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# THE LAKES OF ELK ISLAND NATIONAL PARK: A WATER BALANCE STUDY FOR LAKE IMPROVEMENT

BY

ANDREW GRAHAME PATRICK

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**NAME OF AUTHOR:** Andrew Grahame Patrick

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Andrew G Patrick

Permanent Address
13116-66 Ave
Edmonton, Alberta
T6H 1Y8

Dated: September 23, 1987

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE LAKES OF ELK ISLAND NATIONAL PARK: A WATER BALANCE STUDY FOR LAKE IMPROVEMENT submitted by ANDREW GRAHAME PATRICK in partial fulfilment of the requirements for the degree of Master of Science.

Arleigh H. Laycock
(Supervisor)

Edgar L. Jackson

[illegible]

DATED: September 15, 1987

# ABSTRACT

Elk Island National Park, 35 km east of Edmonton, was created in 1906 primarily for the protection of the wildlife in the area. The topography of the Park was formed largely during the recession of the Wisconsin continental ice sheet. It is primarily a knob and kettle terrain with numerous lakes and marshes, largely luvisolic soils with many areas of organic origin, diverse vegetative cover, and small reserves of low quality groundwater. The study objective was to use the available climatic and water level data to explain the areal and temporal patterns of water resources within the Park.

The Thornthwaite technique was used to determine the water balance patterns of Elk Island National Park. The potential evapotranspiration at the Edmonton International Airport was found to be similar to that of the Park, and much of the temporal study was done using the long record of this station. The precipitation for the four years of record for the Park was, on average, 20 percent greater than that at the Edmonton International Airport station. The greater precipitation in the Park was probably caused by local orographic uplift of air currents over the Cooking Lake moraine. In determining surpluses, the values for the summer months (April-October), and winter months (November-March) were taken from daily and monthly water balance calculations respectively. Six different moisture storage categories were used to determine the potential surpluses from the different vegetation types within the Park. Other techniques to determine potential evapotranspiration were examined, but only the Penman technique was used as a check on the results based upon the Thornthwaite technique.

Once the yield patterns were calculated, it was apparent the Park experienced an average water loss. This was consistent with the measured lake level fluctuations and a general trend towards lower levels from a high in 1974.

A literature review was conducted to examine the various methods of controlling the growth of algae and weeds. It is apparent that there is little the Park staff can do to limit the nutrient input into the lakes, due to the nutrient loading currently underway from adjacent agricultural and forest lands, the atmosphere, and the natural wildlife. The dredging of lake

bottoms, though effective, would be costly and against the present Park policy of minimal interference to the environment. The harvesting of weeds is a possibility, but it is the blue-green algae which are the greatest nuisance in the lakes of Elk Island National Park. The chemical control of the weeds and algae has been carried out previously on Astotin Lake in the 1960's with only a limited success. The dilution with low nutrient water is a possible alternative which has been shown previously to reduce the blue-green algae in the lakes. Within the Park, areas with the lower water storage categories have the greatest potential for supplying surplus water for dilution purposes in the drier and average years.

This study was intended to provide an understanding of the water balance patterns within Elk Island National Park. It is anticipated that this study will help in water resource management, in terms of both quality and quantity.

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I [illegible] like to thank my parents for their support throughout all my school years [illegible] to, and enabled me to complete this degree. My new wife Connie has been instrumental in helping to see [illegible] Masters degree with her encouragement and love. I would like to thank my friend Peter Davis whose help with the different computer programs made it possible to produce this thesis. Andrew Livingstone, a fellow graduate student, was very helpful with his comments and data for this thesis. In time of need, Andrew also gave me a job with Alberta Transportation and Utilities for which I am very grateful.

## TABLE OF CONTENTS

## TABLE OF CONTENTS

TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF PHOTOGRAPHS

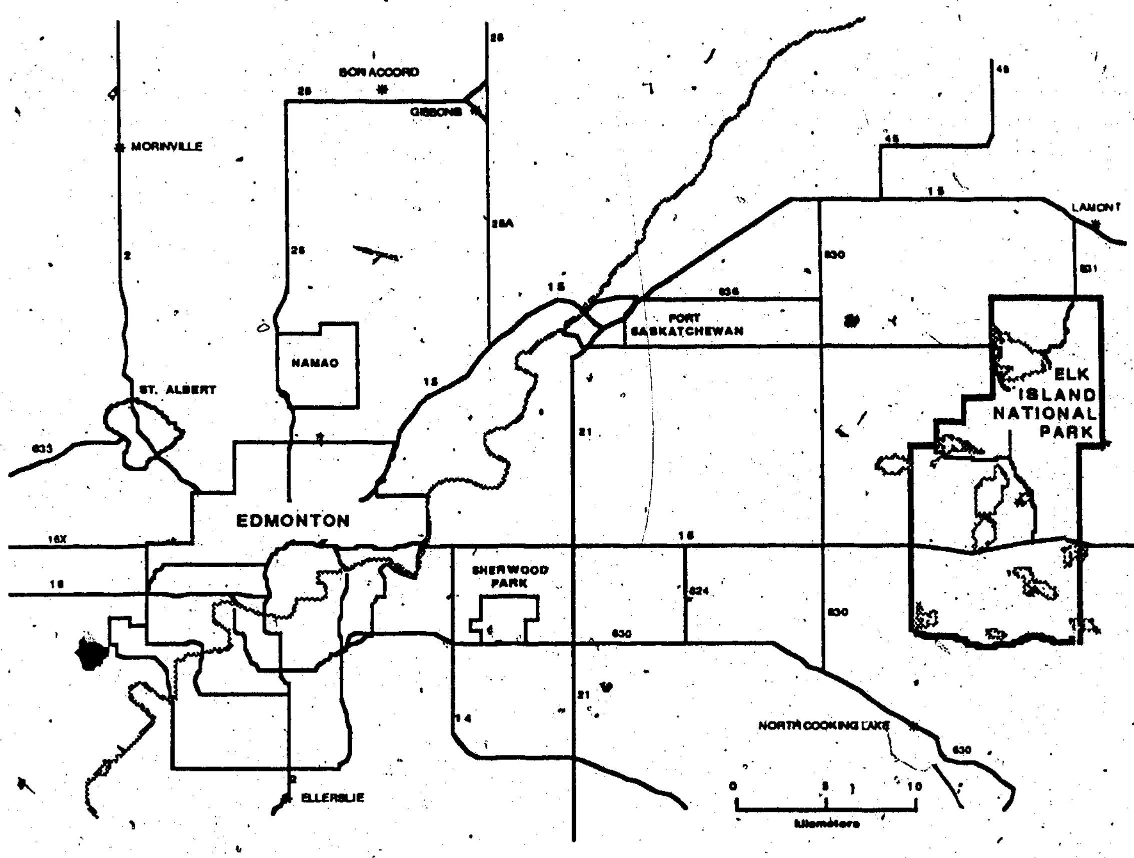
# 1. INTRODUCTION

## 1.1 INTRODUCTION

The setting for this thesis is Elk Island National Park, which is 35 kilometers east of Edmonton Alberta (Fig. 1.1). The Park is located on the Cooking Lake Moraine which rises some 30 to 60 meters above the rest of the plain, and which was largely created during the last glacial period. The vegetation within the Park is classified as Boreal Mixedwood, and is composed primarily of the poplar association of trees. The biophysical features are an important factor in the water balance patterns of the Park in terms of the surplus qualities. Wetlands are abundant in the Park due to the knob and kettle terrain with poor drainage, which promotes the accumulation of water in depressions. The function of the Park at present is to provide a safe natural setting for the wildlife, and for the most part, to promote a primitive recreational experience.

The present data base for water related topics within Elk Island National Park is limited. Miller (1985) prepared an annotated bibliography on the region which indicated very little water related research had been conducted in Elk Island National Park. The author was involved in the collection of data for a report by Laycock (1986) which expanded upon Miller (1985). The author's thesis supervisor, Dr. A.H. Laycock, was approached by Parks Canada to arrange for Masters students to do research within the Park relating to water topics. Upon consultation with Dr. Laycock, it was determined that a water balance study at Elk Island National Park using existing data to provide some perspectives relating to lake levels and water qualities would be an appropriate thesis topic. This would involve establishing yield patterns for the various land and water surface categories and evaluation of different means of improving these yields for lake improvement.

To accomplish the task of determining a water balance, the Thornthwaite technique was used (Precipitation = Potential evapotranspiration - Deficit + Surplus +/- Storage




Source: Department of Energy, Mines, and Resources, 1983., Author, 1987.

**Location of Elk Island National Park**

Figure 1.1

Change). The technique itself is easily computed in a bookkeeping procedure which makes use of readily available meteorological data. Most of the data used were from the Edmonton International Airport meteorological station with data supplements from Elk Island National Park weather station and other stations in the area.

This thesis was not carried out as an exercise in the use of the Thornthwaite procedure but rather as a much more complex issue of defining the water supply patterns of the Park. This was done so that improvements could be made in the management to meet a range of Park objectives. The Thornthwaite procedure is merely a tool in the identification of the changing lake, marsh, and stream patterns. The lakes of Elk Island National Park have experienced a series of variations in quantity and quality during the past 110 years. There was a major drop in lake levels and area during the droughts in the 1880's accompanied by significant burning and cutting of the area. Major recovery in lake levels and quality took place in the early 1900's relating to a series of wet years plus the lower storage use categories following the fires. The pattern since then has been towards lower lake levels and poorer water quality. There have been exceptions during wet years when a partial recovery of lake levels and improved qualities was possible.

Although the Thornthwaite technique was a major tool in this thesis, other techniques were reviewed to see if through use of them, the author could add to this knowledge. In addition, the author selected several refinements of the Thornthwaite procedure such as multiple storage categories and use of daily data to get a better definition of the areal and temporal patterns.

The management of the Parks water resources could be conducted through an alternative futures approach. The Park policies have changed over the years and will continue to do so. For example, during the 1950's and 1960's, the policies promoted a much higher level of recreation than is allowed today. The determination of the water balance patterns will be relative to a range of management options, rather than just relative to wildlife, or even a narrowly defined "natural" setting.

## 1.2 OBJECTIVES

Elk Island National Park has been prone to poor drainage, stagnant waters, and small surpluses. The major objective in this thesis was to define more closely where the surpluses (runoff) come from. This would be done to determine ways of using the surpluses more effectively for recreational use and wildlife. The relationship between high and low surpluses, and variations in water quality will be examined. This would be done to determine when the highest quality surpluses are available. Once the surpluses are created, it is important to determine what happens to the surpluses. Subordinate technique objectives necessary to this thesis are as follows:

1. Present a physical and cultural overview of the Park. The overview is intended to cover the development of the topography, water bodies, vegetation, and groundwater patterns, and the creation of the Park.

2. Report the previous uses of the Thornthwaite technique to show its suitability for this study.

3. Use the Thornthwaite water balance procedure with 16 years of data from Edmonton International Airport to determine the water balance of this region. Meteorological data from stations surrounding the Park, and data from the new station within Elk Island National Park will be used as a check on the data from the Edmonton International Airport. A one hundred year summary from the Edmonton Municipal gauges will be included to illustrate the climatic patterns of the region.

4. The monthly water balance calculations will be carried out using monthly averages for temperature and total monthly precipitation from the Edmonton International Airport weather station. The daily water balance calculations will be similarly made with daily averages for temperature and total daily precipitation values from the Edmonton

International Airport. The two sets of data will be combined to form a yearly water balance with daily data for the summer months (Apr.-Oct.), and monthly data for the winter months (Nov.-Mar.). The Park will be mapped into soil moisture categories so as to determine the surpluses for each respective category. The wetlands will be allocated the value PE + 1/2 D to explain the above average evaporation from wetlands.

5. Compare the measurement of potential evapotranspiration using the Thornthwaite and Penman procedures.
6. Examine other methods to determine potential evapotranspiration.
7. Map the Park drainage basins.
8. Discuss the differences between daily and monthly meteorological data in the water balance procedure.
9. Determine yields within the basins of the Park.
10. Supplement the Edmonton International Airport meteorological data with Elk Island National Park weather data in the determination of yields and lake level fluctuations.
11. Compare lake level fluctuations and diagrammed water balance patterns as a check on the water balance procedure.
12. Compare the lake level fluctuations and calculated yields as a check on the water balance procedure.
13. Examine the different methods of lake rehabilitation usable in Elk Island National Park.

## 1.3 METHOD OF STUDY

A literature review (Chapter 2) of the physical and cultural aspects of Elk Island National Park was carried out to present an overall picture of the Park and how it came into being.

The Thornthwaite procedure was then used to calculate the water balance of Elk Island National Park, and is the focus of much of the research in this thesis. The procedure to determine a water balance in this thesis is outlined in section 3.2.2. Two types of data were incorporated into the water balance procedure; monthly and daily means. An in-depth discussion of the two forms of data can be found in section 4.3. The procedure has been widely tested in Western Canada, and has been used throughout the world with a great deal of success and accuracy. A literature review of other applications of the Thornthwaite procedure is contained in section 3.3. The Thornthwaite and Penman water balance procedures were compared, for which a Penman computer program was developed. The program, adapted directly from a Ph.D thesis by Verma (1969), is shown in Appendix II. Alterations were made to calculation of the Heat Budget in the computer program to account for a difference in albedo. Other procedures to determine potential evapotranspiration were examined in a literature review in section 3.5.

In Chapter 4 the water balance patterns within and around the Park were examined. This necessitated the determination of water storage values for the whole of Elk Island National Park from a 1:15,000 scale air photograph mosaic provided by Parks Canada. The water storage categories were mapped from the air photo mosaic and were cross checked by use of air photo interpretation and field checks. A distance of .9 - 2.2 km outside the Park was also divided into different water storage categories. This was limited to areas where surpluses would flow into the Park. The distance mapped was regulated by the available air photo coverage in the mosaic. Field checks consisted of examining the Park on foot and by car to check on the accuracy of the plotted water storage categories. Very few changes were necessary to the tracing after field checks and air photo interpretation was completed. Upon field checking, it was determined that the majority of the 50 mm water storage category should be changed to the 100 mm water storage category due to the wet conditions during the summer of 1986 which promoted heavy growth of the grasses. The only remaining areas for which the 50 mm water storage category is still applicable include playing fields, and road side grasses. The water storage value maps were mapped by drainage basins from the hydrogeological map in Stein (1976). The first basin was subdivided to produce a more localized picture of the yields. This information could be of some importance regarding short distance water transfer. In employment with the Planning Division of Alberta Environment, the author has gained extensive experience in the use of an electronic planimeter. It was therefore decided to use this same planimeter to measure the areas on the water storage value maps. The area of each water storage value within each basin was totalled. After the water storage category areas were determined, the surpluses for each of the categories were calculated. Surpluses were determined for the summer months of April - October using daily data, and for the winter months of November - March using monthly data.

The yields of each basin were calculated once the area and surpluses of the water storage categories had been determined. The Park yields were determined as follows: 1. The total winter precipitation was multiplied by the wetland area. 2. The land area surpluses were multiplied by the respective water storage category areas. The results were in units of hectare decimetres which is equal to cubic decametres. 3. For the summer, the surpluses were multiplied by the respective water storage category areas. The equation ((Precipitation - Potential evapotranspiration + 1/2 Deficit) * wetland areas) results in the summers yield or water loss from the wetland areas. 4. All the yields were added and water losses subtracted to determine whether there were yields or net water losses within the Park.[1]

Lake level data were obtained from Elk Island National Park records and were compared with calculated lake level fluctuations (table 4.10). To determine the calculated lake level fluctuations the total yield or water loss in hectare decimetres for a basin was divided by the basins' wetland area in hectares. The result in decimetres was converted to centimetres to be consistent with the measured lake level fluctuation values obtained from

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[1] An explanation of the 1/2 deficit value may be found in section 4.2.

Elk Island National Park records. The level fluctuations were calculated for only those basins with gauged lake levels. For example, Moss and Astotin Lakes are in Basin 2, therefore the level fluctuations between the spring breakup and fall freezeup are calculated by the subtraction of the yearly yield or water loss from the second basins' wetland area.

A literature review (Chapter 5) was conducted to determine the different methods to control nutrient loading, weeds, and algae within Elk Island National Park. The present Park policy is directed towards maintaining a natural progression of lake aging in the lakes of the Park. If greater use of the lakes were desired, some measures would have to be taken to improve the quality of the water bodies. Based upon the literature review and water balance patterns within the Park, a discussion of the various methods to improve the water quality of Astotin Lake was carried out.

Conclusions may be found in Chapter 6. This section is intended to discuss various improvements and questions about the methodology of this thesis as well as possible alternatives. In section 6.2, recommendations for future management of the water resources within Elk Island National Park are discussed. Such recommendations focus upon management decisions based upon water balance and field observations. A series of recommendations based upon a literature search on lake rehabilitation methods was also included. An insight into future water supply patterns was given in section 6.3. This was based upon present knowledge of the effects of the "greenhouse" gases on the earths atmosphere and ultimately upon the future water resource patterns of the world. This topic was presented to emphasize the need for present and future water resource decisions within Elk Island National Park.

Four appendices were included in this thesis to complement the text. Appendix I was intended to illustrate yearly water balances using monthly data from the Edmonton

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[1] The 1978 Elk Island National Park Policies are currently under review by Park Management.

International Airport. The winter values were taken from these tables for use in determining the yearly yields within Elk Island National Park.

Appendix II is a computer spread sheet with the necessary data to calculate potential evapotranspiration using the Penman procedure. The results have been compared to the Thornthwaite results in a discussion in section 3.4. In the text of Appendix II a step by step description of the Penman procedure and the necessary formulas was performed.

Appendix III was intended to provide the summer daily water balance values through use of daily data from the Edmonton International Airport. These values were used in the determination of yields within Elk Island National Park.

The water balance tables in appendix IV use the weather data from Elk Island National Park. The record is short because the station was only recently opened (1982).

# 2. PHYSICAL AND CULTURAL OVERVIEW

## 2.1 INTRODUCTION

The physical and cultural background of the Park and the surrounding area is discussed in this chapter. The geology and geomorphology of the region will be reviewed first to indicate how the Park's physical characteristics came into being. The following section on soils is an overview of the major soil subgroups and where they are located. Section 2.3 on hydrogeology is a description of the various water bearing strata under the Park as well as the probable water yields and qualities. The next section is a brief overview of the vegetation characteristics in the Park and surrounding area. A cultural history of the Park and its surrounding area comprises the last section of this chapter. Within the chapter, the bearing that each section has on the Park's water resources will be discussed.

## 2.2 GEOLOGY AND GEOMORPHOLOGY

The bedrock surface within the Edmonton district is sculptured in unconsolidated material comprising the Edmonton Formation of the late Cretaceous age (Carlson, 1967). The Edmonton Formation is made up of non-marine shales and sandstones interbedded with coal seams (Lang, 1974). Erosion during the Tertiary and early Pleistocene time largely created the major land form patterns of the Alberta plains. The whole of the Beaver Hills which includes Elk Island National Park represents a topographic high of the preglacial land surface (Carlson, 1967). The preglacial land surface was then modified during the glacial age (Carlson, 1967).

The Cooking Lake Moraine land forms are of glacial origin and result from the recession of the last continental ice sheet (Alberta Environment, 1977a). The melting of the last ice sheet in the area left a mantle of glacial till in the form of a ground moraine. Resting on top of the ground moraine, and forming the higher part of the Beaver Hills which includes Elk Island National Park is a large hummocky stagnant ice moraine (Lang, 1974). The hummocky moraine on the pre-glacial topographic high has resulted in Elk Island National Park being 30 to 60 m. above the general level of the surrounding countryside.

The varied topography, characteristic of a hummocky moraine is referred to also as a knob and kettle type terrain. The variable relief of the hummocky moraine is mainly responsible for the diversity in the plant communities within the Park (Bichlmaier, 1985). Most of the lakes within Elk Island National Park are in depressions that have resulted mainly from the uneven amount of glacial drift deposited over the area (Lang, 1974).

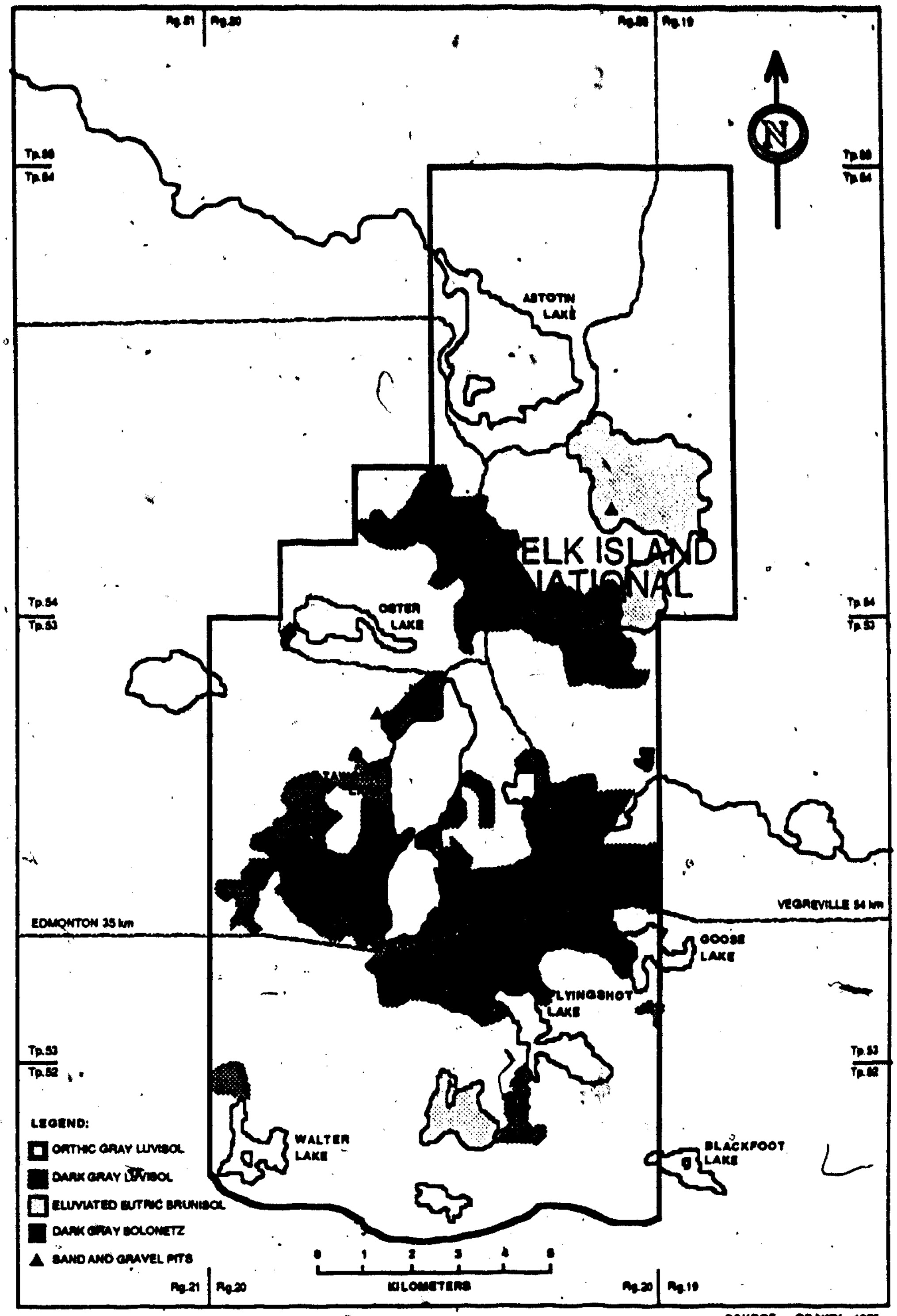
## 2.3 SOILS

Soils belonging to the Luvisolic order are the predominant soils within Elk Island National Park. The luvisolic order is characterized by well drained mineral soils. The hummocky terrain also produces many poorly drained, low-lying and depressional areas where Gleysolic soils have developed (Crown, 1977). Organic soils are dominant in the kettle type depressions (Bichlmaier, 1985). The sand and gravel pits within and adjoining the Park have been created by outwash deposits and ice proximous kame deposits. The sand and gravel deposits, scattered throughout the Park, are shown on figure 2.1 (Crown, 1977).

The predominant glacial deposits within the Park are unsorted tills that contain enough clay to make them only very slowly permeable. The low permeability of the soils has resulted in a limited internal drainage within the Park. The knob and kettle topography and the limited internal drainage are responsible for the abundant marshes and lakes.

## 2.4 HYDROGEOLOGY

The Cretaceous Belly River Formation forms the hydrogeological basement under Elk Island National Park. This formation under the Park is approximately 250 m. thick and is made up of sandstone, shale, siltstone, and mudstone (Stein, 1976). The probable yield from this formation is 4.5-22.5 L/minute. In general, the water quality from bedrock formations in this region is poor with the total dissolved solids ranging from 1000 mg/L to more than 6000 mg/L (Stein, 1976). The average total dissolved solids in the bedrock




SOURCE: CROWN, 1976

**Generalized Soil Map and Location of Sand and Gravel Pits in Elk Island National Park**

Figure 2.1

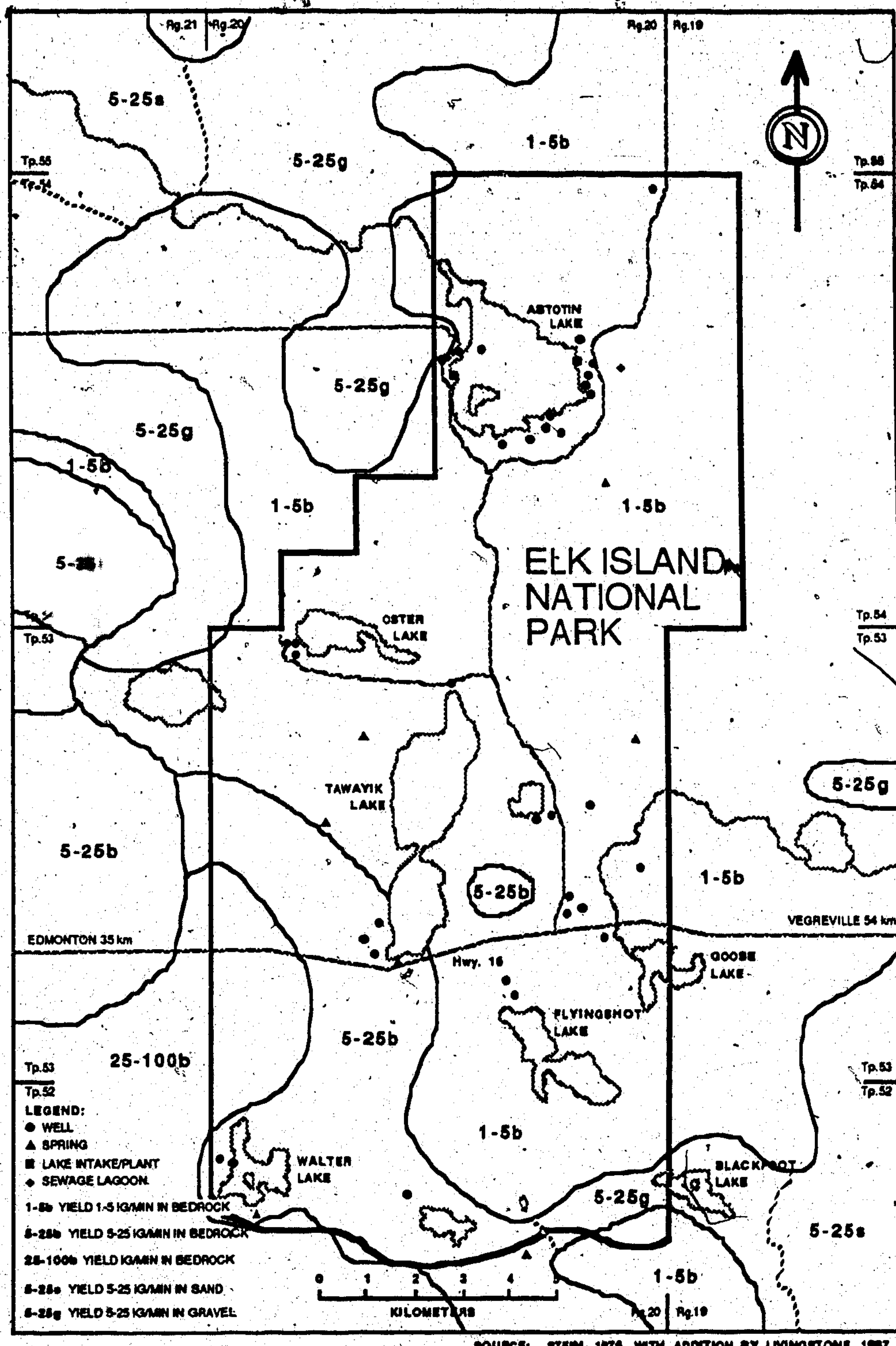
formations ranges from 1000-2000 mg/L. The areas of high total dissolved solids contain primarily high chloride levels, and secondarily, high sulfate levels (Stein, 1976).

The Cretaceous Bearspaw Formation overlays the Cretaceous Belly River Formation. The Bearspaw Formation is approximately 40 m thick and is composed of marine shales and interbedded nonmarine sandstone and shale (Stein, 1976). Overlying the Cretaceous Bearspaw Formation lies the Cretaceous Horseshoe Canyon Formation. The Horseshoe Canyon Formation, which is 100 m thick on the west side of the Park and 0 m. thick on the eastern side, is composed of interbedded nonmarine and brackish sandstones, shales, and siltstones (Stein, 1976). Both the Bearspaw and Horseshoe Canyon Formations suffer from poor water quality with total dissolved solid values ranging from 1000-2000 mg/L and being primarily composed of sodium bicarbonate in the recharge zones, and sodium sulphate in the discharge zones (Stein, 1976). The probable yield from these two formation ranges from 4.5-22.5 L/minute. Interbedded coal seams are present in the Horseshoe Canyon Formation in the southwest corner of the Park. These coal seams are reported to have the ability of producing 22.5-454 L/minute. The coal seams of the Horseshoe formation have been reported by Stein (1976) to be among the best aquifers in the area.

Regional groundwater flow within the bedrock is limited due to the low permeability and extensive faulting of the bedrock. Higher rates of recharge and discharge, through groundwater flow are possible in the surficial deposits (Livingstone, 1987a).

The surficial deposits of concern in this region include the hummocky moraine, prairie mounds, and till ridges. The thickness of these surficial deposits ranges from 10-40 m. with deposits on the west side of the Park being somewhat thicker (Livingstone, 1987a).

Individual well yields from surficial deposits are in the 4.5-22.5 L/minute range (Figure 2.2). The water quality from the wells is variable depending upon the location.




Location of Water Sources in Elk Island National Park

Figure 2.2

The quality is good in upland recharge areas with total dissolved solids counting less than 1000 mg/L. In the lowland discharge areas the quality of the well-water is poor with total dissolved solids ranging from 1000-2000 mg/L (Livingstone, 1987a). The major cations which incidently result in the hardness of the water, are calcium and magnesium, and the major anions present are carbonate and bicarbonate. The sulphate anion is found predominantly in the discharge areas (Livingstone, 1987a). A high iron content in the water is a common problem in the shallow wells of the region. Iron staining has been found to be a problem which occurs at springs in the region (Stein, 1976). High levels of nitrate have been recorded in surficial deposit wells. The recommended limit of nitrates in a sample is 15 mg/L, while many of these wells have recorded over 100 mg/L in samples. The most likely source of these nitrates is from animal and human wastes according to Stein (1976).

Outwash sand and gravel deposits northwest of Astotin Lake and beyond the Park boundaries to the west are areas of known greater yields. Other probable high yield sand and gravel deposits within the Park are located in figure 2.2. The known deposits are rated at 22.5-114 L/minute. The water quality in the recharge areas of these sand and gravel deposits is good. The qualities are good because the surpluses in the low storage sandy soils are high and there is much greater flushing of dissolved solids. This is in contrast to most till areas where surpluses are small and involve mostly surface flow (Laycock, 1987). The water quality is poor in the discharge areas where salinities in excess of 1500 mg/L have been recorded (Stein, 1976).

## 2.5 SURFACE WATER SUPPLIES

The knob and kettle topography and the impervious nature of the soil are responsible for the formation of 220 ponds and lakes within the Park. The ponds and lakes are all very shallow, with the largest lake, Astotin Lake having a maximum depth of 7.6 m (Griffiths, 1979). As a result of the shallowness of the water bodies and the recent decreases in lake levels, "the symptoms of lake aging such as aquatic growth, algal blooms, poor water quality, and collapsed fisheries have become more noticeable (Alberta Environment, p17, 1977c)." The pond and lake levels are quick to respond to beaver activity and heavy prolonged rains. Due to the knob and kettle type terrain there is no well defined stream pattern within the Park. In this type of terrain much of the flow (both surface and groundwater) is in local flow systems into the ponds and lakes where much of the small positive balance of the land areas is lost in the negative balance of the wetland areas. There is one small stream which begins in the northwest corner of the Park and exits out the east side. During the dry seasons this stream shrinks to a series of ponds. The largest permanent stream within the Park begins at Goose Lake and flows north across Highway 16 and exits out the east side of the Park (Fig 2.2). There are numerous channels formed during the spring melt period, most of which become marshes or dry up during the summer. In regions of the Park where wetland areas are small, streams are evident in some seasons of most years. During the wetter years or series of wet years such as 1972-1974, many more local streams are evident. The ponds and lakes during these years are prone to overflowing their banks.

## 2.6 VEGETATION

The Cooking Lake area, according to Rowe(1972), is classified into two major forest regions. The Cooking Lake Moraine characterized by knob and kettle topography is classified as having a Boreal Mixedwood vegetation cover. The area surrounding the Cooking Lake Moraine is relatively flat land lower in elevation and classified as aspen-grove or aspen parkland (Rowe, 1972). Strong and Leggatt (1981) reported similar conclusions.

The majority of the forest category within Elk Island National Park fits into the poplar association of trees. Trembling aspen (*Populus tremuloides*) occupy drier sites with balsam poplar (*Populus balsamifera* ) in more moist locations. The most extensive cover type is the trembling aspen because it regenerates quickly following disturbances such as fire or clearing (Alberta Environment, 1977c).

Extensive stands of white spruce (*Picea glauca*) existed in Elk Island National Park prior to the 1890's when fires removed most of these (Nyland, 1966). The islands of Astotin Lake and a few other scattered areas throughout the Park are the only locations where more than local stands of white spruce survived.

Marshes are a dominant feature of Elk Island National Park and they usually surround open water bodies and fill in many depressions. Vegetation species of marshes within the Park include:

Sedges (*Carex* sp.), cattails (*Typha latifolia*), bullrush (*Scripus validus*), spikerush (*Eleocharis* sp.), slough grass (*Beckmannia* sp.), rush (*Juncus* sp.), (*Scolochloa* sp.), manna grass (*Glyceria* sp.), reed grass (*Calamagrostis* sp.), and blue grass (*Poa* sp.) (Alberta Environment, 1977c, p.27).

Lewis et al (1928) identify a profile of dominant plants from an open water body to a dry upland. *Typha* - *Scripus* > *Scolochloa* - *Carex* > *Calamagrostis* - *Salix* > poplar forest. Environmental disturbances such as grazing, mowing, burning, and flooding can maintain earlier stages such as reedgrass or sedge communities and prevent willow and aspen forest encroachment (Alberta Environment, 1977c).

The bogs have formed in the morainic basins similar to those occupied by marshes but have more organic soils and therefore have different successional patterns. An example of the dominant plants from open water to the dry upland is as follows: *Carex* > *Betula* - *Larix* - *Sphagnum* > *Ledum* - *Sphagnum* > seedling *Picea* > *Picea* - *Sphagnum*. Eventually the black spruce (*Picea mariana*) gives way to the balsam poplar-white spruce forest climax characteristics (Alberta Environment, 1977c).

Vegetation beside a large permanent water body is much the same as in a marsh except that the wetland vegetation is restricted to a narrow band along the lakeshore (Alberta Environment , 1977c).

The type of vegetation has a great deal to do with an area's water balance. Different types of vegetation are associated with different moisture storage categories.[1] For example, a closely grazed grass cover would typically be related to a 50 mm moisture storage capacity and a maturing forest to a 250 mm capacity before surpluses occur. In areas with limited storage capacities, surpluses occur earlier and more frequently because of the lesser recharge requirement. It is evident that the 50 mm storage capacity area would be much more prone to surpluses than the 250 mm storage capacity area. Therefore the type of vegetation present in a region has a great deal of impact on the surplus patterns of that area.

## 2.7 HISTORY

The first white men in the Cooking Lake area were trappers and fur traders of the Hudson's Bay Company who came up the North Saskatchewan River (Bichlmaier, 1985). The earliest permanent settlement in the Cooking Lake area occurred on the shores of the Beaverhill Lake by Metis settlers in 1870 (Alberta Environment , 1977d). In 1870 this region was incorporated into the Dominion of Canada, and as a result of incorporation this portion of the Prairie Provinces was first surveyed by G.A. Simpson and M. Deane in 1883 (Nyland, 1969). The Cooking Lake Moraine was the scene of the earliest attempt at conservation in the province of Alberta, when in 1892 the Cooking Lake Timber Reserve was established due to fires caused by farmers clearing land (Alberta Environment , 1977d). During the spring and summer of 1895 the greatest fire of the region occured which destroyed nearly all the timber in the region including that in the timber reserve

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[1] A further discussion on moisture storage categories may be found in Chapter 4.

(Bichlmaier, 1985). Fires were the main force which destroyed much of the timber that grew but were not the only cause for the depletion of the timber in the region. Prior to and after the great fire of 1895, the sawmills removed a great deal of timber for the newly expanding population (Alberta Environment, 1977d).

In 1898 the limits of the Cooking Lake Forest Reserve were redefined by the government in response to the pressures of settlers and in part relating to the distribution of past forest fires. The area designated as forest reserve in 1898 included what is now Elk Island National Park and the Blackfoot Grazing Reserve (Alberta Environment, 1977d).

In 1906 a part of the forest reserve around Astotin Lake was fenced off to protect a herd of naturally occurring elk. Elk Island Park was established with an area of 41 square kilometers. In 1913 the area became a Dominion Park and in 1930 the Park became officially recognized as Elk Island National Park (Crown, 1977). The size of the Park was increased in 1922 to 134.2 square kilometers when the remainder of the present park north of Highway 16 was included (Griffiths, 1979). The size of the Park was again increased in 1947 to 194.2 square kilometers when the present portion south of Highway 16 was incorporated (Willman, 1987).

In the early 1900s more settlers arrived in the Beaver Hills when plans were revealed that a railway was going to be built near there. In 1909 the line connecting Winnipeg and Edmonton was completed by the Grand Trunk Pacific Company (Morrow, 1964).

In 1910, Alberta's first tree nursery was established near Cooking Lake. Two years later the site was moved to the new forestry headquarters which was located on the present south boundary of Elk Island National Park. During the years 1919 to 1930 the head warden Charles Bailey and his assistant Freeman Kelly were responsible for the reforestation of an area of 400 ha. In 1924 and 1929 most of the tree plantations were destroyed by fire. The station of the forest reserve was eventually closed in 1941 (Bichlmaier, 1985).

The Park at present is primarily oriented towards the preservation of the wildlife within its boundary. A secondary orientation of the Park is towards the day-use recreationist who partakes in hiking, cross-country skiing, snowshoeing, picnicing, and golfing. There are two primitive campsites, one of which is open all year round, and one semi-serviced campground which is only open during the summer (Parks Canada, 1985). The policy of the Park in keeping with National Park Policy is to keep the Park as primitive as possible and to prevent further change from occuring within the Park.

## 2.8 HISTORICAL REGIONAL CLIMATIC PATTERNS

The 104 year water balance record for the Edmonton Municipal Airport is shown in table 2.1. The Edmonton Municipal Airport was used because of its long record compared to the short 16 year record of the Edmonton International Airport. The results indicate that there are groupings of years with similar records. From 1883-1899 the table indicates a dry period, because of the small surpluses and the large deficits. The period from 1900-1904 was a wet one which caused many lakes to overflow. The years 1905-1932 were marked by dry years with interspersed wet years such as 1907 and 1920. The dry period was followed by 10 moderately wet years from 1933 to 1943. The period from 1944 to 1956 was not marked by any wet or dry trends, but contained both wet and dry years. The years 1957-1971 were dry years except for 1965, and were followed by 3 wet years from 1972-1974. From 1975 to 198[illegible] the region has experienced mostly dry years with occasional wet years interspersed.

The water balance record is for areas with 100 mm (approximately 4 inches) of soil moisture storage capacity, a level typical of agricultural land rather than forest land. It will be necessary to prepare a record that is more appropriate for the area under study. It can be suggested that surpluses and deficits will have been smaller than those shown, except possibly, in a few years after the major fires of the 1890s. Allowance must also be made for wetland evaporation and evapotranspiration because much of the runoff would have been into local water bodies with little surplus in many years for flow out of the Park. A better understanding of water balance patterns through time can reflect how effective various management measures were in modifying water supply and quality patterns in the Park.

TABLE 2.1

**Edmonton Municipal Airport**
**Historical Surpluses And Deficits**
100 mm Moisture Storage Category

| DATE | SURPLUS (mm) | DEFICIT (mm) | DATE | SURPLUS (mm) | DEFICIT (mm) |
|---|---|---|---|---|---|
| 1883 | 101.6 | 251.5 | 1936 | 101.6 | 154.9 |
| 84 | 0 | 101.6 | 37 | 0 | 76.2 |
| 85 | 2.5 | 139.7 | 38 | 17.8 | 73.7 |
| 86 | 0 | 149.9 | 39 | 88.9 | 162.6 |
| 87 | 0 | 203.2 | 1940 | 147.3 | 157.5 |
| 88 | 76.2 | 35.6 | 41 | 0 | 127.0 |
| 89 | 0 | 378.5 | 42 | 53.3 | 5.1 |
| 1890 | 0 | 0 | 43 | 99.1 | 38.1 |
| 91 | 25.4 | 81.3 | 44 | 0 | 91.4 |
| 92 | 0 | 127 | 45 | 17.8 | 167.6 |
| 93 | 10.2 | 66 | 46 | 5.1 | 76.2 |
| 94 | 20.3 | 132.1 | 47 | 38.1 | 91.4 |
| 95 | 5.1 | 180.3 | 48 | 121.9 | 215.9 |
| 96 | 20.3 | 177.8 | 49 | 0 | 210.8 |
| 97 | 0 | 215.9 | 1950 | 0 | 188.0 |
| 98 | 10.2 | 271.8 | 51 | 27.9 | 35.6 |
| 99 | 0 | 0 | 52 | 43.2 | 116.8 |
| 1900 | 127.0 | 0 | 53 | 78.7 | 0 |
| 1 | 185.4 | 0 | 54 | 22.9 | 0 |
| 2 | 109.2 | 71.1 | 55 | 35.6 | 132.1 |
| 3 | 7.6 | 0 | 56 | 66.0 | 63.5 |
| 4 | 106.7 | 132.1 | 57 | 0 | 254.0 |
| 5 | 0 | 160.0 | 58 | 17.8 | 142.2 |
| 6 | 0 | 188.0 | 59 | 0 | 58.4 |
| 7 | 101.6 | 17.8 | 1960 | 2.5 | 20.3 |
| 8 | 0 | 182.9 | 61 | 0 | 236.2 |
| 9 | 2.5 | 172.7 | 62 | 30.5 | 106.7 |

TABLE 2.1 CONTINUED

| DATE | SURPLUS (mm.) | DEFICIT (mm.) | DATE | SURPLUS (mm.) | DEFICIT (mm.) |
|---|---|---|---|---|---|
| 1910 | 0 | 185.4 | 63 | 5.1 | 233.7 |
| 11 | 0 | 0 | 64 | 0 | 185.4 |
| 12 | 0 | 5.1 | 65 | 129.5 | 101.6 |
| 13 | 5.1 | 35.6 | 66 | 0 | 132.1 |
| 14 | 20.3 | 0 | 67 | 17.8 | 193.0 |
| 15 | 15.2 | 63.5 | 68 | 0 | 154.9 |
| 16 | 0 | 20.3 | 69 | 0 | 119.4 |
| 17 | 61.0 | 147.3 | 1970 | 12.7 | 99.1 |
| 18 | 0 | 81.3 | 71 | 22.9 | 177.8 |
| 19 | 5.1 | 200.7 | 72 | 63.5 | 48.3 |
| 1920 | 147.3 | 58.4 | 73 | 0 | 21.8 |
| 21 | 10.2 | 165.1 | 74 | 63.5 | 38.1 |
| 22 | 0 | 208.3 | 75 | 0 | 123.0 |
| 23 | 0 | 188.0 | 76 | 0 | 167.3 |
| 24 | 0 | 109.2 | 77 | 0 | 53.4 |
| 25 | 66.0 | 152.4 | 78 | 0 | 0 |
| 26 | 0 | 149.9 | 79 | 49.4 | 71.4 |
| 27 | 66.0 | 55.9 | 1980 | 24.4 | 84.9 |
| 28 | 22.9 | 99.1 | 81 | 11.5 | 94.1 |
| 29 | 7.6 | 213.4 | 82 | 50.6 | 108.3 |
| 1930 | 0 | 203.2 | 83 | 0 | 136.4 |
| 31 | 0 | 40.6 | 84 | 0 | 158.5 |
| 32 | 17.8 | 190.5 | 85 | 95.8 | 106.4 |
| 33 | 27.9 | 83.8 | 86 | 0 | 90.9 |
| 34 | 86.4 | 48.3 | | | |
| 35 | 91.4 | 96.5 | | | |

Source: Laycock (1986)

# 3. THE WATER BALANCE

## 3.1 INTRODUCTION

The focus in this chapter is on the water balance calculation procedure. The calculation of the water balance procedure is necessary to better understand the water balance patterns throughout the Park for management purposes. The objective in this thesis was not to test the Thornthwaite procedure against other water balance procedures. The author tried to use whatever procedures were available to reach the basic objective of providing better water balance information for management purposes. Testing of the Thornthwaite procedure in Elk Island National Park would entail much more measurement, and many more years than would be allowed for a Masters degree. The first section is a discussion of the Thornthwaite technique which will be used in the remaining chapters of the thesis. Within this section, the reasons for choosing the technique and the components of the procedure are discussed. Section 3.3 is an illustration of the world-wide practicality of the Thornthwaite procedure. The next section is a shorter discussion of the Penman technique which is the main alternative to the Thornthwaite technique. A review of the Penman technique will be followed by a comparison of the Thornthwaite and Penman methods. The last section in this chapter is a brief review of other empirical methods of determining potential evapotranspiration, which could lead to the calculations of a water balance.

## 3.2 THE THORNTHWAITE PROCEDURE

The Thornthwaite procedure has been chosen for the determination of the water balance of Elk Island National Park. There are numerous reasons for the use of the procedure, the first of which is a readily available supply of climatic data. There are a number of first and third order weather stations in close proximity to the Park for use in making and checking the calculations. The wide use of the technique throughout the Prairies would indicate the procedures acceptance as a viable procedure for this area. If there are any questions concerning the procedure, there are enough references available on the Thornthwaite technique and refinements of it for particular purposes to solve the problem. The procedure, through use of tables, is easy to use and does not require any lengthy calculations, making it look much more favourable than the Penman or Turc techniques which require lengthy calculations.[1] Methods such as Penman and Turc require considerable data, and so are neither easy to use or of widespread applicability (Mather, 1984). One main advantage of the two above listed procedures is that they use a greater data base, and with the availbility of the data are more likely to be accurate. In using the two procedures, however, estimates are often used for some of the generally unmeasured terms, resulting in a lower confidence in the accuracy (Mather, 1984). Mather (1984) accepts that the Thornthwaite procedure might be less accurate on a daily and monthly basis, but he contends that the procedures wide usefulness and world-wide applicability far outweigh its inability to reflect short-term changes in wind and humidity.

### 3.2.1 THE THORNTHWAITE WATER BALANCE EQUATION

The term water balance (water budget) has several different meanings depending upon the particular scale being considered. For example, on the macroscale, the water budget can be used in the same sense as a hydrological cycle, or annual global balance. At the mesoscale, the water budget of a region or drainage basin is determined. Determination of a water budget for a field of vegetation, a forest stand, or a single tree would constitute a microscale investigation (Mather, 1978). The annual water balance has been summarized by Mather (1959) as follows:

> When the potential evapotranspiration is compared with the precipitation, and allowance is made for the storage of water in the ground and its subsequent use, periods of moisture deficiency and excess are clearly revealed, and an understanding of the relative moistness or aridity of a climate is obtained. ... Under normal conditions both of these conditions will occur during the course of a year or several years at a place so that a

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[1]The Penman and Turc techniques will be examined later in this chapter.

comparison of the potential evapotranspiration with the precipitation will show both a wet or a cold season in which water need is less than the available precipitation and a dry or hot season in which the water need exceeds the precipitation. Under such circumstances there usually occurs a period of full soil moisture storage when precipitation is greater than the moisture demand and a moisture surplus accumulates; a drying period, when the moisture in the soil is used by the plants, the soil moisture storage is diminished, and a moisture deficit occurs; and a re-moistening season, when precipitation exceeds water use and the soil moisture storage is replenished. The values of moisture surplus and deficiency as well as of the other factors of the water balance can be computed by means of a simple water balance bookkeeping procedure.

The principal factors of a water balance include precipitation, temperature, and average day length to correct for season and latitude. The above principal factors were first used by Thornthwaite in 1948 in his determination of a water balance. The water balance of an area may be determined by use of the following formula:

$$P = PE - D + S +/- St\ Ch$$

P = Precipitation

PE= Potential Evapotranspiration

D = Deficit

S = Surplus

St Ch = Storage Change

The equation in effect represents a balance between all forms of incoming precipitation (rain, snow, and condensation) on the left side, and the use of the precipitation including surface runoff, groundwater discharge, surface evaporation and transpiration from plants on the right side. The storage change factor on the right side represents the net addition to or removal from the soil moisture in storage in the period under study. During November and December in some years enough precipitation will fall to fill and exceed the lower moisture storage categories. This will result in a net snow detention storage change in those categories.

### 3.2.2 PRECIPITATION

Precipitation (P) which makes up the left side of the water balance equation, is measured by stick and Nipher gauges for snow, and by the standard Canadian rain gauge. The Nipher gauge is used exclusively at first order weather stations which are primarily located at major airports, while the stick gauge is employed at third order weather stations. A third order station can be set up anywhere that a daily measurement can be taken. At first order stations equipped with a Nipher gauge, the total precipitation which is measured hourly is determined after melting the contents, whereas at third order stations, the water equivalent of snowfall is obtained by dividing the amount of snow by 10 (Environment Canada, 1981). All stations use the standard Canadian rain gauges, with hourly readings at first order stations, and daily readings at third order stations. There are a number of possible errors in the measurement of precipitation which are of some concern. The source of error which is of most concern involves the aerodynamic interactions between the falling precipitation, wind, and the gauge and its surroundings (Ward, 1975). The air flow around the gauge is speeded up, causing the falling rain (and especially snow) to be carried past rather than be collected in the gauge (Ward, 1975).

In a U.S.S.R. Interdepartmental Committee for the International Hydrological Decade (1967), gauge catch was found to be underestimated due to wind, loss of liquid in wetting the container, and evaporation from the gauge before a measurement could be taken. The wind factor was found to be the most prominent. The committee made a number of recommendations for correcting the precipitation values due to gauge undercatch. It was suggested that:

> For liquid precipitation, the average correction necessary to the rain gauge reading varies between 12 % and 22 % (it is usually between 14 % and 16); for solid precipitation, between 20 % and 100% (usually between 40 % and 60 %), and for annual total between 17 % and 56 % (usually between 20 % and 30 %).

(U.S.S.R. Interdepartmental Committee for the Hydrological Decade, p. 1, 1967)[1]

Wind will also have an effect on the measurement of snow when using the stick gauge. Due to the wind there is the possibility of a gross under measurement or over measurement of snow caused by drifting.

Condensation on cool surfaces from saturated or nearly saturated air is in most water balance calculations either included with precipitation or omitted on the assumption that it is either small or already compensated for in underestimates of evapotranspiration (Ferguson and others, 1970). The lack of measurement of condensation upon surfaces is a potential error which is most pronounced in winter. The condensation upon surfaces probably balances evaporation from snow surfaces and limited melting which is also recorded.

The errors in recording precipitation during the summer and winter are recognized, but any correction factors used would be similar for all stations. The empirical procedures used are based on measured and not corrected precipitation. It is probable that errors on the precipitation side of the water balance equation are at least as large as those on the potential evapotranspiration side of the equation.

### 3.2.3 POTENTIAL EVAPOTRANSPIRATION

Potential evapotranspiration is defined by Thornthwaite (p. 201, 1954) as "the water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation." The term evapotranspiration comprises two parts; evaporation, being the process by which a liquid or a solid is changed to a gas, and transpiration, which is the process by which water vapour escapes from the living plant, principally through the leaves and enters the atmosphere (Ward, 1975). Evapotranspiration therefore comprises the total

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[1] Further discussion of snow undercatch may be found in Section 4.4.3.

volume of water transpired from vegetation and plants, and evaporated from soil, snow, and intercepted precipitation in any given area (Ward, 1975). Evapotranspiration represents the most important aspect of water loss in the hydrologic cycle, accounting for as much as 100 percent of precipitation in arid climates and 75 percent in humid regions (Ward, 1975). In the Edmonton area the average would be about 90-95 percent with a range of 70-100 percent. The percentage will vary with surfaces, such as 30 percent for paved surfaces to almost 1[illegible] percent for some mature forests (Laycock, 1987). Tables in subsequent sections of this thesis illustrate the percentage differences in evapotranspiration for different surfaces.

The formula to determine potential evapotranspiration was the result of numerous world-wide empirical observations with evapotranspirometers and is a best fit conclusion. The first formula to determine PE used values of mean temperature and relative humidity. The formula was refined by Thornthwaite in 1948 to use meteorological data which would be readily available almost anywhere. The new formula using mean temperature and average day length became the foundation of Thornthwaites climatic classification of 1948 (Thornthwaite, 1955). The formula has been found by Mather (1984) to provide reliable values of monthly evapotranspiration, especially if there were no marked monthly changes in humidity (ie. monsoon climate).

The formula to determine potential evapotranspiration is as follows:

$$e = 1.6\ (10t/I)^{a}$$

where $t$ = mean monthly temperature in °C

$I$ = an annual heat index (determined from the sum

of the 12 monthly heat index values

$I = i$ where $i = (t/5)^{1.514}$

$a$ is a non-linear function of the heat index equal to

$$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} I + 0.49$$

(Mather, p.69, 1984)

Thornthwaite and Mather (1957) developed a series of tables from this equation to determine the potential evapotranspiration. The tables have made the calculation of the above formula unnecessary, resulting in the simplification of the water balance procedure.

Criticism of the Thornthwaite procedure has been primarily directed to the use of the data used to determine evapotranspiration (Chang, 1968). The first and most serious criticism is that temperature is not a good indicator of the energy necessary for evapotranspiration. In the spring and early summer much of the solar radiation is used to melt the snow and ice and less energy is available for evapotranspiration (Wight, 1973).

Thornthwaite's estimates of potential evapotranspiration tend to lag behind the measured values due to increases in solar radiation preceding air temperature increases. The last statement would indicate that potential evapotranspiration estimates should be higher in the spring and lower in the fall. The day length correction factor would result in higher deficits in the spring and smaller deficits in the fall(Chang, 1968). The argument which Chang (1968) puts forth may be adequate for a more humid area such as Ottawa, but is inadequate for the Edmonton area. The day length correction for Thornthwaite in the highest sun period is probably inadequate while the prevalence of frost in the spring and fall may result in reduced PE in these seasons. The two errors are roughly compensating, therefore, the daylength correction has been untouched.

