089	3,694,595	3,614,674	-79,920	
AUG.	3,614,674	.0398	156,494	117,334	76,682	3,577,152	3,579,651	2,499	
SEPT.	3,579,651	.0922	362,530	57,306	177,640	3,707,236	3,485,827	-221,409	
OCT.	3,485,827	.0124	48,757	29,000		3,505,584			
NOV.		.0573	225,304						
DEC.		.0074	29,097						
JAN.	1987	.0058	22,806						
FEB.		.0328	128,970						
MAR.		.0075	29,490						
APR.		.0017	6,684						
MAY		.0595	233,954	111,000	114,637		3,538,381		
JUNE	3,538,381	.0524	206,037	158,656	100,958	3,484,803	3,450,539	-34,265	
	Annual totals	**.4576**	1,799,283	604,957	641,006	4,201,503			-750,964
month	1987/88 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,450,539	.1178	463,190	123,254	226,963	3,563,511	3,436,151	-127,360	
AUG.	3,436,151	.0919	361,351	115,203	177,062	3,505,236	3,435,400	-69,836	
SEPT.	3,435,400	.0156	61,339	71,040	30,056	3,395,643	3,429,700	34,057	
OCT.	3,429,700	.0276	108,523	29,000		3,509,223			
NOV.		.0142	55,834						
DEC.		.0237	93,188						
JAN.	1988	.0091	35,781						
FEB.		.0113	44,333						
MAR.		.0357	140,241						
APR.		.0062	24,378						
MAY		.0421	165,668	126,214	81,177				
JUNE		.0825	324,193	182,810	158,855		3,225,822		
	Annual totals	**.4776**	1,878,022	618,522	674,113	4,035,925			-810,103

Appendix E Gull Lake Monthly Water Balance 1972-1991

1	2	3	4	5	6	7	8	9	10
month	1988/89 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,225,822	.1158	455,326	189,440	223,110	3,268,598	3,282,238	13,640	
AUG.	3,282,238	.0427	167,962	119,347	82,301	3,248,551	3,179,630	-68,922	
SEPT.	3,179,630	.0731	287,298	67,014	140,776	3,259,137	3,174,140	-84,997	
OCT.	3,174,140	.0279	109,624	29,000		3,254,764			
NOV.		.0232	91,026						
DEC.		.0332	130,444						
JAN.	1989	.0393	154,528						
FEB.		.0082	32,242						
MAR.		.0203	79,820						
APR.		.0160	62,912						
MAY		.0701	275,633	121,952	135,060		3,352,663		
JUNE	3,352,663	.1352	531,606	124,912	260,487	3,498,870	3,342,251	-156,620	
	Annual totals	**.6049**	2,378,421	651,666	841,734	4,110,843			-768,593
month	1989/90 Lake Volume	Precip. (m.)	Precipitation (cu.m.)	Lake evap. (cu.m.)	Pot.evapotr (cu.m.)	Exp. lake vol. (cu.m.)	Actual lk.vol. (month end)	(A-E) vol. (monthly)	Annual Gain/Loss
JULY	3,342,251	.0620	243,784	154,749	119,454	3,311,832	3,213,895	-97,936	
AUG.	3,213,895	.0748	294,114	134,976	144,116	3,228,917	3,161,645	-67,273	
SEPT.	3,161,645	.0145	57,014	78,144	27,937	3,112,578	3,060,929	-51,648	
OCT.	3,060,929	.0313	123,072	29,000		3,155,001			
NOV.		.0148	58,194						
DEC.		.0170	66,844						
JAN.	1990	.0553	217,440						
FEB.		.0157	61,732						
MAR.		.0384	150,989						
APR.		.0310	121,892						
MAY		.0507	199,352	110,000	97,683		3,179,819		
JUNE	3,179,819	.1839	723,095	142,080	354,316	3,406,517	3,269,175	-137,342	
	Annual totals	**.5894**	2,317,521	648,949	743,506	4,267,317			-998,142