A third source of error in the Thornthwaite potential evapotranspiration equation stems from the use of daily averages of temperature. Evapotranspiration may be underestimated during the day if the mean temperatures are below 0°C but the maximum is above 0°C (Chang, 1968). In defense of Thornthwaite's use of mean daily temperature, it should be pointed out that PE values during these days are very minute and can be ignored as long as the user is aware of them and of compensating factors. For example, a snow cover with a high albedo would reduce evaporation through limiting heating. The angle of the sun would also be low during the winter which would in effect limit the heating power of the sun.

In some areas wind might be an important factor in the determination of potential evapotranspiration. In these windy environments according to Chang (1968) the Thornthwaite estimates and measured values only agree after a correction factor for wind has been applied. This could be significant for chinook areas of Alberta, but would not be significant for Elk Island National Park.

A fifth criticism by Chang (1968) of the Thornthwaite estimates stems from the fact that the formula does not take into consideration the effect of warm and cool air advection on temperature. In regions of warm air advection, the air temperature may increase while the solar radiation and evapotranspiration do not, while in regions of cool air advection the estimated evapotranspiration may not be as large as the measured evapotranspiration. Guerrini (1954) found the cool advected air in Ireland during the winter created smaller estimates of evapotranspiration than were being measured. This discrepancy was corrected by Guerrini with the use of a correction factor during the winter. After the correction factor was added, the estimated runoff equaled the measured local runoff. The Penman procedure is known to be accurate for a Marine West Coast climate because it is empirical for such areas with a warm air advection resulting in a strong positive temperature anomaly for the latitude. There are no such anomalies in the Edmonton area.

At times the humidity of the air might become more important than the local temperature. The writer has allowed for this in water bodies and marshes in dry seasons by adding half the deficit to PE rather than subtracting it.[1]

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[1] Further discussion of this point may be found in Section 4.2.

The writers approach to the water balance problem has been to start with the basic Thornthwaite procedure, and to make refinements such as, the use of multiple storage levels, and daily data. These types of additions to the procedure have been found by the author to be more beneficial than revisions to the PE calculation procedure.

### 3.2.4 DEFICITS

When the precipitation is less than the potential evapotranspiration, the moisture within the soil is evaporated from the soil and transpired by plants faster than it can be replaced. If precipitation continues to be less than the potential evapotranspiration, soil moisture loss will proceed until there is no more available moisture and a deficit condition exists. When a soil dries out, it becomes increasingly difficult for evaporation to occur (Thornthwaite and Mather, 1953). Full potential evapotranspiration is not realized during dry periods, while the actual evapotranspiration is the true measure. The actual evapotranspiration (AE) is equal to the potential evapotranspiration (PE) when precipitation is greater than PE. When precipitation is less than PE, the soil begins to dry out and the formula PE - D = AE results in the true value of evapotranspiration (Thornthwaite and Mather, 1957).

### 3.2.5 SURPLUS

In periods when precipitation exceeds the potential evapotranspiration, the excess moisture that infiltrates the soil is first used to recharge the soil root zone (Mather, 1978). When a specific moisture storage capacity is full, any excess precipitation which occurs is counted as moisture surplus. The moisture surplus does not remain in the soil but either percolates down to the groundwater where (in most cases) it cannot be used by plants, or collects on the surface and is subject to runoff. There are no surpluses during months when the temperature is below -1 °C. This will be true in the calculation of a water balance, but groundwater flow near the surface will continue well after the temperature has dropped below -1 °C. The precipitation which falls as snow does not constitute a surplus, but is held in storage until the spring when the temperature rises above -1 °C. In the spring the meltwater either infiltrates into the ground when the moisture storage capacity is not full, or collects on the surface and is subject to runoff. In terms of surpluses, the surface and groundwater flows for most purposes are not separated. Surplus groundwater flows may be separated from surface flows at natural springs which occur throughout the Park (Fig. 2.2).

### 3.2.6 STORAGE CHANGE ST CH

The last factor in the water balance equation is the change in storage. In the equation, precipitation adds to the soil moisture content, while evapotranspiration subtracts from it. From the two quantities it is possible to obtain on a daily or monthly basis a knowledge of the actual moisture content of the soil (Thornthwaite and Mather, 1955). The result of the two quantities will indicate a net change for the period of study.

### 3.2.7 THE MAKING OF A WATER BALANCE

The first step in determining an areas monthly water balance is to plot the mean monthly temperature as illustrated in line 1[1].

| | | J | F | M | A | M | J | J | A | S | O | N | D | Yr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ln 1 | °C | -10 | -12.6 | -2.0 | 4.8 | 12.2 | 13.1 | 17.3 | 14.0 | 7.1 | 3.5 | -14.0 | -5.7 | |
| Ln 2 | I | 0 | 0 | 0 | .94 | 3.86 | 4.3 | 6.55 | 4.7 | 1.7 | .58 | 0 | 0 | 22.68 |

[1] Complete water balance tables using meteorological data from the Edmonton International Airport for the years 1971-1986 may be found in appendix I.

The next step is to obtain the heat index (Ln 2) from table 2 of Thornthwaite and Mather (1957). The addition of the 12 monthly values gives the annual heat index I. When the mean monthly temperature is below 0 °C the monthly I value is 0.

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ln 1 °C | -10 | -12.6 | -2.0 | 4.8 | 12.2 | 13.1 | 17.3 | 14.0 | 7.1 | 3.5 | -14.0 | -5.7 | |
| Ln 3 UPE | 0 | 0 | 0 | 1.0 | 2.3 | 2.4 | 3.1 | 2.6 | 1.4 | .2 | 0 | 0 | |

The third step is to determine the unadjusted potential evapotranspiration from table 4 of Thornthwaite and Mather (1957). The yearly heat index (I) from line 2 controls which column will be used in table 4. The monthly temperatures from line 1 are cross referenced with the yearly I value to determine the daily unadjusted PE.

The fourth step in the determination of a water balance is to adjust the UPE from line 3. This is done by multiplying the proper correction factor for month and daylength located in table 6 of Thornthwaite and Mather (1957) by the unadjusted daily PE to give the adjusted monthly potential evapotranspiration in line 4.

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ln 3 UPE(mm) | 0 | 0 | 0 | 1.0 | 2.3 | 2.4 | 3.1 | 2.6 | 1.4 | .2 | 0 | 0 | |
| Ln 4 PE(mm) | 0 | 0 | 0 | 34.5 | 91.8 | 97.9 | 127.4 | 97.5 | 44.5 | 5.5 | 0 | 0 | 499.1 |
| Ln 5 P(mm) | 12.2 | 12.5 | 4.2 | 46.0 | 26.1 | 65.6 | 31.1 | 91.4 | 56.0 | 18.8 | 11.5 | 24.0 | 399.4 |
| Ln 6 SC(mm) | 12.2 | 12.5 | 4.2 | 11.5 | -65.7 | -32.3 | -96.3 | -6.1 | 11.5 | 13.3 | 11.5 | 24.0 | |

The fifth step is to plot the total monthly precipitation in line 5 in the same units as the PE in line 4.

The sixth step in line 6 is to determine whether moisture supplies increased or decreased during the month. This is obtained from the equation P-PE. If the value in line 6 is positive, it reflects a potential moisture increase, and if the value is negative it reflects a potential moisture decrease. The next step in the procedure is to insert the different moisture storage capacity categories which are common to the study area into the water balance (1). The characteristics of each moisture storage category may be found in Chapter 4.

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ln 6 SC(mm) 1985 | 12.2 | 12.5 | 4.2 | 11.5 | -65.7 | -32.3 | -96.3 | -6.1 | 11.5 | 13.3 | 11.5 | 24.0 | |
| 13[2] 13mm[1] | 13 | 13 | 13 | 13 | 0 | 0 | 0 | 0 | 11.5 | 13 | 13 | 13 | |
| 36.4[3] S[5] | 12.2 | 12.5 | 4.2 | 11.5 | | | | | | 11.8 | 11.5 | 24.0[4] | 88.6 |
| D[6] | | | | | 52.7 | 32.3 | 96.3 | 6.1 | | | | | 187.4 |

399.4 = 499.1 - 187.4 + 88.6 - .9 [7]

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50[2] 50mm[1] | 50 | 50 | 50 | 50 | 0 | 0 | 0 | 0 | 11.5 | 24.8 | 36.3 | 50 | |
| 36.4[3] S[5] | 12.2 | 12.5 | 4.2 | 11.5 | | | | | | | | 10.3[4] | 76.8 |
| D[6] | | | | | 15.7 | 32.3 | 96.3 | 6.1 | | | | | 150.4 |

399.4 = 499.1 - 150.4 + 76.8 - 26.1 [7]

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100[2] 100mm[1] | 100 | 100 | 100 | 100 | 34.3 | 2 | 0 | 0 | 11.5 | 24.8 | 36.3 | 60.3 | |
| 36.4[3] S[5] | 12.2 | 12.5 | 4.2 | 11.5 | | | | | | | | | 76.8 |
| D[6] | | | | | | | 94.3 | 6.1 | | | | | 100.4 |

399.4 = 499.1 - 100.4 + 76.8 - 76.1 [7]

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 139.9[2] | | | | | | | | | | | | | |
| 150mm [1] | 150 | 150 | 150 | 150 | 84.3 | 52 | 0 | 0 | 11.5 | 24.8 | 36.3 | 60.3 | |
| δ[3] S[5] | 2.1 | 12.5 | 4.2 | 11.5 | | | | | | | | | 30.3 |
| D[6] | | | | | | | 44.3 | 6.1 | | | | | 50.4 |

399.4 = 499.1 - 50.4 + 30.3 - 79.6 [7]

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 139.9[2] | | | | | | | | | | | | | |
| 250mm[1] | 152.1 | 164.8 | 168.8 | 180.3 | 114.6 | 82.3 | 0 | 0 | 11.5 | 24.8 | 36.3 | 60.3 | |
| 0 [3] S [5] | | | | | | | | | | | 0 | | |
| D [6] | | | | | | | 14.0 | 6.1 | | | | | 20.1 |

399.4 = 499.1 - 20.1 + 0 - 79.6 [7]

The level of moisture in storage at the end of the previous year for each category is recorded at 2. It is from this value that the new years balance will continue. The previous years surplus carry over ( moisture in snow detention storage in excess of soil moisture recharge capacity) is located at 3. This surplus value is added to the yearly surplus total for 1985 (when it melts and runs off). The surpluses underlined at 4 represent the surplus carry over from the present year which will be added to the next years surplus total. The underlined surpluses are in the form of snow which rests on the surface, and are not released until the temperature rises above 0 °C. The present years surpluses are recorded on the line marked by a 5 and make-up the yearly surplus total. Deficits are created after the negative soil moisture change from line 6 has reduced the storage level to 0 mm. Deficits will continue from month to month until a positive storage change during a month recharges soil moisture category. The deficits for each month are recorded on the line marked by a 6, and are totalled for the year. The final step in making a water balance table is to check the calculations through the water balance equation (7). The total yearly precipitation from line 5 is put on the left side, and the total yearly potential evapotranspiration from line 4 is put on the right side of the equation. The total yearly deficit of the specific water storage category is subtracted from the PE, and the total yearly surplus of the specific water storage category is added to the PE. To determine the storage change in the formula, the December storage value of the previous year is subtracted from the December storage value of the present year.

3.2.8 THE SELECTION OF METEOROLOGICAL STATIONS

The meteorological data necessary for the Thornthwaite procedure were obtained from the Edmonton International Airport station. The Edmonton Municipal Airport weather station was not chosen because of the heat island effect over the city of Edmonton and the lower elevation. The heat island effect over the past twenty years has served to increase the potential evapotranspiration in the city, resulting in the International Airport becoming a more representative station for Elk Island National Park (table 3.1). In a study on the climate of Vancouver by Hay and Oke (1973), it was found that city climates were created by urbanization, which resulted from a disruption of the natural landscape and atmosphere. The built up areas were found on average to be 1 to 2 °C warmer than the surrounding countryside in any one month with a maximum recorded daily difference of 11.6 °C. The Municipal and International Airport meteorological records in the form of water balances are compared in table 3.1. It was expected that higher deficits would have been recorded at the Municipal Airport because of the heat island effect creating higher evapotranspiration levels. The Municipal Airport station results produced the higher expected deficits (table 3.1). It was also expected that higher surpluses would have been recorded at the International Airport because it was not affected by the heat island effect. In the 20 years of record the International Airport station only had 10 years with higher surpluses. The results in table 3.1 would nevertheless indicate that the heat island effect does have some influence on the Municipal Airport meteorological station data and the International Airport data were selected for use in this thesis.

A third order weather station in Elk Island National Park was established in 1982. The length of record is too short to show any possible trends, but the Parks data has been used as a check on the International Airport values (Table 3.2).

TABLE 3.1

**Water Balances at the Edmonton Municipal and International Airports**

| DATE | STORAGE VALUE (mm) | MUNICIPAL AIRPORT SURPLUS (mm) | MUNICIPAL AIRPORT DEFICIT (mm) | INTERNATIONAL AIRPORT SURPLUS (mm) | INTERNATIONAL AIRPORT DEFICIT (mm) |
|---|---|---|---|---|---|
| 1971 | 13 | 109.2 | 264.2 | 121.9 | 238.8 |
| | 50 | 73.6 | 226.0 | 99.1 | 200.7 |
| | 100 | 22.9 | 175.3 | 48.3 | 149.9 |
| | 150 | 0 | 152.4 | 0 | 101.6 |
| | 250 | 0 | 152.4 | 0 | 101.6 |
| 1972 | 13 | 152.4 | 161.3 | 147.3 | 73.7 |
| | 50 | 114.3 | 124.4 | 119.4 | 33.0 |
| | 100 | 63.5 | 73.7 | 66.0 | 0 |
| | 150 | 12.7 | 22.9 | 17.8 | 0 |
| | 250 | 0 | 8.1 | 0 | 0 |
| 1973 | 13 | 88.9 | 111.7 | 121.9 | 86.4 |
| | 50 | 30.5 | 53.3 | 53.3 | 17.8 |
| | 100 | 0 | 21.8 | 17.8 | 0 |
| | 150 | 0 | 21.8 | 15.2 | 0 |
| | 250 | 0 | 21.8 | 0 | 0 |
| 1974 | 13 | 152.4 | 127.0 | 154.9 | 154.9 |
| | 50 | 114.3 | 88.9 | 114.3 | 116.0 |
| | 100 | 63.5 | 38.1 | 99.1 | 63.5 |
| | 150 | 12.7 | 0 | 96.5 | 17.8 |
| | 250 | 0 | 0 | 27.9 | 0 |
| 1975 | 13 | 95.0 | 217.0 | 82.0 | 106.0 |
| | 50 | 43.0 | 166.0 | 45.0 | 69.0 |
| | 100 | 0 | 123.0 | 0 | 24.0 |
| | 150 | 0 | 109.0 | 0 | 24.0 |
| | 250 | 0 | 98.0 | 0 | 0 |

TABLE 3.1 CONTINUED

| DATE | STORAGE VALUE (mm) | MUNICIPAL AIRPORT SURPLUS (mm) | MUNICIPAL AIRPORT DEFICIT (mm) | INTERNATIONAL AIRPORT SURPLUS (mm) | INTERNATIONAL AIRPORT DEFICIT (mm) |
|---|---|---|---|---|---|
| 1976 | 13 | 81.9 | 249.2 | 75.8 | 146.6 |
| | 50 | 41.1 | 208.4 | 38.8 | 109.6 |
| | 100 | 0 | 167.3 | 0 | 70.8 |
| | 150 | 0 | 167.3 | 0 | 70.8 |
| | 250 | 0 | 167.3 | 0 | 8.8 |
| 1977 | 13 | 121.9 | 175.3 | 91.8 | 159.1 |
| | 50 | 48.6 | 102.0 | 34.9 | 102.1 |
| | 100 | 0 | 53.4 | 0 | 67.3 |
| | 150 | 0 | 53.4 | 0 | 67.3 |
| | 250 | 0 | 53.4 | 0 | 67.3 |
| 1978 | 13 | 103.8 | 73.5 | 141.5 | 151.9 |
| | 50 | 29.8 | 25.7 | 67.5 | 109.3 |
| | 100 | 0 | 0 | 0 | 90.5 |
| | 150 | 0 | 0 | 0 | 90.5 |
| | 250 | 0 | 0 | 0 | 90.5 |
| 1979 | 13 | 143.4 | 195.7 | 99.1 | 169.0 |
| | 50 | 95.6 | 121.7 | 93.5 | 132.0 |
| | 100 | 49.4 | 71.4 | 92.2 | 82.0 |
| | 150 | 0 | 22.0 | 42.2 | 32.0 |
| | 250 | 0 | 22.0 | 0 | 0 |
| 1980 | 13 | 162.1 | 192.3 | 191.5 | 120.8 |
| | 50 | 88.1 | 134.9 | 104.7 | 62.1 |
| | 100 | 24.4 | 84.9 | 10.0 | 17.4 |
| | 150 | 0 | 60.5 | 0 | 17.4 |
| | 250 | 0 | 56.3 | 0 | 17.4 |
| 1981 | 13 | 68.2 | 181.1 | 82.8 | 229.8 |
| | 50 | 47.8 | 144.1 | 48.5 | 167.4 |
| | 100 | 11.5 | 94.1 | 48.5 | 117.4 |
| | 150 | 0 | 82.6 | 8.5 | 67.4 |
| | 250 | 0 | 82.6 | 0 | 58.9 |
| 1982 | 13 | 177.0 | 234.7 | 211.8 | 189.0 |
| | 50 | 103.0 | 160.7 | 137.8 | 115.0 |
| | 100 | 50.6 | 108.3 | 52.4 | 37.0 |
| | 150 | 0.6 | 58.3 | 2.4 | 0 |
| | 250 | 0 | 57.7 | 0 | 0 |

TABLE 3.1 CONTINUED

| DATE | STORAGE VALUE (mm) | MUNICIPAL AIRPORT SURPLUS (mm) | MUNICIPAL AIRPORT DEFICIT (mm) | INTERNATIONAL AIRPORT SURPLUS (mm) | INTERNATIONAL AIRPORT DEFICIT (mm) |
|---|---|---|---|---|---|
| 1983 | 13 | 111.7 | 248.1 | 87.3 | 208.1 |
| | 50 | 37.7 | 174.1 | 14.2 | 135.1 |
| | 100 | 0 | 136.4 | 0 | 120.9 |
| | 150 | 0 | 136.4 | 0 | 120.9 |
| | 250 | 0 | 136.4 | 0 | 120.9 |
| 1984 | 13 | 143.5 | 217.7 | 144.3 | 238.0 |
| | 50 | 69.5 | 181.9 | 70.3 | 201.0 |
| | 100 | 0 | 158.5 | 3.5 | 184.2 |
| | 150 | 0 | 158.5 | 0 | 184.2 |
| | 250 | 0 | 158.5 | 0 | 184.2 |
| 1985 | 13 | 99.7 | 193.4 | 88.5 | 187.4 |
| | 50 | 99.7 | 156.4 | 76.8 | 150.4 |
| | 100 | 95.8 | 106.4 | 76.8 | 100.7 |
| | 150 | 45.8 | 56.4 | 30.3 | 50.4 |
| | 250 | 0 | 7.5 | 0 | 20.1 |
| 1986 | 13 | 113.7 | 178.6 | 101.0 | 150.0 |
| | 50 | 46.0 | 136.9 | 48.9 | 94.9 |
| | 100 | 0 | 90.9 | 0 | 46.0 |
| | 150 | 0 | 90.9 | 0 | 46.0 |
| | 250 | 0 | 90.9 | 0 | 46.0 |

Source: Calculations by Author Using the Thornthwaite Procedure

TABLE 3.2

**A Comparison Of Water Balance Values Between Elk Island National Park And Edmonton International Airport**

| | EINP | | EDMONTON | | % DIFFERENCE EINP TO EDMONTON | |
|---|---|---|---|---|---|---|
| Year | Ppt. | PE | Ppt. | PE | Ppt. | PE |
| 1982 | 632.2 | 499.1 | 516.4 | 493.6 | +22.4 | +1.1 |
| 1983 | 585.4 | 524.8 | 409.4 | 529.8 | +43.0 | -0.9 |
| 1984 | 502.1 | 520.8 | 448.8 | 517.1 | +11.9 | +0.7 |
| 1985 | 417.5 | 516.7 | 399.4 | 499.1 | +4.5 | +3.5 |
| TOTAL | 2137.2 | 2061.4 | 1774.0 | 2039.4 | +20.5 | +1.1 |

From the four years of comparison, it is evident that the Park received on average 20 percent more precipitation (Ppt.) than the Edmonton International Airport. The precipitation amounts during the winter at the Edmonton International Airport and Elk Island National Park are very similar. The major differences in precipitation amounts occured during the summer (App. I, IV). The potential evapotranspiration (PE) over the four years was however, very similar with only a 1.1percent difference between the two stations.

The yearly surplus and deficit values for the different stations are listed in table 3.3. It is evident when comparing the Edmonton International Airport and Elk Island National Park weather data for 1982 and 1983 that the surpluses were higher than the deficits in the Park. At the Airport in 1983 and other years, the deficits were greater than the surpluses. This is a result of lower precipitation levels at the Airport. The length of record however does not enable the writer to make any predictions and conclusions.

There are other third order weather stations near Elk Island National Park including Ellerslie, Vegreville, Tofield, and Fort Saskatchewan. The record from these stations is incomplete, and therefore unreliable, resulting in their limited use as a check on existing data from the first order Edmonton International Airport station.

The Vegreville weather station data are not representative of the Elk Island National Park climate, due to the drier conditions of the Vegreville area. In table 3.3 it is apparent from the 9 years of record that on average the Vegreville weather station received the lowest amounts of precipitation. The Tofield North and Ellerslie weather data were found to be unreliable due to missing data which had to be estimated from other stations. The Fort Saskatchewan data were not included in table 3.3 because of numerous gaps.

The Namao meteorological station is closer to Elk Island National Park and Edmonton than the International Airport. The Namao weather station is close enough to Edmonton to be affected by the city's heat island effect. In the 9 years of record in table 3.3, the Namao weather station recorded the highest potential evapotranspiration in 8 of the 9 years.

## 3.3 PREVIOUS USES OF THE THORNTHWAITE TECHNIQUE

The Thornthwaite technique has been used and modified throughout the world to determine regional water balances. Al-Khashab (1958) used the Thornthwaite procedure to construct a water budget to determine the amounts and distribution of runoff in the Tigris and Euphrates basins. The values for the runoff were desired to determine the amounts available for irrigation requirements in Iraq. Thornthwaite, Mather, and Carter (1958) constructed 3 water balance maps of Southwest Asia. These maps were similar to those made by Thornthwaite, Mather, and Carter (1958) which covered the Northeast United States. The 3 maps individually depicted the potential evapotraspiration, surpluses, and deficits. The maps of Southwest Asia primarily focused on India and have been revised and expanded upon by local Indian scholars such as L.A. Ramdas (1972). The

## TABLE 3.3

**Water Balance Equations For Weather Stations In The Elk Island National Park Area**

(100mm Water Storage Category)

| | Ppt. = PE - D + S ± ΔST |
|---|---|
| 1977 | |
| Edm. Int. | 435.8 = 511.9 - 67.3 + 0 - 8.8 |
| Namao | 458.9 = 544.3 -66.4 + 0 -19 |
| Vegreville | 448.9 = 531 -87 + 0 + 4.9 |
| Tofield N. | 510.5 = 536.6 - 42.5 + 19.7 - 3.3 |
| 1978 | |
| Edm. Int. | 540.6 = 533.9 - 90.5 + 0 - 97.2 |
| Namao | 558.3 = 844.3 - 29.8 + 0 +44 |
| Vegreville | 425.3 = 534.6 - 118.6 + 0 + 9.3 |
| Tofield N. | 716.4 = 540.5 - 0 + 94 + 81.9 |
| Ellerslie | 520.6 = 555.1 - 52.3 + 0 + 17.8 |
| 1979 | |
| Edm. Int. | 429.5 = 510.4 - 82 + 92.2 - 91.1 |
| Namao | 441.9 = 52[illegible]8 - 75.7 + 30.9 - 42.1 |
| Vegreville | 396.7 = 504.5 - 115.3 + 26 - 18.5 |
| Tofield N. | 494.9 = 507.6 - 36.6 + 130.6 +106.7 |
| Ellerslie | 387.7 = 515.1 - 131.2 + 25.7 - 21.9 |
| 1980 | |
| Edm. Int. | 614.9 = 533.7 - 17.4 + 10 +88.6 |
| Namao | 601.6 = 561.8 - 9.5 + 4.4 + 44.9 |
| Vegreville | 417.4 = 546.2 - 153.4 + 0 + 24.6 |
| Tofield N. | 623.1 = 548.4 - 45.8 + 24 + 96.5 |
| Ellerslie | 563.2 = 545.9 - 61.5 + 0 + 78.8 |
| 1981 | |
| Edm. Int. | 370.6 = 540 - 117.4 + 48.5 - 100.5 |
| Namao | 387.5 = 563.1 - 119.3 + 1.4 - 57.7 |
| Vegreville | 278.8 = 541.2 - 228.3 + 0 - 34.1 |
| Tofield N. | 349.9 = 539.5 - 165.9 + 64.5 - 88.2 |
| Ellerslie | 395.4 = 547.1 - 89.3 + 28.5 - 90.9 |
| 1982 | |
| Edm. Int. | 516.4 = 493.6 - 37 + 52.4 + 7.4 |
| Namao | 465.1 = 518.6 - 93 + 37 + 2.5 |
| Vegreville | 436.7 = 490.5 - 60.8 + 5 + 2 |
| Tofield N. | 489.1 = 501.[illegible] - 74.3 + 74.8 - 13.3 |
| Ellerslie | 457.5 = 500.2[illegible] 61.2 + 20.4 - 1.9 |
| EINP | 632.2 = 499.1 - 19 + 107.4 + 44.7 |

TABLE 3.3 CONTINUED

| | |
|---|---|
| **1983** | |
| Edm. Int. | 409.4 = 529.8 - 120.9 + 0 + .5 |
| Namao | 420.4 = 548 - 131 + 0 + 3.4 |
| Vegreville | 516.7 = 527.7 - 40.5 + 0 + 29.5 |
| Tofield N. | 588.4 = 524.4 - 0 + 31.2 + 32.8 |
| Ellerslie | 405.6 = 530.1 - 136.6 + 0 + 12.1 |
| EINP | 585.4 = 524.8 - 30.8 + 129.7 - 38.3 |
| **1984** | |
| Edm. Int. | 448.8 = 517.1 - 184.2 + 3.5 + 112.4 |
| Namao | 476.0 = 521.2 - 126.1 + 0 + 80.9 |
| Vegreville | 430.1 = 523.7 - 134.7 + 0 + 41.1 |
| Tofield N. | 520.4 = 523.3 - 79.6 + 5 + 71.7 |
| Ellerslie | 397.9 = 517.1 - 216.7 + 0 + 97.5 |
| EINP | 502.1 = 520.8 - 138.3 + 14 + [illegible].6 |
| **1985** | |
| Edm. Int. | 399.4 = 499.1 - 100[illegible] 76.2 |
| Namao | 445.8 = 522.9 - 47[illegible] 59.4 |
| Vegreville | 402.5 = 497.8 - [illegible]7 - 30.9 |
| Tofield N. | 452.6 = 504.5 - 9[illegible]9 - 34.1 |
| Ellerslie | 370.7 = 511.1 - 102[illegible] 48.9 - 86.7 |
| EINP | 417.5 = 516.7 - 108.0 + 68.6 - 59.8 |
| **1986** | |
| Edm. Int. | 491.5 = 549.2 - 46.0 + 0 - 11.7 |
| Namao | 457.3 = 541.0 - 105.0 + 0 + 21.3 |
| Vegreville | N/A |
| Tofield N. | N/A |
| Ellerslie | N/A |
| EINP | N/A |

Source: Calculations by Author using the Thornthwaite Procedure

Thornthwaite procedure has been used in Ireland by Guerrini (1972) to determine and compare the PE and surpluses with the measured river runoff. The procedures values were found to closely resemble the measured values during the spring, summer, and fall but differed from measured values during the winter. A number of revisions to the procedure were carried out by Guerrini during the winter period which let the calculated runoff resemble the measured runoff. The determination of PE has been carried out in Nigeria using the Thornthwaite technique (Garnier, 1952). The object of this experiment was to determine the PE of several stations in Nigeria through use of an evapotranspirometer and by calculations. On a worldwide scale, Leith and Box (1971), constructed a map of the world's primary productivity through correlations with its Thornthwaite evapotranspiration patterns.

On the North American continent, Sanderson (1948) used the Thornthwaite procedure to construct maps of potential evapotranspiration, surpluses, and deficits of Canada. The data for these maps were gathered from 650 weather stations across Canada, most of which had more than 20 years of record. Sanderson found a close agreement between measured runoff and the computed water surpluses in Canada.

Thornthwaite and Mather (1955) tested the Thornthwaite technique in Arizona, Ohio, the Tennessee River Basin, and in Virginia and found a very close agreement between monthly and annual computed values of runoff and measured values.

In 1967 Sanderson and Phillips used the Thornthwaite procedure to construct water surplus maps of Canada. The maps of Canadian water surpluses were were similar to the maps prepared by Thornthwaite, Mather, and Carter (1958) of water surpluses along the United States border. An early map by Thornthwaite (1944) showing runoff in the eastern United States was compared by Langbein and others (1949) with maps of measured runoff. Langbein and others (1949) found Thornthwaite's results to be quite representative of the measured runoff.

Baily and Johnson (1972) used the Thornthwaite procedure to compare the potential evapotranspiration of Kansas City and Oakland. This was done to provide examples of continental and maritime temperature regimes, and their relation to potential evapotranspiration.

An application of Thornthwaite by Muller (1972) served to illustrate the differences between individual years and a thirty year average in five areas of the United States. Muller (1972) stressed the need for analyses based on daily, weekly, or monthly data rather than on traditional averages.

In 1976 Phillips used and modified the Thornthwaite procedure in Canada which has a cold weather climate. Phillips found there was an underestimation of winter runoff and an overestimation of spring runoff when compared to measured results. A modification was carried out which would increase the winter runoff and therefore in effect decrease the spring runoff. The approach was found to eliminate the wider swings from high to low runoff which resulted from use of the unmodified Thornthwaite procedure.

There have been numerous uses of the Thornthwaite procedure closer to the thesis study area. Sanderson (1954) used Thornthwaite in Norman Wells N.W.T. to compare measured evapotranspiration from evapotranspirometers with PE calculated using the Thornthwaite technique. During the two seasons of testing, work with the formula produced results in the correct order of magnitude in spite of the fact that the length-of-day correction factor for 50 °N was used in the calculation. Laycock (1957) used precipitation and evapotranspiration data to determine approximate stream flow patterns in the eastern slopes of the Canadian Rockies. The precipitation was determined through use of data from meteorological stations, temporary precipitation gauges, and topographically adjusted isohyets (lines joining points of equal precipitation). The evapotranspiration was determined through use of the Thornthwaite technique. The yields were determined through the equation : Precipitation - Evapotranspiration = Yield. Laycock (1957) also suggested possible watershed management alternatives to improve the yields within an area.

Water deficiency patterns using the Thornthwaite technique were first determined by Laycock in 1964. The results were compiled into moisture deficit maps of the Prairie Provinces. The findings and maps from this report were later used in a report on deficiency and surplus patterns by Laycock in 1967. Laycock (1967) primarily used the Thornthwaite procedure to map the major patterns of drought and moisture surplus in the Prairie Provinces. The Thornthwaite procedure was the major technique used in this report, while other procedures such as Lowry and Johnson, and Blaney and Criddle were used as checks on the Thornthwaite procedure. Laycock (1967) reported that local studies of streamflow, surplus and deficiency patterns on the whole confirmed the patterns established through use of the Thornthwaite technique. Laycock (1973) used the Thornthwaite procedure in the Cooking Lake Moraine to determine the surpluses and deficits of the area. The surpluses and deficits were compared to the level fluctuations of Gull and Cooking Lakes, whereupon a close correlation was found to exist between the two forms of data.

MacIver (1966) used the Thornthwaite procedure to determine surpluses and deficits in the Spring Creek Basin southwest of Valleyview. An objective of the thesis was to discuss the various problems associated with the transformation of the forests into crop land and pastures, particularly with respect to surpluses. Various water storage categories for different vegetation and soil groups were included into the surplus and deficit calculations. A number of problems associated with increased surpluses were found, such as erosion, flooding, and sedimentation. The Thornthwaite procedure was used to determine the annual runoff during 1966 and the future potential post-development runoff.

Kakela (1969) used the Thornthwaite procedure to determine the water balance of the Yellowknife area. Particular attention was paid by Kakela to the effects of the winter snow accumulation on the measured spring runoff and the corresponding computed spring runoff.

MacIver (1970) used the Thornthwaite procedure in a thesis on the macroclimatic zonation of Northern Alberta. The Thornthwaite technique was used to determine the regions potential evapotranspiration, and water deficiency above the 4 inch water storage category.

In 1972, Erxleben studied the effects of different land use patterns upon snowmelt runoff in the Whitemud Creek Basin. The Thornthwaite procedure was used to determine surpluses which were found to be in relatively close agreement with the measured runoff values. The land surfaces were separated into water storage categories to determine how much and where the surpluses were taking place.

Wight (1973) used the Thornthwaite procedure to attempt to define the average patterns of evaporation from lakes, and evapotranspiration for certain vegetative surfaces in the Baker Creek Basin near Yellowknife N.W.T. Hallock (1976) calculated the soil moisture surpluses of the Gregoire Lake Basin using Thornthwaite to compare to the observed stream flow characteristics, and hydrographs. The water storage categories were based largely on vegetative cover differences. In 1977 Wiche completed a thesis which used Thornthwaite water balance procedures to define present and future water balance patterns in the Beaver Creek Basin near Fort McMurray. Yield estimates from the procedure were compared with gauged yields. During the five years of record, three of the years had estimated results which were very similar to the gauged results, and two years with results which were dissimilar. Woodburn (1977) used the Thornthwaite procedure to determine surplus patterns within the Cooking Lake Moraine. Estimates of snow melt runoff for 1975-1976 were made using Thornthwaite which were then compared to actual gauged runoffs. Woodburn (1977) reported a high correlation between spring surpluses using Thornthwaite and the spring to fall lake level changes. An inventory of surficial cover and assignment of appropriate moisture storage categories within the Baker Creek Basin was carried out by Park (1979). The values that were derived were then inserted into the Thornthwaite bookkeeping procedure. It was thought by Park that the Thornthwaite water balance for the Baker Creek Basin was a close fit using calculated soil moisture storage values based upon a number of categories.

MacKenzie (1987), a Doctoral candidate at the University of Alberta, is at present studying the water surpluses within the city of Edmonton. The surpluses are being calculated within a range of moisture storage categories to determine the annual water yield for the city of Edmonton. Hurley (1987), a Masters student at the University of Alberta, is conducting a study on the effect of urbanization on surpluses in a new 5,000 acre development in south Edmonton. The area was divided into moisture storage categories, and yields were calculated to determine the possible capacity requirements for stormwater lakes in the development.

## 3.4 THE PENMAN PROCEDURE

The Penman technique is another method of determining the potential evapotranspiration of an area. This equation is more complex than the Thornthwaite technique and requires many more data for its different set of parameters. The Penman equation should be termed "equations", because multiple equations are necessary to determine the potential evapotranspiration. The data necessary to complete the equations are hard to find and are not always available. For example there are no radiation datum available from the Edmonton International Airport, resulting in data from Stony Plain being used for Elk Island National Park studies.

There are three basic equations which make up the Penman procedure. The first equation is meant to measure the drying power of the air and takes the form;

$$Ea = .35(1 + U/100)(e_w - e_d)$$

where U is the wind speed in miles per day at a height of 2 m, $e_w$ the saturation vapour pressure at mean air temperature (mbar), and $e_d$ represents the vapour pressure of the atmosphere (mbar), (Ward, 1975). In the calculation of this formula, the Goff-Gratch (1946) formula was used to measure $e_w$[1]. To determine $e_d$ the formula $e_d = e_w \times$ relative humidity taken from Verma (1968) was used.

The second equation called the Heat Budget "provides an estimate of the net radiation necessary for evaporation and heating at the earths surface" (Ward, p. 115, 1975). The heat budget equation takes the form;

$$H = Ri\ (1-r) - R_b$$

where Ri is the total incoming short wave radiation, r is the albedo crop coefficient, and Rb is the longwave outgoing radiation. The incoming short wave radiation can be determined from radiation tables, but the long wave outgoing radiation must be determined from the following equation:

$$Rb = \sigma T^4\ (.56 - .09\ e_d^{1/2})(.1 + .9\ n/N)$$

(Wiche, 1977)

The $\sigma T^4$ is the Stefan-Boltzmann Law and is intended to measure the total power radiated per unit area of a black body (°K). The $e_d$ value is the mean vapour pressure of the atmosphere (mm. Hg), and the n/N equation is a percentage of the actual hours of sunshine in relation to the total possible hours of sunshine (Penman, 1963). The incoming solar radiation (Ri) is converted from langleys to an evaporation equivalent by dividing by the factor of 59 (1 mm evaporation per day - 59 calories/cm$^2$/day) (Verma,1968).

The third equation used to measure the potential evapotranspiration of an area includes the two previous equations. The third equation to measure PE takes the form;

---

[1] A working example of this and following Penman equations can be found in appendix II.

$$E = (\Delta/\alpha * H + Ea)/(\Delta/\alpha + 1)$$

(Ward, 1975)

where, $\Delta$ is the slope of the saturation vapour pressure curve for water at mean air temperature in mm/Hg/°C, and $\alpha$ is the constant (.62197) of the wet-and -dry bulb psychrometer equation. The ratio $\Delta/\alpha$ is dimensionless and is in effect a weighting factor used to assess the relative effects of energy supply and ventilation on evaporation (Penman, 1963). The value H is the heat budget equation, and Ea is the equation to measure the drying power of the air.

The Penman equation to measure potential evapotranspiration has had widespread use throughout the world. Chang (1968), has stated that experimental evidence has shown the Penman equation to be the best formula if required data are available. Recently, Mather (1975, p. 71) has stated that "the Penman method appears to provide reliable values for daily or monthly evapotranspiration under a wide range of environmental conditions". Comparisons between the Penman and Thornthwaite methods by Pruitt in California and Washington (1960), Stanhill in Israel (1960); Chapas and Rees in Rhodesia (1964), and Chang in Hawaii (1961) would indicate the Penman method to be more accurate where enough input data are available (Chang, 1968). The equation has proven to be effective in determining PE in marine west coast climates including Southern England where the equation was first tested (Wiche, 1977). Verma (1968) in his doctoral thesis in Alberta used the Penman procedure because it was a major technique which was based on the energy balance and-aerodynamic approaches.

The Penman method has not proven to be the most accurate under continental climates. The Penman procedure according to Laycock (1987) underestimates PE in a continental climate. Baker (1958) in Minnesota found the Thornthwaite procedure to be equal to or superior to the Penman method. In the Beaver Creek Basin of Alberta, Wiche

(1977), found the Thornthwaite method to be more accurate than the Penman method due to the low PE values from the Penman procedure. The Penman procedure is not suited to a continental climate due to the large fluctuations in seasonal temperature. "The solar insolation is the dominating variable while mean monthly air temperature is subordinate in this equation" (Wiche, 1977, p. 90). The Penman method is suited to a west coast marine climate where the seasonal fluctuations in temperature are small, and the positive temperature anomaly for the latitude is large. (Penman, 1948; Laycock, 1987).

A comparison of Thornthwaite and Penman monthly potential evapotranspiration totals may be found in table 3.4. The full year was not calculated because the PE during the months with a mean temperature below 0 °C is zero. The Thornthwaite procedure from the 10 year average recorded a higher yearly potential evapotranspiration (Table 3.4). It is apparent that PE values are higher from April - June using the Penman procedure, and are higher from July - October using the Thornthwaite procedure (Table 3.4). The Penman values were unexpectedly similar to those values from the Thornthwaite procedure. The Penman results are similar to those arrived at by Verma (1968), although no direct yearly comparison was possible. There is some doubt by the writer about the high PE values for April and May when using the Penman procedure. The mean temperatures in April and early May are near 0 °C which can result in heavy frosts which impede the growth of plants. Secondly, there is still snow on the ground in April in central Alberta which would increase the albedo of the ground surface relative to summer values. An increased albedo would decrease the amount of energy available to heat the air.

There are a number of reasons as to why the author has not used the Penman procedure. The first problem stated earlier relates to the availability of data. The radiation data only being found at Stony Plain creates problems concerning the similarity between values received in Stony Plain and those received in Elk Island National Park. Using the Thornthwaite procedure, data from Elk Island National Park were used as a check on the

TABLE 3.4

**A Comparison Of The Thornthwaite And Penman Procedures in Measuring Potential Evapotranspiration (mm)**

| Year/Month | Thornthwaite | Penman |
|---|---|---|
| 1976 | | |
| April | 41.4 | 65.1 |
| May | 83.8 | 98.5 |
| June | 89.8 | 99.3 |
| July | 115.1 | 113.0 |
| August | 108.8 | 79.6 |
| September | 70.0 | 49.5 |
| October | 22.1 | 15.0 |
| Seasonal Total | 531.0 | 520.0 |
| 1977 | | |
| April | 51.8 | 70.0 |
| May | 79.8 | 84.3 |
| June | 106.1 | 120.6 |
| July | 106.9 | 103.3 |
| August | 82.5 | 72.9 |
| September | 57.2 | 37.7 |
| October | 27.6 | 12.8 |
| Seasonal Total | 511.9 | 501.6 |
| 1978 | | |
| April | 34.5 | 51.1 |
| May | 71.8 | 88.2 |
| June | 114.2 | 123.5 |
| July | 123.3 | 115.2 |
| August | 93.8 | 80.4 |
| September | 60.4 | 28.8 |
| October | 35.9 | 11 |
| Seasonal Total | 533.9 | 498.2 |
| 1979 | | |
| April | 6.9 | 50.3 |
| May | 63.8 | 81.8 |
| June | 106.1 | 115.1 |
| July | 123.3 | 115.6 |
| August | 101.3 | 88.9 |
| September | 73.1 | 48.2 |
| October | 35.9 | 11.8 |
| Seasonal Total | 510.4 | 511.7 |

TABLE 3.4 CONTINUED

| Year/Month | Thornthwaite | Penman |
|---|---|---|
| 1980 | | |
| April | 55.2 | 70 |
| May | 83.8 | 92.6 |
| June | 106.1 | 104.3 |
| July | 115.1 | 118.7 |
| August | 86.3 | 72.4 |
| September | 54.1 | 34.9 |
| October | 33.1 | 14.1 |
| Seasonal Total | 533.7 | 507.0 |
| 1981 | | |
| April | 31.1 | 60.6 |
| May | 83.8 | 85.9 |
| June | 93.8 | 110.2 |
| July | 119.2 | 108.1 |
| August | 120.0 | 107.3 |
| September | 70.0 | 51.1 |
| October | 22.1 | 12.6 |
| Seasonal Total | 540.0 | 535.8 |
| 1982 | | |
| April | 0 | 0 |
| May | 75.8 | 96.6 |
| June | 114.2 | 115.7 |
| July | 119.2 | 103.1 |
| August | 90.0 | 75.9 |
| September | 66.8 | 42.6 |
| October | 27.6 | 10.2 |
| Seasonal Total | 493.6 | 444.1 |
| 1983 | | |
| April | 34.5 | 56.9 |
| May | 75.8 | 89.0 |
| June | 102.0 | 93.6 |
| July | 123.3 | 113.3 |
| August | 112.5 | 101.0 |
| September | 54.1 | 37.0 |
| October | 27.6 | 12.3 |
| Seasonal Total | 529.8 | 503.1 |
| 1984 | | |
| April | 44.9 | 63.6 |
| May | 67.8 | 80.2 |
| June | 106.1 | 110.8 |
| July | 123.3 | 127.7 |
| August | 116.3 | 95.7 |
| September | 47.7 | 33.8 |
| October | 11.0 | 10.7 |
| Seasonal Total | 517.1 | 522.5 |

TABLE 3.4 CONTINUED

| Year/Month | Thornthwaite | Penman |
|---|---|---|
| 1985 | | |
| April | 34.5 | 57.8 |
| May | 91.8 | 111.6 |
| June | 97.9 | 98.0 |
| July | 127.4 | 137.3 |
| August | 97.5 | 84.5 |
| September | 44.5 | 33.2 |
| October | 5.5 | 13.9 |
| Seasonal Total | 499.1 | 536.3 |
| 10 Year Average | | |
| April | 37.2 | 60.6 |
| May | 77.8 | 90.9 |
| June | 103.6 | 109.1 |
| July | 119.6 | 115.3 |
| August | 100.9 | 85.9 |
| September | 60.9 | 39.7 |
| October | 24.8 | 12.5 |
| Seasonal Total | 524.8 | 514.0 |

Source: Calculations by Author Using the Thornthwaite and Penman Procedures With Data from the Edmonton International Airport Annual Meteorological Summary Produced by the Atmospheric Environment Service.

data from the Edmonton International Airport, while with the Penman procedure, no checks of this kind are possible. The next problem with the data concerns the measurement of wind. The Penman procedure requires two measurements from different levels which arent available at the Edmonton International Airport. The Penman equation becomes more empirical with every change in the data to accommodate its use in Elk Island National Park. If the Penman procedure were used, and once the potential evapotranspiration was determined, the Thornthwaite bookkeeping procedure would probably be used to determine the water balance for the area in question.

The Penman technique is oriented towards the determination of potential evapotranspiration which alone cannot be used to determine a water balance. Potential evapotranspiration must be used in conjunction with precipitation and soil moisture availability to determine an areas water balance.

## 3.5 OTHER EMPIRICAL METHODS

There are other methods of measuring potential evapotranspiration besides the Thornthwaite and Penman procedures. The first of these methods is by Blaney and Criddle (1950). Originally Blaney and Criddle (1950) sought an empirical formula to relate evaporation to temperature, relative humidity, and day length in areas such as Texas and New Mexico. In order to give the procedure greater applicability throughout the world, the relative humidity factor was dropped and the formula U = KF was derived (Penman, 1963). In this formula, U = consumptive use of water in inches for any period, K = empirical consumptive- use coefficient, and F = sum of the monthly consumptive-use factors for the period (Blaney and Criddle, 1950). In Blaney and Criddle (1950), the intention in the use of the formula was to determine the seasonal irrigation requirement of a crop provided the necessary climatological and irrigation data were available.

This formula, as in Thornthwaite, was intended for estimating the consumptive use when water supply was not limiting (Ward, 1975). As in the Thornthwaite procedure, Blaney and Criddle assumed a relationship between evaporation and the heating of the air enabling the use of the mean air temperature as an index of water loss (Penman, 1963).

There has been criticism of this procedure due to its empirical nature. The coefficient K was empirically determined for a range of crops to correct for the length of growing season and climatic variations. A range of values was necessary for different geographical and climatic areas. There has also been criticism of the factor F on grounds that the F value may be applied differently according to the crop and in turn, each crop according to its geographical location. This results in different estimates of potential evapotranspiration where identical climatic conditions occur (Ward, 1975). Greater stress has been placed on the differences of PE with different plants than in Thornthwaite. The Blaney and Criddle procedure tends to make too big an allowance in the calculations for the length of day for this region. The procedure works well up to 49 °N, but further north, the procedure is much less accurate. For example, if theBlaney and Criddle formula were used as outlined,it could be concluded that the most northerly part of Alberta should have the best growing season due to the extended day length during the summer. Once the limitations of the Blaney and Criddle procedure have been identified, modifications or corrections to the procedure could probably be made to adapt it for use in this area (Laycock, 1987). The experimental studies to make such modifications or corrections are however well beyond the scope of this study.

Another procedure which has received some use in the United States is by Lowry and Johnson. The procedure involves an equation which is intended to estimate consumptive use for agricultural lands on an annual basis (Chow, 1964). In this procedure, soil moisture measurements are made in the spring and would be entered into the growing season requirement calculations. Winter moisture changes including possible surpluses would not be included in the calculations. Thus the procedure is incomplete in terms of an annual water balance (Laycock, 1987). In Laycock (1967), the Blaney and

Criddle, and Lowry and Johnson methods were tested against the Thornthwaite procedure on the Prairies. Both procedures were inadequate in providing a water balance for the year, resulting in the necessity to adapt the Thornthwaite moisture storage allowances in the spring to the above procedures. Once this correction was carried out the two methods provided very similar results to Thornthwaite results.

Turc (1954) developed a procedure similar to Penmans' to determine potential evapotranspiration. The previous methods of measuring potential evapotranspiration were attempts at estimating the rate of water use when the water supply was non-limiting. Turc took the view that in nature this condition is not always a reality, whereby rainfall may be inadequate in total or too unevenly distributed to satisfy the condition of water non-limiting. (Penman, 1963). Based on this premise, Turc designed two formulas. The first is intended to relate annual evaporation from catchment areas to rainfall and air temperature (Penman, 1963). This formula is similar to Thornthwaites in that it is intended to give a data base measure of evaporation.

The second and more complex formula was intended to apply to short periods of time to determine the level of soil moisture content. This application has been used to measure water deficiencies in Europe by Mohrmann and Kessler (1959). The Turc procedure is a lengthy one which is complicated and difficult to operate. Mohrmann and Kessler (1959) in their use of the Turc procedure took a number of shortcuts to simplify the procedure. One such shortcut involved the calculation of an average evapotranspiration and the use of precipitation as the main variable. Mohrmann and Kessler (1959) found it necessary to use a large number of observation stations to make accurate estimates in Europe. In Alberta there are not enough stations for this level of accuracy. This procedure has proven to be useful in research basins, but is not adequate for determining regional patterns (Mohrmann and Kessler, 1959).

A procedure developed in the U.S.S.R. by Budyko (1974) is similar to the Thornthwaite procedure. Because of this, only a brief discussion will be given concerning the Budyko procedure. The Budyko method produces an accurate water balance during the summer, but is not as useful as Thornthwaite because the moisture carry over during the winter is not well determined. There is no clear indication of the moisture storage levels during the spring. The Budyko procedure has been adapted to accommodate this shortcoming to produce results which are very similar to Thornthwaite's.

The Thornthwaite procedure has been chosen over other procedures for use in this area as a result of the complicated and empirical nature of the Penman procedure, the incompleteness in terms of an annual water balance in the Blaney-Criddle and Lowry-Johnson procedures, the lack of data and number of observation stations for the Turc procedure, and the similarity of the Budyko procedure, and the availability of information on moisture storage patterns in this region of use in the Thornthwaite procedure.

The focus in this chapter has been to discuss the theory and technical aspects of the Thornthwaite procedure, and compare it with other procedures. The Thornthwaite technique will now be used in Chapter 4 to determine the surpluses and yields within Elk Island National Park.

# 4. WATER BALANCE PROCEDURES IN ELK ISLAND NATIONAL PARK

## 4.1 INTRODUCTION

Discussion in this chapter is focused upon on the water balance patterns within Elk Island National Park, and on the determination of the water yields from various basins within the Park. The first point of discussion encompasses the moisture storage capacities, what they consist of, and their related characteristics. The differences between the use of daily and monthly data in the water balance equations will be discussed in the next section. Section 4.4 is a discussion of the yield patterns within the Park, and the reasons for positive land area yields and losses from lakes. The following subsections discuss alternative management practices within the Park and possible corrections to the water balance procedure used in Elk Island National Park. In the next section, lake level data provided by the Park staff are used as a check on the water balance calculations. The final subsection is a comparison of the measured lake level fluctuations with the calculated level fluctuations.

## 4.2 MOISTURE STORAGE CAPACITIES

When precipitation exceeds the potential evapotranspiration after a drier period there is a recharge of soil moisture storage. Surpluses occur when this recharge surpasses the capacity of the soil to hold any more water, resulting in runoff along the surface and/or seepage down to the groundwater. Conversely, when the potential evapotranspiration is higher than the precipitation and the soil moisture in storage has been expended, deficits will be experienced. This causes all the precipitation to be evaporated and transpired before it can go into moisture storage for use later on. The surface soils within Elk Island Park are primarily composed of orthic gray luvisols formed in till (Fig. 2.1). There are exceptions to this, such as a scattering of sand deposits around the Park which have been noted in

Chapter 2, and small areas of Dark Gray and brunisolic gray luvisols (Fig. 2.1). Due to the similarity of the soils within the Park the moisture storage capacities will be based primarily upon the vegetation cover and its depth of rooting. This procedure has been carried out previously by Laycock (1967) in the Prairies, I. MacIver (1966) in the Spring Creek Basin, Kakela (1969) in the Yellowknife area, D. MacIver (1970) in Northern Alberta, Erxleben (1972) in the Whitemud Creek Basin in Edmonton, Wight (1973) in the Yellowknife area, Hallock (1976), in the Gregoire Lake Basin, Wiche (1977), in the Beaver Creek Basin, Park (1979), in the Yellowknife area, MacKenzie (1987), in the Edmonton River Valley, and Hurley (1987) on storm water lakes, and others.

The following categories, based largely upon the above sources, are the moisture storage capacities which will be used later in this chapter. An example of a Park areas division into the different water storage categories is illustrated in figure 4.1.

a. Within the Park boundary there are scattered areas with paved surfaces such as roads and parking lots which might typically have 2mm of moisture retention. Runoff will occur after limited wetting, but there is some surface detention resulting in a 2mm storage value (Photograph 4.1).[1] Some of this shower runoff is detained locally to be later evaporated. The surpluses over the 16 year period of study ranged from a high of 409.7 mm. to a low of 226.8 mm with an average yield of 305.5 mm (Table 4.1). The highest surpluses and deficits of all the water storage categories occurs in the 2 mm moisture storage category.

b. A bare soil with sparse to no cover would typically have a moisture storage capacity of 13 mm. This type of cover would result in evaporation from a very shallow soil depth. Gravelled roads and packed trails make up the majority of the area represented by the 13 mm storage capacity in Elk Island Park (Photograph 4.2). Due to the low

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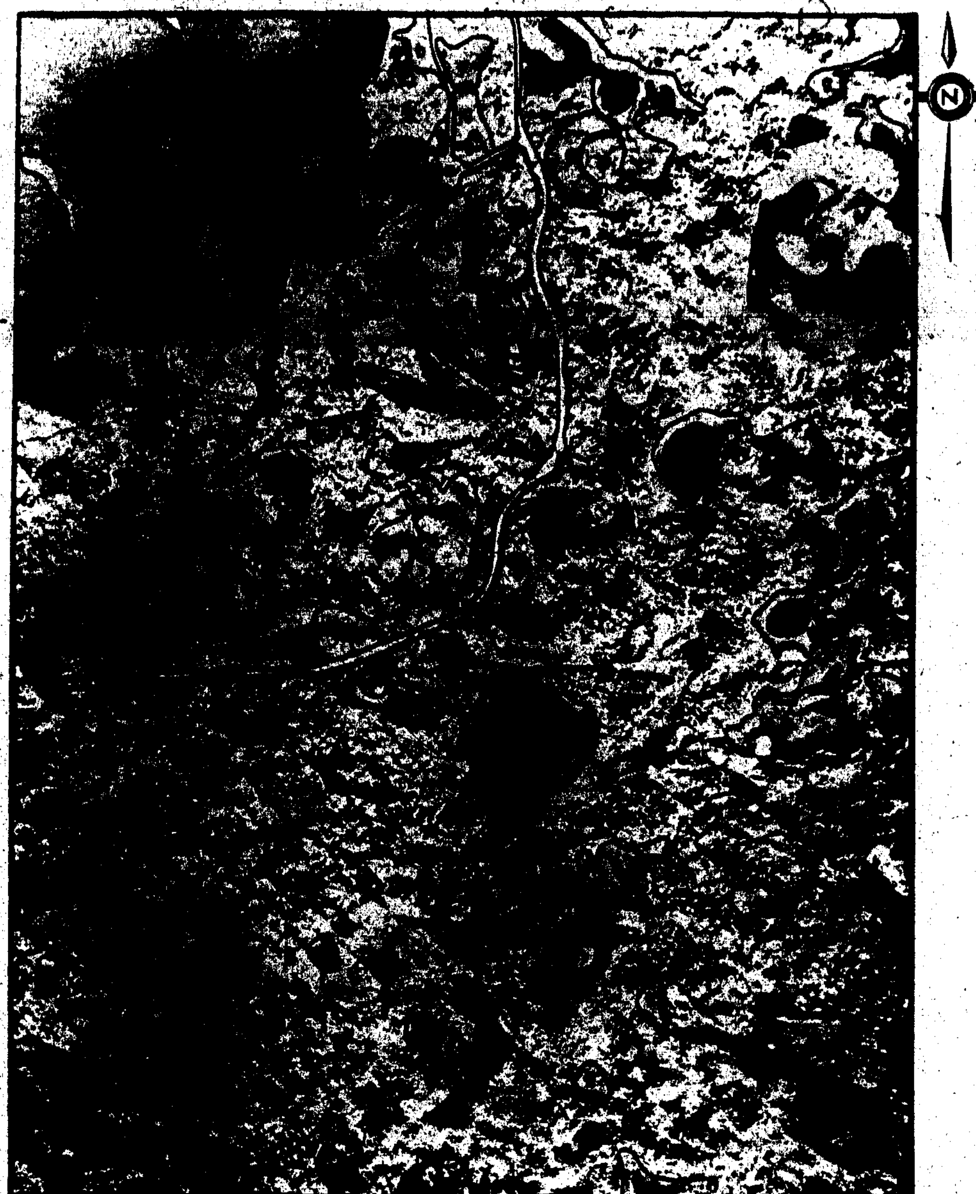
[1] Locations where the pictures were taken are illustrated in figure 4.2.




Legend:

Source: Categories by Author

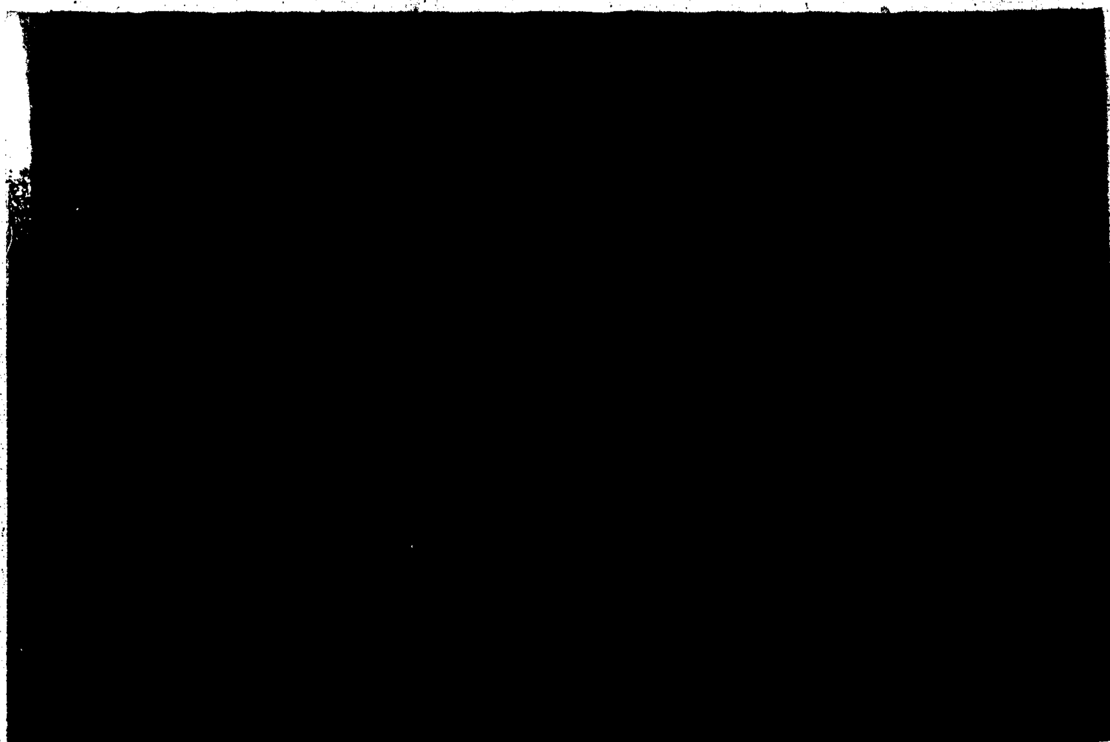
<u>Water Storage Categories (mm)</u>

a - 2
b - 13
c - 50
d - 100
e - 150
f - 250
g - Wetland

**Example of an A[illegible]oto Divided into Water Storage Categories**

Figure 4.1

Photograph 4.1



This photograph illustrates a combination of 2 mm of storage capacity for the paved surfaces, and probably 50 mm (100 mm if long grass) of storage capacity for the central zone. The location of this photograph may be found in figure 4.2.

TABLE 4.1

**Calculated Surpluses in the Respective Water Storage Categories in Elk Island National Park - Using Edmonton International Airport Data Daily data for April-October(S),Monthly data for November-March(W) Surpluses in mm**

Water Storage Categories (mm.)

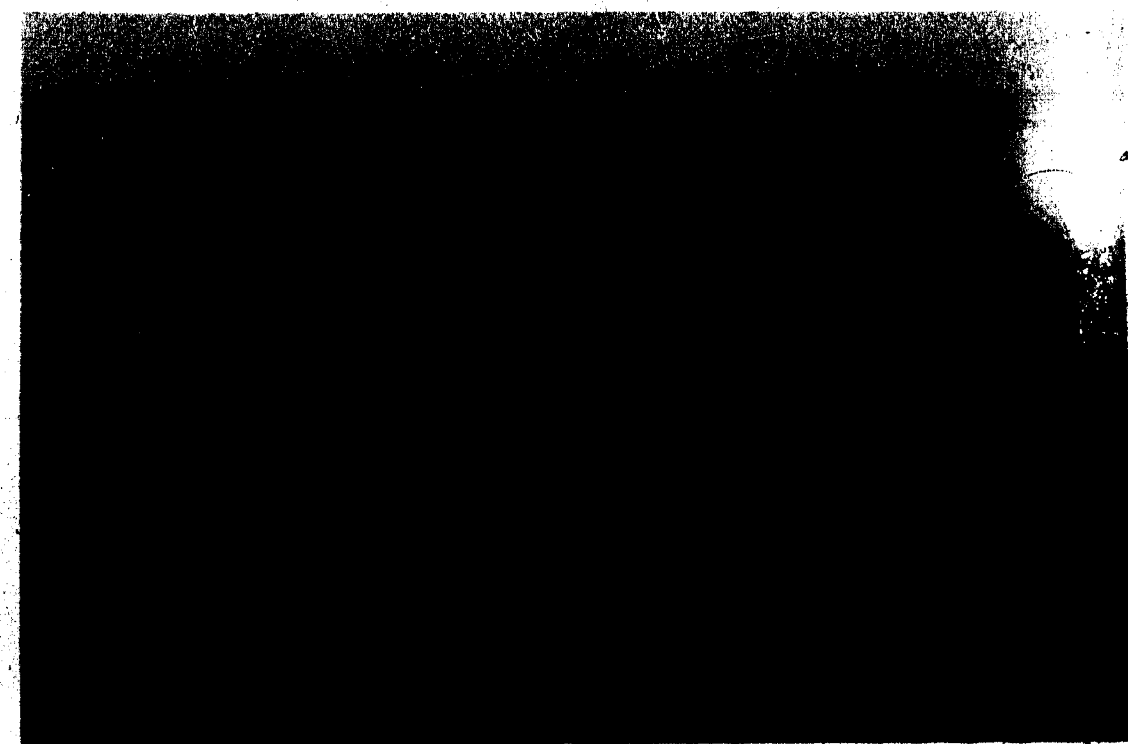
| | | PE | Ppt. | 2<br>a | 13<br>b | 50<br>c | 100<br>d | 150<br>e | 250<br>f | Wetland<br>g |
|---|---|---|---|---|---|---|---|---|---|---|
| 1971 | W | 0 | 123.4 | 123.3 | 123.3 | 101.5 | 52.3 | 2.3 | 0 | 123.4 |
| | S | 531.6 | 264.5 | 148.1 | 84.4 | 18.9 | 0 | 0 | 0 | -322.9 |
| | T | 531.6 | 387.9 | 271.4 | 207.7 | 120.4 | 52.3 | 2.3 | 0 | -199.5 |
| 1972 | W | 0 | 141.7 | 139.7 | 128.7 | 91.7 | 41.7 | 0 | 0 | 141.7 |
| | S | 496.9 | 436.1 | 246.2 | 113.8 | 33 | 21.6 | 9.3 | 0 | -60.8 |
| | T | 496.9 | 577.8 | 385.9 | 242.5 | 124.7 | 63.3 | 9.3 | 0 | 80.9 |
| 1973 | W | 0 | 75.2 | 73.3 | 52.3 | 25.4 | 0 | 0 | 0 | 74.7 |
| | S | 516 | 497.4 | 319.5 | 197.2 | 83.3 | 30.6 | 30.6 | 0 | -18.6 |
| | T | 516 | 572.6 | 392.8 | 249.5 | 108.7 | 30.6 | 30.6 | 0 | 56.1 |
| 1974 | W | 0 | 160.3 | 158.3 | 152.9 | 115.9 | 95.7 | 95.7 | 24.5 | 160.3 |
| | S | 495.7 | 343.1 | 182.3 | 94.2 | 42.1 | 5.7 | 5.7 | 5.7 | -154.6 |
| | T | 495.7 | 503.4 | 340.6 | 247.1 | 158 | 101.4 | 101.4 | 30.2 | 5.7 |
| 1975 | W | 0 | 66.1 | 64.1 | 53.1 | 16.1 | 0 | 0 | 0 | 66.1 |
| | S | 496.3 | 387.6 | 196.8 | 99.1 | 26.1 | 0 | 0 | 0 | -131.5 |
| | T | 496.3 | 462.7 | 260.9 | 152.2 | 42.2 | 0 | 0 | 0 | -65.4 |
| 1976 | W | 0 | 80.8 | 80.8 | 72.8 | 35.8 | 0 | 0 | 0 | 80.8 |
| | S | 529.9 | 371.4 | 186.0 | 73.8 | 0 | 0 | 0 | 0 | -198.8 |
| | T | 529.9 | 458.0 | 266.8 | 146.6 | 35.8 | 0 | 0 | 0 | -118.0 |
| 1977 | W | 0 | 65.7 | 63.7 | 52.7 | 15.7 | 0 | 0 | 0 | 65.7 |
| | S | 513.7 | 378.9 | 225.0 | 105.5 | 25.7 | 0 | 0 | 0 | -170 |
| | T | 513.7 | 444.6 | 288.7 | 158.2 | 41.4 | 0 | 0 | 0 | -104.3 |
| 1978 | W | 0 | 68.8 | 66.8 | 55.8 | 18.8 | 0 | 0 | 0 | 68.8 |
| | S | 534.6 | 454.7 | 268.3 | 181.1 | 98.2 | 48.2 | 0 | 0 | -144.2 |
| | T | 534.6 | 523.5 | 335.1 | 236.9 | 117 | 48.2 | 0 | 0 | -75.4 |
| 1979 | W | 0 | 87.8 | 85.8 | 74.8 | 69.2 | 67.9 | 17.9 | 0 | 87.8 |
| | S | 515.7 | 352.7 | 187.7 | 83 | 26.3 | 26.3 | 26.3 | 0 | -182.7 |
| | T | 515.7 | 440.5 | 273.5 | 157.8 | 95.5 | 94.2 | 44.2 | 0 | -94.9 |
| 1980 | W | 0 | 94.7 | 92.7 | 81.7 | 44.7 | 0 | 0 | 0 | 94.7 |
| | S | 530.3 | 509.7 | 317 | 218.5 | 81.2 | 28.1 | 0 | 0 | -39.8 |
| | T | 530.3 | 604.4 | 409.7 | 300.2 | 125.9 | 28.1 | 0 | 0 | 54.9 |

TABLE 4.1 CONTINUED

| | | | | Water Storage Categories (mm.) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2 | 13 | 50 | 100 | 150 | 250 | Wetland |
| | | PE | Ppt. | a | b | c | d | e | f | g |
| 1981 | W | 0 | 70.4 | 68.4 | 57.4 | 48.5 | 48.5 | 8.5 | 0 | 70.4 |
| | S | 546.1 | 330.5 | 175.4 | 81.1 | 2.8 | 0 | 0 | 0 | -260.7 |
| | T | 546.1 | 400.9 | 243.8 | 138.5 | 51.3 | 48.5 | 8.5 | 0 | -190.3 |
| 1982 | W | 0 | 128.5 | 128.5 | 123.0 | 86.0 | 36.0 | 0 | 0 | 128.5 |
| | S | 515.6 | 391.9 | 237.8 | 158.0 | 86.8 | 36.8 | 0.6 | 0 | -126.0 |
| | T | 515.6 | 520.4 | 366.3 | 281.0 | 172.8 | 72.8 | 0.6 | 0 | 2.5 |
| 1983 | W | 0 | 52.7 | 52.7 | 51.2 | 14.2 | 0 | 0 | 0 | 52.7 |
| | S | 521.9 | 344.7 | 196.7 | 129.4 | 92.4 | 36.9 | 0 | 0 | -228.3 |
| | T | 521.9 | 397.4 | 249.4 | 180.6 | 106.6 | 36.9 | 0 | 0 | -175.6 |
| 1984 | W | 0 | 66.8 | 64.8 | 53.8 | 16.8 | 0 | 0 | 0 | 66.8 |
| | S | 522.6 | 330.6 | 186.9 | 103.2 | 0 | 0 | 0 | 0 | -280.5 |
| | T | 522.6 | 397.4 | 251.7 | 157.0 | 16.8 | 0 | 0 | 0 | -213.7 |
| 1985 | W | 0 | 65.3 | 65.3 | 65.3 | 65.3 | 65.3 | 18.8 | 0 | 65.3 |
| | S | 517.2 | 330.5 | 161.5 | 72.0 | 18.9 | 18.9 | 18.9 | 0 | -236.0 |
| | T | 517.2 | 395.8 | 226.8 | 137.3 | 84.2 | 84.2 | 37.7 | 0 | -170.7 |
| 1986 | W | 0 | 74.7 | 65.5 | 65.5 | 40.2 | 0 | 0 | 0 | 74.7 |
| | S | 545.6 | 423.0 | 257.1 | 148.9 | 66.9 | 25.5 | 0 | 0 | -146.5 |
| | T | 545.6 | 497.7 | 322.6 | 214.4 | 107.1 | 25.5 | 0 | 0 | -71.8 |

Source: Calculations by Author Using the Thornthwaite Procedure with Data from the Edmonton International Airport Annual Meteorological Summary Procuced by the Atmospheric Environment Service.

Photograph 4.2

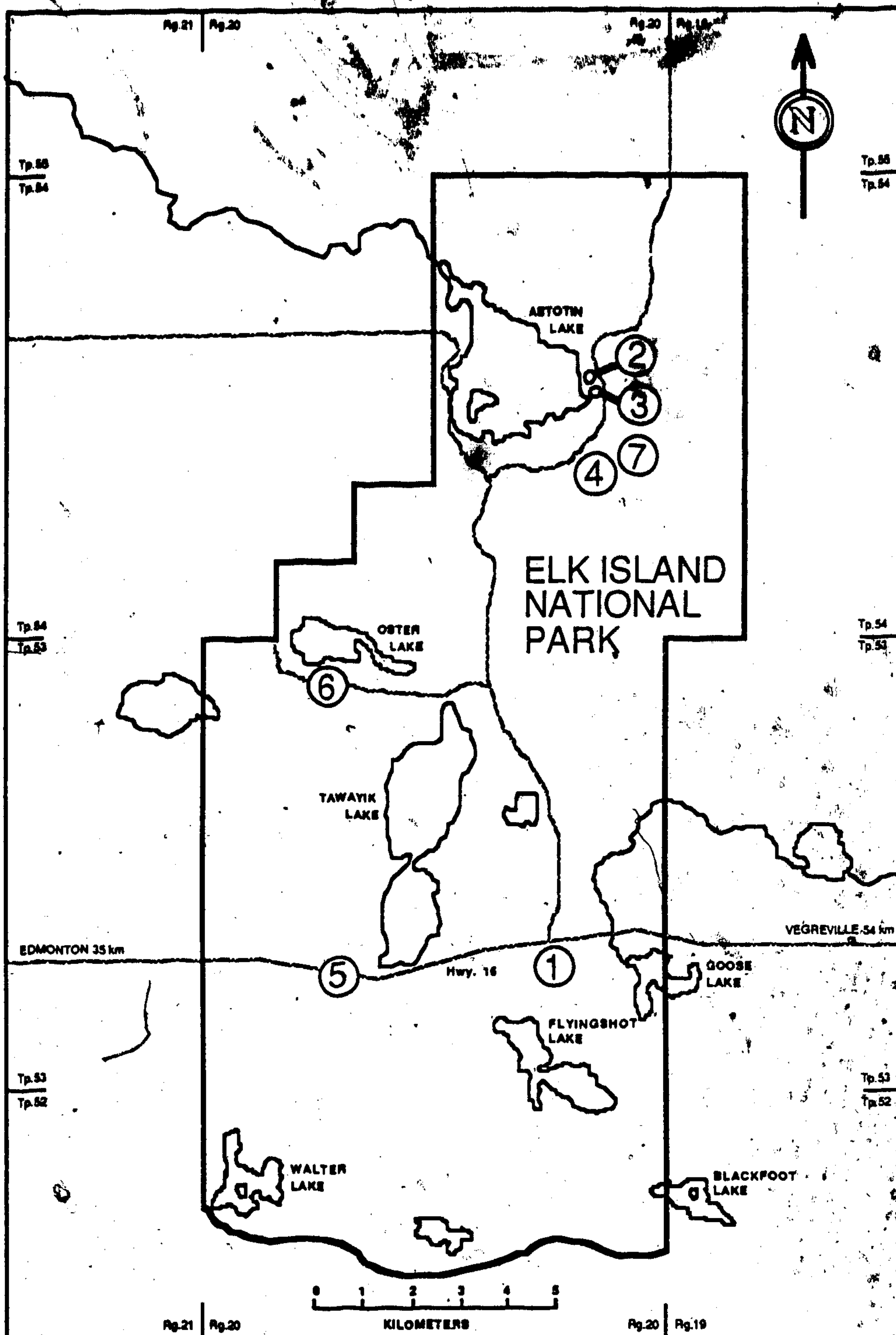


The gravel parking lot is characteristic of the 13 mm moisture storage category, with much of the open woodland in the distance being in the 150 mm water storage category (Fig. 4.2).

moisture storage capacity, high surpluses and deficits are experienced in this category. The surpluses over the 16 year study period ranged from a high of 300.2 mm to a low 137.3 mm, and an average yield of 200.9 mm (Table 4.1).

c. A thin or trampled grassy cover or fallow with some weed growth in agricultural areas would have a 50 mm soil moisture capacity. The majority of this category would be represented by the grass shoulders adjacent to roads, the playing fields, and fields intensively grazed by buffalo (Photograph 4.3). Much of the area covered by pastures which would normally fall under this category have been allocated to the 100 mm moisture storage capacity due to the wet conditions during the summer of 1986. In the 16 year period of study, the surplus range varied from a high of 172.8 mm in 1982 to a low of 16.8 mm in 1984 with an average yield of 94.5 mm (Table 4.1). A water balance diagram (based on data in App. I) of the 50 mm moisture storage category during the year 1984 is shown in figure 4.3. The water balance diagram is based on data presented in table 4.1.

d. The cover with a maximum of 100 mm of soil moisture storage would be characterized by cereal grain crops in agricultural areas and a rough grazed or browsed incomplete cover including shrubs and herbaceous plants (Photograph 4.4). The golf course is also representative of the 100 mm soil moisture storage category, because of the root depth being comparable to cereal grain crops. The sandy ice proximous deposits within the Park can be allotted to the 100 mm soil moisture category. The latter areas have good internal drainage resulting in more groundwater than surface water routing of surpluses. Due to the higher groundwater routing of surpluses, the ice proximous areas with mature vegetation would tend to experience more deficits or droughts than a similar mature vegetation on different soils. The good drainage results in no surface storage of water in depressional areas within the ice proximous sand and gravel deposits. This category can be expected to have smaller and less frequent surpluses than previous




NOTE: NUMBERS 1 - 7 ARE PHOTO LOCATIONS

SOURCE: AUTHOR, 1987

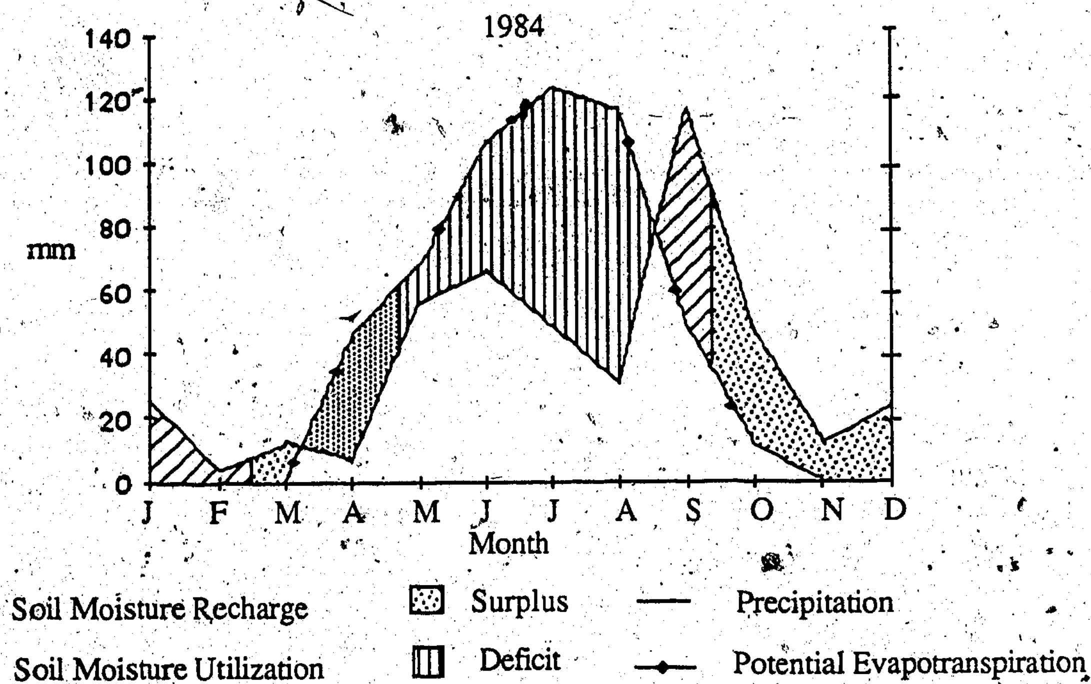
**Locations of Photographs Taken in Elk Island National Park**

Figure 4.2

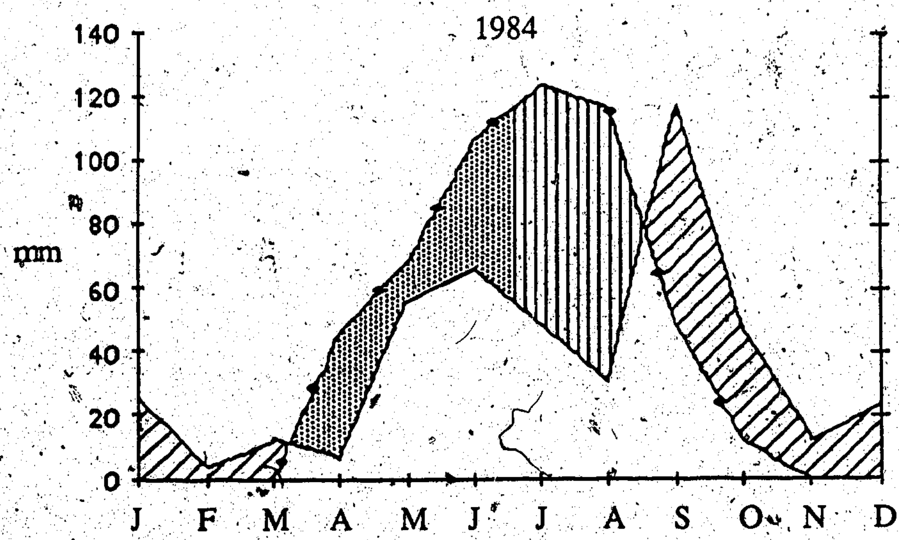
Photograph 4.3

This photograph illustrates a combination of the 50 mm storage category in the well used grass area, and the 100 mm storage category in the less used grassed areas. The woodland in the distance would be in the 150 mm and 250 mm storage categories (Fig. 4.2).

50 mm Moisture Storage Category



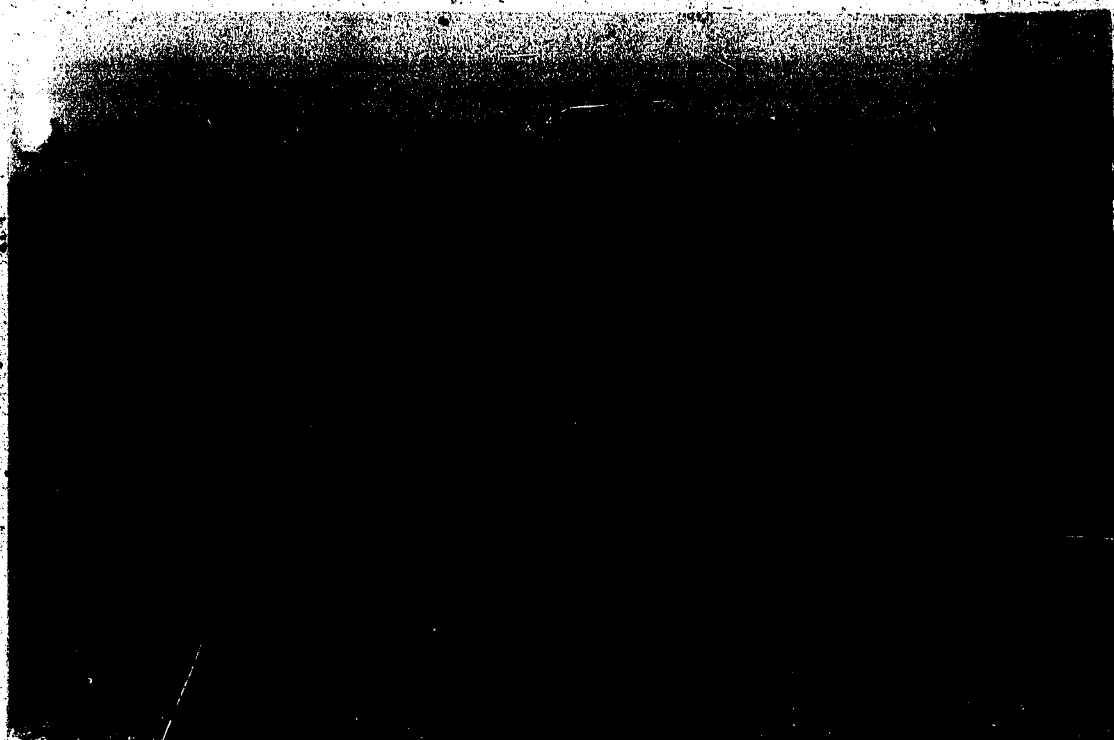

150 mm Water Storage Category




**Water Balance Diagrams**

Figure 4.3

Photograph 4.4



The grasslands in this photograph would be in the 100 mm water storage category. The stands of trees in the distance would probably be in the 250 mm storage category, while the small bushes on the near right side of the photograph would probably be in the 150 mm moisture storage category (Fig. 4.2).

categories. The average yield from the 16 year period of study is 43.1 mm, with a high of 103.7 mm in 1974 and a low of 0 mm in four years (Table 4.1).

e. Areas of scrub forest with lesser depths of rooting or an open forest cover would have approximately 150 mm. of soil moisture storage (Photograph 4.5). This cover would experience fewer surpluses, and drought a little later in the summer than the previous categories. The monthly and daily data for the 16 years in table 4.1 illustrate the previous statement with a surplus high of 102.2 mm, a low of 0 mm in 9 years, and an average yield of 14.6 mm. A water balance diagram of the 150 mm moisture storage category based on data in Appendix I is located in figure 4.3.

f. A mature forest cover on a well drained soil could have access to 250 mm of soil moisture from storage (Photograph 4.6). The potential evapotranspiration will normally exceed the precipitation in the summer months, resulting in deficits occuring when the storage supply is depleted. Surpluses are rare in the summer months but are possible in winter months with an above average snow fall. The climatic potential within this area is for surpluses to be small and infrequent, and for deficits to be larger and more frequent. The deficits although larger than the surpluses are smaller than for any of the other categories because of the large potential evapotranspiration from storage. The year 1974 was the sole year among the 16 years studied which reported a surplus in the 250 mm category using Edmonton International Airport data (Table 4.1).

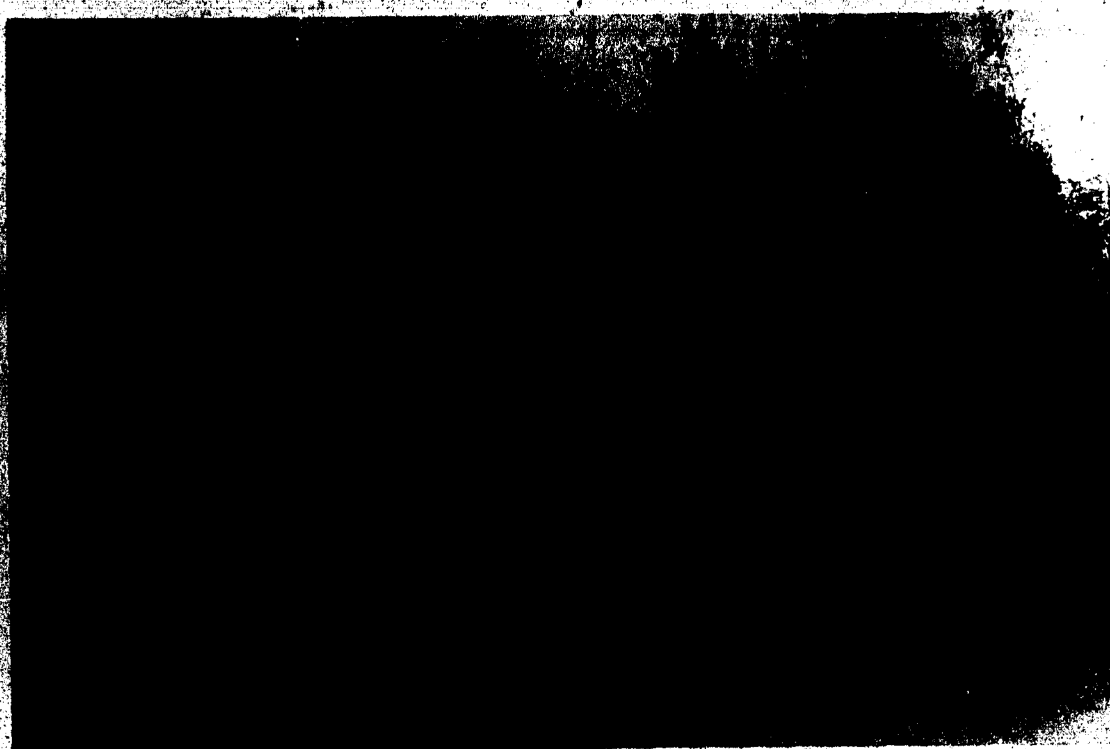
g. Wetlands within Elk Island National Park are primarily made up of marshes and permanent water bodies (Photograph 4.7).

> Marshes are grassy, wet mineral soil areas, periodically inundated up to a depth of 2 m or less with standing or slow moving water. Surface water levels may fluctuate seasonally, with declining levels exposing drawdown zones of matted vegetation or mudflats.

Photograph 4.5

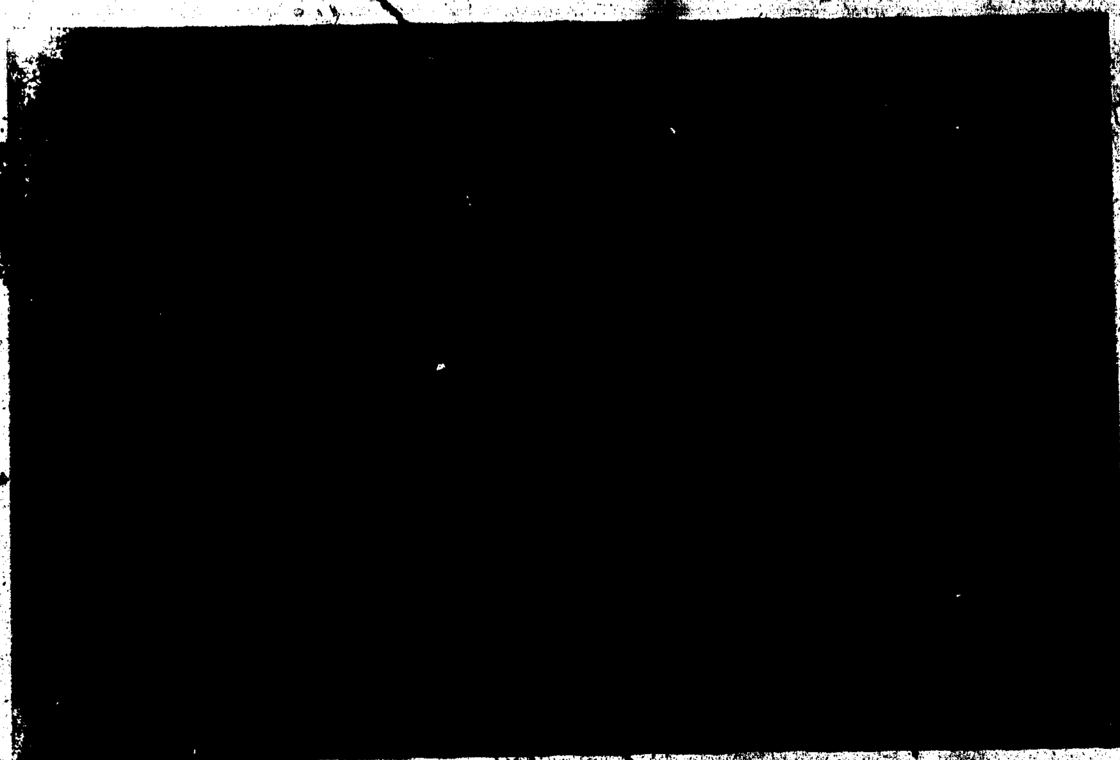
The long grass in the forefront of this photograph would probably be in the 100 mm storage category, with the majority of the open stands of trees being in the 150 mm storage category. The vegetation to the rear right side of the photograph is more dense and would probably be in the 250 mm storage category (Fig. 4.2).

Photograph 4.6



The low level vegetation at the bottom of this photograph would be in the 150 mm moisture storage category, while the dense trees and bush would be in the 250 mm moisture storage category (Fig. 4.2).

Photograph 4.7



This photograph depicts a wetland (marsh and water body) which will use PE + 1/2 D as the rate of potential evapotranspiration during the summer. The deficit value used will be taken from the 150 mm moisture storage category which is the local average for the Park. The vegetation in the open stands of trees close to the marsh would be in the 150 mm moisture storage category. The closed stands of trees on the hill in the distance would be in the 250 mm storage category.

> Marshes characteristically show zonal or mosaic surface patterns of vegetation, consisting of unconsolidated grass and sedge sods, frequently interspersed with channels or pools of open water.
>
> (Zoltai, 1983, p. 249).

There are approximately 220 permanent and seasonal lakes within Elk Island National Park. During the summer a wetland surface would tend to have more evaporation than the potential evapotranspiration assigned to it. The low albedo of the water surfaces would tend to allow a greater proportion of solar insolation to be used in the evaporation ofwater. Warm dry air from adjoining areas which passes over the lakes and marshes creates a rise in the evaporation rates to above the normal PE values for the temperatures present. This rise is approximately equal to 1/2 the deficit of the surrounding dry areas from which the warm dry air is received. The half deficit value is based upon deficits in the 150 mm moisture storage areas (the local average for the Park). The formula, PE + 1/2 D to determine potential evapotranspiration over small lakes was suggested by Hobbs (1967), and it has been more widely applied in several subsequent studies.

## 4.3 THE USE OF DAILY VS. MONTHLY DATA[1]

There are two forms of meteorological data which may be used in the Thornthwaite procedure to determine potential evapotranspiration, surpluses, and deficits. The first and easiest of the two is monthly data, such as mean monthly temperature, and total monthly precipitation values. The second form which involves a more involved bookkeeping procedure is daily data such as mean daily temperature, and total daily precipitation.

The monthly data are appropriate for use during the winter when there is little or no potential evapotranspiration, and only moisture storage recharge and surpluses are

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[1] Monthly and daily water balance tables may be found in appendices I and III respectively.

recorded. During the summer months the use of monthly data often masks climatic variations which may occur during the month. A surplus from a moderate to heavy storm event might not be apparent because evapotranspiration in the rest of the month may be large enough to cancel it. A balancing deficit may also be hidden, especially where storage capacities are low.

The use of daily data during the summer months has made the use of the Thornthwaite procedure more sensitive to the climatic patterns of an area. With the use of daily data both surpluses and deficits are possible during any summer month, especially in the lower storage categories.

The potential evapotranspiration estimates using the daily data during the 16 years of study are on average 2.3 mm higher than when using monthly data (Table 4.2). The higher PE estimates occur in part during the months of October - April. During these months the mean monthly temperature may be below $0^{o}C$ resulting in no PE estimate using the monthly data. There will be a number of days during these months with a temperature above $0^{o}C$ which would be recorded using the daily data, thus allowing PE to be registered.

The most significant difference between daily and monthly data lies in the surpluses and deficits. From table 4.2 it is evident that surpluses in the lower storage categories (2,13,50 mm) are much higher using daily data. The average daily data surplus over a 16 year record in the 13 mm category was 196.8 mm whereas in the monthly data it was only 121.4 mm. In the 150 mm category the average daily surplus was 14.5 mm. while the monthly data showed a 13.1 mm surplus. Using the daily data over the monthly data resulted in a 38 percent greater surplus in the 13 mm category, and a 10 percent greater surplus in the 150 mm category. The lower moisture storage categories (2,13, 50 mm)

TABLE 4.2

**Comparison of Daily and Monthly Weather Data for Yearly Results Using Edmonton International Airpirt Data (1971 - 1986)**

| | Daily Data | | | | Monthly Data | | |
|---|---|---|---|---|---|---|---|
| YEAR/PE | Storage Value (mm.) | Surplus (mm.) | Deficit (mm.) | YEAR/PE | Storage Value (mm.) | Surplus (mm.) | Deficit (mm.) |
| 1971 | 2 | 271.4 | 384.9 | 1971 | 2 | 133.4 | 263.3 |
| 531.6 | 13 | 206.8 | 308.7 | 525.8 | 13 | 121.9 | 238.8 |
| | 50 | 11[illegible]5 | 230.4 | | 50 | 99.1 | 200.7 |
| | 100 | 48.8 | 161.5 | | 100 | 48.2 | 149.9 |
| | 150 | 0 | 111.6 | | 150 | 0 | 101.6 |
| | 250 | 0 | 109.2 | | 250 | 0 | 101.6 |
| 1972 | | | | 1972 | | | |
| 496.9 | 2 | 385.9 | 304.1 | 502.9 | 2 | 165.9 | 85.4 |
| | 13 | 240.8 | 166.7 | | 13 | 147.3 | 73.7 |
| | 50 | 129.5 | 55.3 | | 50 | 119.3 | 33.0 |
| | 100 | 67.3 | 0 | | 100 | 66.0 | 0 |
| | 150 | 9.3 | 0 | | 150 | 15.2 | 0 |
| | 250 | 0 | 0 | | 250 | 0 | 0 |
| 1973 | | | | 1973 | | | |
| 516.0 | 2 | 392.2 | 336.0 | 533.4 | 2 | 151.0 | 114.2 |
| | 13 | 260.7 | 211.9 | | 13 | 121.9 | 86.4 |
| | 50 | 108.7 | 77.1 | | 50 | 53.3 | 17.8 |
| | 100 | 30.6 | 0 | | 100 | 17.8 | 0 |
| | 150 | 30.6 | 0 | | 150 | 15.2 | 0 |
| | 250 | 0 | 0 | | 250 | 0 | 0 |
| 1974 | | | | 1974 | | | |
| 495.7 | 2 | 340.6 | 330.1 | 510.5 | 2 | 158.6 | 127.0 |
| | 13 | 2[illegible].6 | 231.0 | | 13 | 154.9 | 154.9 |
| | 50 | 156.4 | 141.9 | | 50 | 114.3 | 116.0 |
| | 100 | 103.7 | 55.5 | | 100 | 99.1 | 63.5 |
| | 150 | 102.2 | 6.3 | | 150 | 96.5 | 17.8 |
| | 250 | 33.6 | 0 | | 250 | 27.9 | 0 |
| 1975 | | | | 1975 | | | |
| 496.3 | 2 | 260.9 | 309.4 | 470 | 2 | 106.1 | 126.0 |
| | 13 | 151.1 | 204.6 | | 13 | 82.0 | 106.0 |
| | 50 | 41.1 | 95.1 | | 50 | 45.0 | 69.0 |
| | 100 | 0 | 51.6 | | 100 | 0 | 24.0 |
| | 150 | 0 | 51.6 | | 150 | 0 | 24.0 |
| | 250 | 0 | 0 | | 250 | 0 | 0 |

TABLE 4.2 CONTINUED

| | Daily Data | | | | Monthly Data | | |
|---|---|---|---|---|---|---|---|
| Year/PE | Storage Value (mm.) | Surplus (mm.) | Deficit (mm.) | Year/PE | Storage Value (mm.) | Surplus (mm.) | Deficit (mm.) |
| 1976 529.9 | 2 | 266.8 | 344.6 | 1976 531 | 2 | 81.1 | 157.9 |
| | 13 | 146.6 | 223.4 | | 13 | 75.8 | 146.6 |
| | 50 | 38.8 | 113.6 | | 50 | 38.8 | 109.6 |
| | 100 | 0 | 80.5 | | 100 | 0 | 70.8 |
| | 150 | 0 | 80.5 | | 150 | 0 | 70.8 |
| | 250 | 0 | 23.9 | | 250 | 0 | 8.8 |
| 1977 513.7 | 2 | 288.7 | 347.1 | 1977 511.9 | 2 | 115.8 | 183.1 |
| | 13 | 158.2 | 227.1 | | 13 | 91.8 | 159.1 |
| | 50 | 41.4 | 112.2 | | 50 | 34.9 | 102.1 |
| | 100 | 0 | 70.4 | | 100 | 0 | 67.3 |
| | 150 | 0 | 70.4 | | 150 | 0 | 67.3 |
| | 250 | 0 | 70.4 | | 250 | 0 | 67.3 |
| 1978 534.6 | 2 | 335.1 | 345.2 | 1978 533.9 | 2 | 163.5 | 173.9 |
| | 13 | 236.9 | 241.8 | | 13 | 141.5 | 151.9 |
| | 50 | 117.0 | 153.1 | | 50 | 67.5 | 109.3 |
| | 100 | 48.2 | 128.5 | | 100 | 0 | 90.5 |
| | 150 | 0 | 128.5 | | 150 | 0 | 90.5 |
| | 250 | 0 | 128.5 | | 250 | 0 | 90.5 |
| 1979 515.7 | 2 | 273.5 | 345.9 | 1979 510.4 | 2 | 110.1 | 180.0 |
| | 13 | 157.8 | 233.1 | | 13 | 99.1 | 169.0 |
| | 50 | 95.5 | 139.0 | | 50 | 93.5 | 132.0 |
| | 100 | 94.2 | 89.1 | | 100 | 92.2 | 82.0 |
| | 150 | 44.2 | 39.4 | | 150 | 42.2 | 32.0 |
| | 250 | 0 | 0 | | 250 | 0 | 0 |
| 1980 530.3 | 2 | 409.7 | 342.6 | 1980 533.7 | 2 | 224.5 | 133.9 |
| | 13 | 300.2 | 238.5 | | 13 | 191.5 | 120.8 |
| | 50 | 125.9 | 99.0 | | 50 | 104.7 | 62.1 |
| | 100 | 28.1 | 23.2 | | 100 | 10 | 17.4 |
| | 150 | 0 | 23.2 | | 150 | 0 | 17.4 |
| | 250 | 0 | 0 | | 250 | 0 | 17.4 |
| 1981 546.1 | 2 | 243.8 | 385.4 | 1981 540 | 2 | 104.8 | 251.8 |
| | 13 | 138.5 | 284.2 | | 13 | 82.8 | 229.8 |
| | 50 | 51.3 | 182.0 | | 50 | 48.5 | 167.4 |
| | 100 | 48.5 | 132.0 | | 100 | 48.5 | 117.4 |
| | 150 | 8.5 | 90.1 | | 150 | 8.5 | 67.4 |
| | 250 | 0 | 88.1 | | 250 | 0 | 58.9 |

## TABLE 4.2 CONTINUED

| | Daily Data | | | | Monthly Data | | |
|---|---|---|---|---|---|---|---|
| Year/PE | Storage Value (mm.) | Surplus (mm.) | Deficit (mm.) | Year/PE | Storage Value (mm.) | Surplus (mm.) | Deficit (mm.) |
| 1982 | | | | 1982 | | | |
| 515.6 | 2 | 366.3 | 369.2 | 493.6 | 2 | 237.8 | 211.0 |
| | 13 | 281.0 | 273.1 | | 13 | 211.8 | 189.0 |
| | 50 | 172.8 | 171.8 | | 50 | 137.8 | 115.0 |
| | 100 | 72.8 | 70.9 | | 100 | 52.4 | 37.0 |
| | 150 | 0.6 | 4.6 | | 150 | 2.4 | 0 |
| | 250 | 0 | 4.6 | | 250 | 0 | 0 |
| 1983 | | | | 1983 | | | |
| 521.9 | 2 | 249.4 | 367.8 | 529.8 | 2 | 99.8 | 230.2 |
| | 13 | 180.6 | 289.6 | | 13 | 87.3 | 208.1 |
| | 50 | 106.6 | 215.3 | | 50 | 14.2 | 135.1 |
| | 100 | 36.9 | 145.7 | | 100 | 0 | 120.9 |
| | 150 | 0 | 102.0 | | 150 | 0 | 120.9 |
| | 250 | 0 | 102.0 | | 250 | 0 | 120.9 |
| 19[illegible] | | | | 1984 | | | |
| 522.6 | 2 | 251.7 | 379.2 | 517.1 | 2 | 166.3 | 249.0 |
| | 13 | 157.0 | 291.8 | | 13 | 144.3 | 238.0 |
| | 50 | 16.8 | 195.6 | | 50 | 70.3 | 201.0 |
| | 100 | 0 | 176.3 | | 100 | 3.5 | 184.2 |
| | 150 | 0 | 176.3 | | 150 | 0 | 184.2 |
| | 250 | 0 | 176.3 | | 250 | 0 | 184.2 |
| 1985 | | | | 1985 | | | |
| 517.2 | 2 | 226.8 | 353.4 | 499.1 | 2 | 99.5 | 198.4 |
| | 13 | 137.3 | 266.1 | | 13 | 88.5 | 187.4 |
| | 50 | 84.2 | 183.1 | | 50 | 76.8 | 150.4 |
| | 100 | 84.2 | 133.1 | | 100 | 76.8 | 100.7 |
| | 150 | 37.7 | 83.1 | | 150 | 30.3 | 50.4 |
| | 250 | 0 | 45.4 | | 250 | 0 | 20.1 |
| 1986 | | | | 1986 | | | |
| 545.6 | 2 | 257.1 | 379.4 | 549.2 | 2 | 123.0 | 183.0 |
| | 13 | 148.9 | 260.2 | | 13 | 101.0 | 150.0 |
| | 50 | 66.9 | 160.3 | | 50 | 48.9 | 94.9 |
| | 100 | 25.5 | 93.3 | | 100 | 0 | 46.0 |
| | 150 | 0 | 67.8 | | 150 | 0 | 46.0 |
| | 250 | 0 | 67.8 | | 250 | 0 | 46.0 |

TABLE 4.2 CONTINUED

| | Daily Data | | | | Monthly Data | | |
|---|---|---|---|---|---|---|---|
| | Storage | | | | Storage | | |
| | Value | Surplus | Deficit | | Value | Surplus | Deficit |
| Year/PE | (mm.) | (mm.) | (mm.) | Year/PE | (mm.) | (mm.) | (mm.) |
| 16 Year | 2 | 301.2 | 351.5 | | 2 | 140.1 | 179.3 |
| Average | 13 | 196.8 | 247.0 | | 13 | 121.5 | 163.1 |
| 520.6 | 50 | 92.0 | 145.3 | 518.3 | 50 | 72.9 | 113.5 |
| | 100 | 43.1 | 88.2 | | 100 | 32.2 | 73.2 |
| | 150 | 14.6 | 64.7 | | 150 | 13.1 | 55.6 |
| | 250 | 2.1 | 51.0 | | 250 | 1.7 | 44.7 |

Source: Calculations by Author Using the Thornthwaite Procedure with Data from the Edmonton International Airport Annual Meteorological Summary Produced by the Atmospheric Environment Service.

surpluses result from storms lasting one or two days which produce enough precipitation to exceed the local moisture st[illegible]ities. During the course of a month the use of the daily data would have record[illegible]f these surpluses than use of the monthly balance would have.

The deficits experi[illegible]re also much higher when using daily data over monthly data. This is especially [illegible] lower storage categories (2,13, 50 mm). The average daily data deficit over a 16 year period in the 13 mm category was 251.8 mm. opposed to 163.1 mm. when using monthly data (Table 4.2). In the 150 mm category the average deficit using daily data was 67.8 mm versus 55.7 mm when using monthly data. Using the daily data over the monthly data resulted in a 35 percent greater deficit in the 13 mm category and a 18 percent greater deficit in the 150 mm category.

The use of daily data creates a greater awareness of the climatic conditions of an area during the spring, summer, and fall months, while monthly data is more than adequate for measuring surpluses during the winter months. In this thesis the two forms of data are used in conjunction with each other. The winter months have been designated from November-March, whereas the spring, summer, and fall months include April-October. This was an arbitrary decision on the writers part based upon the following discussion.

Previously in this section it has been stated that the major differences between daily and monthly data were in the surpluses and deficits in the lower water storage categories. During the winter months there are few differences between the two forms of data in terms of surpluses and deficits. For example in table 4.3 in the 13 mm moisture storage category the average surplus in March over a 12 year record using daily data was 16.1 mm whereas the average monthly data surplus was 18.1 mm. In November over the same 12 year record in the 13 mm category the daily data surplus was 7.0 mm and the monthly data surplus was 6.7 mm. The actual difference in terms of amounts between the two forms of data is minimal. When reviewing the values it should be noted that the lower storage categories were the most likely to have the highest differences.

Deficits are possible in the lower storage categories (2, 13 mm) during the months of March and November when using daily data. This is partly the reason why the daily deficits are larger than the monthly deficits. In table 4.3 it is apparent that with an average of 1.4 mm of deficit in the 13 mm category, the larger daily data summer deficits are not a result of November values.

The data used in the Thornthwaite procedure will therefore consist of monthly data during the winter months (Nov.-Mar.) and daily data during the summer months (Apr.-Oct.).

## 4.4 WATER YIELDS

The determination of water yields within and around Elk Island National Park is of some importance when an overall picture of the resource is desired. The Park and surrounding area were divided into water basins (Fig 4.4). The procedure described in the methodology was then used to determine the yearly yields within the different basins. An average water loss of -371.5 $Dm^3$ for the 16 years of study within the 7 basins of the Park was recorded. The range was from a high yield of 9183.6 $Dm^3$ in 1974 to a low total water loss of 11,311.2 $Dm^3$ in 1984 (Table 4.4). There were a number of other years such as 1971, 1976, 1981,1983,1985 which also recorded large negative values similar to that of 1984. An average water loss would be consistent with the lake level fluctuations illustrated in figures 4.7 and 4.8. The general trend of the lake levels over the past 16 years has been to lower levels.