Appendix E Gull Lake Monthly Water Balance 1972-1991									
1	2	3	4	5	6	7	8	9	10
month	1990/91	Precip.	Precipitation	Lake evap.	Pot.evapotr	Exp. lake vol.	Actual lk.vol.	(A-E) vol.	Annual
	Lake Volume	(m.)	(cu.m.)	(cu.m.)	(cu.m.)	(cu.m.)	(month end)	(monthly)	Gain/Loss
JULY	3,269,175	.0681	267,769	150,000	131,207	3,255,738	3,175,275	-80,462	
AUG.	3,175,275	.0318	125,038	120,000	61,268	3,119,044	3,043,891	-75,153	
SEPT.	3,043,891	.0359	141,316	73,000	69,245	3,042,962	3,010,000	-32,962	
OCT.		.0065	25,558	29,000					
NOV.		.0300	117,829						
DEC.		.0171	67,139						
JAN.	1991	.0186	73,135						
FEB.		.0095	37,256						
MAR.		.0423	166,324						
APR.		.0510	200,401						
MAY		.0566	222,394	110,000	108,973		3,048,056		
JUNE	3,048,056	.1401	550,742	135,000	269,864	3,193,934	3,258,195	64,261	
	Annual totals	**.5074**	1,994,900	617,000	640,557	4,006,519			-748,324

Appendix F

Drillers' Reports (Basin Stratigraphy Assessment)

The following are selected drillers reports supplied by the Water Resources Branch, of deep wells in the vicinity of Gull Lake. A general stratigraphic profile of the basin was formed by selecting wells that formed a line along the south shore of the lake. This profile is illustrated in figure 4.7. There were too few deep wells to do the same for the north shore.

LOCATION - 35-16-07E

1. Owner - J DERKSEN
Well ID -
Date Completed - Sep/07/89
Driller - ECHO DRILLING
Well Use - Production
Water Use - Domestic

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	3	SAND
3	26	TILL WITH BOULDERS
26	120	SOFT CLAY
120	190	SOFT TILL
190	227	SAND TILL
227	238	SAND

Aquifer - SG

WELL CONSTRUCTION

From	To (ft.)		Inside Dia.(in)	Outside Dia.(in)	Screen Slot Size (in)	Type	Material
0	231	casing	4.2			INSERT	BLACK IRON
231	236	perforations	4		.015	WIRE WOUND	S. S.
215	237	gravel pack					SILICA S.

Top of Casing - 1.5 ft. above ground

PUMPING TEST

Date : Sep 07 89 Pumping @ 10 Imp. gallons/minute
Water level before pumping: 60 ft. below ground
Pumping level at end of test: 115 ft. below ground
Test duration: 12 hours, minutes Water temperature: ?? degrees F

REMARKS

32 ARNOLD ST., GULL LAKE

LOCATION - 35-16-07E

2. Owner - KEARNEY
Well ID -
Date Completed - Jun/08/87
Driller - HYGAARD'S WELL DRILLING
Well Use - Production
Water Use - Domestic

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	16	BOULDERS GRAVEL AND SAND
16	19	LIGHT BROWN TILL
19	22	SAND
22	87	GREY TILL AND BOULDERS
87	163	GREY TILL WITH LAYERS OF SOFT CLAY
163	216	GREY TILL
216	221	FINE SAND
221	255	GREY TILL
255	264	SAND AND COARSE GRAVEL
264	266	GRANITE BOULDERS

Aquifer - SG

WELL CONSTRUCTION

From	To (ft.)		Inside Dia.(in)	Outside Dia.(in)	Screen Slot Size (in)	Type	Material
0	258	casing	4			INSERT	GALVANIZED
258	263	perforations	4.5			WIRE WOUND	S. S.
250	265	gravel pack				NO. 10-30	SILICA S.