The years 1972-1974 could be classed as wet years due to the large amounts of precipitation illustrated in table 4.1 which consequently led to the years 1972-1974 becoming high yield years. One wet year amongst a series of dry years is not sufficient to produce large positive values in yield. For example, 1980 had the highest precipitation in

TABLE 4.3

**Comparison Of Surpluses And Deficits During March And November Using Daily And Monthly Data (1971-1982)**

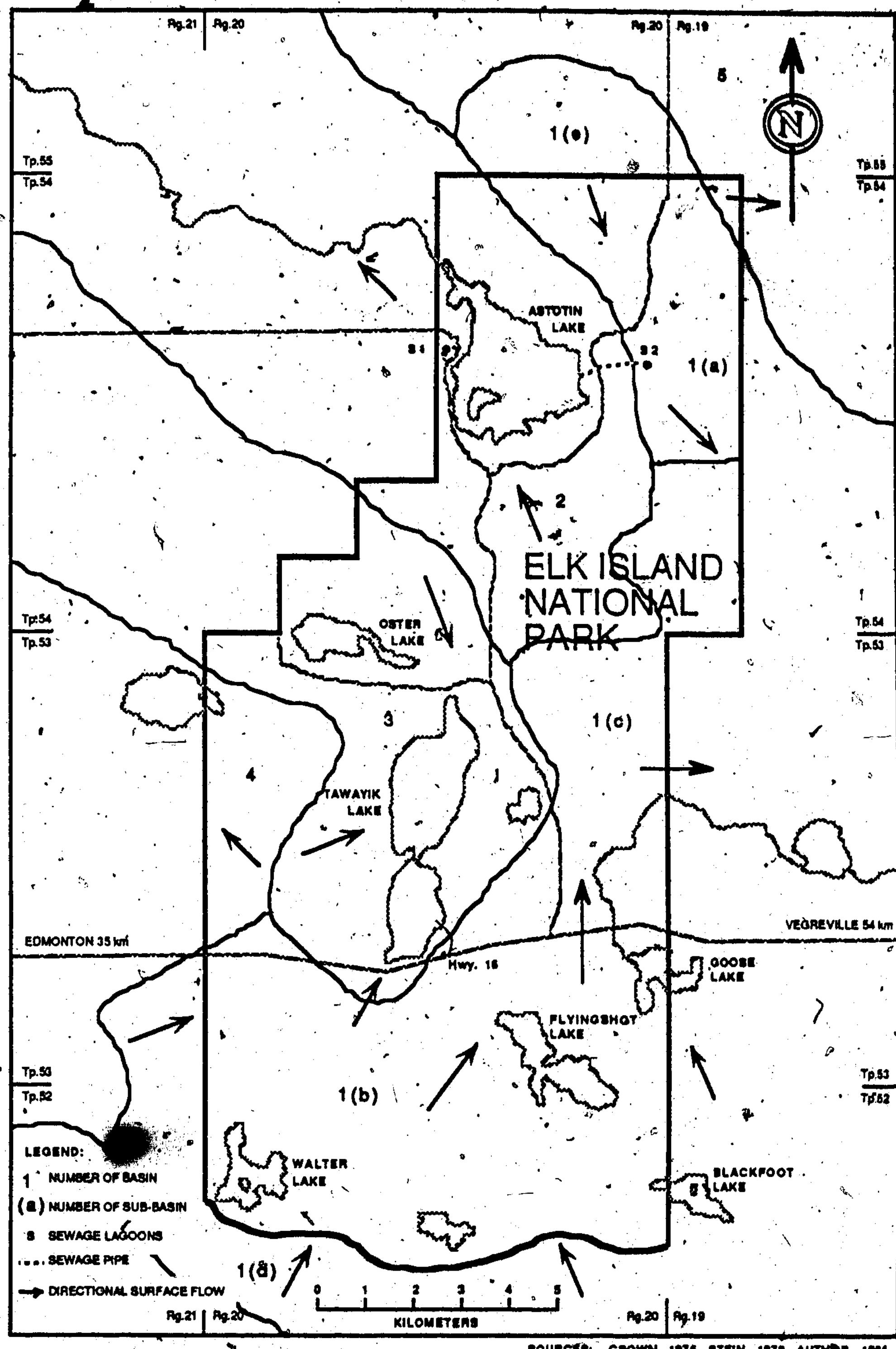
13 mm. Moisture Storage Capacity

| Year/Month | | Daily Data (mm.) Surplus | Deficit | | Monthly Data (mm.) Surplus | Deficit |
|---|---|---|---|---|---|---|
| 1971 | | | | | | |
| | March | 21.3 | 0 | March | 21.3 | 0 |
| | November | 11.2 | 0 | November | 11.2 | 0 |
| 1972 | | | | | | |
| | March | 27.0 | 0 | March | 30.5 | 0 |
| | November | 19.3 | 0 | November | 15.2 | 0 |
| 1973 | | | | | | |
| | March | 9.5 | 0 | March | 10.7 | 0 |
| | November | 26.3 | 0 | November | 20.3 | 0 |
| 1974 | | | | | | |
| | March | 39.8 | 0 | March | 40.6 | 0 |
| | November | 0 | 2.3 | November | 0 | 0 |
| 1975 | | | | | | |
| | March | 15.7 | 0 | March | 15 | 0 |
| | November | 0 | 0 | November | 0 | 0 |
| 1976 | | | | | | |
| | March | 15.9 | 0 | March | 15.9 | 0 |
| | November | 0 | 4.8 | November | 0 | 0 |
| 1977 | | | | | | |
| | March | 3.7 | 0 | March | 6.8 | 0 |
| | November | 0 | 1.3 | November | 0 | 0 |
| 1978 | | | | | | |
| | March | 0.9 | 0 | March | 5.2 | 0 |
| | November | 26.7 | 0 | November | 26.4 | 0 |
| 1979 | | | | | | |
| | March | 0 | 0 | March | 8.3 | 0 |
| | November | 0 | 3.9 | November | 0 | 0 |
| 1980 | | | | | | |
| | March | 19.5 | 0 | March | 19.5 | 0 |
| | November | 0 | 1.3 | November | 0 | 0 |

TABLE 4.3 CONTINUED

| Year/Month | | Daily Data (mm.) Surplus | Daily Data (mm.) Deficit | Year/Month | Monthly Data (mm.) Surplus | Monthly Data (mm.) Deficit |
|---|---|---|---|---|---|---|
| 1981 | | | | | | |
| | March | 7.4 | 0 | March | 11.8 | 0 |
| | November | 0 | 3.1 | November | 0 | 0 |
| 1982 | | | | | | |
| | March | 32.1 | 0 | March | 32.1 | 0 |
| | November | 0.5 | 0 | November | 7.5 | 0 |
| Avg. March | | 16.1 | 0 | | 18.1 | 0 |
| Avg. November | | 7.0 | 1.4 | | 6.7 | 0 |

Source: Calculations by Author Using the Thornthwaite Procedure with Data from the Edmonton International Airport Annual Meteorological Summary Produced by the Atmospheric Environment Service.




**Drainage Basins and Direction of Flow Within Elk Island National Park**

Figure 4.4

TABLE 4.4.

**Water Yield Totals of Seven Drainage Basins and Three Subbasins of Basin One Within Elk Island National Park 1971-1986**

(Cubic Decameters)

-Daily Data for April-October, Monthly Data for November-March-

| | Drainage Areas Within the Park | | | | | Drainage Areas With Flow into the Park | | |
|---|---|---|---|---|---|---|---|---|
| Area | 1 | 2 | 3 | 4 | 5 | 6 (1d) | 7 (1e) | Total |
| (Km $^2$) | 107.8 | 37.47 | 37.81 | 14.06 | 1.02 | 36.89 | 3.41 | 238.46 |
| (hectares) | 10780 | 3747 | 3781 | 1406 | 102 | 3689 | 341 | 23846 |
| Year | Calculated Basin Yield | | | | | | | Net Flow All Basins |
| 1971 | -3848.5 | -2184.0 | -2217.1 | -686.7 | 24.6 | -437.2 | 59.6 | -9289.3 |
| 1972 | 2583.2 | 1208.6 | 1050.1 | 374.6 | 27.6 | 1013.9 | 141.9 | 6399.9 |
| 1973 | 1852.8 | 897.9 | 743.2 | 466.1 | 26.5 | 614.0 | 84.2 | 4684.7 |
| 1974 | 3521.5 | 1118.5 | 994.2 | 944.6 | 56.9 | 1726.8 | 261.5 | 8624.0 |
| 1975 | -1239.6 | -683.1 | -723.0 | -228.9 | 14.1 | -287.6 | -11.8 | -3159.9 |
| 1976 | -2427.3 | -1316.9 | -1332.3 | -416.9 | 13.2 | -542.9 | -22.9 | -6046.0 |
| 1977 | -2098.6 | -1143.9 | -1170.6 | -367.7 | 14.4 | -474.2 | -20.2 | -5260.8 |
| 1978 | -1049.4 | -690.3 | -779.5 | -262.1 | 26.5 | 122.2 | 77.5 | -2555.1 |
| 1979 | -1287.3 | -898.7 | -963.7 | 38.9 | 19.5 | 445.4 | 175.1 | -2470.8 |
| 1980 | 1836.3 | 886.1 | 547.0 | 205.0 | 31.4 | 578.4 | 68.1 | 4152.3 |
| 1981 | -3776.4 | -2134.8 | -2127.0 | -603.5 | 14.3 | -453.0 | 55.4 | -9025.0 |
| 1982 | 551.9 | 171.1 | 103.7 | 84.8 | 34.2 | 472.4 | 95.9 | 1494.1 |
| 1983 | -3434.2 | -1930.1 | -1958.4 | -621.5 | 21.5 | -466.2 | 34.6 | -8354.3 |
| 1984 | -4600.0 | -2469.8 | -2443.8 | -758.2 | 12.3 | -1008.6 | -43.1 | -11311.2 |
| 1985 | -2596.6 | -1835.5 | -1857.5 | -287.1 | 17.1 | -802.3 | 137.7 | -7224.2 |
| 1986 | -1118.0 | -678.4 | -759.1 | -249.9 | 23.9 | -65.6 | 35.5 | -2811.6 |
| Avg.(71-86) | -1070.6 | -730.2 | -805.8 | -148.0 | 23.6 | 28.9 | 75.0 | -2628.8 |
| High | 3521.0 | 1208.6 | 1050.1 | 944.6 | 56.9 | 1726.8 | 261.5 | 8624.0 |
| Low | -4600.0 | -2469.8 | -2443.8 | -758.2 | 12.3 | -1008.6 | -43.1 | -11311.2 |

Source: Calculations by Author Using the Thornthwaite Procedure
Note 1: Refer to Figure 4.4 for Location of Drainage Basins
Note 2: Table 4.4 is a Summary Table of Table 4.5

TABLE 4.4 CONTINUED

(Cubic Decameters)

Subbasins of Basin 1

| | 1(a) | 1(b) | 1(c) |
|---|---|---|---|
| Area (Km2) | 17.1 | 59.68 | 31.0 |
| (hectares) | 1710 | 5968 | 3102 |
| Year | Calculated Basin Yield | | |
| 1971 | -827.9 | -2503.7 | -517.0 |
| 1972 | 451.2 | 1518.7 | 613.0 |
| 1973 | 334.5 | 1122.0 | 396.0 |
| 1974 | 512.4 | 1781.0 | 1228.0 |
| 1975 | -262.0 | -753.4 | -224.0 |
| 1976 | -500.8 | -1499.1 | -427.0 |
| 1977 | -436.0 | -1290.2 | -372.0 |
| 1978 | -265.9 | -730.4 | -53.0 |
| 1979 | -337.7 | -1010.2 | 60.6 |
| 1980 | 326.1 | 1132.3 | 377.0 |
| 1981 | -807.1 | -2460.5 | -509.0 |
| 1982 | 62.5 | 258.0 | 232.0 |
| 1983 | -731.9 | -2210.0 | -492.0 |
| 1984 | -936.1 | -2868.6 | -795.0 |
| 1985 | -691.0 | -2122.6 | -277.0 |
| 1986 | -261.2 | -723.4 | -133.0 |
| Avg. (71-86) | -273.1 | -772.6 | -56.0 |
| High | 512.4 | 1781.0 | 1228.0 |
| Low | -936.1 | -2868.6 | -795.0 |

Source: Calculations by Author Using the Monthly Meteorological Record and Thornthwaite Procedures in Calculating the Water Balance.

Note: Refer to Figure 4.4 for Location of Drainage Basins.

the 16 years of record but did not produce as large a yield as those during 1972-1974. The low 1980 yield was a result of a series of dry years prior to 1980 and a need for a large amount of recharge before surpluses could be produced (Table 4.4). A series of wet years such as 1972-1974 was necessary to produce the high positive yields of 1973 and 1974. The wet years in series resulted in a rare surplus in the extensive 250 mm moisture storage category (forest) which produced the significant yields of those two years (Table 4.5). During a wet year such as 1974 it is evident from table 4.5 that all moisture storage capacities contributed flow into the local wetlands. The wetland losses during the summer of 1974 were more than balanced by the previous precipitation amounts, which along with the major inflow, resulted in the substantial increase in lake levels. Very little of the yield, however, is available in most years for flow out of the Park. Most of the yield is employed in wetland water level support and recovery. Basin contributing areas ( to flow out of the Park) will range from almost nil in drier years to most of the region in the wettest years after overflow levels have been achieved.

The large number of years with water losses is due in part to the amount of wetland within the Park (Table 4.4). It is the water losses from marshes and lakes which are primarily responsible for an overall basin water loss (Table 4.5). On average, 27.3 percent of the area within the park is covered by water with a high of 32 percent of basin 2 and a low of 21 percent of basin 1 (Table 4.6.2). When there are no wetlands or water bodies such as in the fifth basin, there are yields every year despite the dryness or wetness of any one year (Table 4.5). Another factor to account for the years with high water losses is the amount of forest covering the Park. The denser mature forest cover which has a 250 mm moisture storage capacity produces a surplus only in a series of wet years, thus limiting the yields during average and dry years. The area covered by forest within the different basins ranges from a high of 84.3 percent in basin 5 to a low of 14 percent in

## TABLE 4.5

**Water Yields on a Yearly Basis of the Seven Drainage Basins and Three Subbasins of Basin One Within Elk Island National Park**

Hectare Decimeters (Cubic Decameters)

By Water Storage Categories

| 1971 Basins | 2 a | 13 b | 50 c | 100 d | 150 e | 250 f | Wetland(g)[1] Winter | Summer | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 124.8 | 83.1 | 136.1 | 284.5 | 1.8 | 0 | 2770.3 | -7249.1 | -3848.5 |
| 2 | 27.1 | 68.5 | 65.0 | 39.7 | 1.7 | 0 | 1475.9 | -3861.9 | -2184.0 |
| 3 | 24.4 | 4.2 | 20.5 | 41.3 | 0.8 | 0 | 1427.7 | -3736.0 | -2217.1 |
| 4 | 0 | 6.2 | 0 | 0 | 19.4 | 0 | 440.5 | -1152.8 | -686.7 |
| 5 | 0 | 14.5 | 9.6 | 0.5 | 0 | 0 | 0 | 0 | 24.6 |
| 6 | 0 | 14.5 | 44.5 | 460.2 | 1.3 | 0 | 592.3 | -1550.0 | -437.2 |
| 7 | 0 | 2.1 | 1.2 | 97.3 | 0.9 | 0 | 25.9 | -67.8 | 59.6 |
| 1[a] | 10.9 | 18.7 | 25.3 | 16.2 | 0.8 | 0 | 556.5 | -1456.3 | -827.9 |
| 1[b] | 108.6 | 39.5 | 101.1 | 60.1 | 0 | 0 | 1739.9 | -4552.9 | -2503.7 |
| 1[c] | 5.3 | 24.9 | 9.6 | 208.2 | 0.9 | 0 | 473.9 | -1240.0 | -517.2 |

| 1972 Basins | a | b | c | d | e | f | g | | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 177.5 | 97.0 | 140.9 | 344.4 | 7.2 | 0 | 3181.2 | -1365.0 | 2583.2 |
| 2 | 38.6 | 80.0 | 67.3 | 48.1 | 7.1 | 0 | 1694.7 | -727.2 | 1208.6 |
| 3 | 34.7 | 4.9 | 21.2 | 50.0 | 3.3 | 0 | 1639.5 | -703.5 | 1050.1 |
| 4 | 0 | 7.3 | 0 | 0 | 78.5 | 0 | 505.9 | -217.1 | 374.6 |
| 5 | 0 | 17.0 | 10.0 | 0.6 | 0 | 0 | 0 | 0 | 27.6 |
| 6 | 0 | 17.0 | 46.1 | 557.0 | 5.4 | 0 | 680.2 | -291.8 | 1013.9 |
| 7 | 0 | 2.4 | 1.2 | 117.7 | 3.6 | 0 | 29.8 | -12.8 | 141.9 |
| 1[a] | 15.4 | 21.8 | 26.2 | 19.6 | 3.3 | 0 | 639.1 | -274.2 | 451.2 |
| 1[b] | 154.4 | 46.1 | 104.7 | 72.8 | 0 | 0 | 1998.0 | -857.3 | 1518.7 |
| 1[c] | 7.7 | 29.1 | 10.0 | 251.9 | 3.9 | 0 | 544.1 | -233.5 | 613.2 |

[1] The winter value represents the total precipitation received by the wetland. The summer value represents the total precipitation received by the wetland minus the potential evapotranspiration and half the summers deficit from the 150 mm. moisture storage category.

TABLE 4.5 CONTINUED

Water Storage Categories (mm.)

| 1973 Basins | 2 a | 13 b | 50 c | 100 d | 150 e | 250 f | Wetland(g) Winter | Summer | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 180.7 | 99.8 | [illegible] | 166.5 | 23.6 | 0 | 1677.0 | -417.6 | 1852.8 |
| 2 | 39.3 | [illegible] | [illegible] | 23.3 | 23.3 | 0 | 869.5 | -222.5 | 897.9 |
| 3 | 35.4 | 5.0 | 18.5 | 24.2 | 11.0 | 0 | 841.1 | -215.2 | 743.2 |
| 4 | 0 | 7.5 | 0 | 0 | 258.3 | 0 | 259.6 | -66.4 | 466.1 |
| 5 | 0 | 17.5 | 8.7 | 0.3 | 0 | 0 | 0 | 0 | 26.5 |
| 6 | 0 | 17.5 | 40.2 | 269.3 | 17.7 | 0 | 349 | -89.3 | 614.0 |
| 7 | 0 | 2.5 | 1.1 | 56.9 | 11.9 | 0 | 15.3 | -3.9 | 84.2 |
| 1[a] | 15.7 | 22.5 | 22.8 | 9.5 | 11.0 | 0 | 327.9 | -83.9 | 334.5 |
| 1[b] | 157.1 | 47.4 | 91.3 | 35.2 | 0 | 0 | 1025.0 | -262.3 | 1122.0 |
| 1[c] | 7.9 | 30.0 | 8.7 | 121.8 | 12.6 | 0 | 279.2 | -71.4 | 396.4 |

| 1974 Basins | a | b | c | d | e | f | g | | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 156.7 | 98.8 | 178.5 | 551.6 | 78.1 | 2329.9 | 3598.7 | -3470.8 | 3521.5 |
| 2 | 34.1 | 81.5 | 85.3 | 77.1 | 77.1 | 695.2 | 1917.2 | -1849.0 | 1118.5 |
| 3 | 30.7 | 4.9 | 26.7 | 80.1 | 36.5 | 749.3 | 1854.7 | -1788.7 | 994.2 |
| 4 | 0 | 7.4 | 0 | 0 | 855.8 | 61.0 | 572.3 | -551.9 | 944.6 |
| 5 | 0 | 17.3 | 12.6 | 1.0 | 0 | 26.0 | 0 | 0 | 56.9 |
| 6 | 0 | 17.3 | 58.5 | 892.3 | 58.8 | 672.6 | 769.4 | -742.1 | 1726.8 |
| 7 | 0 | 2.5 | 1.6 | 188.6 | 39.5 | 28.1 | 33.7 | -32.5 | 261.5 |
| 1[a] | 13.6 | 22.2 | 33.2 | 31.4 | 36.5 | 349.7 | 723.0 | -697.2 | 512.4 |
| 1[b] | 136.2 | 46.9 | 132.7 | 116.6 | 0 | 1268.4 | 2260.2 | -2180.0 | 1781.0 |
| 1[c] | 6.9 | 29.7 | 12.6 | 403.6 | 41.6 | 711.8 | 615.6 | -593.7 | 1228.1 |

| 1975 Basins | a | b | c | d | e | f | g | | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 120.0 | 60.9 | 47.7 | 0 | [illegible] | 0 | 1483.9 | -2952.2 | -1239.6 |
| 2 | 26.1 | 50.2 | 22.8 | 0 | 0 | 0 | 790.6 | -1572.7 | -683.1 |
| 3 | 23.5 | 3 | 7.2 | 0 | 0 | 0 | 764.8 | -1521.5 | -723.0 |
| 4 | 0 | 4.6 | 0 | 0 | 0 | 0 | 2[illegible]6.0 | -469.5 | -228.9 |
| 5 | 0 | 10.7 | 3.4 | 0 | 0 | 0 | 0 | 0 | 14.1 |
| 6 | 0 | 10.7 | 15.6 | 0 | 0 | 0 | 317.3 | -631.2 | -287.6 |
| 7 | 0 | 1.5 | 0.4 | 0 | 0 | 0 | 13.9 | -27.6 | -11.8 |
| 1[a] | 10.4 | 13.7 | 8.9 | 0 | 0 | 0 | 298.1 | -893.1 | -262.0 |
| 1[b] | 104.4 | 28.9 | 35.4 | 0 | 0 | 0 | 932.0 | -1854.2 | -753.4 |
| 1[c] | 5.2 | 18.3 | 3.4 | 0 | 0 | 0 | 253.8 | -505.0 | -224.2 |

## TABLE 4.5 CONTINUED

Water Storage Categories (mm.)

| 1976 | 2 | 13 | 50 | 100 | 150 | 250 | Wetland (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| Basins | a | b | c | d | e | f | Winter | Summer | Net Yield |
| 1 | 122.7 | 58.6 | 40.5 | 0 | 0 | 0 | 1814.0 | -4463.1 | -2427.3 |
| 2 | 26.7 | 48.4 | 19.3 | 0 | 0 | 0 | 966.4 | -2377.6 | -1316.9 |
| 3 | 24.0 | 2.9 | 6.1 | 0 | 0 | 0 | 934.9 | -2300.1 | -1332.3 |
| 4 | .0 | 4.4 | 0 | 0 | 0 | 0 | 288.5 | -709.7 | -416.9 |
| 5 | 0 | 10.3 | 2.9 | 0 | 0 | 0 | 0 | 0 | 13.2 |
| 6 | 0 | 10.3 | 13.2 | 0 | 0 | 0 | 387.8 | -954.2 | -542.9 |
| 7 | 0 | 1.5 | 0.4 | 0 | 0 | 0 | 17.0 | -41.7 | -22.9 |
| 1[a] | 10.7 | 13.2 | 7.5 | 0 | 0 | 0 | 364.4 | -996.7 | -500.8 |
| 1[b] | 106.7 | 27.9 | 30.1 | 0 | 0 | 0 | 1139.3 | -2803.1 | -1499.1 |
| 1[c] | 5.3 | 17.5 | 2.9 | 0 | 0 | 0 | 310.3 | -763.4 | -427.4 |
| **1977** | | | | | | | | | |
| Basins | a | b | c | d | e | f | g | | Net Yield |
| 1 | 132.8 | 63.3 | 46.8 | 0 | 0 | 0 | 1475.0 | -3816.5 | -2098.6 |
| 2 | 28.9 | 52.2 | 22.4 | 0 | 0 | 0 | 785.8 | -2033.2 | -1143.9 |
| 3 | 26.0 | 3.2 | 7 | 0 | 0 | 0 | 760.0 | -1966.9 | -1170.6 |
| 4 | 0 | 4.7 | 0 | 0 | 0 | 0 | 234.5 | -606.9 | -367.7 |
| 5 | 0 | 11.1 | 3.3 | 0 | 0 | 0 | 0 | 0 | 14.4 |
| 6 | 0 | 11.1 | 15.3 | 0 | 0 | 0 | 315.4 | -816.0 | -474.2 |
| 7 | 0 | 1.6 | 0.4 | 0 | 0 | 0 | 13.8 | -35.7 | -20.2 |
| 1[a] | 11.5 | 14.2 | 8.7 | 0 | 0 | 0 | 296.3 | -766.7 | -436.0 |
| 1[b] | 115.5 | 30.1 | 34.8 | 0 | 0 | 0 | 926.4 | -2397.0 | -1290.2 |
| 1[c] | 5.8 | 19.0 | 3.3 | 0 | 0 | 0 | 252.3 | -652.8 | -372.4 |
| **1978** | | | | | | | | | |
| Basins | a | b | c | d | e | f | g | | Net Yield |
| 1 | 154.1 | 94.8 | 132.2 | 262.2 | 0 | 0 | 1544.6 | -3237.3 | -1049.4 |
| 2 | 33.5 | 78.2 | 63.2 | 36.6 | 0 | 0 | 822.8 | -1724.6 | -690.3 |
| 3 | 30.2 | 4.7 | 19.9 | 38.1 | 0 | 0 | 796.0 | -1668.4 | -779.5 |
| 4 | 0 | 7.1 | 0 | 0 | 0 | 0 | 245.6 | -514.8 | -262.1 |
| 5 | 0 | 16.6 | 9.4 | 0.5 | 0 | 0 | 0 | 0 | 26.5 |
| 6 | 0 | 16.6 | 43.3 | 424.2 | 0 | 0 | 330.2 | -692.2 | 122.2 |
| 7 | 0 | 2.4 | 1.2 | 89.7 | 0 | 0 | 14.4 | -30.3 | 77.5 |
| 1[a] | 13.4 | 21.3 | 24.6 | 14.9 | 0 | 0 | 310.3 | -650.3 | -265.9 |
| 1[b] | 134.0 | 45.0 | 98.3 | 55.4 | 0 | 0 | 970.1 | -2033.2 | -730.4 |
| 1[c] | 6.7 | 28.5 | 9.3 | 191.9 | 0 | 0 | 264.2 | -553.7 | -53.1 |

## TABLE 4.5 CONTINUED

Water Storage Categories (mm.)

| 1979 Basins | 2 a | 13 b | 50 c | 100 d | 150 e | 250 f | Wetland (g) Winter | Wetland (g) Summer | Net Yields |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.8 | 63.1 | 107.9 | 512.4 | 34.0 | 0 | 1971.1 | -4101.6 | -1287.3 |
| 2 | 27.4 | 52.1 | 51.6 | 71.6 | 33.6 | 0 | 1050.1 | -2185.1 | -898.7 |
| 3 | 24.6 | 3.2 | 16.2 | 74.4 | 15.9 | 0 | 1015.8 | -2113.8 | -963.7 |
| 4 | 0 | 4.7 | 0 | 0 | 373.0 | 0 | 313.4 | -652.2 | 38.9 |
| 5 | 0 | 11.0 | 7.6 | 0.9 | 0 | 0 | 0 | 0 | 19.5 |
| 6 | 0 | 11.0 | 35.3 | 829.0 | 25.6 | 0 | 421.4 | -877.0 | 445.4 |
| 7 | 0 | 1.6 | 1.0 | 175.2 | 17.2 | 0 | 18.4 | -38.4 | 175.1 |
| 1[a] | 10.9 | 14.2 | 20.1 | 29.2 | 15.9 | 0 | 396.0 | -824.0 | -337.7 |
| 1[b] | 109.4 | 30.0 | 80.2 | 108.3 | 0 | 0 | 1238.0 | -2576.1 | -1010.2 |
| 1[c] | 5.5 | 18.9 | 7.6 | 374.9 | 18.1 | 0 | 337.2 | -701.6 | 60.6 |

| 1980 Basins | a | b | c | d | e | f | g | | Net Yields |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 188.5 | 120.1 | 142.3 | 152.9 | 0 | 0 | 2126.0 | -893.5 | 1836.3 |
| 2 | 41.0 | 99.1 | 68.0 | 21.4 | 0 | 0 | 1132.6 | -476.0 | 886.1 |
| 3 | 36.9 | 6.0 | 21.4 | 22.2 | 0 | 0 | 1095.7 | -460.5 | 547.0 |
| 4 | 0 | 9.0 | 0 | 0 | 0 | 0 | 338.1 | -142.1 | 205.0 |
| 5 | 0 | 21.0 | 10.1 | 0.3 | 0 | 0 | 0 | 0 | 31.4 |
| 6 | 0 | 21.0 | 46.6 | 247.3 | 0 | 0 | 454.6 | -191.0 | 578.4 |
| 7 | 0 | 3.0 | 1.3 | 52.3 | 0 | 0 | 19.9 | -8.4 | 68.1 |
| 1[a] | 16.4 | 27.0 | 26.4 | 8.7 | 0 | 0 | 427.1 | -179.5 | 326.1 |
| 1[b] | 163.9 | 57.0 | 105.8 | 32.3 | 0 | 0 | 1335.3 | -561.2 | 1132.3 |
| 1[c] | 8.2 | 36.1 | 10.1 | 111.9 | 0 | 0 | 363.6 | -152.8 | 377.1 |

| 1981 Basins | a | b | c | d | e | f | g | | Net Yields |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 112.1 | 55.4 | 58.0 | 263.8 | 6.5 | 0 | 1580.5 | -5852.7 | -3776.4 |
| 2 | 24.4 | 45.7 | 27.7 | 36.9 | 6.5 | 0 | 842.0 | -3118.0 | -2134.8 |
| 3 | 21.9 | 2.8 | 8.7 | 38.3 | 3.1 | 0 | 814.5 | -3016.3 | -2127.0 |
| 4 | 0 | 4.2 | 0 | 0 | 71.7 | 0 | 251.3 | -730.7 | -603.5 |
| 5 | 0 | 9.7 | 4.1 | 0.5 | 0 | 0 | 0 | 0 | 14.3 |
| 6 | 0 | 9.7 | 19.0 | 426.8 | 4.9 | 0 | 337.9 | -1251.4 | -453.0 |
| 7 | 0 | 1.4 | 0.5 | 90.2 | 3.3 | 0 | 14.8 | -54.7 | 55.4 |
| 1[a] | 9.8 | 12.5 | 10.8 | 15.0 | 3.1 | 0 | 317.5 | -1175.8 | -807.1 |
| 1[b] | 97.5 | 26.3 | 43.1 | 55.8 | 0 | 0 | 992.6 | -3675.9 | -2460.5 |
| 1[c] | 4.8 | 16.6 | 4.1 | 193.0 | 3.4 | 0 | 270.3 | -1001.1 | -508.9 |

# TABLE 4.5 CONTINUED

Water Storage Categories (mm.)

| 1982 Basin | 2 a | 13 b | 50 c | 100 d | 150 e | 250 f | Wetland (g) Winter | Summer | Net Yields |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 168.5 | 112.4 | 195.3 | 396.0 | 0.5 | 0 | 2884.8 | -2828.7 | 551.9 |
| 2 | 36.6 | 92.7 | 93.3 | 55.3 | 0.5 | 0 | 1536.9 | -1507.0 | 171.1 |
| 3 | 33.0 | 5.6 | 29.4 | 57.5 | 0.2 | 0 | 1486.7 | -1457.8 | 103.7 |
| 4 | 0 | 8.4 | 0 | 0 | 5.1 | 0 | 458.7 | -450.0 | 84.8 |
| 5 | 0 | 19.7 | 13.8 | 0.7 | 0 | 0 | 0 | 0 | 14.3 |
| 6 | 0 | 19.7 | 63.9 | 640.6 | 0.3 | 0 | 616.8 | -604.8 | 472.4 |
| 7 | 0 | 2.8 | 1.7 | 135.4 | 0.2 | 0 | 27.0 | -26.5 | 95.9 |
| 1[a] | 14.7 | 25.3 | 36.3 | 22.6 | 0.2 | 0 | 579.5 | -568.3 | 62.5 |
| 1[b] | 146.5 | 53.4 | 145.2 | 83.7 | 0 | 0 | 1811.9 | -1776.6 | 258.0 |
| 1[c] | 7.3 | 33.7 | 13.8 | 289.7 | 0.3 | 0 | 493.4 | -483.8 | 231.5 |

| 1983 Basins | a | b | c | d | e | f | g | | Net Yields |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 114.7 | 72.2 | 120.5 | 200.7 | 0 | 0 | 1183.1 | -5125.3 | -3434.2 |
| 2 | 24.9 | 59.6 | 57.6 | 28.0 | 0 | 0 | 630.3 | -2730.5 | -1930.1 |
| 3 | 22.4 | 3.6 | 18.1 | 29.2 | 0 | 0 | 609.7 | -2641.4 | -1958.4 |
| 4 | 0 | 5.4 | 0 | 0 | 0 | 0 | 188.1 | -815.0 | -621.5 |
| 5 | 0 | 12.6 | 8.5 | 0.4 | 0 | 0 | 0 | 0 | 21.5 |
| 6 | 0 | 12.6 | 39.4 | 324.7 | 0 | 0 | 253.0 | -1095.8 | -466.2 |
| 7 | 0 | 1.8 | 1.1 | 68.6 | 0 | 0 | 11.1 | -47.9 | 34.6 |
| 1[a] | 10 | 16.3 | 22.4 | 11.4 | 0 | 0 | 237.7 | -1030.0 | -731.9 |
| 1[b] | 99.8 | 34.3 | 89.5 | 42.4 | 0 | 0 | 743.1 | -3219.0 | -2210.0 |
| 1[c] | 4.9 | 21.6 | 8.6 | 146.9 | 0 | 0 | 202.4 | -876.7 | -492.3 |

| 1984 Basin | a | b | c | d | e | f | g | | Net Yields |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 115.8 | 62.8 | 19.0 | 0 | 0 | 0 | 1500.0 | -6297.2 | -4600.0 |
| 2 | 25.2 | 51.8 | 9.1 | 0 | 0 | 0 | 798.9 | -3354.8 | -2469.8 |
| 3 | 22.7 | 3.1 | 2.9 | 0 | 0 | 0 | 772.9 | -3245.4 | -2443.8 |
| 4 | 0 | 4.7 | 0 | 0 | 0 | 0 | 238.5 | -1001.4 | -758.2 |
| 5 | 0 | 11.0 | 1.3 | 0 | 0 | 0 | 0 | 0 | 12.3 |
| 6 | 0 | 11.0 | 6.2 | 0 | 0 | 0 | 320.6 | -1346.4 | -1008.6 |
| 7 | 0 | 1.6 | 0.2 | 0 | 0 | 0 | 14.0 | -58.9 | -43.1 |
| 1[a] | 10.1 | 14.1 | 3.5 | 0 | 0 | 0 | 301.3 | -1265.1 | -936.1 |
| 1[b] | 100.7 | 29.8 | 14.1 | 0 | 0 | 0 | 941.9 | -3955.1 | -2868.6 |
| 1[c] | 5.0 | 18.9 | 1.4 | 0 | 0 | 0 | 256.5 | -1077.1 | -795.3 |

TABLE 4.5 CONTINUED

Water Storage Categories (mm.)

| 1985 Basin | 2 a | 13 b | 50 c | 100 d | 150 e | 250 f | Wetland (g) Winter | Summer | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 104.3 | 549.2 | 95.1 | 458.0 | 29.0 | 0 | 1466.0 | -5298.2 | -2596.6 |
| 2 | 22.7 | 45.3 | 45.4 | 64.0 | 28.7 | 0 | 781.0 | -2822.6 | -1835.5 |
| 3 | 20.4 | 2.7 | 14.3 | 66.5 | 13.6 | 0 | 755.5 | -2730.5 | -1857.5 |
| 4 | 0 | 4.1 | 0 | 0 | 318.2 | 0 | 233.1 | -842.5 | -287.1 |
| 5 | 0 | 9.6 | 6.7 | 0.8 | 0 | 0 | 0 | 0 | 17.1 |
| 6 | 0 | 9.6 | 31.2 | 741.0 | 21.9 | 0 | 313.4 | -1132.8 | -802.3 |
| 7 | 0 | 1.4 | 0.8 | 156.6 | 14.7 | 0 | 13.7 | -49.6 | 137.7 |
| 1[a] | 9.1 | 12.4 | 17.7 | 26.1 | 13.6 | 0 | 294.5 | -1064.4 | -691.0 |
| 1[b] | 90.7 | 26.1 | 70.7 | 96.8 | 0 | 0 | 920.7 | -3327.6 | -2122.6 |
| 1[c] | 4.5 | 16.4 | 6.7 | 335.1 | 15.4 | 0 | 250.8 | -906.2 | -277.4 |

| 1986 Basin | a | b | c | d | e | f | g | | Net Yields |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 148.4 | 85.8 | 121.0 | 138.7 | 0 | 0 | 1677.0 | -3288.9 | -1118.0 |
| 2 | 32.3 | 70.8 | 57.8 | 19.4 | 0 | 0 | 893.4 | -1852.1 | -678.4 |
| 3 | 29.0 | 4.3 | 18.2 | 20.1 | 0 | 0 | 864.3 | -1695.0 | -759.1 |
| 4 | 0 | 6.4 | 0 | 0 | 0 | 0 | 266.7 | -523.0 | -249.9 |
| 5 | 0 | 15.0 | 8.6 | 0.3 | 0 | 0 | 0 | 0 | 23.9 |
| 6 | 0 | 15.0 | 39.6 | 224.4 | 0 | 0 | 358.6 | -703.2 | -65.6 |
| 7 | 0 | 2.1 | 1.1 | 47.4 | 0 | 0 | 15.7 | -30.8 | 35.5 |
| 1[a] | 12.9 | 19.3 | 22.5 | 7.9 | 0 | 0 | 336.9 | -660.7 | -261.2 |
| 1[b] | 129.0 | 40.7 | 90.0 | 29.3 | 0 | 0 | 1053.3 | -2065.7 | -723.4 |
| 1[c] | 6.5 | 25.7 | 8.6 | 101.5 | 0 | 0 | 286.8 | -562.6 | -133.4 |

Source: Calculations by Author Using the Monthly Data Record and Thornthwaite Procedures for Calculating the Water Balance

TABLE 4.6.1

**Areas Covered by the Moisture Storage Categories Within the Different Drainage Basins of Elk Island National Park**
**Km 2**

| | Drainage Areas Within the Park | | | | | Drainage Areas With Flow Into The Park | | Subbasins of Basin 1 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Water Storage Values mm. | 1 | 2 | 3 | 4 | 5 | 6(1d) | 7(1c) | 1(a) | 1(b) | 1(c) |
| a (2) | 0.46 | 0.10 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.40 | 0.02 |
| b (13) | 0.40 | 0.33 | 0.02 | 0.03 | 0.07 | 0.07 | 0.01 | 0.09 | 0.19 | 0.12 |
| c (50) | 1.13 | 0.54 | 0.17 | 0.00 | 0.08 | 0.37 | 0.01 | 0.21 | 0.84 | 0.08 |
| d (100) | 5.44 | 0.76 | 0.79 | 0.00 | 0.01 | 8.80 | 1.86 | 0.31 | 1.15 | 3.98 |
| e (150) | 0.77 | 0.76 | 0.36 | 8.44 | 0.00 | 0.58 | 0.39 | 0.36 | 0.00 | 0.41 |
| f (250) | 77.15 | 23.02 | 24.81 | 2.02 | 0.86 | 22.27 | 0.93 | 11.58 | 42.00 | 23.57 |
| g Wetland | 22.45 | 11.96 | 11.57 | 3.57 | 0.00 | 4.80 | 0.21 | 4.51 | 14.10 | 3.84 |
| Total | 107.80 | 37.47 | 37.81 | 14.06 | 1.02 | 36.89 | 3.41 | 17.10 | 59.68 | 31.02 |

Source: Areas Computed by Author

TABLE 4.6.2

## PERCENTAGES OF AREA COVERED BY THE MOISTURE STORAGE CATEGORIES WITHIN THE DIFFERENT BASINS OF ELK ISLAND NATIONAL PARK

| Water Storage Values mm. | Drainage Areas Within the Park (%) 1 | 2 | 3 | 4 | 5 | Park Total | Drainage Areas With Flow into the Park (%) 6 (1d) | 7 (1e) | Subbasins of Basin 1 (%) 1(a) | 1(b) | 1(c) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| a (2) | 0.43 | 0.27 | 0.24 | 0.00 | 0.00 | .3 | 0.00 | 0.00 | 0.23 | 0.68 | 0.06 |
| b (13) | 0.37 | 0.88 | 0.05 | 0.21 | 6.86 | .4 | 0.19 | 0.29 | 0.53 | 0.32 | 0.37 |
| c (50) | 1.05 | 1.44 | 0.45 | 0.00 | 7.84 | 1.0 | 1.00 | 0.29 | 1.23 | 1.43 | 0.25 |
| d (100) | 5.05 | 2.03 | 2.10 | 0.00 | 0.98 | 3.6 | 23.85 | 54.55 | 1.81 | 1.96 | 12.43 |
| e (150) | 0.71 | 2.03 | 0.95 | 60.03 | 0.00 | 5.2 | 1.57 | 11.44 | 2.11 | 0.00 | 1.28 |
| f (250) | 71.57 | 61.44 | 65.62 | 14.37 | 84.31 | 64.5 | 60.37 | 27.27 | 67.72 | 71.57 | 73.61 |
| g Wetland | 20.82 | 31.91 | 30.59 | 25.39 | 0.00 | 25.0 | 13.01 | 6.16 | 26.38 | 24.08 | 11.99 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Source: Areas Computed by Author

basin 4, with an average of 54.9 percent of the Park and surrounding area being covered by forest. During a dry yearsuch as 1984 it is apparent that virtually all of the small yield came from those small areas with low water storage categories (Table 4.5). The net losses from the wetland areas was 33.5 times greater than the yields resulting in major water level drops.

The first basin has been sub-divided into five subbasins, three within the Park and two outside (Fig. 4.4). The intent of dividing the first basin into three subbasins within the Park was to illustrate the differences in yield. It is evident that subbasin 1c is the area where a positive net yield is most likely to occur (Table 4.5). For example, in 1980 this subbasin produced a positive net yield while the other two subbasins (1a, 1b) during this year incurred water losses. The major explanation for the previous yield difference stems from the lands covered by wetlands, water bodies, and the 100 mm storage category. The wetlands and waterbodies cover only 12 percent of subbasin 1c, while the area covered by them in subbasins 1a, 1b, is 26 percent and 24 percent respectively. The higher the percentage of wetlands and waterbodies covering a basin, the greater the water losses within that basin. The areas with 100mm storage capacity is 12 percent in 1c, and only 2 percent in subbasins 1a and 1b (Table 4.6.2). The yields produced in a basin will rise with increasing percentages of area with a lower water storage category such as 100 mm. From the data in table 4.4 it is apparent that subbasin 1b has the highest unit area yields and the largest water losses among the three subbasins. The large water losses are caused by 24 percent of the areas being covered by wetlands, which includes Flyingshot and Walter Lakes (Fig. 4.4). The higher yields in subbasin 1b can be attributed to the lower water storage categories. The yields from subbasin 1a are the lowest among the three subbasins (Table 4.4). There are two primary reasons for the low recorded yield, the first of which is that 26 percent of the area is covered by wetlands, and secondly, 68 percent of the area is covered by the 250 mm moisture storage category. These two factors do not promote a high net yield in this subbasin.

There are two subbasins (1d, 1e) which are outside the Park boundary but are included in the calculations because their surpluses pass into the Park (Fig. 4.4). From table 4.5 it is evident that the two subbasins have multiple years with positive yields. This is in part due to the relatively small area covered by wetlands, 13 percent and 6 percent respectively. Pastures and crop land (100 mm storage capacity) are common in these two subbasins, (24 percent and 55 percent of area) and result in large yields when surpluses occur in the 100 mm category. The yields from the 100 mm moisture storage category are usually larger than the water losses of the marshes and water bodies resulting in the positive yearly yields within these two basins.

The yields from the two subbasins outside the Park in certain years partly balance the water losses produced in the adjacent subbasins within the Park. For example, in 1979 subbasin 1a had a water loss of 337.7 $Dm^3$ while subbasin 1e had a net yield of 175.1 $Dm^3$ (Table 4.5). It is not known how much, but some of this yield should make its way into subbasin 1a due to the slope of the terrain.

#### 4.4.1 YIELD MANAGEMENT

In the dry ~~years such as~~ 1971, 1975-77, and 1984 there were few surpluses within the Park. The surpluses which were present were derived from the low water storage categories (2, 13 mm). These low water storage categories are characterized by paved and gravelled surfaces. The yields in table 4.5 illustrate the importance of the low water storage categories to the total yield from the land surfaces. For example, in 1971 in basin one, 124.8 $Dm^3$ was the recorded yield for the 2 mm moisture storage category with an area of .46 $Km^2$, and 265.5 $Dm^3$ was the recorded yield for the 100 mm moisture storage category with and area of 5.44 $Km^2$. The 100 mm moisture storage category produced only twice as much yield as the 2 mm category, yet it is 11.8 times as large (Table 4.6.1).

In 1984, half of the land surpluses came from the 2 mm. moisture storage category which had an area one-fifth the size of the other two categories (13, 50 mm) which produced yields. The author is not recommending the Park be paved over, only that more management of the lower categories to maximize the present yields for potential flow into lakes be exercised. This type of management could involve the paving and proper levelling of gravel parking lots to increase and direct the runoff to a desired area. To accompany such a project, proper channelling to accommodate the increased runoff should be planned, and when built, properly maintained.

Other factors to consider in the management of water yields include the thinning and clearing of brush. This would have the function of reducing the moisture storage utilization of those areas. A reduction of the moisture storage capacity would increase surpluses and therefore increase yields.

In the management of water yields, another factor to consider includes the clearing of channels and reduction of water-filled depressions. The clearing of a channel would involve the removal of obstructive vegetation in the channel, the improvement of the ditches, and clearance of culverts to promote the flow of water and reduce ponding. The reduction of water-filled depressions might only involve the clearance of a channel or it might involve the digging of a new channel to drain a water-filled depression.

A factor which Environment Canada, Parks is not able to control is the summer fallowing of fields adjacent to Elk Island National Park. The fallowing of fields in effect reduces the moisture storage capacity of the field from 100 to 50 mm which causes greater surpluses. These surpluses at present collect in the ditches to evaporate, or flow into the local marshes within the Park. These are local imbalances relative to the natural setting, and nothing has been done within the Park to compensate for these wetter than normal conditions. It is possible that these surpluses, and those of the wetter years in the receiving areas might be diverted to Astotin Lake or other water bodies that might be improved in quality and better stabilized levels by the additional inflow and flow-through. The selection of possible areas for the collection of the spring runoff from these areas is certainly a possible method by which water could be collected and transported to needed areas a short distance away. It is apparent that the limited yields of the upland areas are evaporated from the large lakes and marsh areas within most basins in most years. If, with limited and controlled drainage, the ratios were to be changed, there could be improvement in water supplies in the remaining lakes and marshes. Park policies would probably preclude any substantial drainage development, but wet areas in and near parking, playground, golf courses, and administration areas could be reduced by better surface and tile drainage. This type of selection is however beyond the scope of this study.

### 4.4.2 POSSIBLE YIELD DATA CORRECTIONS

The Thornthwaite procedure is a calculation of the water balance based on the relationship of potential evapotranspiration and precipitation. The precipitation in the Thornthwaite procedure is assumed to be rain. This fact can create errors in the water balance procedure in such climates as that of Elk Island National Park, where up to half of the yearly precipitation may fall as snow. In the measurement of snow using the Nipher gauge such as the one used at the Edmonton International Airport it is likely that the total snow fall will not be measured. The biggest problem with snow gauges is that the snow catch is less than the actual snowfall. This is caused primarily by the gauge disturbing the wind flow around the gauge which creates vertical air currents over the gauge orifice. The vertical air currents serve to prevent some of the snowfall from being caught (Ferguson and Pollock, 1971). Ferguson and Pollock (1971) in comparisons of simultaneous snow ruler and Nipher gauge measurements across Canada found that the Nipher gauge had an average undercatch of 16 percent. In Alberta, using data from 200 stations, Ferguson and Pollock estimated the average undercatch by the Nipher gauge is 23 percent. The total correction over the U.S.S.R. according to Bochkof and Struzer(1970) ranges from 10 percent to 50 percent. The correction was found to be most attributable to wind-effect error in the measurement of snow. For winds up to 5.5 m/s, Goodison (1978a) suggested that the catch of the Nipher Gauge is within 10 percent of the true amount. Studies such as that by Hare and Hay (1971) would indicate that the most likely source of error in precipitation measurement is in the measurement of snowfall. A low wind speed according to Goodison (1978a) could result in an overcatch in the Nipher Gauge. An overcatch could result if hard snow particles bounce off the rim and into the collector. Snow could also collect on the rim at low wind speeds and be subsequently blown into the collector by a gust of wind. At temperatures near 0°C wet snow has been observed by Goodison (1978a) to build up on the snow collector thus making the measurement difficult.

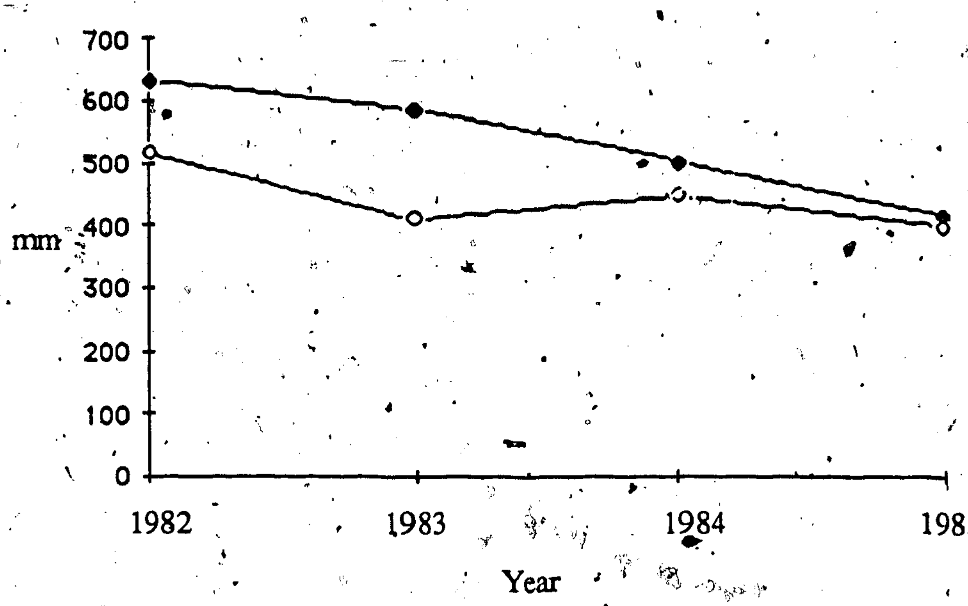
Other corrections to the Nipher Gauge are possible to overcome undercatch. Trace amounts of snowfall are not measured or included in the snowfall record. A trace is a water equivalent total, which is less than .20 mm. In field observations, Goodison (1978b) concluded that over 80 percent of all observations of precipitation were trace amounts. Goodison (1978b) deduced that if all trace amounts equalled .07 mm the total measured Nipher water equivalent would have been 39 percent greater.

Two other possible reasons for the undercatch of rain and snow include losses by evaporation which during the summer amounts to 6 percent of the total precipitation (Sokolov, and Chapman, 1974). The contents of the Nipher Gauge are melted and measured as a water equivalent. The adhesion of the water droplets to the side of the collector results in the measured total being less than the actual total. Goodison, (1978a) estimated that the retention loss averaged .15 +/- .02 mm. The amount may seem insignificant, but if the Nipher Gauge is emptied frequently, the retention loss could amount to a significant factor (Goodison, 1978a) A correction factor could be added to the collected data, but it is felt that the data base present in this thesis is not extensive enough to suggest one.

Elk Island National Park is situated 30 to 60 meters above the surrounding plain, which includes the Edmonton International Airport. It is possible that the elevation difference between the Park and the surrounding plain could promote an orographic effect, which could result in higher precipitation levels in the Park. Two similar situations have been reported, the first by Wiche (1977), in the Fort McMurray area where an elevation difference of 400 m between two stations resulted in a greater precipitation accumulation at the higher station. Hallock (1976) in a thesis focusing on the Gregoire Lake Basin near Fort McMurray found an elevation difference of 112 m over 24 km between weather stations at Fort McMurray and Anzac. Over the long term record, Anzac recorded on average 9.4 cm more precipitation than Fort McMurray. Hallock (1976) concluded that the increase in precipitation was due to a local orographic effect.

In figure 4.5, it is evident that Elk Island National Park received more precipitation during the course of four years than did the Edmonton International Airport. The length of record for the Park does not permit any conclusions to be made, however, it does allow the writer to speculate on the potential differences in yields and water losses between the International Airport and Elk Island National Park data.

The Elk Island National Park water balances were used to determine the surpluses, yields, and water losses for the period 1982-1985 (Tables 4.7, 4.8, App. IV). The procedure to determine these values was the same as that used to determine the Edmonton International Airport surpluses, yields, and water loss values. It is apparent from table 4.9 that larger yields and smaller water losses were produced when using Elk Island National Park weather data in place of the Edmonton International Airport data. The probable cause




Legend

-◆- Elk Island National Park Precipitation Levels

-○- Edmonton International Airport Precipitation Levels

**A Comparison of Precipitation Amounts Between Elk Island National Park and Edmonton International Airport (1982-1985)**

Figure 4.5

TABLE 4.7

**Calculated Surpluses in the Different Water Storage Categories Using Monthly Data from Elk Island National Park April-October(S)November-March (W)**

Water Storage Categories (mm.)

| | | PE | Ppt. | 2<br>a | 13<br>b | 50<br>c | 100<br>d | 150<br>e | 250<br>f | Wetland<br>g |
|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | W | 0 | 135.0 | 135.0 | 129.9 | 92.9 | 42.9 | 0 | 0 | 135.0 |
| | S | 499.1 | 490.7 | 162.5 | 151.5 | 114.5 | 64.5 | 38.4 | 0 | -8.4 |
| | T | 499.1 | 625.7 | 297.5 | 281.4 | 207.4 | 107.4 | 38.4 | 0 | 126.6 |
| 1983 | W | 0 | 75.0 | 73.0 | 62.0 | 25.0 | 21.1 | 21.1 | 0 | 75.0 |
| | S | 524.8 | 502.6 | 195.4 | 184.4 | 147.4 | 108.6 | 108.6 | 0 | -22.2 |
| | T | 524.8 | 577.6 | 268.4 | 246.4 | 172.4 | 129.7 | 129.7 | 0 | 52.8 |
| 1984 | W | 0 | 65.7 | 63.7 | 52.7 | 15.7 | 0 | 0 | 0 | 65.7 |
| | S | 520.8 | 430.8 | 120.4 | 101.0 | 64.0 | 14.0 | 0 | 0 | -149.6 |
| | T | 520.8 | 496.5 | 184.1 | 153.7 | 79.7 | 14.0 | 0 | 0 | -83.9 |
| | | | | | | | | | 0 | |
| 1985 | W | 0 | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | 21.5 | 0 | 57.5 |
| | S | 516.7 | 342.7 | 32.0 | 21.0 | 11.1 | 11.1 | 11.1 | 0 | -203.0 |
| | T | 516.7 | 400.2 | 89.5 | 78.5 | 68.6 | 68.6 | 32.6 | 0 | -145.5 |

Source: Calculations by Author Using the Monthly Meteorological Record from Elk Island National Park

TABLE 4.8

**Water Yields of the Seven Drainage Basins and Three Subbasins of Basin of Elk Island National Park Using the Parks Monthly Meteorological Record**
Hectare Decimeters (Cubic Decameters)

Water Storage Categories (mm.)

| 1982 | 2 | 13 | 50 | 100 | 150 | 250 | Wetland (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| Basins | a | b | c | d | e | f | Winter | Summer | Net Yield |
| 1 | 137.0 | 112.6 | 234.4 | 584.3 | 29.6 | 0 | 3030.8 | -188.6 | 3940.0 |
| 2 | 29.8 | 92.9 | 112.0 | 81.6 | 29.2 | 0 | 1614.6 | -100.5 | 1859.6 |
| 3 | 26.8 | 5.6 | 35.3 | 84.8 | 13.8 | 0 | 1562.0 | -97.2 | 1631.1 |
| 4 | 0 | 8.4 | 0 | 0 | 324.1 | 0 | 482.0 | -30.0 | 784.5 |
| 5 | 0 | 19.7 | 16.6 | 1.1 | 0 | 0 | 0 | 0 | 37.4 |
| 6 | 0 | 19.7 | 76.7 | 945.1 | 22.3 | 0 | 648.0 | -40.3 | 1671.5 |
| 7 | 0 | 2.8 | 2.1 | 199.8 | 15.0 | 0 | 28.4 | -1.8 | 246.0 |
| 1[a] | 11.9 | 25.4 | 43.6 | 33.3 | 13.8 | 0 | 608.9 | -37.9 | 699.0 |
| 1[b] | 119.0 | 53.5 | 174.2 | 123.5 | 0 | 0 | 1903.5 | -118.4 | 2255.3 |
| 1[c] | 6.0 | 33.8 | 16.6 | 427.5 | 15.7 | 0 | 518.4 | -32.3 | 985.7 |

| 1983 Basins | a | b | c | d | e | f | g | | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 124.0 | 98.6 | 194.8 | 705.6 | 99.9 | 5253.9 | 1683.8 | -498.4 | 7661.7 |
| 2 | 26.8 | 81.3 | 93.1 | 98.6 | 98.6 | 1567.7 | 897.0 | -265.5 | 2597.6 |
| 3 | 24.2 | 4.9 | 29.3 | 102.5 | 46.7 | 1689.6 | 867.8 | -256.9 | 2508.1 |
| 4 | 0 | 7.4 | 0 | 0 | 1094.7 | 137.6 | 267.8 | -79.3 | 1428.2 |
| 5 | 0 | 17.2 | 13.8 | 1.3 | 0 | 58.6 | 0 | 0 | 90.9 |
| 6 | 0 | -17.2 | 63.8 | 1141.4 | 75.2 | 1516.6 | 360.0 | -106.6 | 3067.6 |
| 7 | 0 | 2.5 | 1.7 | 241.2 | 50.6 | 63.3 | 15.8 | -4.7 | 370.4 |
| 1[a] | 10.7 | 22.2 | 36.2 | 40.2 | 46.7 | 788.6 | 338.3 | -100.1 | 1182.8 |
| 1[b] | 107.0 | 46.8 | 144.8 | 149.2 | 0 | 2860.2 | 1057.5 | -313.0 | 4052.9 |
| 1[c] | 5.4 | 29.6 | 13.8 | 516.2 | 53.2 | 1605.1 | 288.0 | -85.2 | 2426.1 |

| 1984 Basins | a | b | c | d | e | f | g | | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 84.7 | 61.5 | 90.1 | 76.2 | 0 | 0 | 1475.0 | -3358.5 | -1571.0 |
| 2 | 18.4 | 50.7 | 43.0 | 10.6 | 0 | 0 | 785.8 | -1789.2 | -881.0 |
| 3 | 16.6 | 3.1 | 13.5 | 11.1 | 0 | 0 | 760.1 | -1730.9 | -926.5 |
| 4 | 0 | 4.6 | 0 | 0 | 0 | 0 | 234.5 | -534.1 | -295.0 |
| 5 | 0 | 10.8 | 6.4 | 0.1 | 0 | 0 | 0 | 0 | 17.3 |
| 6 | 0 | 10.8 | 29.5 | 123.2 | 0 | 0 | 315.4 | -718.1 | -239.2 |
| 7 | 0 | 1.5 | 0.8 | 16.4 | 0 | 0 | 13.8 | -31.4 | 1.1 |
| 1[a] | 7.4 | 13.8 | 16.7 | 4.3 | 0 | 0 | 296.3 | -674.7 | -336.2 |
| 1[b] | 73.6 | 29.2 | 66.9 | 16.1 | 0 | 0 | 926.4 | -2109.4 | -997.2 |
| 1[c] | 3.7 | 18.4 | 6.4 | 55.7 | 0 | 0 | 252.3 | -574.5 | -238.0 |

TABLE 4.8 CONTINUED

Water Storage Categories (mm.)

| 1985 Basins | 2 a | 13 b | 50 c | 100 d | 150 e | 250 f | Wetland (g) Winter | Summer | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 41.2 | 31.4 | 77.5 | 373.2 | 25.1 | 0 | 1290.9 | -4557.4 | -2718.1 |
| 2 | 9.0 | 25.9 | 37.0 | 52.1 | 24.8 | 0 | 687.7 | -2427.9 | -1591.4 |
| 3 | 8.1 | 1.6 | 11.7 | 54.2 | 11.7 | 0 | 665.3 | -2348.7 | -1596.1 |
| 4 | 0 | 2.4 | 0 | 0 | 275.1 | 0 | 205.3 | -724.7 | -241.9 |
| 5 | 0 | 5.5 | 5.5 | 0.7 | 0 | 0 | 0 | 0 | 11.7 |
| 6 | 0 | 5.5 | 25.4 | 603.7 | 18.9 | 0 | 276.0 | -974.4 | -44.9 |
| 7 | 0 | 0.8 | 0.7 | 127.6 | 12.7 | 0 | 12.1 | -42.6 | 111.3 |
| 1[a] | 3.6 | 7.1 | 14.4 | 21.3 | 11.7 | 0 | 259.3 | -915.5 | -598.1 |
| 1[b] | 35.8 | 14.9 | 57.6 | 78.9 | 0 | 0 | 810.8 | -2862.3 | -1864.3 |
| 1[c] | 1.8 | 9.4 | 5.5 | 273.0 | 13.4 | 0 | 220.8 | -779.5 | -255.6 |

Source: Calculations by Author Using the Elk Island National Park Monthly Meteorological Data

TABLE 4.9

**A Comparison of Yield Totals for Data from Elk Island National Park and Edmonton International Airport**

**1982-1985**

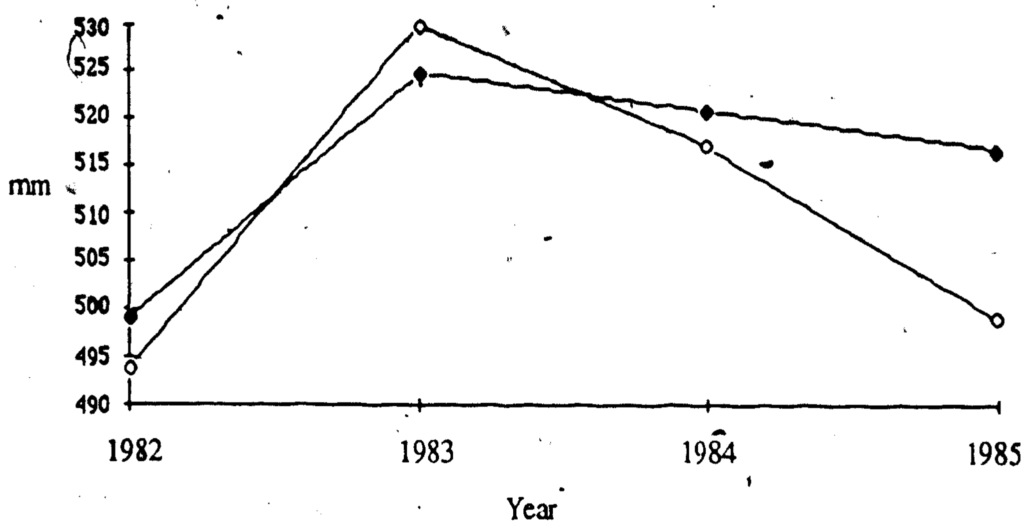
(Cubic Decameters)

| | Drainage Areas Within the Park | | | | | Drainage Areas With Flow into The Park | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 (1d) | 7 (1e) | Total |
| Area (Km 2) | 107.8 | 37.47 | 37.81 | 14.06 | 1.02 | 36.89 | 3.41 | 238.46 |
| (hectares) | 10780 | 3747 | 3781 | 1406 | 102 | 3689 | 341 | 23846 |
| **Using Elk Island National Park Meteorological Data -Monthly Data - January-December** | | | | | | | | |
| 1982 | 3940.0 | 1859.6 | 1631.1 | 784.5 | 37.4 | 1671.5 | 246.5 | 10170.6 |
| 1983 | 7661.7 | 2597.6 | 2508.1 | 1428.2 | 90.9 | 3067.6 | 370.4 | 17724.5 |
| 1984 | -1571.0 | -881.0 | -926.0 | -295.0 | 17.3 | -239.2 | 1.1 | -3893.8 |
| 1985 | -2718.1 | -1591.4 | -1596.1 | -241.9 | 11.7 | -44.9 | 111.3 | -6069.4 |
| **Using Edmonton International Airport Meteorological Data -Daily Data for April-October, Monthly Data for November-March-** | | | | | | | | |
| 1982 | 551.9 | 171.1 | 103.7 | 84.8 | 34.2 | 472.4 | 95.9 | 1494.1 |
| 1983 | -3434.2 | -1930.1 | -1958.4 | -621.5 | 21.5 | -466.2 | 34.6 | -8354.3 |
| 1984 | -4600.0 | -2469.8 | -2443.8 | -758.2 | 12.3 | -1009.0 | -43.1 | -11311.0 |
| 1985 | -2596.6 | -1835.5 | -1857.5 | -287.1 | 17.1 | -802.3 | 137.7 | -7224.2 |

Source: Calculations by Author Using Monthly Meteorological Data of this result is due to the 20 percent higher yearly precipitation levels at the Park rather than any difference in potential evapotranspiration (Fig. 4.6).

In comparing Elk Island National Park and Edmonton International Airport precipitation levels, it is apparent that the Park received over the 4 years of study an average of 20 percent more precipitation than the Airport station. The differences in recorded precipitation in 2 of the 4 years was substantial, while in the other 2 years, only minor differences were recorded. The length of the data record is not sufficient to conclude which patterns are typical. Precipitation levels during a dry year such as 1971, and a wet year such as 1973 were increased by 20 percent to determine what effect increased precipitation levels would have on surpluses and yields. The altered surpluses in table 4.10 when compared to surpluses in table 4.1 were found to be on average 1.7 times greater. In the determination of yields during a dry year, a 20 percent increase in precipitation resulted in a 50 percent reduction in total water loss (Table 4.11). During a wet year the yields increased by as much as 2.7 times when the precipitation is increased by 20 percent. The 20 percent increase in precipitation is intended by the writer to represent an approximation for the purposes of discussion and not a stringent measure of precipitation differences between the two stations.

The size of each water storage category is not a constant, but is in a state of constant change. The major category of concern which could affect the potential yield in a given year is the wetland category. This category during a dry year would shrink and during a wet year would expand. During a series of dry years the marshes and water bodies could decrease in surface area by as much as 20 percent (Laycock, 1986). This 20 percent called a drawdown zone by Zoltai (1983) would consist of mudflats and matted vegetation. The drawdown zone would therefore be allocated to a number of water storage categories. A decrease in the surface area of the marshes and water bodies would increase the yields within the remainder of the park.




Legend

-●- Elk Island National Park Potential Evapotranspiration

-○- Edmonton International Airport Potential Evapotranspiration

**A Comparison of Potential Evapotranspiration Amounts Between Elk Island National Park and Edmonton International Airport 1982-1985**

Figure 4.6

TABLE 4.10

**Example of the Effect on Surpluses Calculated from Edmonton International Airport when Precipitation is Increased by 20 Percent Daily Data- April-October(S), November - March (W)**

| | | | | Water Storage Categories (mm.) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2 | 13 | 50 | 100 | 150 | 250 | Wetland |
| | | PE | Ppt. | a | b | c | d | e | f | g |
| 1971 | W | 0 | 148.1 | 148.1 | 148.1 | 126.5 | 75.9 | 25.1 | 0 | 148.1 |
| | S | 531.6 | 317.4 | 195.5 | 113.1 | 27.4 | 0 | 0 | 0 | -264.8 |
| | T | 531.6 | 465.5 | 343.6 | 261.2 | 153.9 | 75.9 | 25.1 | 0 | -116.7 |
| 1973 | W | 0 | 90.2 | 88.2 | 75.3 | 30.5 | 5.1 | 0 | 0 | 90.2 |
| | S | 516.0 | 596.9 | 407.7 | 276.3 | 109.9 | 91.8 | 70.3 | 0 | 80.9 |
| | T | 516.0 | 687.1 | 495.9 | 351.6 | 140.4 | 96.9 | 70.3 | 0 | 171.1 |

Source: Calculations by Author Using the Monthly Meteorological Record for Edmonton International Airport

TABLE 4.11

**Water Yields of Surpluses Increased by 20 Percent Within the Seven Drainage Basins and Three Subbasins of Basin One in Elk Island National Park**

Hectare Decimeters (Cubic Decameters)

Water Storage Categories (mm.)

| 1971 Basins | 2 a | 13 b | 50 c | 100 d | 150 e | 250 f | Wetland (g) Winter | Wetland (g) Summer | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 158.1 | 104.5 | 173.9 | 412.9 | 19.3 | 0 | 3324.8 | -5944.8 | -1751.3 |
| 2 | 34.4 | 86.2 | 83.1 | 57.7 | 19.1 | 0 | 1771.2 | -3167.0 | -1115.3 |
| 3 | 30.9 | 5.2 | 26.1 | 60.0 | 9.0 | 0 | 1713.5 | -3063.7 | -1219.0 |
| 4 | 0 | 7.8 | 0 | 0 | 211.8 | 0 | 528.7 | -945.3 | -197.0 |
| 5 | 0 | 18.3 | 12.3 | 0.8 | 0 | [illegible] | 0 | 0 | 31.4 |
| 6 | 0 | 18.3 | 56.9 | 667.9 | 14.6 | 0 | 710.9 | -1271.0 | 197.6 |
| 7 | 0 | 2.6 | 1.5 | 141.2 | 9.8 | 0 | 31.1 | -55.6 | 130.6 |
| 1[a] | 13.7 | 23.5 | 32.3 | 23.5 | 9.0 | 0 | 667.9 | -1194.2 | -424.3 |
| 1[b] | 137.4 | 49.6 | 129.3 | 87.3 | 0 | 0 | 2088.2 | -3733.7 | -1241.9 |
| 1[c] | 6.9 | 31.3 | 12.3 | 302.1 | 10.3 | 0 | 568.7 | -1016.8 | -85.2 |

| 1973 Basins | a | b | c | d | e | f | g | | Net Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 228.1 | 141.0 | 158.7 | 527.1 | 54.1 | 0 | 2025.0 | 1816.2 | 4950.2 |
| 2 | 50.0 | 116.3 | 75.8 | 73.6 | 53.4 | 0 | 1078.8 | 967.6 | 2415.5 |
| 3 | 44.6 | 7.1 | 23.9 | 76.6 | 25.3 | 0 | 1043.6 | 936.0 | 2157.1 |
| 4 | 0 | 10.6 | 0 | 0 | 593.3 | 0 | 322 | 288.8 | 1214.7 |
| 5 | 0 | 24.7 | 11.2 | 1.0 | 0 | 0 | 0 | 0 | 36.9 |
| 6 | 0 | 24.7 | 51.9 | 852.7 | 40.8 | 0 | 433.0 | 388.3 | 1791.4 |
| 7 | 0 | 3.5 | 1.4 | 180.2 | 27.4 | 0 | 18.9 | 17.0 | 248.4 |
| 1[a] | 19.8 | 31.7 | 29.5 | 30.0 | 25.3 | 0 | 406.8 | 364.9 | 908.0 |
| 1[b] | 198.4 | 67.0 | 117.9 | 111.4 | 0 | 0 | 1271.8 | 1140.7 | 2907.2 |
| 1[c] | 9.9 | 42.3 | 11.2 | 385.7 | 28.8 | 0 | 346.4 | 310.7 | 1135.0 |

Source: Calculations by Author Using the Edmonton International Airport Meteorological Data in the Thornthwaite Procedure.

## 4.5 WATER BALANCE AND YIELD DATA AND LAKE LEVEL CHANGES

The lakes within Elk Island Park are fed primarily by precipitation on the lakes plus runoff from the areas surrounding them. The yield produced by the surrounding area of Elk Island National Park in any one year will have a direct impact on the lake levels within a particular drainage basin. The Park Wardens have conducted water level surveys at six lakes within Elk Island National Park. The measurement of the water level involves the recording of the lake levels on calibrated posts in the lakes. Within the Park, three of the five major basins have lakes with daily records. The four lakes for which records were kept are illustrated in figures 4.7 and 4.8. Only one lake from each basin was selected which resulted in the exclusion of Oster and Oxbow lakes from the this study.

A moderately high spring runoff in 1971 created a high spring water level within the Park (Figs.4.7, 4.8). The level dropped throughout the remainder of the summer due to high water losses (based on Edmonton International Airport Data Table 4.4). The water losses might not have been as large as those shown if precipitation data from the Park had been available. In both the 50 mm and 150 mm water balance diagrams, most of the summer was in a condition of either soil moisture utilization or deficit (Figs 4.7, 4.8). The following three years (1972-1974) could be classed as wet years and resulted in an overall rise in the lakes from previous levels. The unusually high lake levels in the spring of 1974 illustrated in figures 4.7 and 4.8 were a result of surplus conditions beginning in the fall and winter of 1973 in the 50 mm category and in January of 1974 in the 150 mm storage category. Among the four lakes, Astotin Lake experienced the most severe drop in level during the summers of 1973 and 1974. The severe drop in level was primarily a result of lake level regulation by the Park Wardens. At the northwest corner of Astotin Lake there is a weir which is normally closed but can be opened to allow water to escape. The values in table 4.4 indicate the Park had net yields during 1973 and 1974.

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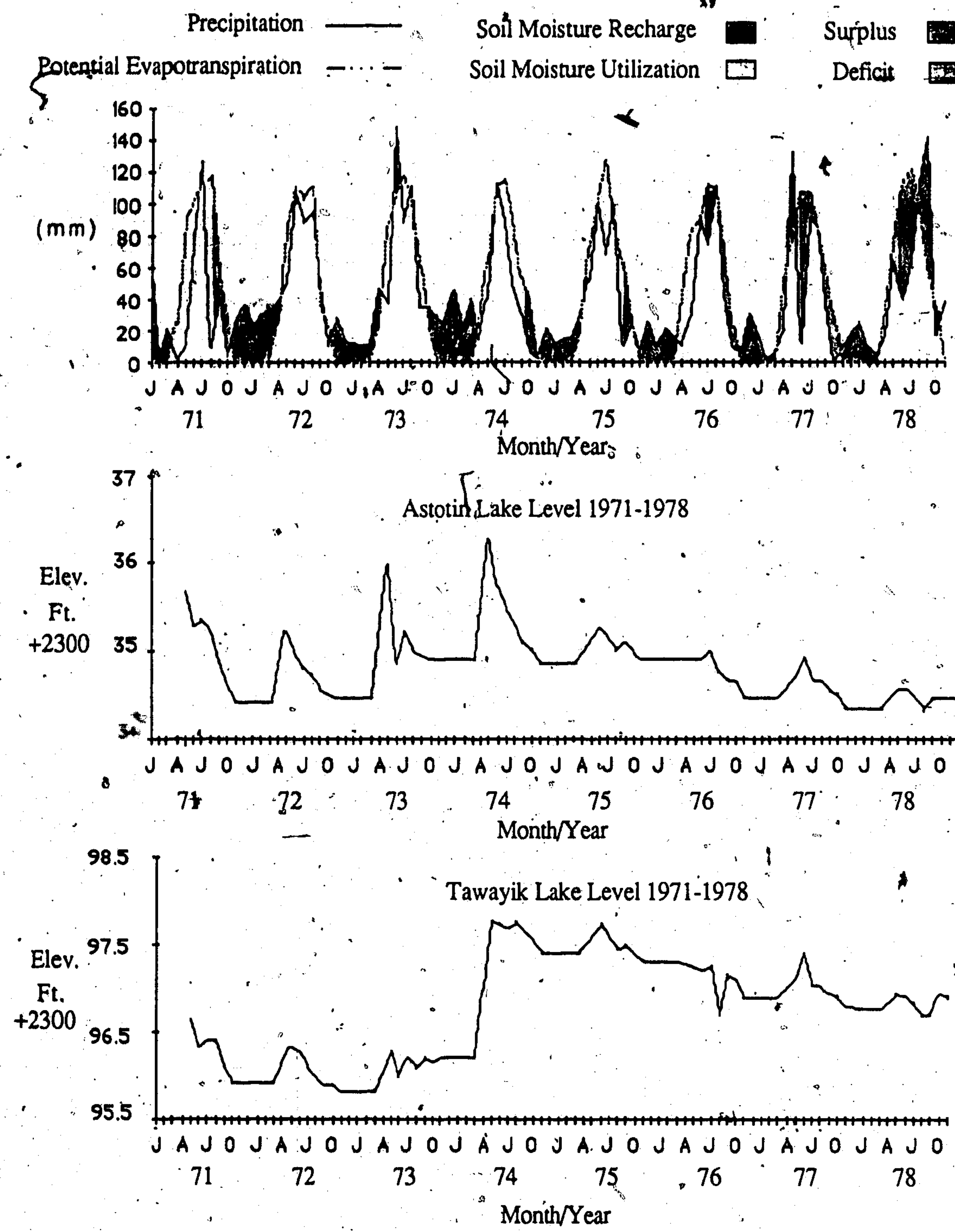
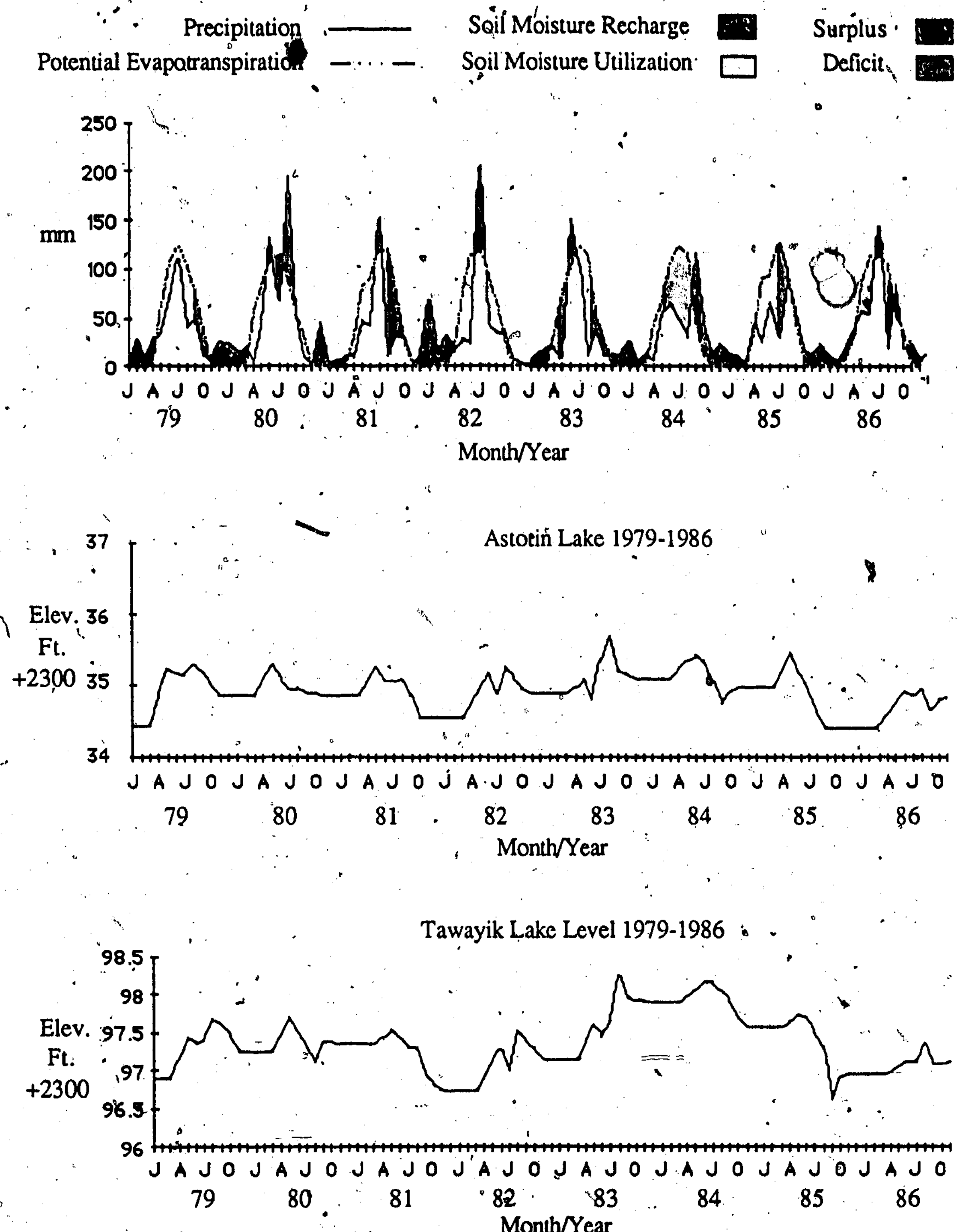


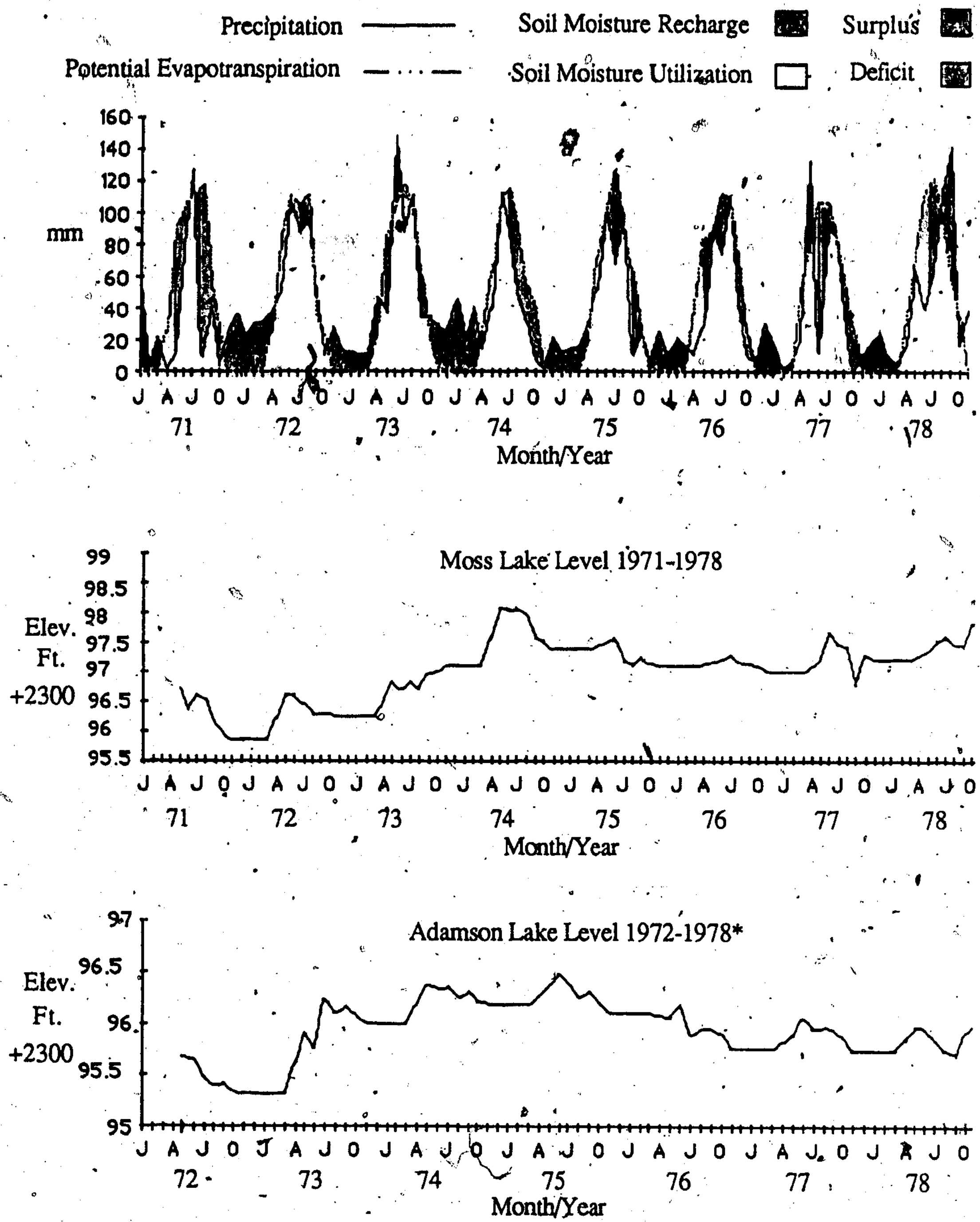

**A Comparison of the 150 mm Water Balance Diagrams and Lake Level Fluctuations 1971-1986**

Figure 4.7




Source: Water Balance Calculations by Author Using the Thornthwaite Procedure, and Lake Level Data from Elk Island National Park Records.

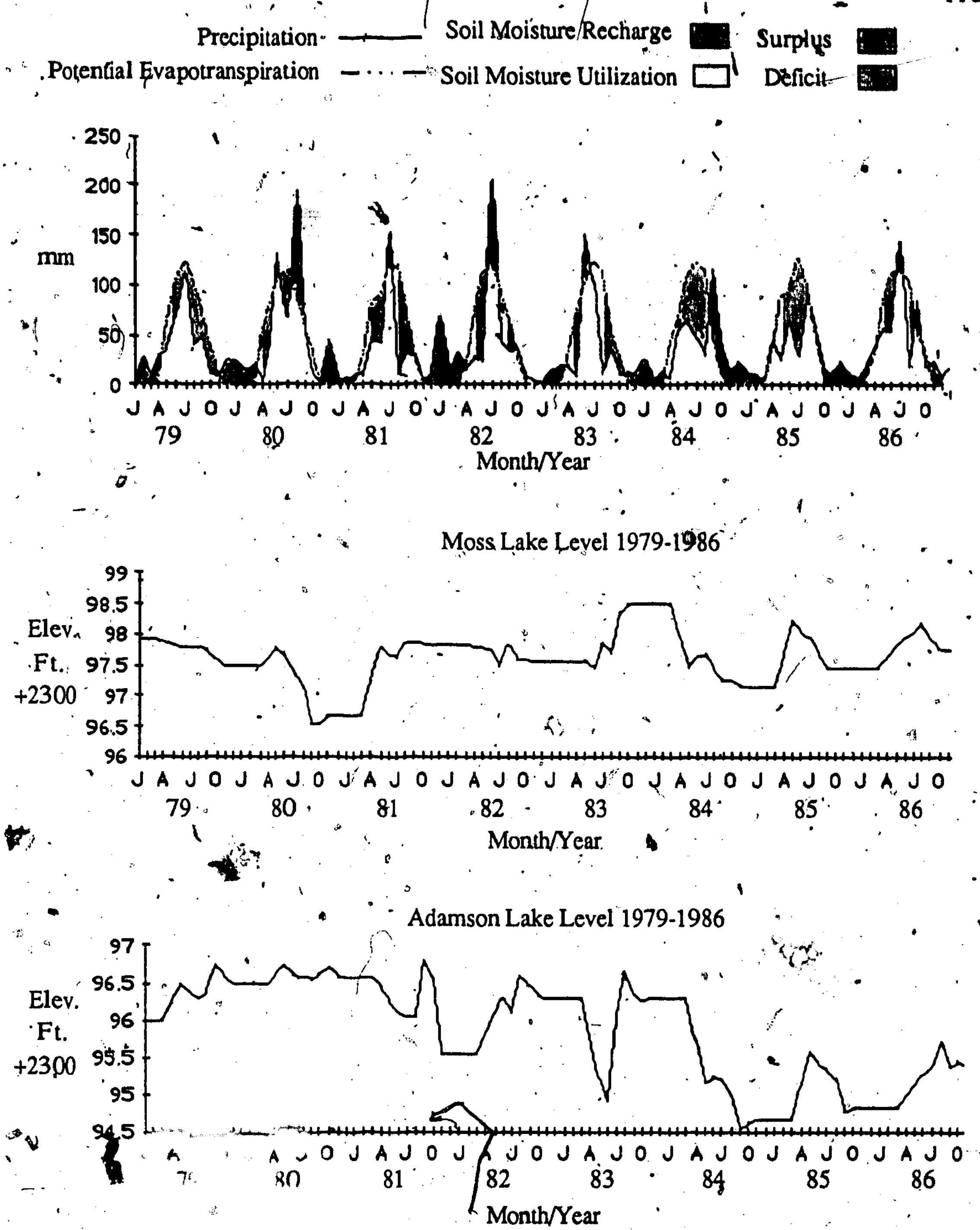
Figure 4.7 Continued




**A Comparison of the 50 mm Water Balance Diagrams and Lake Level Fluctuations 1971-1986**

*Note: Data were not available for Adamson Lake During 1971

Figure 4.8




Source: Water Balance Calculations by Author Using the Thornthwaite Procedure, and Lake Level Data from Elk Island National Park

Figure 4.8 Continued

The following years (1975-1978) were relatively dry years and experienced high overall water losses as illustrated in table 4.4. This is reflected in the decline of the lake levels illustrated in figures 4.7 and 4.8. Moisture storage utilization and deficit conditions reflected the dryness of the summers of 1975 and 1976. Exceptions to this occured in August of 1975 and July of 1976 when lake levels rose in all four lakes. The steep increase in precipitation in the months of August in 1975 and in July of 1976 indicates that storm events were partly the cause for the lake level increases (Figs. 4.6, 4.7).

In 1977 the four lakes rose considerably during the month of May (Figs 4.7, 4.8). High levels of precipitation during May created surpluses in the 50 mm moisture storage category, and provided recharge to the 150 mm moisture storage category. During the remainder of 1977, moisture storage utilization and deficit conditions occured as illustrated by the decline in the four lake levels (Figs. 4.7, 4.8).

Moisture storage utilization and deficit conditions occured during the first half of 1978 when potential evapotranspiration was greater than precipitation. The lake levels reflected these conditions with declines (Figs. 4.7, 4.8). Towards the latter part of the summer of 1978 precipitation exceeded PE resulting in soil moisture recharge in both storage levels, and surpluses in the 50 mm water balance diagram. In conjunction with the wet summer and fall, the lake levels rose (Figs. 4.7, 4.8). The surpluses created in the latter part of 1978 resulted in the high spring runoff of 1979 which raised the lake levels considerably from the previous year. The source for the second rise in lake levels in 1979 is unknown to the writer. The water balance diagram in figures 4.7 and 4.8 indicates only moisture storage utilization and deficit conditions during the entire summer. There is no indication in the daily or monthly water balances of major surpluses during August or September to cause such a rise (App. I ). A very heavy local storm event within the Park could possibly raise the lake levels considerably. However, no meteorological data are available from the Park to confirm this suggestion. There are other possibilities such as beavers and man which might have an effect on the level of a certain lake. There is no shortage of beavers in Elk Island Park which control the level of many of the sloughs through mud dams. There is a possibility that the beavers blocked off some or all of the lake outlet channels from the lakes to cause the level rise. Through discussion with Park Wardens, it is apparent that the beavers build their mud dams faster than the Wardens can destroy them. A second cause for a lake level increase would stem from mans clearing of the channel culverts. This would decrease the detention of water, and allow more runoff to occur into lakes downstream.

The summer of 1979 was moderately dry and this contributed to the lowering of the lake level from the spring value (Table 4.4). Unfortunately no record has been kept concerning channel clearing or the destruction of beaver dams.

Moisture storage utilization and deficit conditions during the early summer of 1980 resulted in lake level declines. A small yield was produced however within the Park during this year (Table 4.4). It was created by soil moisture recharge and surpluses in the 50 mm and 150 mm storage categories and precipitation upon the lake in the late summer which resulted in increases in lake levels to above the previous fall levels (Figs. 4.7, 4.8).

Large water losses within the Park were experienced during the years 1981-1985 as shown in table 4.4. In 1981 soil moisture utilization and deficits in the 50 mm and 150 mm water balance diagrams caused a lowering of the lake levels in the early summer (Figs. 4.7, 4.8). Precipitation exceeded the potential evapotranspiration in June of 1981 resulting in a halt in the decline of lake levels during that month. The high level of precipitation in June created an increase in the levels of Moss and Adamson lakes, and a levelling off of Astotin and Tawayik lakes. Moss and Adamson lakes are small compared to Astotin and Tawayik, and are therefore more likely to be affected by storm events in terms of rising lake levels.

The recharge and surpluses during the winter of 1981-1982 provided a large runoff in the spring of 1982, which served to increase the lake levels (Figs. 4.7, 4.8). The water balance diagrams indicate a dry spring which resulted in a drop in lake levels. During the month of July, precipitation exceeded PE which provided recharge and surpluses in the 50 mm and 150 mm storage categories. A rise in the level of all four lakes occured during this month (Figs. 4.7, 4.8).

There were only minor surpluses in the winter of 1983 which could account for the small rise in lake levels in the spring of 1983. During the months of June and July, precipitation surpassed PE which could explain the increases in levels among the lakes (App. IV). An above average water loss in 1984 resulted in a decline in the lake levels through the summer (Table 4.4, Figs. 4.7, 4.8). The surpluses in the fall of 1984 resulted in an early soil moisture recharge. This created a large spring runoff in 1985 when much of the winter snow was available for runoff. Surpluses occured during the spring of 1985 in the 150 mm. moisture storage category, which contributed to the rise in lake levels (App..III). The water balance diagrams in both the 50 and 150 mm categories indicate that soil moisture utilization and deficit conditions occured during the summer of 1985 which resulted in a large decline in the levels of all lakes. The Park experienced a large decline in moisture and water levels during this summer (Table 4.4).

Low levels of precipitation during the winter of 1985-1986 created surpluses in the 50 mm water balance diagram but not in the 150 mm water balance diagram. The dry conditions of the previous summer necessitated the full recharge of the water storage categories which resulted in the small or lack of surpluses. There was only a small spring runoff in 1986 which resulted in below average level increases (Figs. 4.7,4.8). Field investigations during the spring of 1986 revealed a very small spring runoff. During the month of July the precipitation exceeded the P.E. which created the level increases in the lakes illustrated in figures 4.7 and 4.8.

The water balance diagrams and lake level fluctuations in figures 4.7 and 4.8 indicate there is a close and direct relationship between the lake level fluctuations and the changing weather patterns over Elk Island National Park. It is apparent that the lake level increases which occur during the summer are primarily derived from surface flow response rather than any large groundwater contribution due to the short span of time between a storm event and a lake level change. Any major groundwater contribution to the lakes would show more seasonal lag even in local flow systems. The water balance calculations should be continued in future so that major relationships illustrated in this report might be better understood for current management planning.

### 4.5.1 YIELD CALCULATIONS VS LAKE LEVEL FLUCTUATIONS

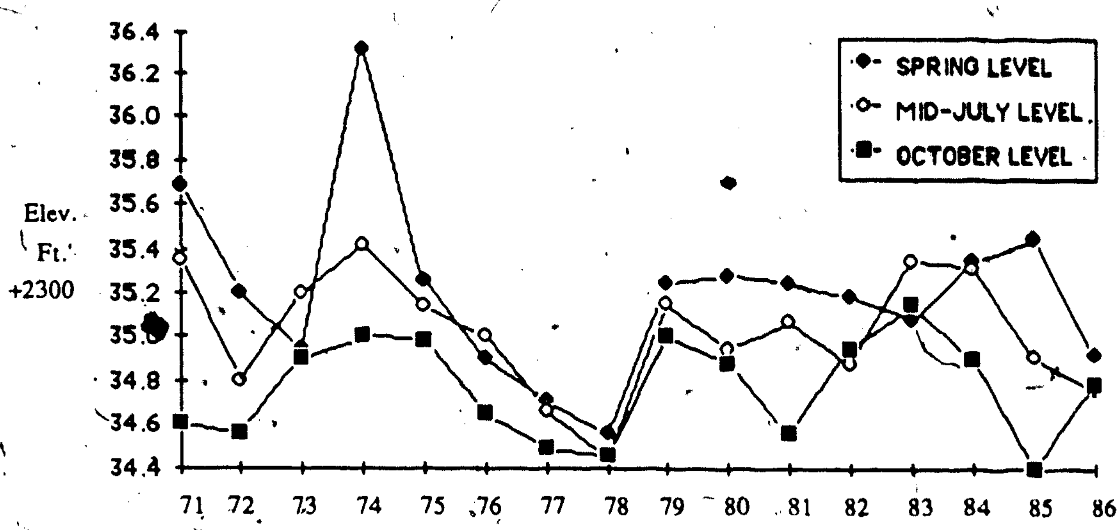
A check on the water balance procedure used involves the comparison of calculated lake level fluctuations with measured lake level fluctuations. The measured lake level fluctuation was determined through the subtraction of the October level from the earliest spring level measured. The result gives an approximation of the lakes seasonal fluctuation in level in most years (Figs 4.9, 4.10). A possible error would occur in this calculation if the lake levels were incorrectly measured, or were not recorded on the earliest possible day following the spring breakup. The calculated lake level fluctuations were determined by the division of the wetland area covering the specific basin from the water loss of the water body (Tables 4.5, 4.6). The results from both procedures are compiled in table 4.12.

It is apparent in table 4.12 that many of the calculated values are similar, yet there are some that are dissimilar. The causes of these differences can take many forms. For example, in a small study area such as in this thesis, snow drifting can greatly influence the runoff amounts (Woodburn, 1977). Local surpluses may be extremely large in some areas due to this drifting. In winters of low precipitation snow drifting has its greatest relative effect, resulting in surpluses and runoff in spring where it was not expected. This could result in additional runoff into local lakes, which according to calculations should not have received much.

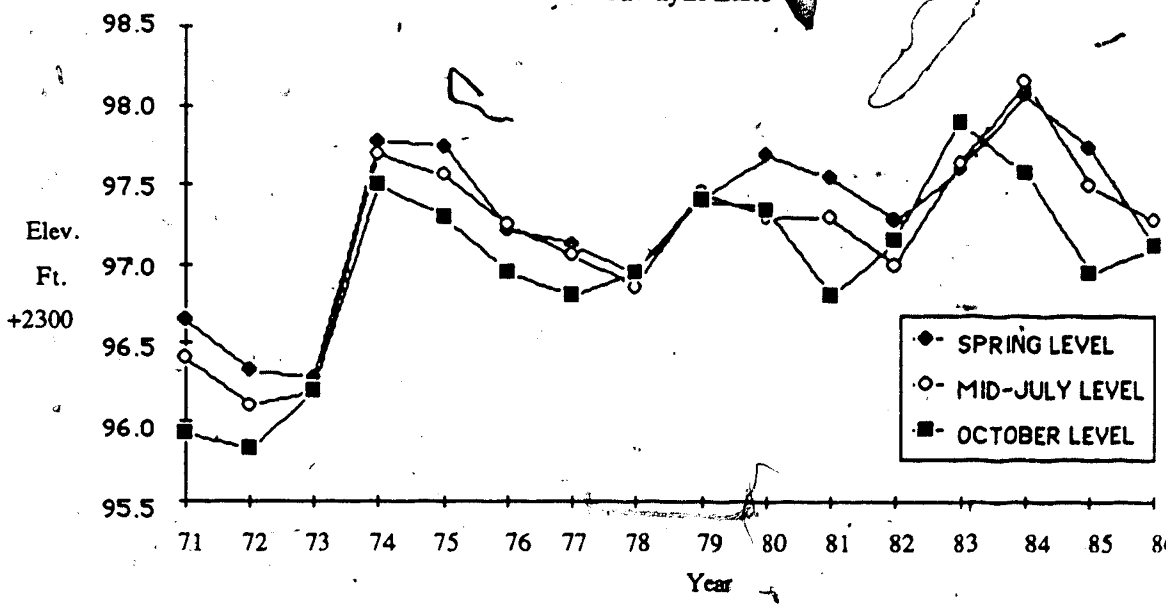
In some years the precipitation in summer, although resulting in little runoff into lakes can result in substantial direct level changes. Precipitation is rarely as great as evaporation in summer, but when it is large, the evaporation is usually not extreme because there is relatively little advected heat available. Conversely, when precipitation is low in summer, advected heat from adjoining dry areas will add to the evaporation and the spring to fall water level changes can be large.

The calculated lake level changes would be significantly altered if the precipitation were actually greater in Elk Island National Park than at the Edmonton International Airport. With an increased precipitation the lakes should not have the drastic differences in water losses between measured and calculated fluctuations illustrated in table 4.12. In table 4.13 it is apparent that an increased Park precipitation has altered the calculated lake level fluctuations, and in some cases has brought them closer to the measured values.
When large differences occur between measured increases and calculated increases, it is possible that the type of vegetation surrounding the lake has more to do with the level changes than do the different storage categories for the entire basin. The beavers noted in the previous section with their continual damming of lake outlet channels, could certainly be considered a factor responsible for differences in level fluctuation. Other possible factors covered previously include the artificial control of Astotin Lake, and ditch clearing to promote drainage.

Astotin Lake



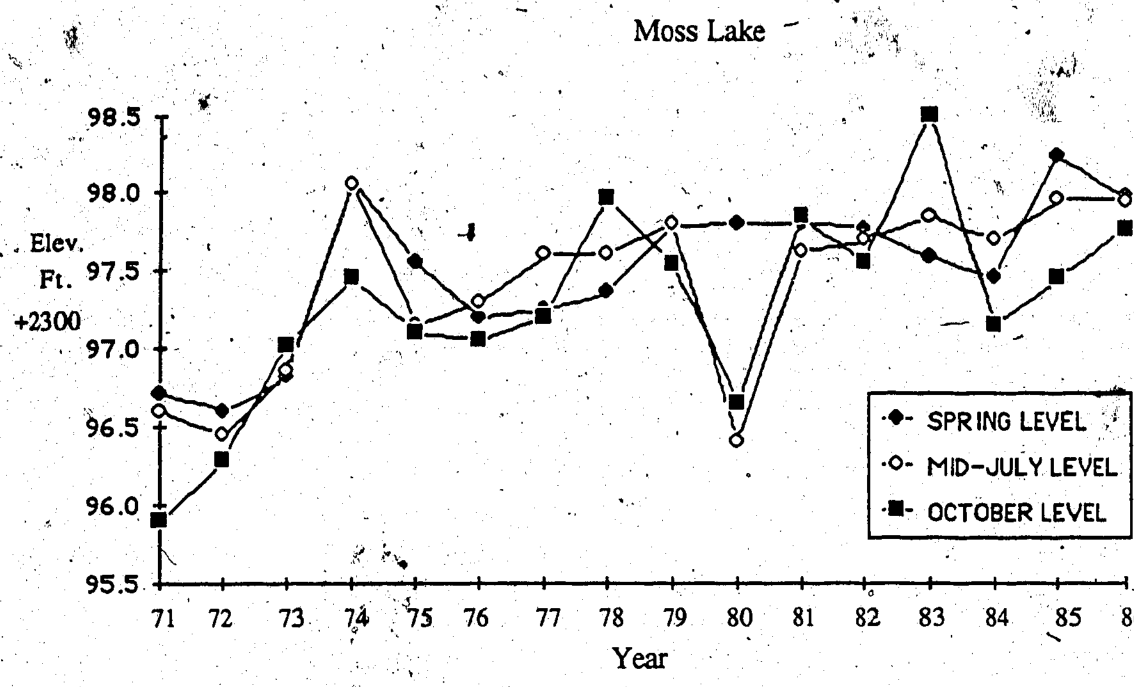

Tawayik Lake

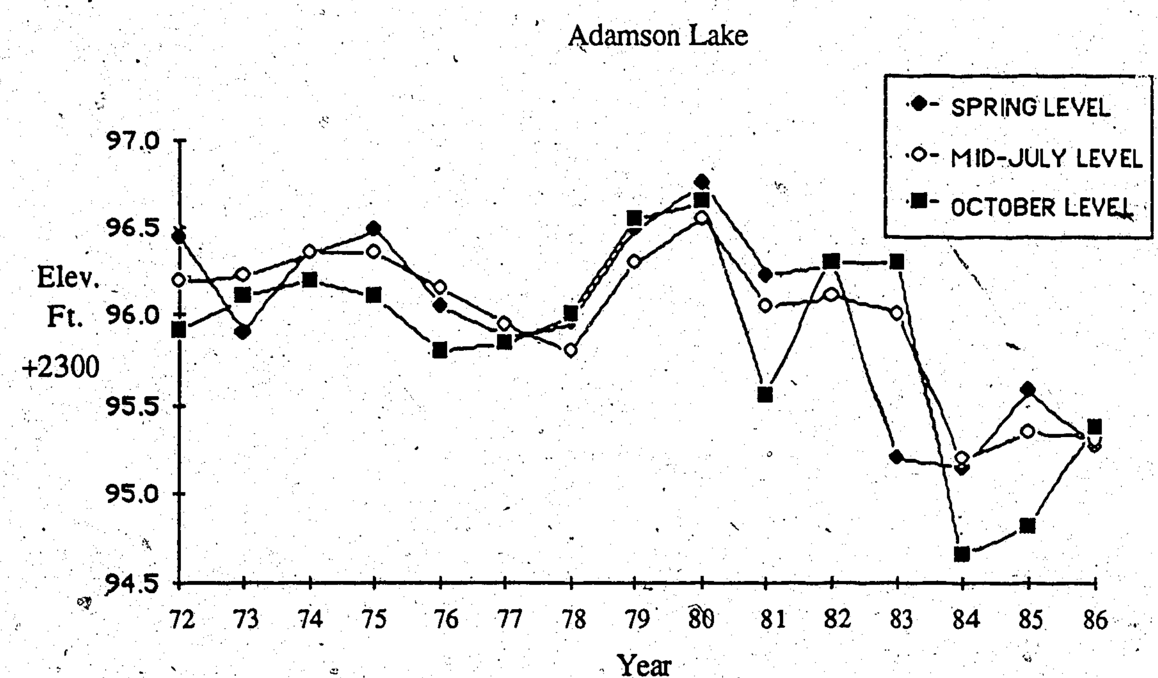



Source: Measured Lake Level Fluctuations from Park Records

**Yearly Lake Level Fluctuations-Astotin, Tawayik Lakes.**

Figure 4.9




Source: Measured Lake Level Fluctuations from Park Records

**Yearly Lake Level Fluctuations-Moss, Adamson Lakes**

Figure 4.10

TABLE 4.12

## Measured Versus Calculated Lake Level Fluctuations Of Four Lakes Within Elk Island National Park

Early Spring to Late Fall Level Changes

| Lakes | Measured (cm.) | Calculated (cm.) | | Measured (cm.) | Calculated (cm.) | | Measured (cm.) | Calculated (cm.) |
|---|---|---|---|---|---|---|---|---|
| 1971 | | | 1978 | | | 1985 | | |
| Moss | -24.4 | -18.3 | Moss | 18.0 | -5.8 | Moss | -23.7 | -15.3 |
| Astotin | -33.5 | -18.3 | Astotin | -4.6 | -5.8 | Astotin | -30.5 | -15.3 |
| Tawayik | -24.4 | -19.2 | Tawayik | - | -6.7 | Tawayik | -24.1 | -16.1 |
| Adamson | - | -19.8 | Adamson | 1.2 | -7.3 | Adamson | -23.2 | -8.0 |
| 1972 | | | 1979 | | | 1986 | | |
| Moss | -7.6 | 10.1 | Moss | -7.6 | -7.5 | Moss | -6.0 | -5.7 |
| Astotin | -18.9 | 10.1 | Astotin | -6.1 | -7.5 | Astotin | -3.0 | -5.7 |
| Tawayik | -16.8 | 9.1 | Tawayik | -0.9 | -8.3 | Tawayik | - | -6.6 |
| Adamson | -15.2 | 10.5 | Adamson | 1.8 | 1.1 | Adamson | 3.0 | -7.0 |
| 1973 | | | 1980 | | | Avg. (71-86) | | |
| Moss | - | 7.5 | Moss | -35.1 | 7.4 | Moss | -8.4 | -6.1 |
| Astotin | -3.0 | 7.5 | Astotin | -12.7 | 7.4 | Astotin | -12.7 | -6.1 |
| Tawayik | -2.4 | 6.4 | Tawayik | -10.7 | 4.7 | Tawayik | -8.9 | -6.9 |
| Adamson | 6.1 | 13.0 | Adamson | -2.7 | 5.7 | Adamson | -3.3 | -4.2 |
| 1974 | | | 1981 | | | | | |
| Moss | -18.9 | 10.0 | Moss | 1.8 | -17.8 | | | |
| Astotin | -39.6 | 10.0 | Astotin | -18.3 | -17.8 | | | |
| Tawayik | -8.2 | 9.3 | Tawayik | -22.9 | -18.4 | | | |
| Adamson | -4.9 | 26.8 | Adamson | -20.7 | -16.9 | | | |
| 1975 | | | 1982 | | | | | |
| Moss | -13.7 | -5.7 | Moss | -6.7 | 1.4 | | | |
| Astotin | -9.1 | -5.7 | Astotin | -6.1 | 1.4 | | | |
| Tawayik | -13.4 | -5.7 | Tawayik | -4 | 0.9 | | | |
| Adamson | -11.6 | -6.4 | Adamson | - | 2.3 | | | |
| 1976 | | | 1983 | | | | | |
| Moss | -6.1 | -11 | Moss | -2.4 | -16.1 | | | |
| Astotin | -4.6 | -11 | Astotin | 1.5 | -16.1 | | | |
| Tawayik | -7.9 | -11.5 | Tawayik | 8.8 | -16.9 | | | |
| Adamson | -7.6 | -11.7 | Adamson | 33.2 | -17.4 | | | |
| 1977 | | | 1984 | | | | | |
| Moss | -1.5 | -9.6 | Moss | -9.1 | -20.7 | | | |
| Astotin | -12.2 | -9.6 | Astotin | -14.9 | -20.7 | | | |
| Tawayik | -9.8 | -10.1 | Tawayik | -14.9 | -21.2 | | | |
| Adamson | -0.9 | -10.3 | Adamson | -14.9 | -21.2 | | | |

Source: Calculations by Author Using the Monthly Meteorological Record and the Lake Level Data Provided by the Park Staff.

TABLE 4.13

**Measured Versus Calculated Lake Level Fluctuations Using Elk Island National Park and Edmonton International Airport Data for Lakes Within Elk Island National Park (Cm)**

| Year/Lake | Measured | EINP Calculated | Int'l Airport Calculated |
|---|---|---|---|
| 1982 | | | |
| Moss | -6.7 | 15.5 | 1.4 |
| Astotin | -6.1 | 15.5 | 1.4 |
| Tawayik | -4 | 14.1 | 0.9 |
| Adamson | - | 22.0 | 2.3 |
| 1983 | | | |
| Moss | -2.4 | 21.7 | -16.1 |
| Astotin | 1.5 | 21.7 | -16.1 |
| Tawayik | 8.8 | 21.7 | -16.9 |
| Adamson | 33.2 | 40.0 | -17.4 |
| 1984 | | | |
| Moss | -9.1 | -7.4 | -20.7 |
| Astotin | -14.9 | -7.4 | -20.7 |
| Tawayik | -14.9 | -8.0 | -21.1 |
| Adamson | -14.9 | -8.3 | -21.2 |
| 1985 | | | |
| Moss | -23.7 | -13.3 | -15.3 |
| Astotin | -30.5 | -13.3 | -15.3 |
| Tawayik | -24.1 | -13.8 | -16.1 |
| Adamson | -23.2 | -6.8 | -8.0 |

Source: Calculations by Author Using Elk Island National Park and Edmonton International Airport Monthly Meteorological Data

# 5. LAKE REHABILITATION

## 5.1 INTRODUCTION

The lakes of Elk Island National Park have very little inflow and outflow of water resulting in their stagnant nature. In discussions with the Park Superintendent, Jack Willman, it was stated that eutrophication was thought to be increased through the construction of the weir at the north west corner of Astotin Lake. A review of the present procedures for lake maintenance are soon to commence (Willman, 1987). The present stagnant condition has contributed to the lakes becoming eutrophic.

> Eutrophication refers to the aging of a water body...which ...occurs because nutrients, plants and sediments reach the lake in runoff from the land. As the enrichment process takes place, it eventually produces diminishing returns in terms of life, and plants and aquatic life die in greater numbers, adding to the accumulating debris at the lake bottom. The lake grows narrower, shallower, and warmer. Eventually, it returns to marsh and then to dry land.
>
> (Canada Water Year Book, p. 177, 1975)

The water quality of lakes within Elk Island National Park is directly related to the amount and quality of runoff within the drainage basins. The water balance of the Park in terms of surpluses is therefore linked to the water quality of lakes within the Park. There is a wide spectrum of methods which are available to correct eutrophication in lakes. A physical correction of the eutrophic conditions within the lakes of Elk Island National Park would however be against a basic Park policy.