Top of Casing - 1.0 ft. above ground

PUMPING TEST

Date : Jun 08 87 Pumping @ 15 Imp. gallons/minute
Water level before pumping: 78 ft. below ground
Pumping level at end of test: 85 ft. below ground
Test duration: 1 hours, minutes Water temperature: ?? degrees F

REMARKS

LOT 40, GULL LAKE

3. LOCATION - 35-16-07E

Owner - F EDWARDS	Driller - FORD DRILLING LTD.
Well ID -	Well Use - Test Well
Date Completed - Jul/31/73	Water Use -

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	12	SAND, GRANITE& BOULDERS
12	38	COARSE SAND
38	200	BLUISH GREY CLAY

Aquifer - DW

WELL CONSTRUCTION

From	To (ft.)		Inside Dia.(in)	Outside Dia.(in)	Screen Slot Size (in)	Type	Material
0	200	open hole					

Top of Casing - 0.0 ft. below ground

---

4. LOCATION - 35-16-07E

Owner - J HOBLEY	Driller - ECHO DRILLING
Well ID -	Well Use - Production
Date Completed - Oct/11/89	Water Use - Domestic

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	6	GRAVEL
6	75	SOFT BLUE CLAY
75	192	GREY TILL
192	205	SAND
205	230	GREY TILL

Aquifer - SG

WELL CONSTRUCTION

From	To (ft.)		Inside Dia.(in)	Outside Dia.(in)	Screen Slot Size (in)	Type	Material
0	198	casing	5			INSERT	PVC
198	203	perforations	4		.015	WIRE WOUND	S. S.
185	205	gravel pack					SILICA S.

Top of Casing - 0.0 ft. below ground

PUMPING TEST

Date : Oct 11 89 Pumping @ 3 Imp. gallons/minute
Water level before pumping: 75 ft. below ground
Pumping level at end of test: 85 ft. below ground
Test duration: 1 hours, minutes Water temperature: ?? degrees F

REMARKS

174 ARNOLD ST., GULL LAKE

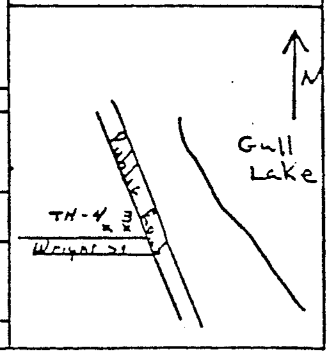
5.

DRILLER'S REPORT

Appendix F

WELL LOCATION
QTR. NE SEC. 35 TWP. 16 RGE. 7 E.☒W.□
LOT ______ PARISH ______
REMARKS Test Hole for Community Well at Gull Lake Test Hole # 4

LOCATION SKETCH OF WELL



WELL IDENTIFICATION (NR, NAME)

WELL OWNER
NAME R.M of ST. Clements and M.W.S.B
ADDRESS ______

WELL USE
PRODUCTION . . . . . □ TEST WELL . . . . . ☒
RECHARGE . . . . . □ OBSERVATION WELL . . □

WATER USE
DOMESTIC . . . . . . □ LIVESTOCK . . . . . □ MUNICIPAL . . . . . ☒
INDUSTRIAL . . . . . □ IRRIGATION . . . . . □ AIR CONDITIONING . . □
OTHER . . . . □

DATE WELL COMPLETED: DAY 2 MONTH Aug 19 74

WELL LOG

DEPTH BELOW GROUND IN FEET FROM	TO	DESCRIPTION	WATER RECORD (KIND OF WATER)
0	21	Sand + gravel; coarse	
21	23	Clay	
23	40	Till; light grey, gravelly, rough	
40	50	Clay; grey and sand	
50	200	Clay; grey, firm	
		@ 110 sandy and some pebbles	
		@ 125-130 " " " "	
		@ 165 some cobbles	
		@ 175 some pebbles	
		@ 190 " "	
200	218	Clay; dark grey, firm	
218	230	Sand and gravel	
230	233	Clay; dark grey	
233	236	Boulder of limestone	
236	255	Sand and gravel	
255	256	Granite	
		Surface casing had to be used to	
		control the surface gravel.	
		Logged by Waters and Potter	
		Water Samples Taken for complete analysis	