> ...to protect and preserve the natural process of eutrophication and/or succession of open water bodies, streams, bogs, marshes, swamps, and fens.
>
> (Parks Canada, 1978, p.6)

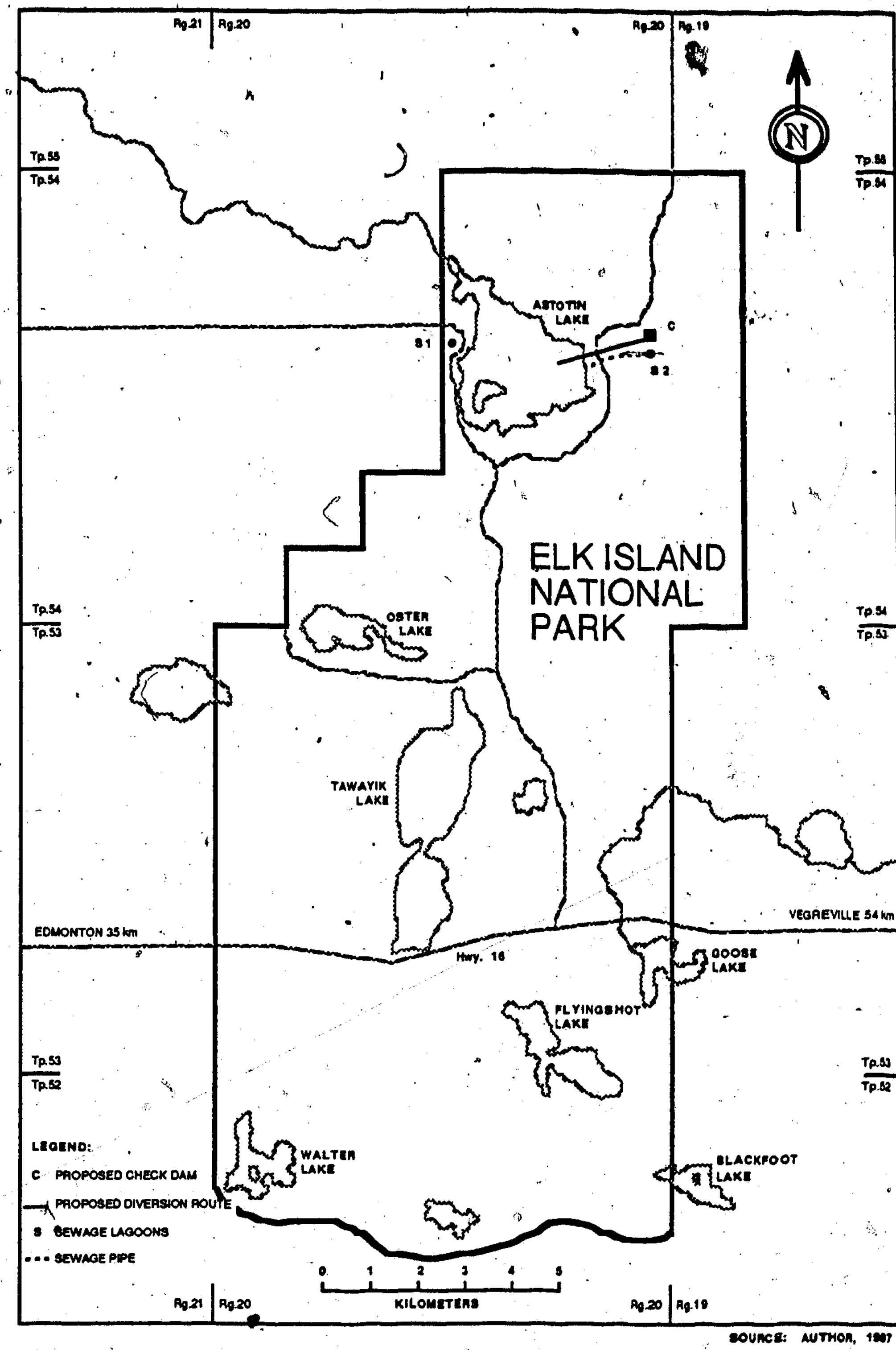
If an improved overall lake quality for recreation and wildlife were desired, then the following chapter on methods of rehabilitating lakes would apply. This review will entail a literature search of present methods to improve overall lake quality, and an attempt to relate these to water balance observations.

The possible methods of limiting nutrient inputs into the lakes are examined and suggestions are given concerning alternative methods of nutrient diversion. A second approach to removing weeds and nutrient rich sediments from the lake involves dredging. The reasons for dredging and past experiences with dredging will be discussed. The harvesting of weeds and algae may be considered to improve the aesthetic character of the main lakes, and reduce the level of nutrients returning to the lake sediments.

The fourth method discussed, involves the use of herbicides to remove weeds and algae from the lakes in Elk Island National Park. The types of chemicals used, their characteristics, and the previous uses of chemicals in the Park and across North America will be noted. Flushing-Dilution is the last and possibly most feasible method discussed to control the nutrients within the lakes of Elk Island National Park. The reasons for dilution, past experiences with dilution across North America, and possible dilution alternatives within Elk Island National Park will be reviewed.

## 5.2 METHODS OF LIMITING NUTRIENT INPUT

Agricultural land use around the Park, seepage from the sewage lagoon adjacent to Astotin Lake, and the wildlife all contribute to the nutrient loading of the lakes within Elk Island National Park. Only one of the factors, seepage from the sewage lagoon, could be controlled (Fig. 5.1). During the wet periods the lagoon has a tendency to overflow, resulting in a discharge of nutrients into Astotin Lake. One method of reducing this aspect of nutrient loading would be to divert the sewage away from the lake through pumping to an area more suitable for a sewage lagoon. There is a local water divide west of the administration office, but diversion of sewage across this divide could result in problems because of the close proximity of the Park boundary. Groundwater qualities could be affected by seepage from a lagoon in this area into the large outwash deposits present. The




**Location of Sewage Lagoons and Potential Diversion to Astotin Lake**

Figure 5.1

pumping of sewage is not a new concept to Elk Island National Park. On the eastern side of Astotin Lake the wastewater from the snack bar, beach area, and campground is diverted towards a collection area north of the campground. From this collection area the wastewater is pumped across a local water divide to a small water body one half mile northeast of the campground (Fig. 5.1). It is apparent that the effluent is dispersed from this small lake into nearby marshes. The nutrients from this lagoon could not flow into the Astotin Lake basin due to the local water divide, but could present problems to areas east of the Park. The flow of surface water from this lagoon is in an easterly direction towards the Park boundary and from there, into private farm lands.

## 5.3 DREDGING

During the vegetation period in shallow lakes the whole water mass can be affected by the nutrient enriched sediments. The leakage of phosphorus from sediments can be considerable, especially during the vegetation period. In the autumn the phosphorus in the lake is recycled back into the sediments (Ryding and Forsberg, 1976). The water quality in lakes such as Astotin would not be significantly improved by external nutrient reduction due to the high level of nutrients already present in the lake sediments. In shallow lakes such as those in Elk Island National Park, dredging could be considered a viable method of improving the water quality through a reduction of the nutrient enriched sediments. The lake bottom of Astotin Lake is covered with several feet of soft black mud which is largely made up of semi-decomposed plant matter ( Elk Island National Park Records, 1966-1976). Dredging in effect deepens a lake and "... decreases the ratio of sediment surface to water volume and could create a sufficient volume of oxygenated water to cope with anoxic conditions" (Alberta Environment, 1977c, p. 89). If dredging of a lake bottom were carried out, a bottom stratum low in organic nutrients would have to be exposed for the operation to be a success (Alberta Environment, 1977c).

Dredging programs at Lake Trummen (1 $Km^2$) in Sweden, and Lake Ramsjon (.37 $Km^2$) in Norway were successful in improving the water quality through removal of nutrient enriched sediments. The results were encouraging, however, the costs of the projects were high for the small lakes with the project at Lake Trummen exceeding $1 million (Alberta Environment, 1977c). In the early 1960's dredging was considered economically unfeasible for Astotin Lake in Elk Island National Park. If a major increase in lake use were to be anticipated another review of the cost of dredging Astotin Lake should be carried out to determine its feasibility.

5.4 HARVESTING OF WEEDS AND ALGAE

The harvesting of weeds and algae involves the complete removal of plant material. For the harvesting to be a success, the submerged and emergent vegetation must be cut and removed from the water. The cut vegetation left in the water would decompose and release nutrients back into the water (California State Water Quality Control Board, 1967). Unlike chemical treatments, the results of harvesting are promptly apparent, and the water body can be used immediately after treatment (Alberta Environment, 1986). Harvesting also allows the maximum control possible over the removal of weeds and algae (Mitchell, 1974). Mechanical methods to control weeds and algae have a number of drawbacks such as being labour intensive, slow to operate, and costly in terms of machinery (Alberta Environment, 1986).

5.5 CHEMICALS TO CONTROL WEEDS/ALGAE AND REDUCE EVAPORATION

There are a number of chemicals available which could be used to control algae and submersed weeds within Elk Island National Park. The most commonly used aquatic herbicide for the control of phytoplankton is copper sulfate. Copper sulfate has a low mammalian toxicity and has proven effective in controlling a wide range of phytoplankton algae (Mulligan, 1967). This chemical is however toxic to fish and fish-food organisms at low concentrations. The copper is precipitated on the gills of fish and causes suffocation (Mulligan, 1967). The copper sulfate herbicide is broken down and is usually removed from the water in 24 hours, although the chemical has been shown to be persistent for several days (Mulligan, 1967). The California State Water Quality Control Board (1967) determined that copper sulfate must be applied before the algal bloom and not during to have its greatest effect. In Alberta, Alberta Agriculture (1978) has recommended copper sulfate for use in farm dugouts, sloughs, and municipal reservoirs for control of all types of algae. To minimize the damage to the aquatic life, Gangstad (1982) has recommended the treatment of lakes in sections so as to provide chemical free zones for fish.

There are a number of examples in North America where copper sulfate has been used with successful results. Edmondson (1967), reported from his studies that copper sulfate treatments resulted in decreases in the algae. In Lake Monona in Wisconsin, continuous treatments of copper sulfate to the shore and bay areas resulted in an effective control of the nuisance algae (California State Water Quality Control Board, 1967). After complete sewage diversion in 1936, the amount of copper sulfate needed to control the algae was lessened. Copper sulfate treatments were carried out with some success in Lake Winnisquam in New Hampshire to reduce the algal blooms (California State Water Quality Control Board, 1967).

The application of chemicals within Elk Island National Park has been a heated topic of discussion for some time. Chemicals, primarily copper sulfate have been applied to Astotin Lake to control the algal blooms. The copper sulfate treatments were reported in the Elk Island National Park Records (1968) to have some control over the algae, but the relief was short lived and treatments had to be repeated periodically throughout the summer. The superintendent of Elk Island National Park, T.L. Ross, in 1969 recommended against any further copper sulfate treatments of Astotin Lake. He reasoned that treatment of the shoreline would only control algae for a short time due to winds which would carry the algae back to the shoreline. Mr. Ross was also concerned about the chemicals' toxicity to fish which are the staple food supply of many waterfowl. The Public Health Engineering Division (1969) in Edmonton on the other hand recommended the periodic application of copper sulfate to shoreline areas to control nuisance algae. Jack Schick, the Park Naturalist for Elk Island National Park in 1973, strongly recommended against any further use of copper sulfate to control algae due to its toxicity to fish and his opinion that the copper sulfate treatments were ineffective. Upon examination of the Park records it is apparent that copper sulfate treatments were discontinued in the late 1960's and have not been resumed since then.

Other chemicals such as Diquat, Fenac, Paraquat, and Simizine, have been approved for use in lakes by Alberta Environment (1986) for control of algae and weeds. All of these aquatic herbicides create a potential fish hazard from oxygen depletion due to the decay of treated vegetation. The herbicides all have minimum time restrictions before the water may be safely used. These time restrictions range from 24 hours for diquat to never fit for consumption or fishing with simizine. Present Park policies would prevent the use of chemicals in lakes within the Park (Environment Canada, 1978a). Since chemicals have been used in the past, it is apparent to the writer that a great deal of care and environmental consideration must be given whether in future to use chemicals in the lakes of Elk Island National Park. Full environmental impact studies on the possible effects of herbicide use within the Park should be carried out before any such herbicide program is carried out again.

The water quality of lakes may be improved by another type of chemical which in effect reduces the evaporation potential in lakes. The chemical hexadeconal has been found to be an effective evaporation suppressant. The theory behind the use of evaporation suppression chemicals is based on the fact that oils and other compounds when placed on water, create a monomolecular film (Alberta Environment, 1977b, p. 89). This film is penetrable by rain drops, but reduces the evaporation of the water molecules from the lake surface. The chemical hexadeconal has been reported to be tasteless, odourless, and non-toxic (Alberta Environment, 1977b). The effectiveness of an evaporation supressing chemical would depend on a number of factors such as wind action, degradation, solubility, and method of application (Alberta Environment, 1977b). In the best possible conditions, increases in lakes levels were predicted at 10 to 13 cm per year when using the evaporation suppressant (Alberta Environment, 1977b). This technique has been estimated to be expensive. It was estimated 20 years ago that the cost of saving one acre-foot of water would be approximately $40 (Laycock, 1987).

## 5.6 DILUTION

An alternate method to control nutrients within a lake involves the technique of flushing-dilution. This technique is designed to replace nutrient rich waters with nutrient poor (Alberta Environment, 1977c). There have been a number of dilution projects throughout North America which have been successful in reducing the nutrients and algae in the water.

In 1968, water from Lake Diefenbaker was used for dilution of Buffalo Pound Lake. The inputs were intermittent during the summer and continuous during the winter in the first year. The water quality of Buffalo Pound Lake improved markedly from a chemical point of view during the first year of artificial water inputs (Hammer, 1973). The total dissolved solids declined from 686 mg/L to 385 mg/L in 1968, to 310 mg/L in 1969. The calcium carbonate, sulphate, chloride, sodium, and potassium values decreased dramatically in the first year. The blue-green algal blooms were not corrected during the first year of dilution, but took 3-4 years before the blooms were brought to sub-nuisance levels (Hammer, 1973).

Another project was developed at Green Lake near Seattle Washington. Surplus water in 1962 was diverted from Seattle through Green Lake with the object of diluting the concentrations of nitrogen and phosphorus, which would thereby limit the growth of algae (Oglesby, 1967). Oglesby (1967) compared the data collected in 1959 and 1965-67, and reported the occurrence of substantial positive changes in water quality which resulted from the addition of dilution water. Nitrogen and phosphorus levels markedly decreased and transparency improved significantly.

In the 1960s, Lake Washington near Seattle Washington received dilution treatments. This resulted in an improvement of water quality and the disappearance of blue-green algal blooms (Hammer, 1973).

There are a number of methods by which the technique may be applied to lakes within Elk Island National Park. The first method involves the internal management of water within the Park. This would involve the maximization of water present in and around the Park. For example, water could be intercepted from surrounding local drainage basins and conveyed by means of channels or pipelines to lakes within the Park. This would in effect increase the water supply within the Park while sacrificing the smaller ponds outside the lake (Alberta Environment, 1974). The optimum time for such a transfer would be during the spring runoff to ensure the highest water quality possible. A transfer of water could be considered from a seasonal creek which begins in the Northwest end of the Park and flows in a Southeast direction out of the Park. In certain high runoff years such as 1973, 1974, 1979, and 1985, meltwater could be diverted from this creek across the divide to Astotin Lake. This project would not be used every year, but would only operate during years of high runoff. The basin area which feeds this creek is made up of an open forest cover. This cover is related to more runoff than a dense forest cover but with a 150/250 mm. moisture storage category. The runoff into this creek during the wet years would include runoff from cleared land outside the Park where yields are larger and more frequent. The following discussion is an example of a potential transfer alternative between this creek and Astotin Lake. The gravity transfer of water by pipe from the creek to Astotin Lake would necessitate the construction of a check dam in the creek. This would detain the spring runoff, increase the elevetion difference (head) between the creek and Astotin Lake, and facilitate its piping to Astotin Lake. A potential location for such a check dam would be situated south of the Beaver Pond. From this location, water would be piped under the local surface water divide, and highway, and discharge close to the water intake near the beach (Fig. 5.1). Discharging the water at this location would have the benefit of increased mixing of the water. The distance between the creek and Astotin Lake is 1440 m with a maximum elevation difference (head) of 10 m. The maximum head loss allowable for such a distance would be .7m/100m with a possible water velocity of 150 cm/sec based upon a 1 percent slope. Over this distance, a range of pipe sizes from 250 mm to 750 mm are available. The quantities of water which can be transferred range from 48 acre ft/day with a 750 mm pipe to 5.8 acre ft/day with a 250 mm pipe. The pipe would need to be large enough to transport large amounts of water in a relatively short period of time (eg. 10 days). For the size of creek present, a 300 mm pipe would be adequate and could pipe 9.3 acre ft/day.

In average runoff years, projects on similar sized creeks in the area allowed the pumping of water for two days during the spring at 50 l/s before the creek was too low to pump water. This type of project would only be beneficial during high runoff years when 10 days of pumping would be possible (Livingstone, 1987b).

At an average price for a municipal project of 50 dollars per metre of pipe installed, this project would cost 74,000 dollars (Livingstone, 1987b).

In terms of impacts on the level of Astotin Lake for such a project, it would take 65 acre feet of water to raise the level 1.0 cm. Over a 10 day spring runoff period at a flow rate of 9 acre ft/day, the level of Astotin Lake would be raised by 1.4 cm (Livingstone, 1987b).

A second internal transfer scheme involves the sacrificing of smaller lakes south of Astotin Lake on the west side of the Park for the benefit of Astotin Lake. During the spring melt period, water could be pumped from some of these lakes (Oster, Adamson, Trappers, Paul, and Spruce Island) into Astotin Lake. The previously mentioned lakes are topographically higher than Astotin Lake which would reduce the costs of pumping water to Astotin Lake. The different feeder lakes level changes are partially determined by the surrounding water storage categories, resulting in some lakes having a greater potential for transfer. Trappers Lake for example is surrounded by a mix of forest (250 mm.) and cropland (50 - 100 mm), while Adamson Lake is surrounded by forest (250 mm.) and open forest (150/250 mm). It would be expected that Trappers Lake would receive more runoff than Adamson due to the lower water storage categories present around Trappers Lake. The last two transfer projects discussed need not be permanent pipelines but could be seasonally positioned to reduce the environmental impact and the costs involved in trenching a pipeline. A non-permanent seasonal pipeline could also be alternated between different lakes to allow a lakes' level to increase. A third internal management technique would involve the depletion of small sloughs and depressions within the Park to improve runoff to the lakes. This scheme would in effect reduce the water losses due to evaporation and infiltration (Alberta Environment, 1974). Further study could be conducted on such a plan to reduce the number of small sloughs and depressions. A fourth internal management technique involves the better use of present low water storage categories such as parking lots (Photograph 4.2). The water from these areas is of good quality and could be re-routed through proper leveling and minimal channeling towards Astotin Lake. In the main gravel parking lot adjacent to the Beach, a tile drainage system could be considered for directing the surpluses towards an existing ditch which leads to Astotin Lake. A tile drainage system would effectively withstand any frost heaving and would maximize the potential runoff from this parking lot into Astotin Lake.

The second technique to obtain water to be used in the dilution of lakes within Elk Island National Park would involve the importation of water from the North Saskatchewan River. This could be accomplished through a variety of alternatives which have been adequately covered in the EPEC report of 1971, and the Alberta Environment report of 1974. The size of importation project necessary for Elk Island National Park would not be as large as the projects for the two previously mentioned reports, but would probably still be prohibitively expensive. Livingstone (1987a) has proposed that water from the Edmonton-Vegreville pipeline located north of the Park be used for Park domestic needs. It is evident that only part of this would be consumed, the rest of which would eventually be added to the local supply.

A third possible, but unlikely source of nutrient poor water for dilution would be from groundwater. Within the Edmonton areas it is evident that major groundwater supplies are not present (EPEC Consultants, 1971). Underground reservoirs such as the Vegreville Channel are capable of producing two and one-quarter million litres per day which equals a flushing rate of .02 cms per day. EPEC Consultants (1971) have estimated the need for .85 cms per day to raise the level of Cooking Lake in a reasonable time. Astotin Lake is smaller than Cooking Lake, but it is apparent that groundwater in the region would not be adequate for flushing at desired rates.

If an increase in the recreational use, and an improvement in the aesthetic quality of Astotin Lake is desired, the water quality of the lake will have to be improved. The alternatives available to improve the quality of Astotin Lake are diverse. It is apparent that reducing the nutrient inputs from the sewage lagoon behind the administration building would not significantly improve lake quality, but it would be a beginning. Dredging is necessary to physically remove the nutrients present in the lake, due to the high level of nutrients in the sediment. The harvesting of weeds is a possibility in Astotin Lake, though it is the blue-green algae which is the major nuisance. It is not certain whether equipment is available to strain the algae from the water. The chemical control of the algae is an unfavorable alternative due to the undesirable environmental effects, and the unknown effectiveness of the chemicals on the algae. The dilution-flushing technique is a desirable alternative, and similar procedures elsewhere have been successful in improving the quality of lake water. An internal management scheme would appear to be more favourable because of the high costs of construction for a water importation scheme from the North Saskatchewan River, and the lack of a suitable groundwater reservoir in the Edmonton region. It should be noted that internal flushing would not be effective in all years and that only limited improvement could be anticipated. This may however be all that is required for the levels of use expected. Recommendations for future study and proposals for change within Elk Island National Park are contained in section 6.2.

# 6. CONCLUSIONS AND RECOMMENDATIONS

## 6.1 CONCLUSIONS

The Thornthwaite technique was used in the determination of a water balance for Elk Island National Park. A literature review of previous uses of the technique was conducted, and it was found that the Thornthwaite procedure was appropriate for Prairie soil moisture conditions in this area. Data for the procedure were easily obtainable by the author from the first order Edmonton International Airport weather station, and from other first to third order stations surrounding the Park. There were, however, few meteorological data from the station at Elk Island National Park for which recording began in 1982. In the calculations with the Thornthwaite procedure it is unlikely that major errors could be made in the bookkeeping procedure to determine the required water balance values. Errors are more likely in the determination of potential evapotranspiration using the Penman technique in which the formulae are complex and the data base more restricted. The results using the Penman technique were lower than, but similar to, those obtained using the Thornthwaite technique. The Penman technique is another procedure besides Thornthwaite which has had worldwide exposure and acceptance. The Penman procedure was therefore performed as a check on the Thornthwaite procedure. With both procedures producing similar results, it is apparent that the water balance calculations using Thornthwaite are acceptable for this area. The Penman technique was not used further than for comparison due to limitations of the data base in Central Alberta.

The type of surface represented by a moisture storage category was a product of previous studies of regional water balance patterns. The wetlands during the summer were given the value PE + 1/2 D to represent the above-average evaporation potential of those surfaces. The higher evaporation potential is in part due to the wind action and availability of advected heat plus an allowance for the low albedo of water surfaces. Through field observations it is evident that many lakes and ponds are surrounded by tall trees which in effect create a wind screen. A wind screen could reduce the evaporation potential of some wetlands and cancellation of part of the 1/2 D value. This would result in the water loss or net yield being closer to the difference between the precipitation and potential evapotranspiration.

It is apparent from the research (Tables 4.1, 4.4, 4.5) that the surpluses created within and around Elk Island National Park are primarily lost to evapotranspiration in most years. The highest evapotranspiration losses occur from the lakes and marshes within the Park. Only during the wet years such as 1973-1974 are surpluses lost from the Park in the form of surface flow.

Water balance patterns are not favourable for intensive recreational use in many years even in the best lakes. The surpluses can be managed for some improvement in lake qualitities, especially in wet years, but major improvement of the lakes within the Park for recreation in the drier years would be expensive.

Yields were calculated from surpluses determined through use of the water balance procedure. Calculation errors are possible in the determination of yields, but effort was taken by the author to prevent them. In the correlation of measured lake level fluctuations and calculated lake level fluctuations it is apparent that certain years did not have similar values. Rather than one reason accounting for the discrepancy, it is apparent after the discussion in Chapter 4 that there are a number of possibilities which, aggregated together, resulted in differences between measured and calculated level fluctuations.

Each of the alternative solutions (in Chapter 5) for improving lake quality could be implemented to a certain extent in Elk Island National Park. Aside from the costs, the degree of accepted environmental impact would dictate which solution or combination of solutions could be implemented. Although the focus of this study has been upon water balance calculation, and some of the possible applications have been noted, a number of recommendations concerning future alternative management options relating to and leading from this study might be noted.

6.2 RECOMMENDATIONS

1. In the measurement of precipitation over the four year period at Elk Island National Park, it is evident that the Park received 20 percent more precipitation than the Edmonton International Airport. Much of this 20 percent fell during the summer months. It is probable that the higher gauged precipitation was a result of an orographic uplift over the Park. An orographic effect could result from the Park rising some 60 m above the surrounding plain. Orographic uplift may also be related to the surface roughness in the Park, which is due to topographic and vegetative cover variation. The rough surface creates a frictional drag upon surface air which may promote uplift of a faster moving air body. This could create a localized precipitation event. Further study on the differences in precipitation should be carried out to determine the representativeness of this larger catch. To determine this, it is recommended that a series of rain gauges be established throughout the Park. Temperature might also be monitored, but smaller variation would be anticipated due the similarity of the results from Elk Island National Park and Edmonton International Airport.

2. There is a great deal of future study possible concerning lake improvement in Elk Island National Park. A multiple technique approach to improve Astotin and other major lakes should be examined due to the numerous interrelated water quality problems. A multiple technique programme would involve a reduction of nutrient inputs, dredging of some lake bottoms, harvesting of weeds and algae, and dilution of the lake with nutrient poor water. The sewage lagoon behind the administration office is prone to overflowing, which in turn allows nutrients to flow into Astotin Lake. It is recommended that the sewage be pumped west of the low drainage divide nearby to an alternate lagoon site where overflow conditions are less likely to occur. A feasibility study on the environmental

effects and costs of dredging some or all of Astotin lake could be examined. The lake sediments are full of nutrients which must be removed before the algae and weed problems could be diminished. An investigation should be carried out to see whether suitable equipment is available to harvest the algae from the lakes. Harvesters are available for weeds, but the blue-green algae are the major nuisance in the lakes of Elk Island National Park. The fourth part of a programme to rejuvenate the major lakes takes the form of dilution. It is recommended that possible dilution alternatives be examined such as water importation from the North Saskatchewan or from possible collection areas outside the Park. The collection of spring runoff within the Park and subsequent pumping to Astotin and other major lakes would appear to be the most feasible and least environmentally destructive. Surpluses suitable for such transfer schemes would be available only in wet years such as 1974. Acceptable quality would be attained only during heavy snow-melt runoffs. In most seasons of most years, surpluses are too small from most areas and too low in quality for diversion to be helpful. However, such "flushing" need not be present in all years to be useful in reducing or briefly reversing the eutrophication process in selected lakes. No long term environmental damage can be foreseen through implementation of the rejuvenation programme, while short term environmental effects would result from noise of the equipment and the burying of pipes.

3. It is recommended that there be greater management of the low water storage category areas such as parking lots to promote drainage towards a lake or pond rather than a ditch where water would stagnate and evaporate. The low water storage categories (2, 13 mm.) are responsible in most years for much of the surplus within Elk Island National Park. After limited wetting of the surface, the precipitation begins to run off resulting in a good quality runoff. During the drier years and summer periods these areas are alone in producing yields. The author is convinced that through increased awareness of the potential surpluses from the low water storage categories, greater use can be made of these

surpluses. To accompany such management, there should also be a programme of ditch clearance and selective depression clearing to promote water flow and reduce ponding.

4. There should also be increased maintenance of the culverts and culvert openings to promote a water exchange between ponds and lakes. During the summer of 1986 the author saw broken and clogged culverts which created ponds and greatly hampered the flow of water. The installation of drainage tiles within gravel parking lots to promote drainage to a desired destination could be investigated. To accompany the implementation of drainage tiles, a program of proper levelling within parking lots to promote surface drainage would be desirable.

The number and wide range of recommendations indicate that there is still a great deal of work to do in the field of water resource management within Elk Island National Park. This study is only a small component of the entire water resource study picture, but it could serve as a perspective base and foundation for future studies of specific action programs.

## 6.3 DATA PROJECTIONS AND THE POTENTIAL IMPACTS OF INCREASING ATMOSPHERIC $CO_2$ UPON WATER RESOURCE PATTERNS IN THE FUTURE

Over 100 years of climatic data are now available for the Edmonton area and most of the limited but apparent warming might be attributed to the expanding "heat island" effect of the growing city. Projections into the future might include allowance for future growth and it might be assumed that this region will continue to have wet and dry years in irregular sequence with widely different surplus and deficiency patterns from year to year. Planning for the more efficient use of the larger surpluses is recommended.

We should be aware of a new factor in climatic change - i.e. the increases in atmospheric $CO_2$ and related "greenhouse gases" such as methane, nitrous oxides, low level ozone and chloro-fluorocarbons - which will result in warmer climates and changes in global atmospheric circulation patterns in the future (EPA, 1984; Environment Canada, 1986). Various projections are now available and an "average" projection for this area is that in 50 to 100 years the area will have a 22 percent increase in evapotranspiration, a 15% increase in precipitation, and a 14 percent increase in runoff (EPA, 1984, pp. 21-23). This regional runoff increase is possible because of the precipitation concentration in the winter (11 to 25 percent increase), and spring (over 25 percent increase), when evapotranspiration is low. The precipitation in summer and fall will experience little change but lake levels will decline seasonally with the greatly increased evapotranspiration (EPA, 1984, pp. 50-53).

The changes noted above will be gradual with wet and dry years in irregular succession. Planning for increased runoff, increased lake evaporation, increased supply variation, and increased demand for lake use can result in an increased importance in water balance understanding and management.

# BIBLIOGRAPHY


Alberta Agriculture, 1978. Aquatic Vegetation Management in Alberta. Edmonton, 18 p..

Alberta Environment, 1974. Cooking Lake Area Study: Potential Alternatives for Water Supply. Edmonton, 8 p..

Alberta Environment, 1977a. Cooking Lake Area Study: Planning Report. Vol. I, Edmonton, 36 p..

Alberta Environment, 1977b. Cooking Lake Area Study: Water Inventory and Demands. Vol. II, App. 1. Edmonton, 122 p..

Alberta Environment, 1977c. Cooking Lake Area Study: Ecology. Vol. IV, App. VI, Edmonton, 136 p..

Alberta Environment, 1977d. Cooking Lake Area Study: Economic Base and Heritage Resources. Vol. V, App. X, Edmonton, 15 p..

Alberta Environment, 1977e. Cooking Lake Area Study: Alternatives. Vol. VI, Edmonton, 120 p..

Alberta Environment, 1986. Aquatic Plant Management. Edmonton, 97 p..

Baily, H.P. and Johnson, C., 1972. "Potential Evapotranspiration in Relation to Annual Waves of Temperature", pp. 131-133 in International Geography 1972, (edited by W.P. Adams, and F.M. Helleiner). Toronto, 694 p..

Baker, D.G., 1958. A Comparison of Two Evapotranspiration Calculation Methods and the Application of One to Determine Some Climatic Differences Between Great Soil Groups of Minnesota. Unpublished Doctoral Dissertation, University of Minnesota.

Bichlmaier, M., 1985. Response of Understory Vegetation of Some Boreal Mixedwood Forest Communities to Native Ungulate Foraging. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, Edmonton, 123 p..

Black, S.A., and Kettry, R.K., 1980. "History of Nutrient Control in Ontario." Notes of Nutrient Control Technology Seminar, Calgary, Alberta, 29 p..

Blaney, H.F., and Criddle, W.D., 1950. Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data. USDA Soil Conservation Service, Washington, 48 p..

Bochkif, A.P., and Struzer, L.P., 1970. "Estimation of Precipitation as a Water Balance Element." Symposium on the World Water Balance I, Pub. 95, Int. Assoc. Sci. Hydrol. (Brussels), pp. 186-193.

Budyko, M.I., 1974. Climate and Life. English Edition, (edited by D.H. Miller), New York: Academic Press, 508 p..

California State Water Quality Control Board, 1967. Eutrophication-A Review. Pub. No. 34, Sacramento, Calif., 188 p..

Canada Department of Agriculture, 1962. Soil Survey of the Edmonton Sheet 83 H E 1/2, 1:126,720. Soil Research Institute, Research Branch, Ottawa.

Canada Department of Energy, Mines, and Resources, 1983. Edmonton 83 H, 1:250,000. Surveys and Mapping Branch, Ottawa.

Carter, V., Garrett, M.K., Shima, L., and Gammon, P., 1977. "The Great Dismal Swamp; Management of a Hydrologic Resource with the Aid of Remote Sensing." American Water Resources Association: Water Resources Bulletin, Vol. 13, No. 1, pp. 1-12.

Carlson, V.A., 1967. Bedrock Topography and Surficial Aquifers of the Edmonton District, Alberta. Research Council of Alberta, Report 66-3, 21 p..

Chang, Jen-Hu, 1968. Climate and Agriculture. Chicago, Aldine Publishing Co., 304 p..

Chow, Ven Te, 1964. Handbook of Applied Hydrology. New York, McGraw Hill, 1452 p..

Crown, P.H., 1977. Soil Survey of Elk Island National Park, Alberta. Alberta Institute of Pedology, S-77-38, 128 p.

Davies, J.A., 1963. "Albedo Investigation in Labrador-Ungava." Arch. Meteorl. Geophys. Bioklim. Ser B13 : pp. 137-151.

Edmondson, W.T., 1969. "Eutrophication in North America." In Eutrophication: Causes, Consequences, Corrections. Nat'l Acad. of Sci., Washington, D.C. pp. 124-149.

Elk Island National Park Records, 1966-1976. Records on Water Quality Observations, Astotin Lake. Park Wardens Office.

Environment Canada, 1975. Canada Water Year Book 1975. Hignell Printing Limited, Ottawa, 232 p..

Environment Canada, 1978a. Elk Island National Park Master Plan: Plan Proposals. Calgary, 29 p.

Environment Canada, 1978b. Elk Island National Park Management Plan Summary. Calgary, 19 p.

Environment Canada, 1981. Monthly Meteorological Record Supplement, Downsview, 346 p..

Environment Canada, 1986. "$CO_2$/Climate Report." *$CO_2$/Climate Research 86-1*. Downsview, Ontario, 10 p..

Environment Canada, Atmospheric Environment Service, 1971-1986. Annual Meteorological Summary; Edmonton International Airport. Edmonton, Canada.

Environmental Protection Agency, 1984. Potential Climatic Impacts of Increasing Atmospheric $CO_2$ with Emphasis on water Availability and Hydrology in the United States. By NASA Goddard Space Flight Centre, Institute for Space Studies, New York, 96 p..

EPEC, 1971. An Economic Analysis of the Cooking Lake and Hastings Lakes. Environmental Planning and Engineering Consulting Limited, Edmonton.

Erxleben, J.P., 1972. Land Use - Snowmelt Runoff Relationships in the Whitemud Creek Basin, Edmonton. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 179 p..

Ferguson, H.L., O'Neill, A.D., and Cork, H.F., 1970. "Mean Evaporation Over Canada." Water Resources Research 6(6), pp. 1618-1633.

Ferguson, H.L., and Pollock, D.M., 1971. "Estimating Snowpack Accumulation for Runoff Prediction." Eighth Canadian Hydrological Symposium on Runoff from Snow and Ice, Vol. 1, pp. 7-27.

Gangstad, E.O., 1982. Weed Control Methods for Recreation Facilities Management. CRC Press Inc. Florida, 297 p..

Garnier, B.J. 1954. "Measuring Potential Evapotranspiration in Nigeria", In The Measurement of Potential Evapotranspiration, (edited by J.R. Mather), Seabrook, New Jersey, pp. 140-176.

Goff, J.A., and Gratch, S., 1946. "Low-Pressure Properties of Water from -160 to 212 $^{o}$F." Trans. 52nd Annual Meeting, Amer. Soc. Heating and Ventilating Eng., New York. pp. 95-122.

Goodison, B.E., 1978a. "Accuracy of Canadian Snow Gauge Measurements." Journal of Applied Meteorology. Vol. 17, No. 10, pp. 1542-1548.

Goodison, B.E., 1978b. "Canadian Snow Gauge Measurements: Accuracy, Implications, Alternatives, Needs." Proceedings, Seventh Symp. on Applied Prairie Hydrology, Water Studies Institute, Saskatoon, May 9-11, pp. 7-15.

Gregg, B.J., 1983. Alternatives in Water Transfer: From the Clearwater to the Red Deer River. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 183 p..

Griffiths, D., 1979. Elk Island National Park: Island Forest Year. University of Alberta Press, Edmonton, 257 p.

Guerrini, V.H., 1954. "A Year of Evapotranspiration in Ireland", In The Measurement of Potential Evapotranspiration, (edited by J.R. Mather), Seabrook, New Jersey, pp. 98-111.

Hallock, M.C., 1976. Water Problems in In-Situ Oilsands Development: The Water Resources of the Gregoire Lake Basin. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 169 p..

Hammer, V.T., 1972. "Eutrophication and its Alleviation in the Upper Qu'Appelle River System, Saskatchewan." Presented at Symp. on the Lakes of Western Canada, University of Alberta, Edmonton, pp. 352-369.

Hare, F.K., 1972. "The Observed Water Balance of North America", pp. 147-148 in International Geography 1972, (edited by W.P. Adams, and F.M. Helleiner). Toronto, 694 p..

Hay, J.E., and Oke, T.R., 1973. "The Climate of Vancouver." British Columbia Geographical Series No. 23, Tantalus Research Limited, Vancouver, 48 p..

Hobbs, R , 1967. Personal Communication with Dr. A.H. Laycock, Dept. of Geography, University of Alberta.

Hurley, K., 1987. Stormwater Runoff For An Ellerslie Subdivision, Edmonton. M.Sc. Thesis (in preparation), Department of Geography, University of Alberta.

Jennings, D., 1983. The Late Quaternary Geomorphology of Elk Island National Park, Central Alberta. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 197 p..

Kakela, P.J., 1969. Snow and the Thornthwaite Water Balance in a Subarctic Environment. Unpublished Ph.D Thesis, Department of Geography, University of Alberta, 289 p..

Kerekes, J.J., 1973. "The Influence of Water Renewal on the Nutrient Supply in Small, Oligotrophic (Newfoundland) and Highly Eutrophic (Alberta) Lakes." In Symp. on the Lakes of Western Canada, Edmonton, pp 383-400.

Lamoureux, W.W., 1962. "Modern Evaporation Formulae Adapted to Computer Use." *Monthly Weather Review* , No. 90, pp. 26-28.

Landsberg, H., 1958. Physical Climatology. Dubois, Pa: Gray Publishing Co., 446 p.

Lang, A.H., 1974. "Guide to the Geology of Elk Island National Park: the Origin of its Hills and Scenery." Geological Survey of Canada, Misc. Report No. 22, 30 p..

Langbein, W.B., and others, 1949. Annual Runoff in the United States. U.S. Dept. of the Interior, Geological Survey Circular 52, 14 p..

Laycock, A.H., 1957. Precipitation and Streamflow in the Mountain and Foothill Region of the Saskatchewan River Basin. Prairie Provinces Water Board Report No. 6, Regina, 34 p..

Laycock, A.H., 1964. Water Deficiency Patterns in the Prairie Provinces. Prairie Provinces Water Board Report No. 8. Regina, 34 p..

Laycock, A.H., 1967. Water Deficiency and Surplus Patterns in the Prairie Provinces. Regina; Prairie Provinces Water Board, Report No. 13, p. 92.

Laycock, A.H., 1973. "Lake Level Fluctuations and Climatic Variations in Central Alberta." Proceedings of symposium on the lakes of Western Canada. Edmonton, pp. 83-98.

Laycock, A.H., 1986. Literature Review of the Water Resources In and Near Elk Island National Park, Alberta. Edmonton, 108 p.

Laycock, A.H., 1987. Personal Communication.

Leith, H., and Box, E., 1972. "Evapotranspiration and Primary Productivity: C.W. Thornthwaite Memorial Model", pp. 156-158 in International Geography 1972.. (edited by W.P. Adams, and F.M. Helleiner). Toronto, p. 694.

Lewis, F.J., Dowding, E.S., and Moss, E.H., 1928. "The Vegetation of Alberta II: The Swamp, Moor, and Bog Forest Vegetation of Central Alberta." *Journal of Ecology 16* , pp. 19-70.

Livingstone, A., 1987a. Surface and Groundwater Withdrawal Management Alternatives in Elk Island National Park, Alberta. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 192 p.

Livingstone, A., 1987b. Personal Communication

MacIver, D.C., 1970. Macroclimatic Zonation in Northern Alberta. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 187 p..

MacIver, Ian, 1966. The Land and Water Resources of the Spring Creek Basin: Some Problems of Settlement on the Agricultural Frontier in Alberta, Canada. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 202 p.

MacKenzie, F. 1987. Annual Water Yields for the City of Edmonton. Ph.d Thesis (in preparation), Department of Geography, University of Alberta.

Mather, J.R., 1954. The Measurement of Potential Evapotranspiration. Laboratory of Climatology, Vol. VII, No. 1. Seabrook, New Jersey, 225 p.

Mather, J.R., 1959. The Moisture Balance in Grassland Climatology in Grasslands. American Assoc. for Advancement of Science, pp. 251-261.

Mather, J.R., 1984. Water Resources: Distribution, Use, and Management. New York, John Wiley and Sons Ltd., 439 p.

Miller, R., 1985. "Annotated Bibliography on Elk Island National Park and Surrounding Area with an Emphasis upon Water and Related Patterns." Edmonton, 140 p..

Mitchell, D.S., ed., 1974. Aquatic Vegetation and Its Uses and Control. UNESCO, Paris, 135 p..

Mohrmann, J.C.J., and Kessler, J., 1959. "Water Deficiencies in European Agriculture: A Climatological Survey." Int. Inst. Land Reclamation and Improvement, Pub. 5, p. 60.

Morrow, J., 1964. "The Deville Story." *Alberta Historical Review* . 12: pp. 15-18.

Muller, R.A., 1972. "Application of Thornthwaite Water Balance Components for Regional Environmental Inventory." pp. 168-170 in International Geography 1972, (edited by W.P. Adams, and F.M. Helleiner), Toronto, 694 p.

Mulligan, H.F., 1969. "Management of Aquatic Vascular Plants and Algae." in Eutrophication: Causes, Consequences, Corrections. Nat'l Acad. of Sci., Washington D.C., pp. 464-482.

Nyland, E., 1969. This Dying Watershed: Alberta Lands-Forests-Parks-Wildlife. Dept. of Lands and Forests, Edmonton.

Oglesby, R.T., 1969. "Effects of Controlled Nutrient Dilution on the Eutrophication of a Lake." in Eutrophication: Causes, Consequences, Corrections. Nat'l Acad. of Sci., Washington D.C., pp. 482-493.

Park, J.O., 1979. Vegetation Patterns and Moisture Availability in the Baker Creek Basin, Near Yellowknife, Northwest Territories. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 237 p..

Parks Canada, 1985. "Elk Island National Park Tourist Guide." Ottawa, 1 p.

Penman, H.L., 1948. "Natural Evaporation from Open Water, Bare Soil, and Grass." Proceedings: Royal Society, Series A, 193, pp. 120-145.

Penman, H.L., 1963. Vegetation and Hydrology. Commonwealth Agricultural Bureaux, Bucks, England, 124 p..

Phillips, D.W., 1976. "Modification of the Climatic Water Balance in Cold Climates", in International Geography 1976, Vol. 2, (edited by I.P. Garasimov), Moscow, pp. 188-192.

Ramdas, L.A., 1972. "Studies on Evaporation, Potential Evapotranspiration from Wet Land Surfaces, Evapotranspiration and Allied Problems", pp. 186-189 in International Geography 1972, (edited by W.P. Adams, and F.M. Helleiner), Toronto, 694 p.

Rowe, J.S., 1972. Forest Regions of Canada. Publication No. 1300 Dept. of Environment, Canadian Forestry Service, Ottawa, 172 p..

Ryding, S.O., and Forsberg, C., 1976. "Six Polluted Lakes: A Preliminary Evaluation of the Treatment and Recovery Processes." pp. 151-158, in *Ambio* . Swedish Academy of Sciences, Vol. V, No. 4, pp. 159-194.

Sanderson, M.E., 1948. "The Climates of Canada According to the New Thornthwaite Classification", Sci. Agri. 28 (11), pp. 501-507.

Sanderson, M.E., 1954. "Measuring Potential Evapotranspiration, Norman Wells, Northwest Territories, Canada", in The Measurement of Potential Evapotranspiration, (edited by J.R. Mather), Seabrook, New Jersey, 225 p.

Sanderson, M.E., and Phillips, D.W., 1967. Average Annual Water Surplus in Canada. Dept. of Transport, Meteorological Branch, Climatological Studies No. 9. Ottawa: Queen's Printer and Controller of Stationary, 76 p.

Smith, G.W., 1954. "Evapotranspiration in Trinidad", in The Measurement of Potential Evapotranspiration, (edited by J.R. Mather), Seabrook, New Jersey, pp. 125-139.

Sokolov, A.A. and Chapman, T.G., eds., 1974. Methods for Water Balance Computations: An international guide for research and practice. The UNESCO Press, Paris, 127 p..

Stein, R., 1976. Hydrogeology of the Edmonton Area (northwest segment), Alberta. Alberta Research Council Report 76-1, Edmonton, 21 p..

Strong, W.L., and Leggat, K.R., 1981. Ecoregions of Alberta. Alberta Energy and Natural Resources. Technical Report T14, Edmonton, 64 p...

Thornthwaite, C.W., 1944. "Report of Committee on Transpiration and Evaporation." Am. Geophys. Union Trans., pt. 5, pp. 686-693.

Thornthwaite, C.W., 1948. "An Approach Towards a Rational Classification of Climate." *Geographical Review* 38(1), pp. 55-94.

Thornthwaite, C.W., 1954. "A Re-Examination of the Concept and Measurement of Potential Evapotranspiration." in The Measurement of Potential Evapotranspiration (edited by J.R. Mather), Seabrook, New Jersey, pp. 200-209.

Thornthwaite, C.W., and Mather, J.R., 1955. "The Water Balance." Publications in Climatology, Vol. VIII, No. 1. Seabrook, New Jersey. p. 104.

Thornthwaite, C.W., and Mather, J.R., 1957. "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance." Publications in Climatology, Vol. X, No. 3. Seabrook, New Jersey, p. 181-311.

Thornthwaite, C.W., Mather, J.R., and Carter, D.B., 1958. "Three Water Balance Maps of Southwest Asia." Publications in Climatology Vol. II, No. 1.

Thornthwaite, C.W., Mather, J.R., and Carter, D.B., 1958. Three Water Balance Maps of Eastern North America. Resources for the Future. Washington D.C.

U.S.S.R. Interdepartmental Committee for the International Hydrological Decade, 1967. "Summary of Methods of Computation of Water Balance (for computation of World Water Balance)", 19 p..

Verma, T.R., 1968. Moisture Balance in Soils of the Edmonton Area. Unpublished Ph.D Thesis, Department of Soil Science, University of Alberta, 204 p..

Ward, R. C., 1975. Principles of Hydrology. London, McGraw-Hill Book Company, pp. 110-117.

Wiche, G.J., 1977. Water Balance Patterns-Beaver Creek Basin: Environmental Management Alternatives in Syncrude Site Development. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 203 p..

Wight, J.B., 1973. Aspects of Evaporation and Evapotranspiration in the Water Balance of Baker Creek Basin, Near Yellowknife, Northwest Territories. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 329 p..

Willman, J, 1987. Personal Communication with Park Superintendent, Elk Island National Park.

Woodburn, R.L., 1977. Surplus Patterns and Water Supply Alternatives: Cooking Lake Moraine. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, 196 p..

Zoltai, S.C., and Pollett, F.C.,1973. "Wetlands in Canada: Their Distribution and Use." Proceedings of the Fourth North American Forest Soils Conference, Laval. (edited by Bernier, B., and Winget, C.W.). pp. 245-268.

# APPENDIX I

## THE CALCULATION OF MONTHLY WATER BALANCES FOR THE EDMONTON INTERNATIONAL AIRPORT 1971-1986

The tables in Appendix I have been prepared to illustrate the monthly water balances at the Edmonton International Airport for the period 1971-1986. The results from these water balances create the major foundations for further study. The surpluses in these tables were used to determine the yields within the different moisture storage categories in chapter 4. Lake level fluctuations within Elk Island National Park were also determined once the yields were calculated. Water balance diagrams created from data in this appendix were compared to the yearly lake level fluctuations in chapter 4 (Figs 4.6, 4.7). This was performed as a check on the water balance procedure.

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1971

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -19.4 | -9.8 | -8.9 | 3.2 | 12.2 | 13.7 | 15 | 17.3 | 8.8 | 3.5 | -4.5 | -17.4 | |
| | PE mm. | 0 | 0 | 0 | 25.4 | 91.4 | 104.1 | 114.3 | 114.3 | 55.9 | 20.3 | 0 | 0 | 525.7 |
| | Ppt. mm. | 56.9 | 2 | 21.3 | 2.3 | 12.4 | 75.7 | 126.5 | 9.9 | 40.4 | 4.8 | 23.9 | 35.8 | 411.9 |
| | St. Ch. mm. | 56.9 | 2 | 21.3 | -23.1 | -79 | -28.4 | 12.2 | -104 | -15.5 | -15.5 | 23.9 | 35.8 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 2 | |
| 43.1 | Surp | 56.9 | 2 | 21.3 | | | | 10.2 | | | | 21.9 | 35.8 | 137.5 |
| | Def. | | | | 21.1 | 79 | 28.4 | | 102.4 | 15.5 | 15.5 | | | 261.9 |
| | 411.9=(525.7-261.9)+133.5+14.6 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 0 | 0 | 0 | 12.2 | 0 | 0 | 0 | 13 | 13 | |
| 43.1 | Surp. | 56.9 | 2 | 21.3 | | | | | | | | 10.9 | 35.8 | 123.3 |
| | Def. | | | | 10.1 | 79 | 28.4 | | 92.2 | 15.5 | 15.5 | | | 240.7 |
| | 411.9=(525.7-240.7)+123.3+3.6 | | | | | | | | | | | | | |
| 50 | St. 50 mm. | 50 | 50 | 50 | 26.9 | 0 | 0 | 12.2 | 0 | 0 | 0 | 23.9 | 50 | |
| 21.3 | Surp. | 56.9 | 2 | 21.3 | | | | | | | | | 9.7 | 101.5 |
| | Def. | | | | | 52.1 | 28.4 | | 92.2 | 15.5 | 15.5 | | | 203.7 |
| | 411.9=(525.7-203.7)+101.5-11.6 | | | | | | | | | | | | | |
| 72.1 | St. 100mm | 100 | 100 | 100 | 76.9 | 0 | 0 | 12.2 | 0 | 0 | 0 | 23.9 | 59.7 | |
| | Surp. | 29 | 2 | 21.3 | | | | | | | | | | 52.3 |
| | Def. | | | | | 2.1 | 28.4 | | 92.2 | 15.5 | 15.5 | | | 153.7 |
| | 411.9=(525.7-153.7)+52.3-12.4 | | | | | | | | | | | | | |
| 72.1 | St. 150 mm. | 129 | 131 | 150 | 126.9 | 47.9 | 19.5 | 21.7 | 0 | 0 | 0 | 23.9 | 59.7 | |
| | Surp. | | | 2.3 | | | | | | | | | | 2.3 |
| | Def. | | | | | | | | 72.7 | 15.5 | 15.5 | | | 10[illegible].7 |
| | 411.9=(525.7-103.7)+2.3-12.4 | | | | | | | | | | | | | |
| 72.1 | St. 250 mm. | 129 | 131 | 152.3 | 129.2 | 50.2 | 21.8 | 34 | 0 | 0 | 0 | 23.9 | 59.7 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | 70.4 | 15.5 | 15.5 | | | 101.4 |
| | 411.9=(525.7-101.4)+0-12.4 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1972

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -19.6 | -16.8 | -6.2 | 2.6 | 11 | 14.6 | 13.4 | 16.4 | 5.6 | 2.7 | -4.6 | -15.9 | |
| | PE mm. | 0 | 0 | 0 | 17.8 | 91.4 | 114.3 | 104.1 | 114.3 | 40.6 | 20.3 | 0 | 0 | 502.8 |
| | Ppt. mm. | 20.1 | 31.2 | 30.7 | 38.9 | 49.8 | 106.4 | 88.1 | 94.5 | 47.8 | 10.7 | 27.7 | 14 | 559.9 |
| | St. Ch. mm. | 20.1 | 31.2 | 30.7 | 21.1 | -41.6 | -7.9 | -16 | -19.8 | 7.2 | -9.6 | 27.7 | 14 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | |
| 57.7 | Surp | 20.1 | 31.2 | 30.7 | 21.1 | | | | | 5.2 | | 25.7 | 14 | 166 |
| | Def. | | | | | 39.6 | 7.9 | 16 | 19.8 | | 7.6 | | | 90.9 |
| | 559.9=(502.8-90.9)+166-18 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 0 | 0 | 0 | 7.2 | 0 | 13 | 13 | |
| 46.7 | Surp. | 20.1 | 31.2 | 30.7 | 21.1 | | | | | | | 14.7 | 14 | 149.8 |
| | Def. | | | | | 28.6 | 7.9 | 16 | 19.8 | | 2.4 | | | 74.7 |
| | 559.9=(502.8-74.7)+149.8-18 | | | | | | | | | | | | | |
| 50 | St. 50 mm. | 50 | 50 | 50 | 50 | 8.4 | 0.5 | 0 | 0 | 7.2 | 0 | 27.7 | 41.7 | |
| 9.7 | Surp. | 20.1 | 31.2 | 30.7 | 21.1 | | | | | | | | | 112.8 |
| | Def. | | | | | | | 15.5 | 19.8 | | 2.4 | | | 37.7 |
| | 559.9=(502.8-37.7)+112.8-18 | | | | | | | | | | | | | |
| 59.7 | St. 100mm | 79.8 | 100 | 100 | 100 | 58.4 | 50.5 | 34.5 | 14.7 | 21.9 | 12.3 | 40 | 54 | |
| | Surp. | | 11 | 30.7 | 21.1 | | | | | | | | | 52.8 |
| | Def. | | | | | | | | | | | | | 0 |
| | 559.9=(502.8-0)+62.8-5.7 | | | | | | | | | | | | | |
| 59.7 | St. 150 mm. | 79.8 | 111 | 141.7 | 150 | 108.4 | 100.5 | 84.5 | 64.7 | 71.9 | 62.3 | 90 | 104 | |
| | Surp. | | | | 12.8 | | | | | | | | | 12.8 |
| | Def. | | | | | | | | | | | | | 0 |
| | 559.9=(502.8-0)+12.8+44.3 | | | | | | | | | | | | | |
| 59.7 | St. 250 mm. | 79.8 | 111 | 141.7 | 162.8 | 121.2 | 113.3 | 97.3 | 77.5 | 84.7 | 75.1 | 102.8 | 116.8 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 0 |
| | 559.9=(502.8-0)+0+57.1 | | | | | | | | | | | | | |

APPENDIX I CONTINUED

### EDMONTON INTERNATIONAL AIRPORT
### WATER BALANCE 1973

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -12.4 | -11.2 | -2.9 | 2.6 | 11.1 | 13.9 | 15.6 | 14.8 | 10 | 3.6 | -14.8 | -12.9 | |
| | PE mm. | 0 | 0 | 0 | 17.8 | 91.4 | 104.1 | 124.5 | 104.1 | 63.5 | 27.9 | 0 | 0 | 533.3 |
| | Ppt. mm. | 12.2 | 10.7 | 10.7 | 46.2 | 37.1 | 147.6 | 87.9 | 110.5 | 34.3 | 33.5 | 28.7 | 25.9 | 585.3 |
| | St. Ch. mm. | 12.2 | 10.7 | 10.7 | 28.4 | -54.3 | 43.5 | -36.6 | 6.4 | -29.2 | 5.6 | 28.7 | 25.9 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 2 | 2 | |
| 39.7 | Surp | 12.2 | 10.7 | 10.7 | 28.4 | | 41.5 | | 4.4 | | 3.6 | 28.7 | 25.9 | 151.2 |
| | Def. | | | | | 52.3 | | 34.6 | | 27.2 | | | | 114.1 |
| | 585.3=(533.3-114.1)+151.2+14.9 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 13 | 0 | 6.4 | 0 | 5.6 | 13 | 13 | |
| 18.7 | Surp. | 12.2 | 10.7 | 10.7 | 28.4 | | 30.5 | | | | | 21.3 | 25.9 | 111.2 |
| | Def. | | | | | 41.3 | | 23.6 | | 22.8 | | | | 87.7 |
| | 585.3=(533.3-87.7)+111.2+28.5 | | | | | | | | | | | | | |
| 41.7 | St. 50 mm. | 50 | 50 | 50 | 50 | 0 | 43.5 | 6.9 | 13.3 | 0 | 5.6 | 34.3 | 50 | |
| | Surp. | 3.9 | 10.7 | 10.7 | 28.4 | | | | | | | | 10.2 | 53.7 |
| | Def. | | | | | 4.3 | | | | 15.9 | | | | 20.2 |
| | 585.3=(533.3-20.2)+53.7+18.5 | | | | | | | | | | | | | |
| 54 | St. 100mm | 66.2 | 76.9 | 87.6 | 100 | 45.7 | 89.2 | 52.6 | 59 | 29.8 | 35.4 | 64.1 | 90 | |
| | Surp. | | | | 16 | | | | | | | | | 16 |
| | Def. | | | | | | | | | | | | | 0 |
| | 585.3=(533.3-0)+16+36 | | | | | | | | | | | | | |
| 104 | St. 150 mm. | 116.2 | 126.9 | 137.6 | 150 | 95.7 | 139.2 | 102.6 | 109 | 79.8 | 85.4 | 114.1 | 140 | |
| | Surp. | | | | 16 | | | | | | | | | 16 |
| | Def. | | | | | | | | | | | | | 0 |
| | 585.3=(533.3-0)+16+36 | | | | | | | | | | | | | |
| 116.8 | St. 250 mm. | 129 | 139.7 | 150.4 | 178.8 | 124.5 | 168 | 131.4 | 137.8 | 108.6 | 114.2 | 142.9 | 168.8 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 0 |
| | 585.3=(533.3-0)+0+52 | | | | | | | | | | | | | |

### EDMONTON INTERNATIONAL AIRPORT
### WATER BALANCE 1974

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -18.9 | -20.7 | -12.1 | 2.6 | 8.1 | 14.6 | 15.1 | 12.7 | 8.7 | 6.7 | -2.8 | -5.9 | |
| | PE mm. | 0 | 0 | 0 | 26.4 | 61 | 114.3 | 114.3 | 96.5 | 55.9 | 43.2 | 0 | 0 | 511.6 |
| | Ppt. mm. | 45 | 20.8 | 39.9 | 14.5 | 40.1 | 116.6 | 88.4 | 48.8 | 31.2 | 4.3 | 2.8 | 21.3 | 473.7 |
| | St. Ch. mm. | 45 | 20.8 | 39.9 | -11.9 | -20.9 | 2.3 | -25.9 | -47.7 | -24.7 | -38.9 | 2.8 | 21.3 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | |
| 54.6 | Surp | 45 | 20.8 | 39.9 | | | 0.3 | | | | | 0.8 | 21.3 | 160.6 |
| | Def. | | | | 9.9 | 20.9 | | 23.9 | 47.7 | 24.7 | 38.9 | | | 166.6 |
| | 473.7=(511.6-166)+166.6-32.5 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 1.1 | 0 | 2.3 | 0 | 0 | 0 | 0 | 2.8 | 13 | |
| 47.2 | Surp. | 45 | 20.8 | 39.9 | | | | | | | | | 11.1 | 152.9 |
| | Def. | | | | | 19.8 | | 23.6 | 47.7 | 24.7 | 38.9 | | | 154.7 |
| | 473.7=(511.6-154.7)+152.9-36.1 | | | | | | | | | | | | | |
| 50 | St. 50 mm. | 50 | 50 | 50 | 38.1 | 17.2 | 19.5 | 0 | 0 | 0 | 0 | 2.8 | 24.1 | |
| 10.2 | Surp. | 45 | 20.8 | 39.9 | | | | | | | | | | 115.9 |
| | Def. | | | | | | | 6.4 | 47.7 | 24.7 | 38.9 | | | 117.7 |
| | 473.7=(511.6-117.7)+115.9-36.1 | | | | | | | | | | | | | |
| 90 | St. 100mm | 100 | 100 | 100 | 88.1 | 67.2 | 69.5 | 43.6 | 0 | 0 | 0 | 2.8 | 24.1 | |
| | Surp. | 35 | 20.8 | 39.9 | | | | | | | | | | 95.7 |
| | Def. | | | | | | | | 4.1 | 24.7 | 38.9 | | | 67.7 |
| | 473.7=(511.6-67.7)+95.7-65.9 | | | | | | | | | | | | | |
| 140 | St. 150 mm. | 150 | 150 | 150 | 138.1 | 117.2 | 119.5 | 93.6 | 45.9 | 21.2 | 0 | 2.8 | 24.1 | |
| | Surp. | 35 | 20.8 | 39.9 | | | | | | | | | | 95.7 |
| | Def. | | | | | | | | | | 17.7 | | | 17.7 |
| | 473.7=(511.6-17.7)+95.7-115.9 | | | | | | | | | | | | | |
| 168.8 | St. 250 mm. | 213.8 | 234.6 | 250 | 238.1 | 217.2 | 219.5 | 193.6 | 145.9 | 121.2 | 82.3 | 85.1 | 106.4 | |
| | Surp. | | | 24.5 | | | | | | | | | | 24.5 |
| | Def. | | | | | | | | | | | | | 0 |
| | 473.7=(511.6-0)+24.5-62.4 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1975

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -12.1 | -15.8 | -9.7 | -0.9 | 9.6 | 12.[illegible] | 17.[illegible] | 12.3 | 10.5 | 3 | -4.7 | -12.4 | |
| | PE mm. | 0 | 0 | 0 | 0 | 76 | 9[illegible] | 127 | 90 | 60 | 19 | 0 | 0 | 470 |
| | Ppt. mm. | 12 | 15 | 15 | 30 | 51 | 10[illegible] | 69 | 98 | 11 | 24 | 6 | 26 | 460 |
| | St. Ch. mm. | 12 | 15 | 15 | 30 | -25 | 5 | -58 | 8 | 4[illegible] | 5 | 6 | 26 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 2 | 2 | |
| 22.1 | Surp | 12 | 15 | 15 | 30 | | 3 | | 6 | | 3 | 6 | 26 | 106.1 |
| | Def. | | | | | 23 | | 58 | | 47 | | | | 126 |
| | 460=(470-126)+106.1+9.9 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 5 | 0 | 8 | 0 | 5 | 11 | 13 | |
| 11.1 | Surp. | 12 | 15 | 15 | 30 | | | | | | | | 24 | 83.1 |
| | Def. | | | | | 12 | | 53 | | 41 | | | | 106 |
| | 460=(470-106)+82+14 | | | | | | | | | | | | | |
| 24.1 | St. 50 mm. | 36.1 | 50 | 50 | 50 | 25 | 30 | 0 | 8 | 0 | 5 | 11 | 37 | |
| | Surp. | | 1.1 | 15 | 30 | | | | | | | | | 46.1 |
| | Def. | | | | | | | 28 | | 41 | | | | 69 |
| | 460=(470-69)+45+14 | | | | | | | | | | | | | |
| 24.1 | St. 100mm | 36.1 | 51.1 | 66.1 | 96.1 | 71.1 | 76.1 | 18.1 | 26.1 | 0 | 5 | 11 | 37 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | 22.9 | | | | 22.9 |
| | 460=(470-24)0+14 | | | | | | | | | | | | | |
| 24.1 | St. 150 mm. | | | | | | | | | | | | | |
| | Surp. | | | Same as 100 mm. | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 22.9 |
| | 460=(470-24)+0+14 | | | | | | | | | | | | | |
| 106.4 | St. 250 mm. | 118.4 | 133.4 | 148.4 | 178.4 | 153.4 | 158.4 | 100.4 | 108.4 | 59.4 | 64.4 | 70.4 | 96.4 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 0 |
| | 460=(470-0)+0-10 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1976

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -12.5 | -8.9 | -6 | 6.3 | 11 | 12 | 15.5 | 16.2 | 11.9 | 3.8 | -2 | -9.9 | |
| | PE mm. | 0 | 0 | 0 | 41.4 | 83.8 | 89.8 | 115.1 | 108.8 | 70 | 22.1 | 0 | 0 | 531 |
| | Ppt. mm. | 11.4 | 21.5 | 15.9 | 11.7 | 30.2 | 90.8 | 74.7 | 111.1 | 43 | 9.9 | 6.7 | 31.4 | 458.3 |
| | St. Ch. mm. | 11.4 | 21.5 | 15.9 | -29.7 | -53.6 | 1 | -40.4 | 2.3 | -27 | -12.2 | 6.7 | 31.4 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 2 | 2 | |
| 32 | Surp | 11.4 | 21.5 | 15.9 | | | | | 0.3 | | | 4.7 | 31.4 | 81.1 |
| | Def. | | | | 27.7 | 53.6 | | 39.4 | | 25 | 12.2 | | | 157.9 |
| | 458.3=(531-157.9)+81.1+4.1 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 0 | 0 | 1 | 0 | 2.3 | 0 | 0 | 6.7 | 13 | |
| 24 | Surp. | 11.4 | 21.5 | 15.9 | | | | | | | | | 25.1 | 72.8 |
| | Def. | | | | 16.7 | 53.6 | | 39.4 | | 24.7 | 12.2 | | | 146.6 |
| | 458.3=(531-146.6)+72.8+1.1 | | | | | | | | | | | | | |
| 37 | St. 50 mm. | 48.4 | 50 | 50 | 20.3 | 0 | 1 | 0 | 2.3 | 0 | 0 | 6.7 | 38.1 | |
| | Surp. | 24.9 | 19.9 | 15.9 | | | | | | | | | | 35.8 |
| | Def. | | | | | 33.3 | | 39.4 | | 24.7 | 12.2 | | | 109.6 |
| | 458.3=(531-109.6)+35.8+1.1 | | | | | | | | | | | | | |
| 37 | St. 100mm | 48.4 | 69.9 | 85.8 | 56.1 | 2.5 | 3.5 | 0 | 2.3 | 0 | 0 | 6.7 | 38.1 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | 36.9 | | 24.7 | 12.2 | | | 73.8 |
| | 458.3=(531-73.8)+0+1.1 | | | | | | | | | | | | | |
| 37 | St. 150 mm. | | | | | | | | | | | | | |
| | Surp. | | Same as 100 mm. | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 73.8 |
| | 458.3=(531-73.8)+0+1.1 | | | | | | | | | | | | | |
| 96.4 | St. 250 mm. | 107.8 | 129.3 | 145.2 | 115.5 | 61.9 | 62.9 | 22.5 | 24.8 | 0 | 0 | 6.7 | 38.1 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | 2.2 | 12.2 | | | 14.4 |
| | 458.3=(531-14.4)+0-58.3 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1977

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -12 | -2.8 | -2.8 | 6.9 | 10.4 | 14.2 | 14.2 | 11.7 | 9.3 | 4.7 | -6.7 | -17 | |
| | PE mm. | 0 | 0 | 0 | 51.8 | 79.8 | 106.1 | 106.9 | 82.5 | 57.2 | 27.6 | 0 | 0 | 511.9 |
| | Ppt. mm. | 18.1 | 2.7 | 6.8 | 18.9 | 131.9 | 12.5 | 90.7 | 86.5 | 38 | 0.4 | 10.4 | 18.9 | 435.8 |
| | St. Ch. mm. | 18.1 | 2.7 | 6.8 | -32.9 | 52.1 | -93.6 | -16.2 | 4 | -19.2 | -27.2 | 10.4 | 18.9 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 2 | 2 | |
| 36.1 | Surp | 18.1 | 2.7 | 6.8 | | 50.1 | | | 2 | | | 8.4 | 18.9 | 115.8 |
| | Def. | | | | 30.9 | | 91.6 | 16.2 | | 17.2 | 27.2 | | | 183.1 |
| | 435.8=(511.9-183.1)+115.8-8.8 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 0 | 13 | 0 | 0 | 4 | 0 | 0 | 10.4 | 13 | |
| 25.1 | Surp. | 18.1 | 2.7 | 6.8 | | 39.1 | | | | | | | 16.3 | 91.8 |
| | Def. | | | | 19.9 | | 80.6 | 16.2 | | 15.2 | 27.2 | | | 159.1 |
| | 435.8=(511.9-159.1)+91.8-8.8 | | | | | | | | | | | | | |
| 38.1 | St. 50 mm. | 50 | 50 | 50 | 17.1 | 50 | 0 | 0 | 4 | 0 | 0 | 10.4 | 29.3 | |
| | Surp. | 6.2 | 2.7 | 6.8 | | 19.2 | | | | | | | | 34.9 |
| | Def. | | | | | | 43.6 | 16.2 | | 15.2 | 27.2 | | | 102.2 |
| | 435.8=(511.9-102.2)+34.9-8.8 | | | | | | | | | | | | | |
| 38.1 | St. 100mm | 56.2 | 58.9 | 65.7 | 32.8 | 84.9 | 0 | 0 | 4 | 0 | 0 | 10.4 | 29.3 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | 8.7 | 16.2 | 3.5 | 15.2 | 27.2 | | | 67.3 |
| | 435.8=(511.9-67.3)+0-8.8 | | | | | | | | | | | | | |
| 38.1 | St. 150 mm. | | | | | | | | | | | | | |
| | Surp. | Same as 100 mm. | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 67.3 |
| | 435.8=(511.9-67.3)+0-8.8 | | | | | | | | | | | | | |
| 38.1 | St. 250 mm. | | | | | | | | | | | | | |
| | Surp. | Same as 100 mm. | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 67.3 |
| | 435.8=(511.9-67.3)+0-8.8 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1978

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -18.2 | -13.4 | -3.6 | 4.7 | 9.8 | 15.3 | 16.4 | 14.1 | 9.9 | 6.5 | -6.8 | -12 | |
| | PE mm. | 0 | 0 | 0 | 34.5 | 71.8 | 114.2 | 123.3 | 93.8 | 60.4 | 35.9 | 0 | 0 | 533.9 |
| | Ppt. mm. | 25.1 | 9.2 | 5.2 | 16.1 | 64.2 | 40.6 | 63.6 | 111.4 | 141.5 | 17.3 | 39.4 | 7 | 540.6 |
| | St. Ch. mm. | 25.1 | 9.2 | 5.2 | -18.4 | -7.6 | -73.6 | -59.7 | 17.6 | 81.1 | -18.6 | 39.4 | 7 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 2 | |
| 29.3 | Surp | 25.1 | 9.2 | 5.2 | | | | | 15.6 | 81.1 | | 37.4 | 7 | 163.5 |
| | Def. | | | | 16.4 | 7.6 | 73.6 | 59.7 | | | 16.6 | | | 173.9 |
| | 540.6=(533.9-173.9)+163.5+17.1 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 0 | 0 | 0 | 0 | 13 | 13 | 0 | 13 | 13 | |
| 16.3 | Surp. | 25.1 | 9.2 | 5.2 | | | | | 4.6 | 81.1 | | 26.4 | 7 | 141.5 |
| | Def. | | | | 5.4 | 7.6 | 73.6 | 59.7 | | | 5.6 | | | 151.9 |
| | 540.6=(533.9-151.9)+141.5+17.1 | | | | | | | | | | | | | |
| 29.3 | St. 50 mm. | 50 | 50 | 50 | 31.6 | 24 | 0 | 0 | 17.6 | 50 | 31.4 | 50 | 50 | |
| | Surp. | 4.4 | 9.2 | 5.2 | | | | | | 48.7 | | 20.8 | 7 | 67.5 |
| | Def. | | | | | | 49.6 | 59.7 | | | | | | 109.3 |
| | 540.6=(533.9-109.3)+67.5+48.5 | | | | | | | | | | | | | |
| 29.3 | St. 100mm | 54.4 | 63.6 | 68.8 | 50.4 | 42.8 | 0 | 0 | 17.6 | 98.7 | 80.1 | 100 | 100 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | 30.8 | 59.7 | | | | | | 90.5 |
| | 540.6=(533.9-90.5)+0+97.2 | | | | | | | | | | | | | |
| 29.3 | St. 150 mm. | | | | | | | | | | | | | |
| | Surp. | Same as 100 mm. | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 90.5 |
| | 540.6=(533.9-90.[illegible] | | | | | | | | | | | | | |
| 156.6 | St. 250 mm. | | | | | | | | | | | | | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 90.5 |
| | 540.6=(533.9-[illegible] | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1979

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -16.4 | -22.9 | -1.7 | 0.8 | 8.1 | 14 | 16.6 | 15 | 11.9 | 6.1 | -2.7 | -9.3 | |
| | PE mm. | 0 | 0 | 0 | 6.9 | 63.8 | 106.1 | 123.3 | 101.3 | 73.1 | 35.9 | 0 | 0 | 510.4 |
| | Ppt. mm. | 4.2 | 28.9 | 8.3 | 31.2 | 36.4 | 70.3 | 111 | 40.9 | 50.2 | 12.7 | 8.6 | 26.8 | 429.5 |
| | St. Ch. mm. | 4.2 | 28.9 | 8.3 | 24.3 | -27.4 | -35.8 | -12.3 | -60.4 | -22.9 | -23.2 | 8.6 | 26.8 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | |
| 44.4 | Surp | 4.2 | 28.9 | 8.3 | 24.3 | | | | | | | 8.6 | 26.8 | 110.1 |
| | Def. | | | | | 25.4 | 35.8 | 12.3 | 60.4 | 22.9 | 23.2 | | | 180 |
| | 429.5=(510.4-180)+110.1-11 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 8.6 | 13 | |
| 33.4 | Surp. | 4.2 | 28.9 | 8.3 | 24.3 | | | | | | | | 22.4 | 99.1 |
| | Def. | | | | | 14.4 | 35.8 | 12.3 | 60.4 | 22.9 | 23.2 | | | 169 |
| | 429.5=(510.4-169)+99.1-11 | | | | | | | | | | | | | |
| 50 | St. 50 mm. | 50 | 50 | 50 | 50 | 22.6 | 0 | 0 | 0 | 0 | 0 | 8.6 | 35.4 | |
| 27.8 | Surp. | 4.2 | 28.9 | 8.3 | 24.3 | | | | | | | | | 93.5 |
| | Def. | | | | | 38.8 | 13.2 | 12.3 | 60.4 | 22.9 | 23.2 | | | 132 |
| | 429.5=(510.4-132)+93.5-42.4 | | | | | | | | | | | | | |
| 100 | St. 100mm | 100 | 100 | 100 | 100 | 72.6 | 36.8 | 24.5 | 0 | 0 | 0 | 8.6 | 35.4 | |
| 26.5 | Surp. | 4.2 | 28.9 | 8.3 | 24.3 | | | | | | | | | 92.2 |
| | Def. | | | | | | | | 35.9 | 22.9 | 23.2 | | | 82 |
| | 429.5=(510.4-82)+92.2-91.1 | | | | | | | | | | | | | |
| 126.5 | St. 150 mm. | 130.7 | 150 | 150 | 150 | 122.6 | 86.8 | 74.5 | 14.1 | 0 | 0 | 8 6 | 35.4 | |
| | Surp. | | 9.6 | 8.3 | 24.3 | | | | | | | | | 42.2 |
| | Def. | | | | | | | | | 8.8 | 23.2 | | | 32 |
| | 429.5=(510.4-32)+42.2-91.1 | | | | | | | | | | | | | |
| 126.5 | St. 250 mm. | 130.7 | 159.6 | 167.9 | 192.2 | 164.8 | 129 | 116.7 | 56.3 | 33.4 | 10.2 | 18.8 | 45.6 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 0 |
| | 429.5=(510.4-0)+0-80.9 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1980

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -16.8 | -10.2 | -7.2 | 8 | 11.3 | 14.5 | 15.5 | 12.5 | 9 | 5.9 | -0.7 | -15.4 | |
| | PE mm. | 0 | 0 | 0 | 55.2 | 83.8 | 106.1 | 115.1 | 86.3 | 54.1 | 33.1 | 0 | 0 | 533.7 |
| | Ppt. mm. | 24.2 | 15.6 | 19.5 | 4 | 43 | 131.9 | 69.2 | 194.8 | 53.6 | 11.2 | 1.2 | 44.7 | 614.9 |
| | St. Ch. mm. | 24.2 | 15.6 | 19.5 | -51.2 | -40.8 | 25.8 | -45.9 | 108.5 | 1.5 | -21.9 | 1.2 | 44.7 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 2 | 2 | 0 | 2 | 2 | |
| 33.4 | Surp | 24.2 | 15.6 | 19.5 | | | 23.8 | | 106.5 | 1.5 | | | 43.9 | 224.5 |
| | Def. | | | | 49.2 | 40.8 | | 43.9 | | | 19.9 | | | 153.8 |
| | 614.9=(533.7-153.8)+224.5+10.5 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 0 | 0 | 13 | 0 | 13 | 13 | 0 | 1.2 | 13 | |
| 22.4 | Surp. | 24.2 | 15.6 | 19.5 | | | 12.8 | | 95.5 | 1.5 | | | 32.9 | 191.5 |
| | Def. | | | | 38.2 | 40.8 | | 32.9 | | | 8.9 | | | 120.8 |
| | 614.9=(533.7-120.8)+191.5+10.5 | | | | | | | | | | | | | |
| 35.4 | St. 50 mm. | 50 | 50 | 50 | 0 | 0 | 25.8 | 0 | 50 | 50 | 28.1 | 29.3 | 50 | |
| | Surp. | 9.6 | 15.6 | 19.5 | | | | | 58.5 | 1 5 | | | 24 | 104.7 |
| | Def. | | | | 1.2 | 40.8 | | 20.1 | | | | | | 62.1 |
| | 614.9=(533.7-62.1)+104.7+38.6 | | | | | | | | | | | | | |
| 35.4 | St. 100mm | 59.6 | 75.2 | 94.7 | 43.5 | 2.7 | 28.5 | 0 | 100 | 100 | 78.1 | 79.3 | 100 | |
| | Surp. | | | | | | | | 8.5 | 1.5 | | | 24 | 10 |
| | Def. | | | | | | | 17.4 | | | | | | 17.4 |
| | 614.9=(533.7-17.4)+10+88.6 | | | | | | | | | | | | | |
| 35.4 | St. 150 mm. | 59.6 | 75.2 | 94.7 | 43.5 | 2.7 | 28.5 | 0 | 108.5 | 110 | 88.1 | 89.3 | 134 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | 17.4 | | | | | | 17.4 |
| | 614.9=(533.7-17.4)+0+98.6 | | | | | | | | | | | | | |
| 45.6 | St. 250 mm. | 69.8 | 85.4 | 104.9 | 53.7 | 12.9 | 38.7 | 0 | 108.5 | 110 | 88.1 | 89.3 | 134 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | 7.2 | | | | | | 7.2 |
| | 614.9=(533.7-7.2)+0+88.4 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1981

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -5.8 | -7.3 | 0.1 | 4.3 | 11.2 | 12.4 | 15.7 | 18 | 12.1 | 4.1 | -0.3 | -10.9 | |
| | PE mm. | 0 | 0 | 0 | 31.1 | 83.8 | 93.8 | 119.2 | 120 | 70 | 22.1 | 0 | 0 | 540 |
| | Ppt. mm. | 4.9 | 7.8 | 11.8 | 9.8 | 46.9 | 42.3 | 157.6 | 10.5 | 33.4 | 30 | 3 | 12.6 | 370.6 |
| | St. Ch. mm. | 4.9 | 7.8 | 11.8 | -21.3 | -36.9 | -51.5 | 38.4 | -110 | -36.6 | 7.9 | 3 | 12.6 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 2 | 2 | |
| 43.9 | Surp | 4.9 | 7.8 | 11.8 | | | | 36.4 | | | 5.9 | 3 | 12.6 | 110.7 |
| | Def. | | | | 19.3 | 36.9 | 51.5 | | 107.5 | 36.6 | | | | 251.8 |
| | 370.6=(540-251.8)+110.7-28.3 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 0 | 0 | 0 | 13 | 0 | 0 | 7.9 | 10.9 | 13 | |
| 32.9 | Surp. | 9 | 16.9 | 27 | | | | 45.3 | | | | | 16.5 | 82.8 |
| | Def. | | | | 8.3 | 36.9 | 51.5 | | 96.5 | 36.6 | | | | 229.8 |
| | 370.6=(540-229.8)+82.8-22.4 | | | | | | | | | | | | | |
| 50 | St. 50 mm. | 50 | 50 | 50 | 28.7 | 0 | 0 | 38.4 | 0 | 0 | 7.9 | 10.9 | 23.5 | |
| 24 | Surp. | 4.9 | 7.8 | 11.8 | | | | | | | | | | 48.5 |
| | Def. | | | | | 8.2 | 51.5 | | 71.1 | 36.6 | | | | 167.4 |
| | 370.6=(540-167.4)+48.5-50.5 | | | | | | | | | | | | | |
| 100 | St. 100mm | 100 | 100 | 100 | 78.7 | 41.8 | 0 | 38.4 | 0 | 0 | 7.9 | 10.9 | 23.5 | |
| 24 | Surp. | 4.9 | 7.8 | 11.8 | | | | | | | | | | 48.5 |
| | Def. | | | | | | 9.7 | | 71.1 | 36.6 | | | | 117.4 |
| | 370.6=(540-117.4)+48.5-100.5 | | | | | | | | | | | | | |
| 134 | St. 150 mm. | 138.9 | 146.7 | 150 | 128.7 | 91.8 | 40.3 | 78.7 | 0 | 0 | 7.9 | 10.9 | 23.5 | |
| | Surp. | | | 8.5 | | | | | | | | | | 8.5 |
| | Def. | | | | | | | | 30.8 | 36.6 | | | | 67.4 |
| | 370.6=(540-67.4)+8.5-110.5 | | | | | | | | | | | | | |
| 134 | St. 250 mm. | 138.9 | 146.7 | 158.5 | 137.2 | 100.3 | 48.8 | 87.2 | 0 | 0 | 7.9 | 10.9 | 23.5 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | 23.3 | 36.6 | | | | 58.9 |
| | 370.6=(540-58.9)+0-110.5 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1982

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -23.2 | -16.2 | -8.6 | -0.6 | 10 | 15.2 | 16.1 | 13 | 10.7 | 4.6 | -8.8 | -9.4 | |
| | PE mm. | 0 | 0 | 0 | 0 | 75.8 | 114.2 | 119.2 | 90 | 66.8 | 27.6 | 0 | 0 | 493.6 |
| | Ppt. mm. | 67.7 | 12.7 | 32.1 | 16.4 | 27.9 | 25.1 | 204.6 | 43.2 | 35.6 | 39.1 | 9 | 3 | 516.4 |
| | St. Ch. mm. | 67.7 | 12.7 | 32.1 | 16.4 | -47.9 | -89.1 | 85.4 | -46.8 | -31.2 | 11.5 | 9 | 3 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 2 | 2 | 2 | |
| 15.6 | Surp | 67.7 | 12.7 | 32.1 | 16.4 | | | 83.4 | | | 9.5 | 9 | 0 | 237.4 |
| | Def. | | | | | 45.9 | 89.1 | | 44.8 | 31.2 | | | | 211 |
| | 516.4=(493.6-211)+237.4-3.6 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 0 | 13 | 0 | 0 | 11.5 | 13 | 13 | |
| 10.5 | Surp. | 67.7 | 12.7 | 32.1 | 16.4 | | | 72.4 | | | | 7.5 | 3 | 211.8 |
| | Def. | | | | 9.3 | 34.9 | 89.1 | | 33.8 | 31.2 | | | | 189 |
| | 516.4=(493.6-189)+137.8+0 | | | | | | | | | | | | | |
| 23.5 | St. 50 mm. | 50 | 50 | 50 | 50 | 2.1 | 0 | 50 | 3.2 | 0 | 11.5 | 20.5 | 23.5 | |
| | Surp. | 41.2 | 12.7 | 32.1 | 16.4 | | | 35.4 | | | | | | 137.8 |
| | Def. | | | | | | 87 | | | 28 | | | | 115 |
| | 516.4=(493.6-115)+137.8+0 | | | | | | | | | | | | | |
| 23.5 | St. 100mm | 91.2 | 100 | 100 | 100 | 52.1 | 0 | 85.4 | 38.6 | 7.4 | 18.9 | 27.9 | 30.9 | |
| | Surp. | | 3.9 | 32.1 | 16.4 | | | | | | | | | 52.4 |
| | Def. | | | | | | 37 | | | | | | | 37 |
| | 516.4=(493.6-37)+52.4+7.4 | | | | | | | | | | | | | |
| 23.5 | St. 150 mm. | 91.2 | 103.9 | 136 | 150 | 102.7 | 13 | 98.4 | 51.6 | 20.4 | 31.9 | 40.9 | 43.9 | |
| | Surp. | | | | 2.4 | | | | | | | | | 2.4 |
| | Def. | | | | | | | | | | | | | 0 |
| | 516.4=(493.6-0)+2.4+20.4 | | | | | | | | | | | | | |
| 23.5 | St. 250 mm. | 91.2 | 103.9 | 136 | 152.4 | 104.5 | 15.4 | 100.8 | 54 | 22.8 | 34.3 | 43.3 | 46.3 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 0 |
| | 516.4=(493.6-0)+0+22.8 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1983

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -10.3 | -8.4 | -4.4 | 4.8 | 9.9 | 13.6 | 16.6 | 16.8 | 8.4 | 4.6 | -4.2 | -19.5 | |
| | PE mm. | 0 | 0 | 0 | 34.5 | 75.8 | 102 | 123.3 | 112.5 | 54.1 | 27.6 | 0 | 0 | 529.8 |
| | Ppt. mm. | 4.9 | 16.5 | 19.3 | 18.3 | 10.2 | 151.1 | 104.5 | 12.2 | 36.2 | 12.2 | 13.4 | 10.6 | 409.8 |
| | St. Ch. mm. | 4.9 | 16.5 | 19.3 | -16.2 | -65.6 | 49.1 | -18.8 | -100 | -17.9 | -15.4 | 13.4 | 10.6 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | |
| 12 | Surp | 4.9 | 16.5 | 19.3 | | | 47.1 | | | | | 11.4 | 10.6 | 99.8 |
| | Def. | | | | 14.2 | 65.6 | | 16.8 | 100.3 | 17.9 | 15.4 | | | 230.2 |
| | 409.4=(529.8-230.2)+99.8+10 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | -13 | 13 | 13 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 13 | 13 | |
| 10.5 | Surp. | 4.9 | 16.5 | 19.3 | | | 36.1 | | | | | 0.4 | 10.6 | 87.3 |
| | Def. | | | | 3.2 | 65.6 | | 5.8 | 100.3 | 17.9 | 15.4 | | | 208.2 |
| | 409.4=(529.8-208.2)+87.3+.5 | | | | | | | | | | | | | |
| 23.5 | St. 50 mm. | 28.4 | 44.9 | 50 | 33.8 | 0 | 49.1 | 30.3 | 0 | 0 | 0 | 13.4 | 24 | |
| | Surp. | 24.9 | 19 | 14.2 | | | | | | | | | | 14.2 |
| | Def. | | | | | 31.8 | | | 70 | 17.9 | 15.4 | | | 135.1 |
| | 409.4=(529.8-135.1)+14.2+.5 | | | | | | | | | | | | | |
| 30.9 | St. 100mm | 35.8 | 52.3 | 71.6 | 55.4 | 0 | 49.1 | 30.3 | 0 | 0 | 0 | 13.4 | 24 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | 10.1 | | | 70 | 17.9 | 15.4 | | | 113.4 |
| | 409.4=(529.8-113.4)+0-6.9 | | | | | | | | | | | | | |
| 43.6 | St. 150 mm. | 48.5 | 65 | 84.3 | 68.1 | 2.5 | 51.6 | 32.8 | 0 | 0 | 0 | 13.4 | 24 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | 67.5 | 17.9 | 15.4 | | | 100.8 |
| | 409.4=(529.8-100.8)+0-19.6 | | | | | | | | | | | | | |
| 46.3 | St. 250 mm. | 51.2 | 67.7 | 87 | 70.8 | 5.2 | 54.3 | 35.5 | 0 | 0 | 0 | 13.4 | 24 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | 64.8 | 17.9 | 15.4 | | | 98.1 |
| | 409.4=(529.8-98.1)+0-22.3 | | | | | | | | | | | | | |

## EDMONTON INTERNATIONAL AIRPORT
## WATER BALANCE 1984

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -7.3 | -2.7 | -3.1 | 5.9 | 8.8 | 14 | 16.8 | 17 | 7.6 | 1.7 | -9.9 | -16.9 | |
| | PE mm. | 0 | 0 | 0 | 44.9 | 67.8 | 106.1 | 123.3 | 116.3 | 47.7 | 11 | 0 | 0 | 517.1 |
| | Ppt. mm. | 25.5 | 4.2 | 13.1 | 6.6 | 55.9 | 66.2 | 48.2 | 30.5 | 116.3 | 45.9 | 12.5 | 23.9 | 448.8 |
| | St. Ch. mm. | 25.5 | 4.2 | 13.1 | -38.3 | -11.9 | -39.9 | -75.1 | -85.8 | 68.6 | 34.9 | 12.5 | 23.9 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | |
| 22 | Surp | 25.5 | 4.2 | 13.1 | | | | | | 66.8 | 34.9 | 12.5 | 23.9 | 166.3 |
| | Def. | | | | 36.3 | 11.9 | 39.9 | 75.1 | 85.8 | | | | | 249 |
| | 448.8=(517.1-249)+166.3+14.4 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 0 | 0 | 0 | 0 | 0 | 13 | 13 | 13 | 13 | |
| 11 | Surp. | 25.5 | 4.2 | 13.1 | | | | | | 55.6 | 34.9 | 12.5 | 23.9 | 144.3 |
| | Def. | | | | 25.3 | 11.9 | 39.9 | 75.1 | 85.8 | | | | | 238 |
| | 448.8=(517.1-238)+144.3+25.4 | | | | | | | | | | | | | |
| 24 | St. 50 mm. | 49.5 | 50 | 50 | 11.7 | 0 | 0 | 0 | 0 | 50 | 50 | 50 | 50 | |
| | Surp. | 24.9 | 3.7 | 13.1 | | | | | | 18.6 | 34.9 | 12.5 | 23.9 | 70.3 |
| | Def. | | | | | 0.2 | 39.9 | 75.1 | 85.8 | | | | | 201 |
| | 448.8=(517.1-201)+70.3+62.4 | | | | | | | | | | | | | |
| 24 | St. 100mm | 49.5 | 53.7 | 66.8 | 28.5 | 16.6 | 0 | 0 | 0 | 68.6 | 100 | 100 | 100 | |
| | Surp. | | | | | | | | | | 3.5 | 12.5 | 23.9 | 3.5 |
| | Def. | | | | | | 23.3 | 75.1 | 85.8 | | | | | 184.2 |
| | 448.8=(517.1-184.2)+3.5+112.4 | | | | | | | | | | | | | |
| 24 | St. 150 mm. | 49.5 | 53.7 | 66.8 | 28.5 | 16.6 | 0 | 0 | 0 | 68.6 | 103.5 | 116 | 139.9 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | 23.3 | 75.1 | 85.8 | | | | | 184.2 |
| | 448.8=(517.1-184.2)+0+115.9 | | | | | | | | | | | | | |
| 24 | St. 250 mm. | | | | | | | | | | | | | |
| | Surp. | Same as 100 mm. | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 184.2 |
| | 448.8=(517.1-184.2)+0+115.9 | | | | | | | | | | | | | |

### EDMONTON INTERNTIONAL AIRPORT
### WATER BALANCE 1985

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -10 | -12.6 | -2 | 4.8 | 12.2 | 13.1 | 17.3 | 14 | 7.1 | 3.5 | -14 | -5.7 | |
| | PE mm. | 0 | 0 | 0 | 34.5 | 91.8 | 97.9 | 127.4 | 97.5 | 44.5 | 5.5 | 0 | 0 | 499.1 |
| | Ppt. mm. | 12.2 | 12.5 | 4.2 | 46 | 26.1 | 65.6 | 31.1 | 91.4 | 56 | 18.8 | 11.5 | 24 | 399.4 |
| | St. Ch. mm. | 12.2 | 12.5 | 4.2 | 11.5 | -65.7 | -32.3 | -96.3 | -6.1 | 11.5 | 13.2 | 11.5 | 24 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | |
| 36.4 | Surp | 12.2 | 12.5 | 4.2 | 11.5 | | | | | 9.5 | 13.2 | 11.5 | 24 | 99.5 |
| | Def. | | | | | 63.7 | 32.3 | 96.3 | 6.1 | | | | | 198.4 |
| | 399.4=(499.1-198.4)+99.5-.9 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 0 | 0 | 0 | 11.5 | 13 | 13 | 13 | |
| 36.4 | Surp. | 12.2 | 12.5 | 4.2 | 11.5 | | | | | | 11.7 | 11.5 | 24 | 88.5 |
| | Def. | | | | | 52.7 | 32.3 | 96.3 | 6.1 | | | | | 187.4 |
| | 399.4=(499.1-187.4)+88.5-.9 | | | | | | | | | | | | | |
| 50 | St. 50 mm. | 50 | 50 | 50 | 50 | 0 | 0 | 0 | 0 | 11.5 | 24.7 | 36.2 | 50 | |
| 36.4 | Surp. | 12.2 | 12.5 | 4.2 | 11.5 | | | | | | | | 10.2 | 76.8 |
| | Def. | | | | | 15.7 | 32.3 | 96.3 | 6.1 | | | | | 150.4 |
| | 399.4=(499.1-150.4)+76.8-26.2 | | | | | | | | | | | | | |
| 100 | St. 100mm | 100 | 100 | 100 | 100 | 34.3 | 2 | 0 | 0 | 11.5 | 24.7 | 36.2 | 60.2 | |
| 36.4 | Surp. | 12.2 | 12.5 | 4.2 | 11.5 | | | | | | | | | 76.8 |
| | Def. | | | | | | | 94.3 | 6.1 | | | | | 100.7 |
| | 399.4=(499.1-100.7)+76.8-76.2 | | | | | | | | | | | | | |
| 139.9 | St. 150 mm. | 150 | 150 | 150 | 150 | 84.3 | 52 | 0 | 0 | 11.5 | 24.7 | 36.2 | 60.2 | |
| | Surp. | 2.1 | 12.5 | 4.2 | 11.5 | | | | | | | | | 30.3 |
| | Def. | | | | | | | 44.3 | 6.1 | | | | | 50.4 |
| | 399.4=(499.1-50.4)+30.3-79.7 | | | | | | | | | | | | | |
| 139.9 | St. 250 mm. | 152.1 | 164.6 | 168.8 | 180.3 | 114.6 | 82.3 | 0 | 0 | 11.5 | 24.7 | 36.2 | 60.2 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | 14 | 6.1 | | | | | 20.1 |
| | 399.4=(499.1-20.1)+0-79.7 | | | | | | | | | | | | | |

### EDMONTON INTERNATIONAL AIRPORT
### WATER BALANCE 1986

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | -6.2 | -13.2 | 1 | 3.9 | 11.7 | 14.9 | 15.2 | 15.7 | 8.1 | 6.6 | -8.9 | -6.4 | |
| | PE mm. | 0 | 0 | 9.2 | 31.1 | 87.8 | 114.2 | 115.1 | 105 | 50.9 | 35.9 | 0 | 0 | 549.2 |
| | Ppt. mm. | 10.6 | 6.2 | 22.4 | 39.8 | 58.6 | 54.8 | 144.1 | 19.7 | 84.7 | 20.8 | 23.8 | 6 | 491.5 |
| | St. Ch. mm. | 10.6 | 6.2 | 13.2 | 8.7 | -29.2 | -59.4 | 29 | -85.3 | 33.8 | -15.1 | 23.8 | 6 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 2 | 0 | 2 | 2 | |
| 35.5 | Surp | 10.6 | 6.2 | 13.2 | 8.7 | | | 27 | | 31.8 | | 21.8 | 6 | 133 |
| | Def. | | | | | 27.2 | 59.4 | | 83.3 | | 13.1 | | | 183 |
| | 491.5=(549.2-183)+133-7.7 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 0 | 13 | 0 | 13 | 0 | 13 | 13 | |
| 25.5 | Surp. | 10.6 | 6.2 | 13.2 | 8.7 | | | 16 | | 20.8 | | 10.8 | 6 | 101 |
| | Def. | | | | | 16.2 | 59.4 | | 72.3 | | 2.1 | | | 150 |
| | 491.5=(549.2-150)+101-8.9 | | | | | | | | | | | | | |
| 50 | St. 50 mm. | 50 | 50 | 50 | 50 | 20.8 | 0 | 29 | 0 | 33.8 | 18.7 | 42.5 | 48.5 | |
| 10.2 | Surp. | 10.6 | 6.2 | 13.2 | 8.7 | | | | | | | | | 48.9 |
| | Def. | | | | | | 38.6 | | 56.3 | | | | | 94.9 |
| | 491.5=(549.2-94.9)+48.9-11.3 | | | | | | | | | | | | | |
| 60.2 | St. 100mm | 70.8 | 77 | 90.2 | 98.9 | 69.7 | 10.3 | 39.3 | 0 | 33.8 | 18.7 | 42.5 | 48.5 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | 46 | | | | | 46 |
| | 491.5=(549.2-46)+0-11.7 | | | | | | | | | | | | | |
| 60.2 | St. 150 mm. | | | | | | | | | | | | | |
| | Surp. | Same as 100 mm. | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 46 |
| | 491.5=(549.2-46)+0-11.7 | | | | | | | | | | | | | |
| 60.2 | St. 250 mm. | | | | | | | | | | | | | |
| | Surp. | Same as 100 mm. | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 46 |
| | 491.5=(549.2-46)+0-11.7 | | | | | | | | | | | | | |

Source: Calculations by Author Using the Thornthwaite Procedure and the Monthly Summary For the Edmonton International Airport Produced by the Atmospheric Environment Service.

## APPENDIX II

## THE CALCULATION OF POTENTIAL EVAPOTRANSPIRATION USING THE PENMAN TECHNIQUE

The Penman equations to measure potential evapotranspiration have been applied in this appendix, whereas in section 3.4 the technique was just described. The Penman procedure was calculated over a 10 year period, and the results were compared to those from the Thornthwaite procedure in table 3.3. A column by column description of the table in this appendix to calculate potential evapotranspiration is as follows.

1. The month and year of study.

2. Indicates the number of days in the month for use in the calculation of monthly PE in column 17.

3. Mean monthly temperature (T) in degrees celcius for use in the determination of $E_w$ (saturation vapour pressure) in column 9 and Delta in column 11.

4. Mean monthly relative humidity measured as a percentage for use in the determination of $E_d$ (vapour pressure) in column 10.

5. Mean monthly wind speed in Kmh.

6. Monthly sunlight as a percentage of the total sunlight possible (N), which is obtained from Environment Canada meteorological tables. This value is used in the calculation of long wave radiation in the determination of the heat budget.

7. The amount of short wave solar insolation (SRAD) measured in langleys and totalled for the month. This value is obtained from Environment Canada Solar radiation tables.

8. The temperature varience (tst) represents the division of a constant 370.92 by the mean monthly temperature in degrees Kelvin.

9. The saturation vapour pressure ($E_w$) is determined in this column through the formula:

$$E_w = 10^{((-7.90298*(tst-1)) + (5.02808 * Log\ 10\ (tst)) - (.00000013816 * (10^{(11.344 * (1-1/tst))} -1)) + (.00813218 * (10^{(-3.49149 * (tst -1))} -1) + Log\ 10\ (935))}$$

(Verma, 1968)

The result is in units of millibars. The formula for the calculation of $E_w$ was originally taken from Goff-Gratch (1946), and was adapted by Verma (1968) and Wiche (1977). The value 935 is meant to represent the average barometric pressure.

10. The vapour pressure ($E_d$) is determined through the formula; $E_d = E_w *$ relative humidity, and is measured in millibars.

(Verma, 1968)

11. The delta value is determined through the formula:

$$Delta = (Ew/(T + 273.16)^2) * (6790.5 - (5.02808 * (T + 273.16)) + (4916.8 * (10^{(-.0304 * (T + 273.16))}) * (T + 273.16)^2)) + 17.4209 - (1302.88 / (T + 273.16)))$$

(Wiche, 1977)

The delta value is the slope of the saturation vapour pressure curve for water at mean air temperature in mm/Hg/$^oC$ (Penman, 1963).

12. The long wave radiation (Rb) used in the calculation of the heat budget is determined through the formula:

$$Rb = .00000000198 * ((T + 273.16)^4) * (.56 - (.09 * SQRT\ (E_d))) * (.1 + (.9 * (N)))$$

(Wiche, 1977)

13. The heat budget (H) is determined in column 13 through the formula:

$$H = ((SRAD/ 59) * 1 - .15) - Rb$$

(Verma, 1968)

The incoming short wave solar insolation (SRAD) is converted from langleys to an evaporation equivalent by dividing by the factor of 59 (1mm. evaporation per day - 59 calories/$cm^2$/day) (Verma, 1968). In the heat budget equation the value 1 is a constant and the value .15 is the average albedo of Elk Island National Park during the summer (Davies, 1963. Landsberg, 1958. Budyko, 1974).

14. The wind speed in Kmh in column 5 is scaled to Mph, and is multiplied by a wind correction factor called a Z ratio (.7239360793) taken from Verma (1968) and Wiche (1977). The final scaled value is indicated by the unit U.

15. The drying power of the air (Ea) is measured by the formula:

$$Ea = .35 * (1 + (U/100)) * ((E_w * .75) - E_d)$$

(Ward, 1975)

16. The potential evapotranspiration (PE) per day is measured by the formula:

$$PE = (( Delta * H) + (.62197 * Ea))/(Delta + .62197)$$

(Ward, 1975)

17. The PE per month is measured by the formula:

$$PE = PE * ( 30 \text{ or } 31)$$

(Verma, 1968)

The PE will be multiplied by 30 or 31 days depending on the number of days in the month.

APPENDIX II

## COMPUTATION OF POTENTIAL EVAPOTRANSPIRATION USING THE PENMAN TECHNIQUE

| MONTH OF | END DATE | TEMP. deg. C | R.H. % | WIND SPD. km/hr | % SUNLIGHT % | SOLAR INS. langleys | TEMP. VAR. | SAT. VAP. PRES. mbar | VAP. PRES. mbar | Δ VAR. | LONG WAVE RADIATION mm H2O/cm^2/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Apr-76 | 30-Apr-76 | 6.3 | 61.5 | 11.5 | 60 | 438 | 1.3273 | 9.8854 | 6.0795 | 0.6834 | 2.6131 |
| May-76 | 31-May-76 | 11.0 | 54.5 | 14.4 | 60 | 504 | 1.3053 | 13.5583 | 7.3893 | 0.9026 | 2.6055 |
| Jun-76 | 30-Jun-76 | 12.0 | 70.0 | 11.9 | 50 | 504 | 1.3007 | 14.4791 | 10.1354 | 0.9562 | 1.9692 |
| Jul-76 | 31-Jul-76 | 15.5 | 72.0 | 10.0 | 62 | 528 | 1.2850 | 18.1491 | 13.0674 | 1.1659 | 2.1226 |
| Aug-76 | 31-Aug-76 | 16.2 | 76.5 | 10.4 | 62 | 411 | 1.2819 | 18.9739 | 14.5150 | 1.2122 | 1.9830 |
| Sep-76 | 30-Sep-76 | 11.9 | 72.0 | 9.5 | 58 | 335 | 1.3012 | 14.3846 | 10.3569 | 0.9508 | 2.1986 |
| Oct-76 | 31-Oct-76 | 3.8 | 66.0 | 12.5 | 44 | 189 | 1.3393 | 8.3150 | 5.4879 | 0.5867 | 2.0176 |
| Apr-77 | 30-Apr-77 | 6.9 | 53.5 | 13.4 | 68 | 464 | 1.3244 | 10.2991 | 5.5100 | 0.7086 | 3.0245 |
| May-77 | 31-May-77 | 10.4 | 70.0 | 13.8 | 52 | 457 | 1.3081 | 13.0309 | 9.1217 | 0.8717 | 2.0954 |
| Jun-77 | 30-Jun-77 | 13.2 | 64.0 | 13.1 | 67 | 587 | 1.2908 | 16.7005 | 10.6883 | 1.0839 | 2.5224 |
| Jul-77 | 31-Jul-77 | 14.2 | 74.5 | 12.1 | 53 | 494 | 1.2908 | 16.7005 | 12.4419 | 1.0839 | 1.8894 |
| Aug-77 | 31-Aug-77 | 11.7 | 77.5 | 9.4 | 55 | 418 | 1.3021 | 14.1973 | 11.0029 | 0.9399 | 2.0282 |
| Sep-77 | 30-Sep-77 | 9.3 | 77.5 | 10.7 | 36 | 265 | 1.3132 | 12.1108 | 9.3859 | 0.8173 | 1.5191 |
| Oct-77 | 31-Oct-77 | 4.7 | 61.5 | 12.8 | 56 | 200 | 1.3349 | 8.8529 | 5.4445 | 0.6201 | 2.4950 |
| Apr-78 | 30-Apr-78 | 4.7 | 66.5 | 16.1 | 41 | 348.2 | 1.3349 | 8.8529 | 5.8872 | 0.6201 | 1.8910 |
| May-78 | 31-May-78 | 9.8 | 63.0 | 13.9 | 52 | 468.5 | 1.3109 | 12.5217 | 7.8887 | 0.8416 | 2.2149 |
| Jun-78 | 30-Jun-78 | 15.3 | 65.5 | 12.0 | 64 | 578.4 | 1.2859 | 17.9193 | 11.7372 | 1.1529 | 2.3323 |
| Jul-78 | 31-Jul-78 | 16.4 | 70.5 | 9.8 | 64 | 527.2 | 1.2810 | 19.2155 | 13.5469 | 1.2257 | 2.1524 |
| Aug-78 | 31-Aug-78 | 14.1 | 72.0 | 9.9 | 58 | 421.4 | 1.2912 | 16.5934 | 11.9472 | 1.0778 | 2.0874 |
| Sep-78 | 30-Sep-78 | 9.9 | 80.0 | 11.4 | 34 | 225.6 | 1.3104 | 12.6053 | 10.0843 | 0.8466 | 1.4150 |
| Oct-78 | 31-Oct-78 | 6.5 | 64.5 | 13.2 | 59 | 198.1 | 1.3263 | 10.0216 | 6.4640 | 0.6917 | 2.5309 |
| Apr-79 | 30-Apr-79 | 0.8 | 62.5 | 11.9 | 49 | 394.9 | 1.3539 | 6.7245 | 4.2028 | 0.4863 | 2.2658 |
| May-79 | 31-May-79 | 8.1 | 60.0 | 14.2 | 56 | 467.4 | 1.3188 | 11.1726 | 6.7036 | 0.7613 | 2.4471 |
| Jun-79 | 30-Jun-79 | 14.0 | 67.5 | 12.1 | 56 | 549.2 | 1.2917 | 16.4869 | 11.1286 | 1.0717 | 2.1124 |
| Jul-79 | 31-Jul-79 | 16.6 | 76.5 | 10.8 | 63 | 530.1 | 1.2801 | 19.4598 | 14.8867 | 1.2393 | 1.9807 |
| Aug-79 | 31-Aug-79 | 15.0 | 75.0 | 8.5 | 66 | 461.7 | 1.2872 | 17.5794 | 13.1846 | 1.1337 | 2.2095 |
| Sep-79 | 30-Sep-79 | 11.9 | 71.0 | 11.3 | 63 | 339.7 | 1.3012 | 14.3846 | 10.2131 | 0.9508 | 2.3753 |
| Oct-79 | 31-Oct-79 | 6.1 | 72.0 | 13.1 | 47 | 184.4 | 1.3282 | 9.7508 | 7.0206 | 0.6752 | 2.0250 |
| Apr-80 | 30-Apr-80 | 8.0 | 60.0 | 15.2 | 63 | 447.5 | 1.3192 | 11.0974 | 6.6585 | 0.7568 | 2.7050 |
| May-80 | 31-May-80 | 11.3 | 57.5 | 16.4 | 57 | 474 | 1.3039 | 13.8290 | 7.9517 | 0.9184 | 2.4335 |
| Jun-80 | 30-Jun-80 | 14.5 | 75.5 | 12.7 | 50 | 501.5 | 1.2894 | 17.0254 | 12.8542 | 1.1024 | 1.7697 |
| Jul-80 | 31-Jul-80 | 15.5 | 73.5 | 11.3 | 60 | 545.1 | 1.2850 | 18.1491 | 13.3396 | 1.1659 | 2.0349 |
| Aug-80 | 31-Aug-80 | 12.5 | 77.0 | 12.3 | 50 | 397.5 | 1.2985 | 14.9598 | 11.5190 | 0.9841 | 1.8458 |
| Sep-80 | 30-Sep-80 | 9.0 | 77.0 | 12.7 | 41 | 265.8 | 1.3146 | 11.8700 | 9.1399 | 0.8030 | 1.6946 |
| Oct-80 | 31-Oct-80 | 5.9 | 68.5 | 12.0 | 47 | 189.7 | 1.3292 | 9.6178 | 6.5882 | 0.6671 | 2.0661 |