WELL CONSTRUCTION

DEPTH BELOW GROUND LEVEL IN FEET FROM	TO	CASING	OPEN HOLE	PERFORATIONS	GRAVEL PACK	CASING GROUT	PITLESS UNIT	INSIDE DIAMETER INCHES	OUTSIDE DIAMETER INCHES	SCREEN SLOT SIZE NR OR INCH	TYPE	MATERIAL	MAKE
											Test #1		
											Slotted 2-inch pipe set		247-255'
											Pumped @ 3½ IGPM for		1 hour
											Recovery data indicates		T = 23573 IGPD/ft
											Field Water Analysis		
											EC - 400 umhos		
											NaCl - 12 ppm		
											Hardness - 11 GPG		Iron - 1.5 ppm

TOP OF CASING OR PITLESS UNIT ______ FEET ABOVE □ BELOW □ GROUND LEVEL

REMARKS Test #2 — Field Water Analysis
Slotted 2-inch pipe set 233 - 240
Pumped @ 6 IGPM for 1 hour — EC - 380 umhos
Recovery data indicates T ≈ 260 IGPD/ft — NaCl - 12 ppm
Hardness - 11 gpg
Iron - 1.0 ppm

PUMPING TEST
DATE OF TEST: DAY 2 MONTH Aug 19 74
PUMPING □ FLOWING □ RATE ______ I.G.P.M.
WATER LEVEL BEFORE PUMPING ______ FT. ABOVE □ BELOW □ GRD. LEVEL
PUMPING LEVEL AT END OF TEST ______ FT. ABOVE □ BELOW □ GRD. LEVEL
DURATION OF TEST ______ HOURS ______ MINUTES
WATER TEMPERATURE ______ °F.
RECOMMENDED PUMPING RATE ______ I.G.P.M. WITH PUMP

CONTRACTOR
LICENSE NR ______
NAME Waters Drilling
ADDRESS Roblin Man
DRILL OPERATOR Lee Waters
[signature]

6. LOCATION - 35-16-07E

Owner - M VANSCHIJNDEL   Driller - ECHO DRILLING
Well ID -   Well Use - Production
Date Completed - May/31/90   Water Use - Domestic

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	27	SANDY BROWN TILL AND BOULDERS
27	55	GREY TILL
55	95	HARD BLUE CLAY
95	227	SOFT GREY TILL
227	240	BOULDERS
240	252	GREY TILL
252	259	SAND
259	260	BOULDERS
260	261	SAND
261	264	GRANITE

7. LOCATION - 36-16-07E

Owner - D MIDDLETON   Driller - INTERLAKE WATER SUPPLY LTD.
Well ID -   Well Use - Production
Date Completed - Apr/23/87   Water Use - Domestic

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	10	SAND
10	265	BLUE CLAY AND SOME GREY TILL
265	270	SANDSTONE OR SILICA SAND
270	272	RED GRANITE

Aquifer - SG

WELL CONSTRUCTION

From	To (ft.)		Inside Dia.(in)	Outside Dia.(in)	Screen Slot Size (in)	Type	Material
0	268	casing	4			INSERT	GALVANIZED
268	272	perforations	3.8		.013	WIRE WOUND	S. S.

Top of Casing - 1.5 ft. above ground

PUMPING TEST

Date : Apr 24 87   Pumping @   Imp. gallons/minute
Water level before pumping: 70 ft. below ground
Pumping level at end of test: ft. below ground
Test duration:??? hours, ?? minutes   Water temperature: ?? degrees F

REMARKS

LOT 287 ARNOLD ST. GULL LAKE
HARDNESS=22 GPG - IRON=0

8. LOCATION - NW35-16-07E

Owner - G SMITH   Driller - ECHO DRILLING
Well ID -   Well Use - Production
Date Completed - Aug/11/89   Water Use - Domestic

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	30	SAND AND SANDY TILL
30	70	GREY TILL
70	168	CLAY
168	192	TILL
192	203	SAND
203	210	TILL

Aquifer - SG

WELL CONSTRUCTION

From	To (ft.)		Inside Dia.(in)	Outside Dia.(in)	Screen Slot Size (in)	Type	Material
0	195	casing	4.2			INSERT	BLACK IRON
195	200	perforations	4		.015	WIRE WOUND	S. S.
180	205	gravel pack					SILICA S.

Top of Casing - 1.0 ft. above ground

PUMPING TEST

Date : Aug 11 89   Pumping @ 10 Imp. gallons/minute
Water level before pumping: 75 ft. below ground
Pumping level at end of test: 95 ft. below ground
Test duration: 3 hours,   minutes   Water temperature: ?? degrees F

REMARKS

JOHN ST., GULL LAKE

9. LOCATION - NW35-16-07E

Owner - F MATIATIONS
Well ID -
Date Completed - Aug/15/89

Driller - ECHO DRILLING
Well Use - Production
Water Use - Domestic

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	50	SAND AND GRAVEL, SANDY TILL
50	110	GREY TILL
110	200	CLAY
200	225	TILL
225	240	SAND

Aquifer - SG

WELL CONSTRUCTION

From	To (ft.)		Inside Dia.(in)	Outside Dia.(in)	Screen Slot Size (in)	Type	Material
0	230	casing	4.5			INSERT	BLACK IRON
230	235	perforations	4		.015	WIRE WOUND	S. S.
210	238	gravel pack					SILICA S.

Top of Casing - 1.5 ft. above ground

PUMPING TEST

Date : Aug 15 89 Pumping @ 10 Imp. gallons/minute
Water level before pumping: 60 ft. below ground
Pumping level at end of test: 80 ft. below ground
Test duration: 2 hours, minutes Water temperature: ?? degrees F

REMARKS

JOHN ST., GULL LAKE

10. LOCATION - SE36-16-07E

Owner - G PRONISHEN
Well ID -
Date Completed - Nov/06/90

Driller - ECHO DRILLING
Well Use - Production
Water Use - Domestic

WELL LOG (Imperial Units)

From	To (ft.)	Log
0	5	TILL
5	21	CLAY
21	35	SAND
35	40	TILL

Aquifer - SG

WELL CONSTRUCTION

From	To (ft.)		Inside Dia.(in)	Outside Dia.(in)	Screen Slot Size (in)	Type	Material
0	30	casing	5			INSERT	PVC
30	35	perforations	4		.015	WIRE WOUND	S. S.
20	35	gravel pack					SILICA S.