APPENDIX II CONTINUED

| MONTH OF | END DATE | TEMP. deg. C | R.H. % | WIND SPD. km/hr | % SUNLIGHT % | SOLAR INS. langleys | TEMP. VAR. | SAT. VAP. PRES. mbar | VAP. PRES. mbar | Δ VAR. | LONG WAVE RADIATION mm H2O/cm^2/day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Apr-81 | 30-Apr-81 | 4.3 | 59.5 | 16.3 | 56 | 424 | 1.3368 | 8.6102 | 5.1230 | 0.6050 | 2.5253 |
| May-81 | 31-May-81 | 11.2 | 62.5 | 16.0 | 47 | 432.2 | 1.3044 | 13.7383 | [illegible] | 0.9131 | 2.0060 |
| Jun-81 | 30-Jun-81 | 12.4 | 66.0 | 12.9 | 60 | 557.9 | 1.2989 | 14.8625 | [illegible] | 0.9785 | 2.3435 |
| Jul-81 | 31-Jul-81 | 15.7 | 73.0 | 11.1 | 54 | [illegible] | 1.2841 | 18.3815 | 13.4185 | 1.1790 | 1.8606 |
| Aug-81 | 31-Aug-81 | 18.0 | 65.0 | 11.8 | 73 | 495.2 | 1.2739 | 21.2473 | 13.8107 | 1.3384 | 2.4294 |
| Sep-81 | 30-Sep-81 | 12.1 | 64.5 | 13.6 | 52 | 316 | 1.3003 | 14.5741 | [illegible] | 0.9618 | 2.1154 |
| Oct-81 | 31-Oct-81 | 4.1 | 71.0 | 15.2 | 46 | 190 | 1.3378 | 8.4910 | 6.0286 | 0.5976 | 2.0389 |
| May-82 | 31-May-82 | 10.0 | 52.5 | 18.7 | 64 | 515 | 1.3099 | 12.6895 | 6.6620 | 0.8515 | 2.8198 |
| Jun-82 | 30-Jun-82 | 15.2 | 64.5 | 11.2 | 52.5 | 525.8 | 1.2863 | 17.8054 | 11.4845 | 1.1465 | 1.9986 |
| Jul-82 | 31-Jul-82 | 16.1 | 78.0 | 8.2 | 54 | 478.4 | 1.2823 | 18.8541 | 14.7062 | 1.2055 | 1.7453 |
| Aug-82 | 31-Aug-82 | 13.0 | 76.5 | 10.5 | 58 | 421.7 | 1.2962 | 15.4544 | 11.8226 | 1.0126 | 2.0691 |
| Sep-82 | 30-Sep-82 | 10.7 | 72.5 | 12.8 | 54 | 308.4 | 1.3067 | 13.2923 | 9.6369 | 0.8870 | 2.1139 |
| Oct-82 | 31-Oct-82 | 4.6 | 68.5 | 13.5 | 57 | 200.9 | 1.3354 | 8.7917 | 6.0223 | 0.6163 | 2.4501 |
| Apr-83 | 30-Apr-83 | 4.8 | 65.0 | 14.1 | 54 | 405.1 | 1.3344 | 8.9145 | 5.7844 | 0.6239 | 2.3781 |
| May-83 | 31-May-83 | 9.9 | 57.5 | 16.3 | 54 | 467.8 | 1.3104 | 12.6053 | 7.2481 | 0.8466 | 2.3664 |
| Jun-83 | 30-Jun-83 | 13.6 | 72.0 | 14.7 | 45 | 456.7 | 1.2935 | 16.0668 | 11.5681 | 1.0477 | 1.7166 |
| Jul-83 | 31-Jul-83 | 16.6 | 76.0 | 11.3 | 58 | 512.4 | 1.2801 | 19.4598 | 14.7894 | 1.2393 | 1.8569 |
| Aug-83 | 31-Aug-83 | 16.8 | 70.5 | 9.0 | 70 | 486.6 | 1.2792 | 19.7068 | 13.8933 | 1.2531 | 2.2942 |
| Sep-83 | 30-Sep-83 | 8.4 | 72.0 | 13.2 | 44 | 276.8 | 1.3174 | 11.4010 | 8.2087 | 0.7750 | 1.8648 |
| Oct-83 | 31-Oct-83 | 4.6 | 68.0 | 11.0 | 44 | 177.6 | 1.3354 | 8.7917 | 5.9783 | 0.6163 | 1.9872 |
| Apr-84 | 30-Apr-84 | 5.9 | 55.0 | 13.3 | 60 | 426.4 | 1.3292 | 9.6178 | 5.2898 | 0.6671 | 2.7128 |
| May-84 | 31-May-84 | 8.8 | 65.0 | 17.0 | 39 | 418.4 | 1.3155 | 11.7118 | 7.6127 | 0.7935 | 1.7591 |
| Jun-84 | 30-Jun-84 | 14.0 | 67.5 | 12.5 | 53 | 526.7 | 1.2917 | 16.4869 | 11.1286 | 1.0717 | 2.0180 |
| Jul-84 | 31-Jul-84 | 16.8 | 62.5 | 10.8 | 64 | 557.1 | 1.2792 | 19.7068 | 12.3167 | 1.2531 | 2.3100 |
| Aug-84 | 31-Aug-84 | 17.0 | 64.0 | 11.0 | 59 | 438.6 | 1.2783 | 19.9565 | 12.7722 | 1.2670 | 2.1109 |
| Sep-84 | 30-Sep-84 | 7.6 | 73.0 | 12.1 | 36 | 250.7 | 1.3211 | 10.8010 | 7.8848 | 0.7389 | 1.6029 |
| Oct-84 | 31-Oct-84 | 1.7 | 71.0 | 14.8 | 40 | [illegible] | 1.3495 | 7.1707 | 5.0912 | 0.5147 | 1.8554 |
| Apr-85 | 30-Apr-85 | 4.8 | 63.0 | 13.5 | 56 | 411.2 | 1.3344 | 8.9145 | 5.6162 | 0.6239 | 2.4752 |
| May-85 | 31-May-85 | 12.2 | 53.0 | 12.3 | 60 | [illegible] | 1.2998 | 14.6697 | 7.7749 | 0.9673 | [illegible] |
| Jun-85 | 30-Jun-85 | 13.1 | 59.5 | 15.1 | 63 | [illegible] | 1.2957 | 15.5550 | 9.2552 | 1.0184 | [illegible] |
| Jul-85 | 31-Jul-85 | 17.3 | 62.5 | 8.7 | 72 | 599.8 | 1.2770 | 20.3363 | 12.7102 | 1.2881 | 2.5209 |
| Aug-85 | 31-Aug-85 | 14.0 | 73.0 | 9.8 | 58 | 438.2 | 1.2917 | 16.4869 | 12.0354 | 1.0717 | 2.0749 |
| Sep-85 | 30-Sep-85 | 7.1 | 76.0 | 13.0 | 32 | 246.6 | 1.3235 | 10.4404 | 7.9347 | 0.7171 | 1.4526 |
| Oct-85 | 31-Oct-85 | 3.5 | 67.5 | 11.4 | 40 | 177.3 | 1.3407 | 8.1422 | 5.4960 | 0.5759 | 1.8623 |

APPENDIX II CONTINUED

| HEAT BUDGET VAR. mm H2O/cm^2/day | SCALED WIND miles/hour | DRYING POWER OF THE AIR | P.E. PER DAY mm H2O/day | P.E. mm H2O | MONTH OF |
|---|---|---|---|---|---|
| 3.6971 | 5.1733 | 0.4912 | 2.1696 | 65.0889 | Apr-76 |
| 4.6555 | 6.4779 | 1.0358 | 3.1788 | 98.5434 | May-76 |
| 5.2918 | 5.3533 | 0.2669 | 3.3115 | 99.3452 | Jun-76 |
| 5.4841 | 4.4985 | 0.1991 | 3.6456 | 113.0121 | Jul-76 |
| 3.9382 | 4.6785 | -0.1043 | 2.5673 | 79.5874 | Aug-76 |
| 2.6277 | 4.2736 | 0.1575 | 1.6508 | 49.5239 | Sep-76 |
| 0.7052 | 5.6232 | 0.2767 | 0.4847 | 15.0253 | Oct-76 |
| 8.6603 | 6.0280 | 0.8217 | 2.3334 | 70.0018 | Apr-77 |
| 4.4885 | 6.2080 | 0.2422 | 2.7203 | 84.3293 | May-77 |
| 5.9343 | 5.8931 | 0.6809 | 4.0189 | 120.5661 | Jun-77 |
| 5.2275 | 5.4432 | 0.0308 | 3.3327 | 103.3149 | Jul-77 |
| 3.9938 | 4.2286 | -0.1295 | 2.3518 | 72.9055 | Aug-77 |
| 2.2987 | 4.8124 | -0.1111 | 1.2573 | 37.7191 | Sep-77 |
| 0.3863 | 5.7581 | 0.4424 | 0.4144 | 12.8467 | Oct-77 |
| 3.1254 | 7.2426 | 0.2824 | 1.7017 | 51.0522 | Apr-78 |
| 4.5346 | 6.2530 | 0.5588 | 2.8451 | 88.1971 | May-78 |
| 6.0006 | 5.3982 | 0.6280 | 4.1179 | 123.5376 | Jun-78 |
| 5.4429 | 4.4086 | 0.3160 | 3.7170 | 115.2278 | Jul-78 |
| 3.9836 | 4.4536 | 0.1820 | 2.5925 | 80.3680 | Aug-78 |
| 1.8351 | 5.1283 | -0.2319 | 0.9597 | 28.7903 | Sep-78 |
| 0.3230 | 5.9381 | 0.3902 | 0.3548 | 10.9995 | Oct-78 |
| 3.4235 | 5.3533 | 0.3099 | 1.6761 | 50.2828 | Apr-79 |
| 4.2866 | 6.3879 | 0.6240 | 2.6398 | 81.8325 | May-79 |
| 5.7998 | 5.4432 | 0.4563 | 3.8375 | 115.1257 | Jun-79 |
| 5.6564 | 4.8584 | -0.1071 | 3.7304 | 115.6429 | Jul-79 |
| 4.4421 | 3.8238 | 0.0000 | 2.8685 | 88.9222 | Aug-79 |
| 2.5187 | 5.0833 | 0.2116 | 1.6063 | 48.1902 | Sep-79 |
| 0.6316 | 5.8931 | 0.1084 | 0.3807 | 11.8031 | Oct-79 |
| 3.7420 | 6.8378 | 0.6225 | 2.3347 | 70.0422 | Apr-80 |
| 4.3953 | 7.3776 | 0.9095 | 2.9878 | 92.6229 | May-80 |
| 5.4553 | 5.7131 | -0.0315 | 3.4762 | 104.2866 | Jun-80 |
| 5.8182 | 5.0833 | 0.1001 | 3.8290 | 118.6980 | Jul-80 |
| 3.8809 | 5.5332 | -0.1105 | 2.3351 | 72.3894 | Aug-80 |
| 2.1347 | 5.7131 | -0.0878 | 1.1646 | 34.9372 | Sep-80 |
| 0.6669 | 5.3982 | 0.2306 | 0.4564 | 14.1482 | Oct-80 |

APPENDIX II CONTINUED

| HEAT BUDGET VAR. mm H2O/cm^2/day | SCALED WIND miles/hour | DRYING POWER OF THE AIR | P.E. PER DAY mm H2O/day | P.E. mm H2O | MONTH OF |
|---|---|---|---|---|---|
| 3.5832 | 7.3326 | 0.5014 | 2.0210 | 60.6295 | Apr-81 |
| 4.2206 | 7.1977 | 0.6443 | 2.7716 | 85.9192 | May-81 |
| 5.6940 | 5.8031 | 0.4953 | 3.6737 | 110.2098 | Jun-81 |
| 5.2564 | 4.9934 | 0.1361 | 3.4877 | 108.1185 | Jul-81 |
| 4.7048 | 5.3083 | 0.7831 | 3.4606 | 107.2780 | Aug-81 |
| 2.4372 | 6.1180 | 0.5684 | 1.7032 | 51.0972 | Sep-81 |
| 0.6984 | 6.8378 | 0.1270 | 0.4070 | 12.6162 | Oct-81 |
| 4.5997 | 8.4123 | 1.0834 | 3.1154 | 96.5786 | May-82 |
| 5.5765 | 5.0384 | 0.6873 | 3.8570 | 115.7094 | Jun-82 |
| 5.1469 | 3.6888 | -0.2053 | 3.3253 | 103.0832 | Jul-82 |
| 4.0063 | 4.7235 | -0.0850 | 2.4495 | 75.9344 | Aug-82 |
| 2.3292 | 5.7581 | 0.1230 | 1.4198 | 42.5951 | Sep-82 |
| 0.4442 | 6.0730 | 0.2122 | 0.3277 | 10.1577 | Oct-82 |
| 3.4581 | 6.3429 | 0.3318 | 1.8973 | 56.9190 | Apr-83 |
| 4.3731 | 7.3326 | 0.8287 | 2.8719 | 89.0294 | May-83 |
| 4.8629 | 6.6129 | 0.1799 | 3.1185 | 93.5536 | Jun-83 |
| 5.5251 | 5.0833 | -0.0716 | 3.6549 | 113.3023 | Jul-83 |
| [illegible]162 | 4.0487 | 0.3229 | 3.2589 | 101.0255 | Aug-83 |
| [illegible] | 5.9381 | 0.1268 | 1.2342 | 37.0258 | Sep-83 |
| 0.5715 | 4.9484 | 0.2261 | 0.3980 | 12.3371 | Oct-83 |
| 3.4303 | 5.9831 | 0.7135 | 2.1194 | 63.5832 | Apr-84 |
| 4.2687 | 7.6475 | 0.4413 | 2.5869 | 80.1940 | May-84 |
| 5.5701 | 5.6232 | 0.4571 | 3.6924 | 110.7734 | Jun-84 |
| 5.7160 | 4.8584 | 0.9041 | 4.1199 | 127.7156 | Jul-84 |
| 4.2079 | 4.9484 | 0.8063 | 3.0879 | 95.7239 | Aug-84 |
| 2.0089 | 5.4432 | 0.0797 | 1.1272 | 33.8159 | Sep-84 |
| 0.6355 | 6.6578 | 0.1071 | 0.3463 | 10.7367 | Oct-84 |
| 3.4489 | 6.0730 | 0.3971 | 1.9253 | 57.7604 | Apr-85 |
| 5.1483 | 5.5332 | 1.1921 | 3.6000 | 111.5993 | May-85 |
| 4.7100 | 6.7928 | 0.9012 | 3.2658 | 97.9740 | Jun-85 |
| 6.1203 | 3.9137 | 0.9245 | 4.[illegible]84 | 137.2789 | Jul-85 |
| 4.2381 | 4.4086 | 0.1205 | 2.7260 | 84.5063 | Aug-85 |
| 2.1001 | 5.8481 | -0.0387 | 1.1067 | 33.2016 | Sep-85 |
| 0.6920 | 5.1283 | 0.2247 | 0.4494 | 13.9308 | Oct-85 |

Source: Calculations by Author Using the Penman Procedure and Data from the Monthly Summaries at the Edmonton International Airport and Stony Plain Weather Stations Produced by the Atmospheric Environment Service.

# APPENDIX III
# THE CALCULATION OF DAILY WATER BALANCES FOR THE EDMONTON INTERNATIONAL AIRPORT 1971-1986

The first table of appendix III is an example of a monthly water balance using daily data. The data were collected at the Edmonton International Airport weather station. The totals from this table would be added to the other summer months to calculate the summer potential evapotranspiration, precipitation, and surpluses.

The second table is a compilation of the monthly water balances using the daily data described in the first table of this appendix. The totals from these tables were used in conjunction with the monthly data winter values in the calculation of yearly surpluses and water losses in table 4.1.

APPENDIX III

## DAILY WATER BALANCE
## EDMONTON INTERNATIONAL AIRPORT
## (mm.)

| July Date | [illegible] | PPT. | S.C. | [0] 2 | +/- | [0] 13 | +/- | [0] 50 | +/- | [0] 100 | +/- | [9.6] 150 | +/- | [9.6] 250 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4.2 | | -4.2 | 0 | -4.2 | 0 | -4.2 | 0 | -4.2 | 0 | -4.2 | 5.4 | | |
| [illegible] | [illegible] | 9.8 | 5.4 | 2 | 3.4 | 5.4 | | 5.4 | | 5.4 | | 10.8 | | same |
| [illegible] | [illegible] | 0.3 | -3.2 | 0 | -1.2 | 2.2 | | 2.2 | | 2.2 | | 7.6 | | as |
| [illegible] | [illegible].2 | 5.2 | 2.0 | 2 | | 4.2 | | 4.2 | | 4.2 | | 9.6 | | 150 |
| 5 | 3.2 | 4.8 | 1.6 | | 1.6 | 5.8 | | 5.8 | | 5.8 | | 11.2 | | |
| 6 | 3.4 | | -3.4 | 0 | -1.4 | 2.4 | | 2.4 | | 2.4 | | 7.8 | | |
| 7 | 3.8 | | -3.8 | | -3.8 | 0 | -1.4 | 0 | -1.4 | 0 | -1.4 | [illegible] | | |
| 8 | 4.2 | | -4.2 | | -4.2 | | -4.2 | | -4.2 | | -4.2 | 0 | -0.2 | |
| 9 | 4.0 | 19.2 | 15.2 | 2 | 13.2 | 13 | 2.2 | 15.2 | | 15.2 | | 15.2 | | |
| 10 | 4.2 | 2.9 | -1.3 | 0.7 | | 11.7 | | 13.9 | | 13.9 | | 13.9 | | |
| 11 | 3.8 | 0.4 | -3.4 | 0 | -2.7 | 8.3 | | 10.5 | | 10.5 | | 10.5 | | |
| 12 | 3.4 | 12.2 | 8.8 | 2 | 6.8 | 13 | 4.1 | 19.3 | | 19.3 | | 19.3 | | |
| 13 | 3.4 | 8.2 | 4.8 | 2 | 4.8 | | 4.8 | 24.1 | | 24.1 | | 24.1 | | |
| 14 | 3.7 | | -3.7 | 0 | -1.7 | 9.3 | | 20.4 | | 20.4 | | 20.4 | | |
| 15 | 3.7 | 0.5 | -3.2 | | -3.2 | 6.1 | | 17.2 | | 17.2 | | 17.2 | | |
| 16 | 3.7 | 1.8 | -1.9 | | -1.9 | 4.2 | | 15.3 | | 15.3 | | 15.3 | | |
| 17 | 3.5 | 33.3 | 29.8 | 2 | 27.8 | 13 | 21.0 | 45.1 | | 45.1 | | 45.1 | | |
| 18 | 3.7 | 6.8 | 3.1 | | 3.1 | | 3[illegible] | 48.2 | | 48.2 | | 48.2 | | |
| 19 | 3.7 | 22.5 | 18.8 | | 18.8 | | 18.8 | 50.0 | 17.0 | 67.0 | | 67.0 | | |
| 20 | 4.4 | | -4.4 | 0 | -2.4 | 8.6 | | 45.6 | | 62.6 | | 62.6 | | |
| 21 | 4.5 | | -4.5 | | -4.5 | 4.1 | | 41.1 | | 58.1 | | 58.1 | | |
| 22 | 4.7 | | -4.7 | | -4.7 | 0 | -0.6 | 36.4 | | 53.4 | | 53.4 | | |
| 23 | 3.3 | 2.2 | -1.1 | | -1.1 | | -1.1 | 35.3 | | 52.3 | | 52.3 | | |
| 24 | 3.6 | 1.7 | -1.9 | | -1.9 | | -1.9 | 33.4 | | 50.4 | | 50.4 | | |
| 25 | 3.5 | 0.4 | -3.1 | | -3.1 | | -3.1 | 30.3 | | 47.3 | | 47.3 | | |
| 26 | 3.2 | | -3.2 | | -3.2 | | -3.2 | 27.1 | | 44.1 | | 44.1 | | |
| 27 | 3.4 | | -3.4 | | -3.4 | | -3.4 | 23.7 | | 40.7 | | 40.7 | | |
| 28 | 3.2 | 5.8 | 2.6 | 2 | 0.6 | 2.6 | | 26.3 | | 43.3 | | 43.3 | | |
| 29 | 2.9 | | -2.9 | 0 | -0.9 | 0 | -0.3 | 23.4 | | 40.4 | | 40.4 | | |
| 30 | 3.3 | 6.4 | 3.1 | 2 | 1.1 | 3.1 | | 26.5 | | 43.5 | | 43.5 | | |
| 31 | 3.6 | 0.2 | -3.4 | 0 | -1.4 | 0 | -0.3 | 23.1 | | 40.1 | | 40.1 | | |
| Tot | 114 | 145 | | | s=81.2 d=50.9 | | s=54.0 d=23.7 | | s=17.0 d=9.8 | | s=0 d=9.8 | | s=0 d=.2 | |

Source: Calculations by Author Using Meteorological Data from the Edmonton International Airport and the Thornthwaite Procedure

# APPENDIX III
## EDMONTON INTERNATIONAL AIRPORT
## SUMMER WATER BALANCE USING DAILY DATA 1971-1986

**1971** — Water Storage Categories

| | | | 2 mm. | | 13 mm. | | 50 mm. | | 100 mm. | | 150 mm. | | 250 mm. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | Ppt. | Month | S | D | S | D | S | D | S | D | S | D | S | D |
| 26.3 | 2.3 | Apr | 0.3 | 22.3 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 91.3 | 12.4 | May | 0 | 78.9 | 0 | 78.9 | 0 | 52.9 | 0 | 2.9 | 0 | 0 | 0 | 0 |
| 103.1 | 75.8 | Jun | 54.3 | 67.4 | 9.4 | 34[illegible] | 0 | 27.5 | 0 | 27.5 | 0 | 0 | 0 | 0 |
| 112.5 | 126.4 | Jul | 87.7 | 73.8 | 60.8 | 46.9 | 18.9 | 4.7 | 0 | 3.2 | 0 | 0 | 0 | 0 |
| 117.4 | 10 | Aug | 0.9 | 108.3 | 0 | 107.4 | 0 | 107.4 | 0 | 90 | 0 | 73.7 | [illegible] | 71.3 |
| 54.7 | 40.7 | Sept | 18.6 | 34.6 | 3.2 | 30.2 | 0 | 30.[illegible] | 0 | 30.2 | 0 | 30.2 | 0 | 30.2 |
| 26.3 | 4.9 | Oct | 0.5 | 21.9 | 0 | 10.9 | 0 | [illegible] | 0 | 7.7 | 0 | 7.7 | 0 | 7.7 |
| 531.6 | 272.5 | Total | 162.3 | 407.2 | 73.4 | 319.7 | 18.9 | 230.4 | 0 | 161.5 | 0 | 111.6 | 0 | 109.2 |

**1972** — Water Storage Categories

| | | | 2 mm. | | 13 mm. | | 50 mm. | | 100 mm. | | 150 mm. | | 250 mm. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | Ppt. | Month | S | D | S | D | S | D | S | D | S | D | S | D |
| 26.3 | 38.5 | Apr | 24.7 | 10.9 | 21.6 | 0 | 21.6 | 0 | 21.6 | 0 | 9.3 | 0 | 0 | 0 |
| 85.1 | 49.9 | May | 24.1 | 57.2 | 0.8 | 32.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 110 | 106.5 | Jun | 63.8 | 67.3 | 28.9 | 33.7 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |
| 103.2 | 88.3 | Jul | 51.3 | 68.2 | 26.7 | 50.1 | 0 | 23.9 | 0 | 0 | 0 | 0 | 0 | 0 |
| 111.9 | 94.4 | Aug | 47 | 62.5 | 21.7 | 33.8 | 11.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36.9 | 47.8 | Sept | 31 | 20.1 | 14.1 | 9.6 | 0 | 6.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23.5 | 10.7 | Oct | 4.3 | 17.9 | 0 | 6.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 496.9 | 436.1 | Total | 246.2 | 304.1 | 113.8 | 166.7 | 33 | 55.3 | 21.6 | 0 | 9.3 | 0 | 0 | 0 |

**1973** — Water Storage Categories

| | | | 2 mm. | | 13 mm. | | 50 mm. | | 100 mm. | | 150 mm. | | 250 mm. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | Ppt. | [illegible]th | S | D | S | D | S | D | S | D | S | D | S | D |
| 23.6 | 46.3 | [illegible]r | 34.3 | 11 | 23.3 | 0 | 23.3 | 0 | 12 | 0 | 12 | 0 | 0 | 0 |
| 86.1 | 37.2 | May | 20.1 | 66.6 | 9 | 48 | 0 | 1.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 104.7 | 147.7 | Jun | 111.3 | 70.3 | 86.6 | 45.9 | 40 | 27.3 | 1.7 | 0 | 1.7 | 0 | 0 | 0 |
| 116.7 | 87.5 | Jul | 50.5 | 77.5 | 20.8 | 44.2 | 15.2 | 3.9 | 16.9 | 0 | 16.9 | 0 | 0 | 0 |
| 102.1 | 110.7 | Aug | 67.5 | 59.1 | 41.8 | 36.8 | 4.8 | 10.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60.8 | 34.4 | Sept | 15.6 | 43.8 | 1.6 | 37 | 0 | 24.8 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 33.6 | Oct | 20.2 | 7.7 | 14.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 516 | 497.4 | Total | 319.5 | 336 | 197.2 | 211.9 | 83.3 | 77.1 | 30.6 | [illegible] | 30.6 | 0 | 0 | 0 |

**1974** — Water Storage Categories

| | | | 2 mm. | | 13 mm. | | 50 mm. | | 100 mm. | | 150 mm. | | 250 mm. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | Ppt. | Month | S | D | S | D | S | D | S | D | S | D | S | D |
| 24.1 | 14.5 | Apr | 5.8 | 14.8 | 5.7 | 3.7 | 5.7 | 0 | 5.7 | 0 | 5.7 | 0 | 5.7 | 0 |
| 63.5 | 40.4 | May | 18.8 | 40.5 | 4.8 | 26.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 112 | 112.3 | Jun | 78.5 | 74.7 | 54.5 | 57.7 | 7.9 | 36.5 | [illegible] | 0 | 0 | 0 | 0 | 0 |
| 114.2 | 87.8 | Jul | 42.9 | 67.7 | 28.5 | 4[illegible].3 | 28.5 | 9.3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 89.6 | 49.2 | Aug | 18.2 | 58.6 | 0 | 40.4 | 0 | 40.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54.5 | 31.6 | Sept | 18.1 | 43 | 0.7 | 32 | 0 | 3[illegible] | 0 | 31.1 | 0 | 0 | 0 | 0 |
| 37.8 | 7.3 | Oct | 0 | 28.5 | 0 | 22.1 | 0 | 22.[illegible] | 0 | 22.1 | 0 | 4 | 0 | 0 |
| 495.7 | 343.1 | Total | 182.3 | 327.8 | 94.2 | 228.7 | 42.1 | 139.6 | 5.7 | 53.2 | 5.7 | 4 | 5.7 | [illegible] |

**1975** — Water Storage Categories

| | | | 2 mm. | | 13 mm. | | 50 mm. | | 100 mm. | | 150 mm. | | 250 mm. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | Ppt. | Month | S | D | S | D | S | D | S | D | S | D | S | D |
| 19.2 | 29.8 | Apr | 20.4 | 7.8 | 17.1 | 0 | 17.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 73.2 | 52.5 | May | 24.6 | 45.3 | 8.9 | 23.1 | 8.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 102.6 | 99.7 | Jun | 63 | 60.1 | 37.6 | 43.5 | 0.6 | 29.6 | 0 | 0 | 0 | 0 | 0 | 0 |
| 127.9 | 88.7 | Jul | 32.7 | 91.1 | 11.6 | 62 | 0 | 13.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 86 | 98.5 | Aug | 46.3 | 39.7 | 23.9 | 25.4 | 0 | 25.4 | 0 | 24.9 | 0 | 24.9 | 0 | 0 |
| 63.1 | 11.4 | Sept | 0 | 49.7 | 0 | 38.7 | 0 | 14.8 | 0 | 14.8 | 0 | 14.8 | 0 | 0 |
| 24.3 | 24.1 | Oct | 9.8 | 15.7 | 0 | 11.9 | 0 | 11.9 | 0 | 11.9 | 0 | 11.9 | 0 | 0 |
| 496.3 | 384.7 | Total | 196.8 | 309.4 | 99.1 | 204.6 | 26.6 | 95.1 | 0 | 51.6 | 0 | 51.6 | 0 | 0 |

APPENDIX III CONTINUED

1976

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41.8 | 11.7 | Apr | 5.5 | 34.9 | 0 | 18.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 82.2 | 30.2 | May | 8.1 | 60.1 | 0 | 52 | 0 | 33.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 89.6 | 90.8 | Jun | 42.5 | 40.3 | 21.9 | 22.7 | 0 | 22.7 | 0 | 22.7 | 0 | 22.7 | 0 | 0 |
| 112.4 | 74.7 | Jul | 35.3 | 75.8 | 13.3 | 62 | 0 | 40.1 | 0 | 40.1 | 0 | 40.1 | 0 | [illegible] |
| 109.2 | 111.1 | Aug | 65.4 | 63.5 | 31.4 | 19.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70.2 | 43 | Sept | 26.8 | 54 | 7.2 | 34.4 | 0 | 3.1 | 0 | 3.1 | 0 | 3.1 | 0 | 3.1 |
| 24.5 | 9.9 | Oct | 2.4 | 16.2 | 0 | 14.6 | 0 | 14.6 | 0 | 14.6 | 0 | 14.6 | 0 | 14.6 |
| 529.9 | 371.4 | Total | 186 | 344.6 | 73.8 | 223.4 | 0 | 113.6 | 0 | 80.5 | 0 | 80.5 | 0 | 23.9 |

1977

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50.1 | 18.9 | Apr | 9 | 38.7 | 1.6 | 24.5 | 1.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79.5 | 131.[illegible] | May | 101.9 | 46.5 | 64.2 | 14.3 | 24.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 106.7 | 12.5 | Jun | 0 | 94.2 | 0 | 87 | 0 | 50 | 0 | 8.2 | 0 | 8.2 | 0 | 8.2 |
| 107.9 | 90.7 | Jul | 52.6 | 60.6 | 21.4 | 48.3 | 0 | 35.3 | 0 | 35.3 | 0 | 35.3 | 0 | 35.3 |
| 84 | 86.5 | Aug | 44.1 | 43.6 | 18.3 | 19.1 | 0 | 10.7 | 0 | 10.7 | 0 | 10.7 | 0 | 10.7 |
| 57.7 | 38 | Sept | 17.4 | 36.1 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27.8 | 0.4 | Oct | 0 | 27.4 | 0 | 22.5 | 0 | 16.2 | 0 | 16.2 | 0 | 16.2 | 0 | 16.2 |
| 513.7 | 378.9 | Total | 225 | 347.1 | 105.5 | 227.7 | 25.7 | 112.2 | 0 | 70.4 | 0 | 70.4 | 0 | 70.4 |

1978

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34.1 | 16.1 | Apr | 5.7 | 21.7 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74.1 | 64.2 | May | 33 | 42.3 | 10.4 | 27.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 112.7 | 40.6 | Jun | 6.6 | 78.7 | 0 | 61.9 | 0 | 51.2 | 0 | 26.6 | 0 | 26.6 | 0 | 26.6 |
| 120.8 | 63.6 | Jul | 31.7 | 88.9 | 19.2 | 76.4 | 0 | 57.2 | 0 | 57.2 | 0 | 57.2 | 0 | 57.2 |
| 96.9 | 111.4 | Aug | 77 | 62.5 | 64 | 49.5 | 27 | 44.7 | 0 | 44.7 | 0 | 44.7 | [illegible] | 44.7 |
| 60.1 | 141.5 | Sept | 106.2 | 24 | 87.5 | 0 | 71.2 | 0 | 48.2 | 0 | 0 | 0 | 0 | 0 |
| 35.9 | 17.3 | Oct | 8.1 | 27.1 | 0 | 18.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 534.6 | 454.7 | Total | 268.3 | 345.2 | 181.1 | 241.8 | 98.2 | 153.1 | 48.2 | 128.5 | 0 | 128.5 | 0 | 128.5 |

1979

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17.8 | 31.2 | Apr | 27.3 | 12.2 | 26.3 | 0.2 | 26.3 | 0 | 26.3 | 0 | 26.3 | 0 | 0 | 0 |
| 63 | 36.4 | May | 23.9 | 50.7 | 5.6 | 32.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 104 | 70.3 | Jun | 35.2 | 67.7 | 10.4 | 43.9 | 0 | 23.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 123.1 | 111 | Jul | 65.7 | 77.8 | 32.7 | 50.8 | 0 | 27 | 0 | 0.3 | 0 | 0 | 0 | 0 |
| 102.7 | 40.9 | Aug | 12.7 | 74.8 | 1.7 | 57.3 | 0 | 46.6 | 0 | 46.6 | 0 | 0 | 0 | 0 |
| 70.9 | 50.2 | Sept | 20.6 | 41.3 | 6.3 | 27.4 | 0 | 21.1 | 0 | 21.1 | 0 | 18.3 | 0 | 0 |
| 34.2 | 12.7 | Oct | 2.3 | 21.4 | 0 | 21.1 | 0 | 21.1 | 0 | 21.1 | 0 | 21.1 | 0 | 0 |
| 515.7 | 352.7 | Total | 187.7 | 345.9 | 83 | 233.1 | 26.3 | 139 | 26.3 | 89.1 | 26.3 | 39.4 | 0 | 0 |

1980

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53.6 | 4 | Apr | 1.4 | 51 | 1.3 | 38.9 | 1.3 | 1.9 | 0 | 0 | 0 | 0 | 0 | 0 |
| 85 | 43 | May | 24 | 63.7 | 13 | 60.8 | 0 | 60.8 | 0 | 16.6 | 0 | 16.6 | 0 | 0 |
| 108.2 | 131.9 | Jun | 68.2 | 46.5 | 46 | 29.5 | 1.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 116.3 | 69.2 | Jul | 30.3 | 75 | 9 | 45.1 | 0 | 8.2 | 0 | 6.6 | 0 | 6.6 | 0 | 0 |
| 86.5 | 194.8 | Aug | 150.1 | 42.7 | 125.7 | 24.1 | 66.1 | 1.5 | 16.1 | 0 | 0 | 0 | 0 | 0 |
| 54.9 | 55.6 | Sept | 36.9 | 35.3 | 23.3 | 13.5 | 12 | 0 | 12 | 0 | 0 | 0 | 0 | 0 |
| 33.4 | 11.2 | Oct | 6.1 | 28.4 | 0 | 26.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 537.9 | 509.7 | Total | 317 | 342.6 | 218.3 | 238.5 | 81 | 72.4 | 28.1 | 23.2 | 0 | 23.2 | 0 | 0 |

APPENDIX III CONTINUED

1981 — Water Storage Categories

| RE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34.7 | 9.8 | Apr | 13.2 | 25.7 | 2.8 | 14.7 | 0 | 0 | 0 | 0 | 0 | 0 | [illegible] | 0 |
| 83.5 | 46.9 | May | 19.5 | 57.8 | 0.8 | 49.8 | 0 | 24.7 | 0 | 0 | 0 | 0 | 0 | 0 |
| 93.1 | 42.3 | Jun | 12.3 | 61.1 | 0 | 37.8 | 0 | 37 | 0 | 14.8 | 0 | 0 | 0 | 0 |
| 116.3 | 157.6 | Jul | 97.3 | 58 | 60.5 | 32.2 | 2.8 | 11.5 | 0 | 11.5 | 0 | 0 | 0 | 0 |
| 123.7 | 10.5 | Aug | 3.2 | 111.5 | 0 | 100 | 0 | 62 | 0 | 58.9 | 0 | 43.3 | 0 | 41.3 |
| 70.7 | 33.4 | Sept | 18.3 | 55.6 | 7.1 | 46.8 | 0 | 46.8 | 0 | 46.8 | 0 | 46.8 | 0 | 46.8 |
| 24.1 | 30 | Oct | 21.6 | 16.7 | 9.9 | 2.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 546.1 | 330.5 | Total | 185.4 | [illegible]5.4 | 31.1 | 284.2 | 2.8 | 182 | 0 | 132 | 0 | 90.1 | 0 | 88.1 |

1982 — Water Storage Categories

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22.7 | 16.4 | Apr | 11.5 | 15.8 | 11.5 | 4.8 | 11.5 | 0 | 11.5 | 0 | 0.6 | 0 | 0 | 0 |
| 76.6 | 27.9 | May | 15 | 63.7 | 2.9 | 52.6 | 0 | 17.5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 113.2 | 25.1 | Jun | 2 | 90.8 | 0 | 88 | 0 | 88 | 0 | 54.6 | 0 | 4.6 | 0 | 4.6 |
| 119.1 | 204.6 | Jul | 154.5 | 69 | 126.9 | 41.4 | 75.3 | 4.4 | 25.3 | 4.4 | 0 | 0 | 0 | 0 |
| 89.7 | 43.2 | Aug | 4.4 | 60.9 | 0 | 53.6 | 0 | 39 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 35.6 | Sept | 17 | 45.4 | 5.3 | 26.6 | 0 | 21.3 | 0 | 10.3 | 0 | 0 | 0 | 0 |
| 29.3 | 39.1 | Oct | 33.4 | 23.6 | 11.4 | 6.1 | 0 | 1.6 | 0 | 1.6 | 0 | 0 | 0 | 0 |
| 515.6 | 391.9 | Total | 237.8 | 369.2 | 158 | 273.1 | 86.8 | 171.8 | 36.8 | 70.9 | 0.6 | 4.6 | 0 | 4.6 |

1983 — Water Storage Categories

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36.1 | 18.3 | Apr | 8.8 | 24.3 | 5.5 | 10.3 | 5.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74.3 | 10.2 | May | 0.6 | 59.8 | 0 | 59.2 | 0 | 32.2 | 0 | 12.6 | 0 | 6.3 | 0 | 6.3 |
| 100.7 | 151.1 | Jun | 109.1 | 60.7 | 91.3 | 53.2 | 54.3 | 53.2 | 4.3 | 53.2 | 0 | 53.2 | 0 | 53.2 |
| 121 | 104.5 | Jul | 72.8 | 56.3 | 34.8 | 32.6 | 0 | 32.6 | 32.6 | 0 | 0 | 0 | 0 | 0 |
| 114.5 | 12.2 | Aug | 0 | 102.1 | 0 | 102.1 | 0 | 99.9 | 0 | 49.9 | 0 | 12.5 | 0 | 12.5 |
| 49.5 | 36.2 | Sept | 15.8 | 29.3 | 0 | 13.5 | 0 | 13.5 | 0 | 13.5 | 0 | 13.5 | 0 | 13.5 |
| 25.8 | 12.2 | Oct | 6.1 | 18.8 | 0 | 16.5 | 0 | 16.5 | 0 | 16.5 | 0 | 16.5 | 0 | 16.5 |
| 521.9 | 344.7 | Total | 213.2 | 351.3 | 131.6 | 287.4 | 59.8 | 247.9 | 36.9 | 145.7 | 0 | 102 | 0 | 102 |

1984 — Water Storage Categories

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39.9 | 6.6 | Apr | 1.1 | 32.4 | 0 | 20.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66.7 | 55.9 | May | 27.7 | 38.3 | 2.8 | 27.2 | 0 | 10.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 104.1 | 66.2 | Jun | 34.9 | 70.3 | 18 | 42.1 | 0 | 19.2 | 0 | 10 | 0 | 10 | 0 | 10 |
| 12[illegible] | 48.2 | Jul | 24.8 | 95.6 | 7.8 | 83.3 | 0 | 68.1 | 0 | 68.4 | 0 | 68.4 | 0 | 68.4 |
| 114.2 | 30.5 | Aug | 1.3 | 90 | 0 | 88.7 | 0 | 88.7 | 0 | 88.7 | 0 | 88.7 | 0 | 88.7 |
| 46.2 | 116.3 | Sept | 96 | 27.1 | 74.6 | 13.5 | 0 | 9.2 | 0 | 9.2 | 0 | 9.2 | 0 | 9.2 |
| 29.5 | 6.6 | Oct | 0 | 25.5 | 0 | 16.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 522.6 | 33[illegible]3 | Total | 185.8 | 379.2 | 103.2 | 291.8 | 0 | 195.3 | 0 | 176.3 | 0 | 176.3 | 0 | 176.3 |

1985 — Water Storage Categories

| PE | Ppt. | Month | 2 mm. S | 2 mm. D | 13 mm. S | 13 mm. D | 50 mm. S | 50 mm. D | 100 mm. S | 100 mm. D | 150 mm. S | 150 mm. D | 250 mm. S | 250 mm. D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34.5 | 46 | Apr | 32.8 | 19.3 | 18.9 | 0 | 18.9 | 0 | 18.9 | 0 | 18.9 | 0 | 0 | 0 |
| 90.6 | 21.6 | May | 4.3 | 75.3 | 0 | 66.5 | 0 | 29.5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 99.2 | 65.6 | Jun | 30.2 | 61.8 | 13 | 43.5 | 0 | 33.6 | 0 | 13.1 | 0 | 0 | 0 | 0 |
| 127.8 | 31.1 | Jul | 6.7 | 105.4 | 0 | 102.9 | 0 | 99.8 | 0 | 99.8 | 0 | 62.9 | 0 | 25.2 |
| 96.6 | 9[illegible] | Aug | 50.3 | 58.5 | 33.8 | 37.8 | 0 | 20.2 | 0 | 20.2 | 0 | 20.2 | 0 | 20.2 |
| 45.3 | 56 | Sept | 27 | 16.5 | 6.3 | 10.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23.2 | 18.8 | Oct | 10.2 | 16.6 | 0 | 4.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 517.2 | 330.5 | Total | 161.5 | 353.4 | 72 | 266.1 | 18.9 | 183.1 | 18.9 | 133.1 | 18.9 | 83.1 | 0 | 45.4 |

APPENDIX III CONTINUED

| 1986 | | | Water Storage Categories | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 mm. | | 13 mm. | | 50 mm. | | 100 mm. | | 150 mm. | | 250 mm. | |
| PE | Ppt. | Month | S | D | S | D | S | D | S | D | S | D | S | D |
| 33.9 | 39.8 | Apr | 22.8 | 16.9 | 5.9 | 0 | 5.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 88.4 | 58.6 | May | 41.3 | 69.1 | 29.4 | 46.2 | 29.4 | 9.2 | 25.5 | 0 | 0 | 0 | 0 | 0 |
| 111.5 | [illegible] | Jun | 27.8 | 84.5 | 1.8 | 58.5 | 0 | 56.7 | 0 | 15.9 | 0 | 0 | 0 | 0 |
| 114.3 | 144.6 | Jul | 81.2 | 50.9 | 54 | 23.7 | 17 | 9.8 | 0 | 9.8 | 0 | 0.2 | 0 | 0.2 |
| 107.3 | 19.7 | Aug | 4.2 | 91.8 | 0 | 87.6 | 0 | 64.5 | 0 | 47.5 | 0 | 47.5 | 0 | 47.5 |
| 51.3 | 84.7 | Sept | 68.7 | 37.3 | 46.7 | 26.3 | 3.5 | 20.1 | 0 | 20.1 | 0 | 20.1 | 0 | 20.1 |
| 38.9 | 20.8 | Oct | 11.1 | 28.9 | 11.1 | 17.9 | 11.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 545.6 | 423 | Total | 257.1 | 379.4 | 148.9 | 260.2 | 66.9 | 160.3 | 25.5 | 93.3 | 0 | 67.8 | 0 | 67.8 |

Source: Calculations by Author Using the Thornthwaite Procedure and Data From the Monthly Summary Produced by the Atmospheric Environment Service

# APPENDIX IV

## THE CALCULATION OF MONTHLY WATER BALANCES FOR ELK ISLAND NATIONAL PARK 1982-1985

The following tables are yearly water balances using the Thornthwaite technique with weather data from Elk Island National Park. The year 1982 was the first year of operation for the station at the Park, therefore, the moisture storage levels and surplus carry over from the previous year was taken from the Edmonton International Airport water balance tables (App. I). The data from these tables were compared with similar data from the Edmonton International Airport in chapter 3. This was done to determine the suitability [illegible] Edmonton International Airport data. In chapter 4, yields were calculated from surpluses listed in these tables. A water balance for 1986 is not available due to an imcomplete record from the Park during 1986.

## APPENDIX IV

### ELK ISLAND NATIONAL PARK
### WATER BALANCE USING THORNTHWAITE PROCEDURES- 1982

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. C | -24.5 | -16.9 | -8.4 | -0.7 | 9.8 | 15.5 | 18 | 12.9 | 10.9 | 5.4 | -9.4 | -10.2 | |
| | PE mm. | 0 | 0 | 0 | 0 | 75.8 | 114.2 | 119.2 | 90 | 66.8 | 33.1 | 0 | 0 | 499.1 |
| | Ppt. mm. | 51.4 | 19 | 49 | 39 | 48.6 | 22.4 | 244.7 | 87.8 | 33.1 | 15.1 | 10.6 | 11.5 | 632.2 |
| | St. Ch. mm. | 51.4 | 19 | 49 | 39 | -27.2 | -91.8 | 125.5 | -2.2 | -33.7 | -18 | 10.6 | 11.5 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 2 | |
| 15.6 | Surp | 51.4 | 19 | 49 | 39 | | | 123.5 | | | | 8.6 | 11.5 | 297.5 |
| | Def. | | | | | 25.2 | 91.8 | | 0.2 | 33.7 | 18 | | | 168.9 |
| | 632.2=(499.1-168.9)+297.5+4.5 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 0 | 13 | 10.8 | 0 | 0 | 10.6 | 13 | |
| 10.5 | Surp. | 51.4 | 19 | 49 | 39 | | | 112.5 | | | | | 9.1 | 281.4 |
| | Def. | | | | | 14.2 | 91.8 | | | 22.9 | 18 | | | 146.9 |
| | 632.2=(499.1-146.9)281.4-1.4 | | | | | | | | | | | | | |
| 23.5 | St. 50 mm. | 50 | 50 | 50 | 50 | 22.8 | 0 | 50 | 47.8 | 14.1 | 0 | 10.6 | 22.1 | |
| | Surp. | 24.9 | 19 | 49 | 39 | | | 75.5 | | | | | | 207.4 |
| | Def. | | | | | | 69 | | | | 3.9 | | | 72.9 |
| | 632.2=(499.1-72.9)+207.4-1.4 | | | | | | | | | | | | | |
| 23.5 | St. 100mm | 74.9 | 93.9 | 100 | 100 | 72.8 | 0 | 100 | 97.8 | 64.1 | 46.1 | 56.7 | 68.2 | |
| | Surp. | | | 42.9 | 39 | | | 25.5 | | | | | | 107.4 |
| | Def. | | | | | | 19 | | | | | | | 19 |
| | 632.2=(499.1-19)+107.4+44.7 | | | | | | | | | | | | | |
| 23.5 | St. 150 mm. | 74.9 | 93.9 | 142.9 | 150 | 122.8 | 31 | 150 | 147.8 | 114.1 | 96.1 | 106.7 | 118.2 | |
| | Surp. | | | | 31.9 | | | 6.5 | | | | | | 38.4 |
| | Def. | | | | | | | | | | | | | 0 |
| | 632.2=(499.1-0)+38.4+94.7 | | | | | | | | | | | | | |
| 23.5 | St. 250 mm. | 74.9 | 93.9 | 142.9 | 181.9 | 154.7 | 62.9 | 188.4 | 186.2 | 152.5 | 134.5 | 145.1 | 156.6 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | | | | | | 0 |
| | 632.2=(499.1-0)+0+133.1 | | | | | | | | | | | | | |

### ELK ISLAND NATIONAL PARK
### WATER BALANCE 1983

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. C | -11.5 | -8.7 | -5.3 | 5.1 | 10 | 13.9 | 16.8 | 17.1 | 8.4 | 4.6 | -4.2 | -20.1 | |
| | PE mm. | 0 | 0 | 0 | 35.5 | 75.8 | 102 | 123.3 | 112.5 | 50.9 | 24.8 | 0 | 0 | 524.8 |
| | Ppt. mm. | 9 | 16.9 | 27 | 13.2 | 9.3 | 254.1 | 168.6 | 9 | 36.2 | 12.2 | 13.4 | 16.5 | 585.4 |
| | St. Ch. mm. | 9 | 16.9 | 27 | -22.3 | -66.5 | 152.1 | 45.3 | -104 | -14.7 | -12.6 | 13.4 | 16.5 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 2 | 2 | |
| 20.1 | Surp | 9 | 16.9 | 27 | | | 150.1 | 45.3 | | | | 11.4 | 16.5 | 268.4 |
| | Def. | | | | 20.3 | 66.5 | | | 101.5 | 14.7 | 12.6 | | | 168.9 |
| | 585.4=(524.8-215.6)+268.4+7.8 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 0 | 0 | 13 | 13 | 0 | 0 | 0 | 13 | 13 | |
| 9.1 | Surp. | 9 | 16.9 | 27 | | | 139.1 | 45.3 | | | | 0.4 | 16.5 | 246.4 |
| | Def. | | | | 9.3 | 66.5 | | | 90.5 | 14.7 | 12.6 | | | 193.6 |
| | 585.4=(524.8-193.6)+246.4+7.8 | | | | | | | | | | | | | |
| 22.1 | St. 50 mm. | 31.1 | 48 | 50 | 27.7 | 0 | 50 | 50 | 0 | 0 | 0 | 13.4 | 29.9 | |
| | Surp. | 24.9 | 19 | 25 | 39 | | 102.1 | 45.3 | | | | | | 172.4 |
| | Def. | | | | | 38.8 | | | 53.6 | 14.7 | 12.6 | | | 119.6 |
| | 585.4=(524.8-119.6)+172.4+7.8 | | | | | | | | | | | | | |
| 68.2 | St. 100mm | 77.2 | 94.1 | 100 | 77.7 | 11.2 | 100 | 100 | 0 | 0 | 0 | 13.4 | 29.9 | |
| | Surp. | | | 21.4 | 39 | | 63.3 | 45.3 | | | | | | 129.7 |
| | Def. | | | | | | | | 3.5 | 14.7 | 12.6 | | | 30.8 |
| | 585.4=(524.8-30.8)+129.7-38.8 | | | | | | | | | | | | | |
| 118.2 | St. 150 mm. | 127.2 | 144.1 | 150 | 127.7 | 61.2 | 150 | 150 | 46.5 | [illegible] | 19.2 | 32.6 | 49.1 | |
| | Surp. | | | [illegible] | | | | 45.8 | | | | | | 129.7 |
| | Def. | | | | | | | | | | | | | 0 |
| | 585.4=(524.8-0)+129.7 [illegible] | | | | | | | | | | | | | |
| 156.6 | St. 250 mm. | 155.6 | 182 [illegible] | [illegible] | [illegible] | [illegible] | 250 | [illegible] | [illegible] | 131.8 | 119.2 | 132.6 | 149.1 | |
| | Surp. | | | | | | 22.8 | 45.3 | | | | | | 68.1 |
| | Def. | | | | | | | | | | | | | 0 |
| | 585.4=(524.8-0)+68.1-7.5 | | | | | | | | | | | | | |

## APPENDIX IV CONTINUED

### ELK ISLAND NATIONAL PARK
### WATER BALANCE 1984

| | | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. C | -8.2 | -2[illegible] | [illegible] | 6.5 | 8.7 | 14.3 | 16.8 | 17.4 | 7.1 | 1.8 | -10.4 | -17 | |
| | PE mm. | 0 | 0 | [illegible] | 48.3 | 67.8 | 106.1 | 123.3 | 116.6 | 47.7 | 11 | 0 | 0 | 520.8 |
| | Ppt. mm. | 11.4 | [illegible] | [illegible] | 15 | 78.2 | 65.2 | 71.4 | 28.3 | 118.5 | 54.2 | 23.1 | 12.4 | 502.1 |
| | St. Ch. mm. | 11.4 | [illegible] | [illegible] | -33.3 | 10.4 | -40.9 | -51.9 | -88.3 | 70.8 | 43.2 | 23.1 | 12.4 | |
| 2 | St. 2 mm | 2 | [illegible] | 2 | 0 | 2 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | |
| 27.9 | Surp | 11.4 | [illegible] | 10.4 | | 8.4 | | | | 68.8 | 43.2 | 23.1 | 12.4 | 184.1 |
| | Def. | | | | 31.3 | | 38.9 | 51.9 | 88.3 | | | | | 210.4 |
| | 502.1=(520.8-210[illegible].1+7.6 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | [illegible] | 13 | 0 | 10.4 | 0 | 0 | 0 | 13 | 13 | 13 | 13 | |
| 16.9 | Surp. | 11.4 | [illegible] | 10.4 | | | | | | 57.8 | 43.2 | 23.1 | 12.4 | 153.7 |
| | Def. | | | | 20.3 | | 30.5 | 51.9 | 88.3 | | | | | 191 |
| | 502.1=(520.8-191)+153.7+18.6 | | | | | | | | | | | | | |
| 29.9 | St. 50 mm. | 41.3 | 50 | 50 | 16.7 | 27.1 | 0 | 0 | 0 | 50 | 50 | 50 | 50 | |
| | Surp. | | 5.3 | 10.4 | | | | | | 20.8 | 43.2 | 23.1 | 12.4 | 79.7 |
| | Def. | | | | | | 13.8 | 51.9 | 88.3 | | | | | 154 |
| | 502.1=(520.8-154)+79.7+55.6 | | | | | | | | | | | | | |
| 29.9 | St. 100mm | 41.3 | 55.3 | 65.7 | 32.4 | 42.8 | 1.9 | 0 | 0 | 70.8 | 100 | 100 | 100 | |
| | Surp. | | | | | | | | | | 14 | 23.1 | 12.4 | 14 |
| | Def. | | | | | | | 50 | 88.3 | | | | | 138.3 |
| | 502.1=(520.8-138.3)+14+105.6 | | | | | | | | | | | | | |
| 49.1 | St. 150 mm. | 60.5 | 74.5 | 84.9 | 51.6 | 62 | 21.1 | 0 | 0 | 70.8 | 114 | 137.1 | 149.5 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | 30.8 | 88.3 | | | | | 119.1 |
| | 502.1=(520.8-119.1)+0+100.4 | | | | | | | | | | | | | |
| 49.1 | St. 250 mm. | 160.5 | 174.5 | 184.9 | 151.6 | 162 | 121.1 | 69.2 | 0 | 70.8 | 114 | 137.1 | 149.5 | |
| | Surp. | | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | 19.1 | | | | | 19.1 |
| | 502.1=(520.8-19.1)+0+.4 | | | | | | | | | | | | | |

### ELK ISLAND NATIONAL PARK
### WATER BALANCE 1985

| | | J | [illegible] | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. C | -10.2 | -13.4 | -2.2 | 4.3 | 12.6 | 12.5 | 1[illegible].3 | 14 | 6.9 | 2.9 | -14.8 | -7.6 | |
| | PE mm. | 0 | 0 | 0 | 31.1 | 95.8 | 97.9 | 127.4 | 97.5 | 47.7 | 19.3 | 0 | 0 | 516.7 |
| | Ppt. mm. | 7.5 | 11.5 | 3 | 42.2 | 33.3 | 70.1 | 49.4 | 57.8 | 58.7 | 31.2 | 19.3 | 33.5 | 417.5 |
| | St. Ch. mm. | 7.5 | 11.5 | 3 | 11.1 | -62.5 | -27.8 | -78 | -39.7 | 11 | 11.9 | 19.3 | 33.5 | |
| 2 | St. 2 mm | 2 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | |
| 35.5 | Surp | 7.5 | 11.5 | 3 | 11.1 | | | | | 9 | 11.9 | 19.3 | 33.5 | 89.5 |
| | Def. | | | | | 60.5 | 27.8 | 76 | 39.7 | | | | | 204 |
| | 417.5=(516.7-204)+89.5+17.3 | | | | | | | | | | | | | |
| 13 | St. 13 mm. | 13 | 13 | 13 | 13 | 0 | 0 | 0 | 0 | 11 | 13 | 13 | 13 | |
| 35.5 | Surp. | 7.5 | 11.5 | 3 | 11.1 | | | | | | 9.9 | 19.3 | 33.5 | 78.5 |
| | Def. | | | | | 49.5 | 27.8 | 78 | 39.7 | | | | | 195 |
| | 417.5=(516.7-195)+78.5+17.3 | | | | | | | | | | | | | |
| 50 | St. 50 mm. | 50 | 50 | 50 | 50 | 0 | 0 | 0 | 0 | 11 | 22.9 | 42.2 | 50 | |
| 35.5 | Surp. | 7.5 | 11.5 | 3 | 11.1 | | | | | | | | 25.7 | 68.6 |
| | Def. | | | | | 12.5 | 27.8 | 78 | 39.7 | | 3.9 | | | 158 |
| | 417.5=(516.7-158)+68.6-9.8 | | | | | | | | | | | | | |
| 100 | St. 100mm | 100 | 100 | 100 | 100 | 37.5 | 9.7 | 0 | 0 | 11 | 22.9 | 42.2 | 75.7 | |
| 35.5 | Surp. | 7.5 | 11.5 | 3 | 101 | | | | | | | | | 68.6 |
| | Def. | | | | | | | 68.3 | 39.7 | | | | | 108 |
| | 417.5=(516.7-108)+68.6-59.8 | | | | | | | | | | | | | |
| 149.5 | St. 150 mm. | 150 | 150 | 150 | 150 | 87.5 | 59.7 | 0 | 0 | 11 | 22.9 | 42.2 | 75.7 | |
| | Surp. | 7 | 11.5 | 3 | 11.1 | | | | | | | | | 32.6 |
| | Def. | | | | | | | 18.3 | 39.7 | | | | | 58 |
| | 417.5=(516.7-58)+32.6-73.8 | | | | | | | | | | | | | |
| 149.5 | St. 250 mm. | 156.5 | 168 | 171 | 182.1 | 119.6 | 91.8 | 13.8 | 0 | 11 | 22.9 | 42.2 | 75.7 | |
| | Surp. | - | | | | | | | | | | | | 0 |
| | Def. | | | | | | | | 25.9 | | | | | 25.9 |
| | 417.5=(516.7-25.9)+0-73.8 | | | | | | | | | | | | | |

Source: Calculations by Author Using the Thornthwaite Procedure and the Monthly Summary Data From Elk Island National Park Produced by the Atmospheric Environment Service.