Top of Casing - 1.0 ft. above ground

PUMPING TEST

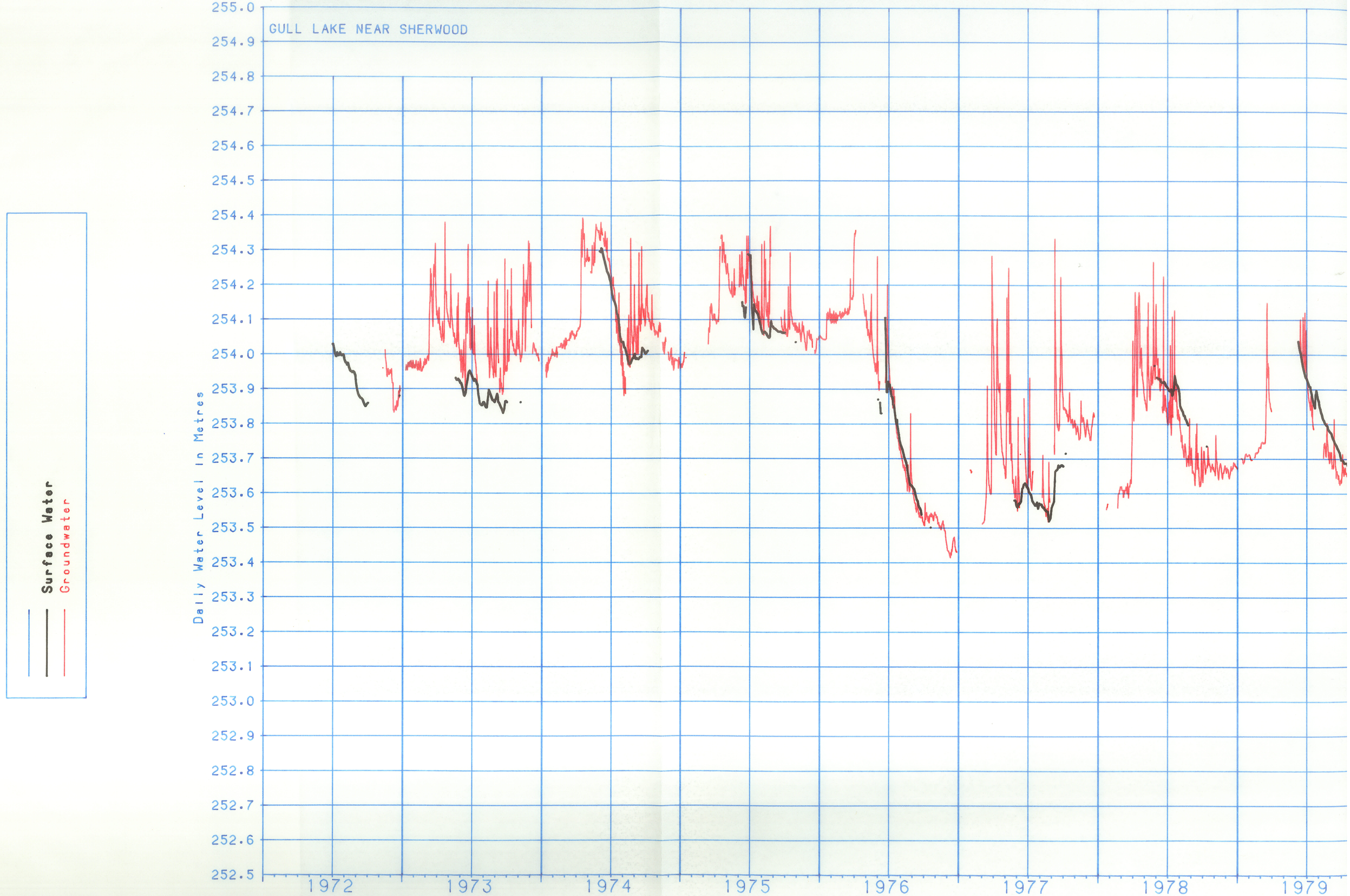
Date : Nov 06 90 Pumping @ 10 Imp. gallons/minute
Water level before pumping: 12 ft. below ground
Pumping level at end of test: 30 ft. below ground
Test duration: 1 hours, minutes Water temperature: ?? degrees F

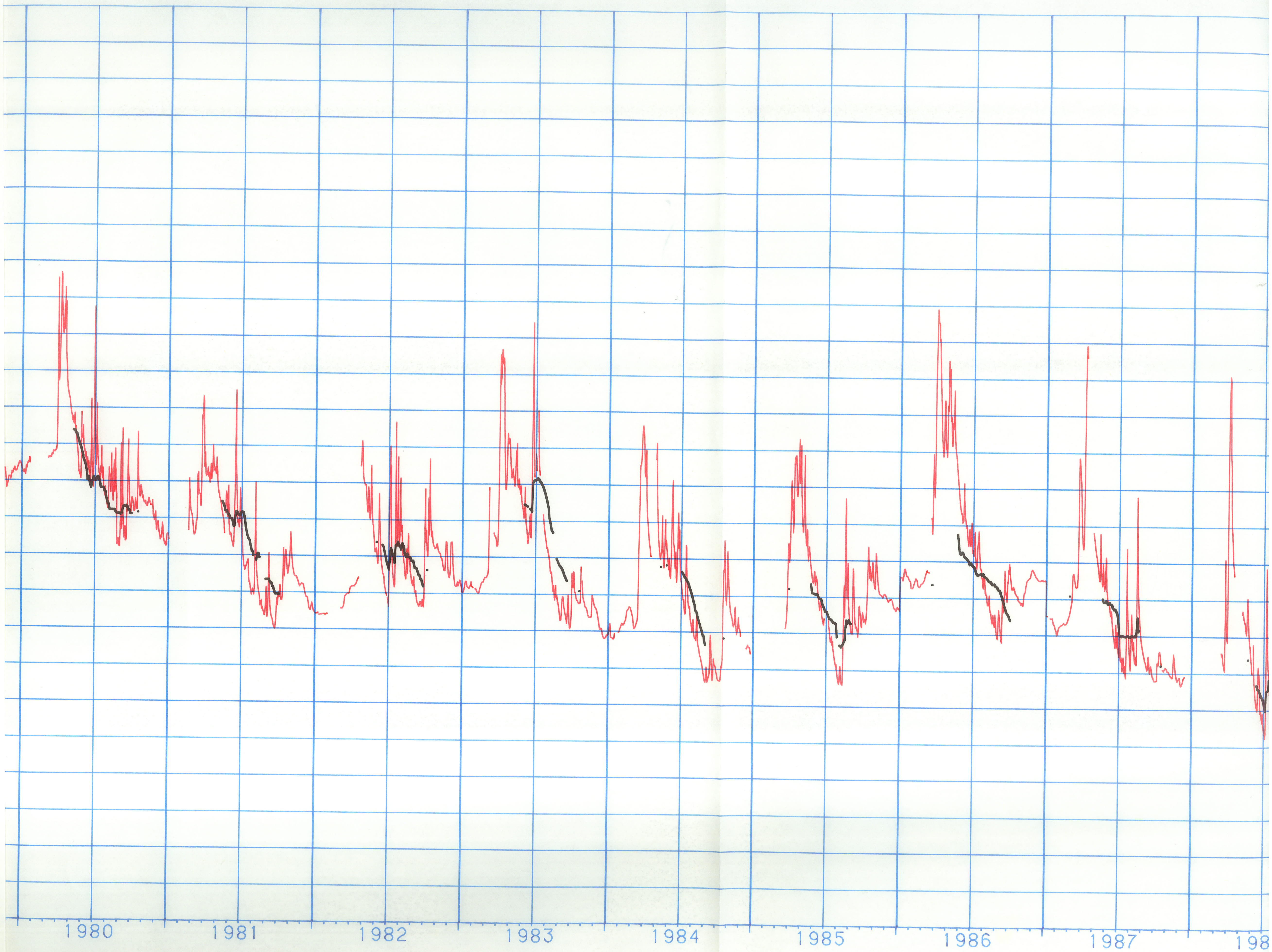
REMARKS

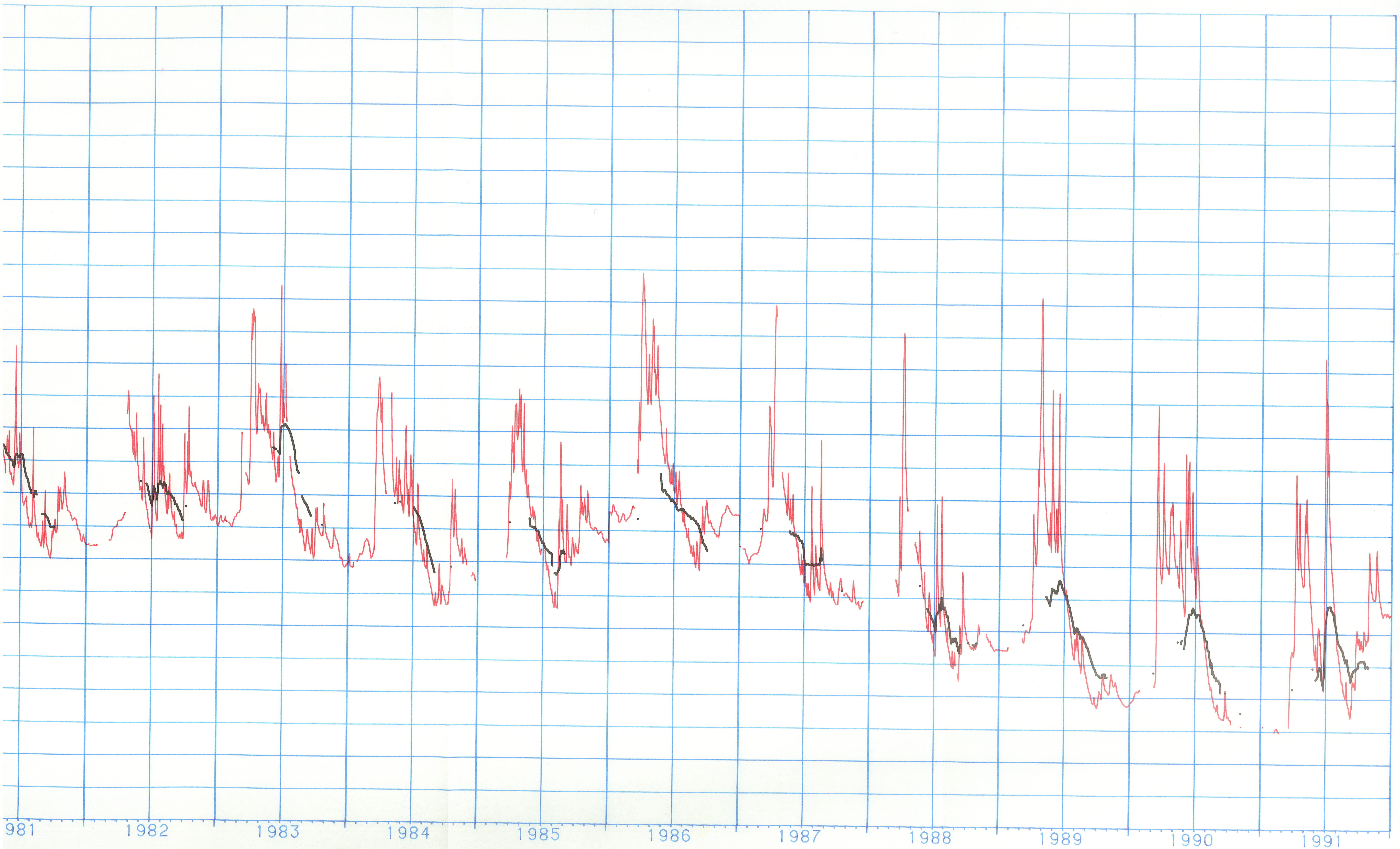
LOT 346 JOHN ST., GULL LAKE

Appendix G

Gull Lake Hydrograph (1972-91)


GULL LAKE NEAR SHERWOOD
Daily Water Level in Metres
255.0
254.9
254.8
254.7
254.6
254.5
254.4
254.3
254.2
254.1
254.0
253.9
253.8
253.7
253.6
253.5
253.4
253.3
253.2
253.1
253.0
252.9
252.8
252.7
252.6
252.5
1972
1973
1974
1975
1976
1977
1978
1979
Surface Water
Groundwater


1980
1981
1982
1983
1984
1985
1986
1987
198


981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991