HATFIELD VALLEY AQUIFER SYSTEM IN THE WYNYARD REGION, SASKATCHEWAN.

Volume 1

Text and Appendices A to E

H. Maathuis
B.T. Schreiner
Geology Division
Saskatchewan Research Council

Prepared for Saskatchewan Environment under the Canada-Saskatchewan Interim Subsidiary Agreement of Water Development for Regional Economic Expansion and Drought Proofing.

June, 1982

SRC Publication No. G-744-4-C-82

TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1 INTRODUCTION

1.1 Purpose and Scope of Study

The study presented is the second phase of a three phased study of the Hatfield Valley and the Swift Current Valley Aquifer Systems in the area bounded by 50°35' and 52°10' latitude and 104° and 106°10' longitude. This study was commissioned by the Saskatchewan Department of the Environment (contract #97-80/81) under the Canada -Saskatchewan Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing.

The aim of this study is a definition of the aquifers and an evaluation both in terms of quantity and quality of the groundwater resources in the Hatfield Valley and Swift Current Valley Aquifer Systems.

This study presents, explains and illustrates the work carried out under Phase II, which included:

- Preparation of field work program;
- supervision of approximately 2743 m. (9,000 ft) of test drilling and E-logging;
- collecting and analyzing of water samples;
- supervision of piezometer installation;
- presentation, and interpretation of data collected in the form of maps and cross sections, including a preliminary evaluation of the aquifer systems in terms of groundwater quantity and quality, and
- preparation of cost estimate for formal printing of the Phase II report.

A large portion of the study area previously had been investigated by Maathuis (1980a).

The increase in area to be studied and a considerable amount of new testhole information which became available prior to the fieldwork necessitated a major update of previous work.

1.2 Location of study area

The study area is located between 50°35' and 52°10' latitude and 104° and 106°10' longitude and covers an area of approximately 31,100 km^2 (Figure 1). The area includes the NTS map sheet Wynyard (72P) and portions of the Regina (72I), Swift Current (72J), Rosetown (72O), Melfort (73A) and Saskatoon (73B) sheet areas.

1.3 Data Collection

1.3.1 Existing Data

Data collected include testhole and augerhole logs from the Saskatchewan Research Council, drillhole information from the Family Farm Improvement Branch and oil and potash company logs. Other logs such as water well logs have not been used in this study because of the lack of electric logs which make these data incompatible with other logs.

Geohydrological data compiled include information on water quality, water levels, flowing wells, hydraulic properties, and groundwater allocations.

1.3.2 Fieldwork

During the period June 8 - July 20, 1981, a total of 21 testholes were drilled under contract to Hayter Drilling Ltd., Watrous, Saskatchewan. Ten testholes were drilled in the Wynyard area (72P), eight in the Regina area (72I) and three in the Yorkton area (62M) to confirm continuity of the Hatfield Valley Aquifer System to the east. A piezometer was completed in the Swift Current Valley Aquifer, east of Last Mountain Lake.

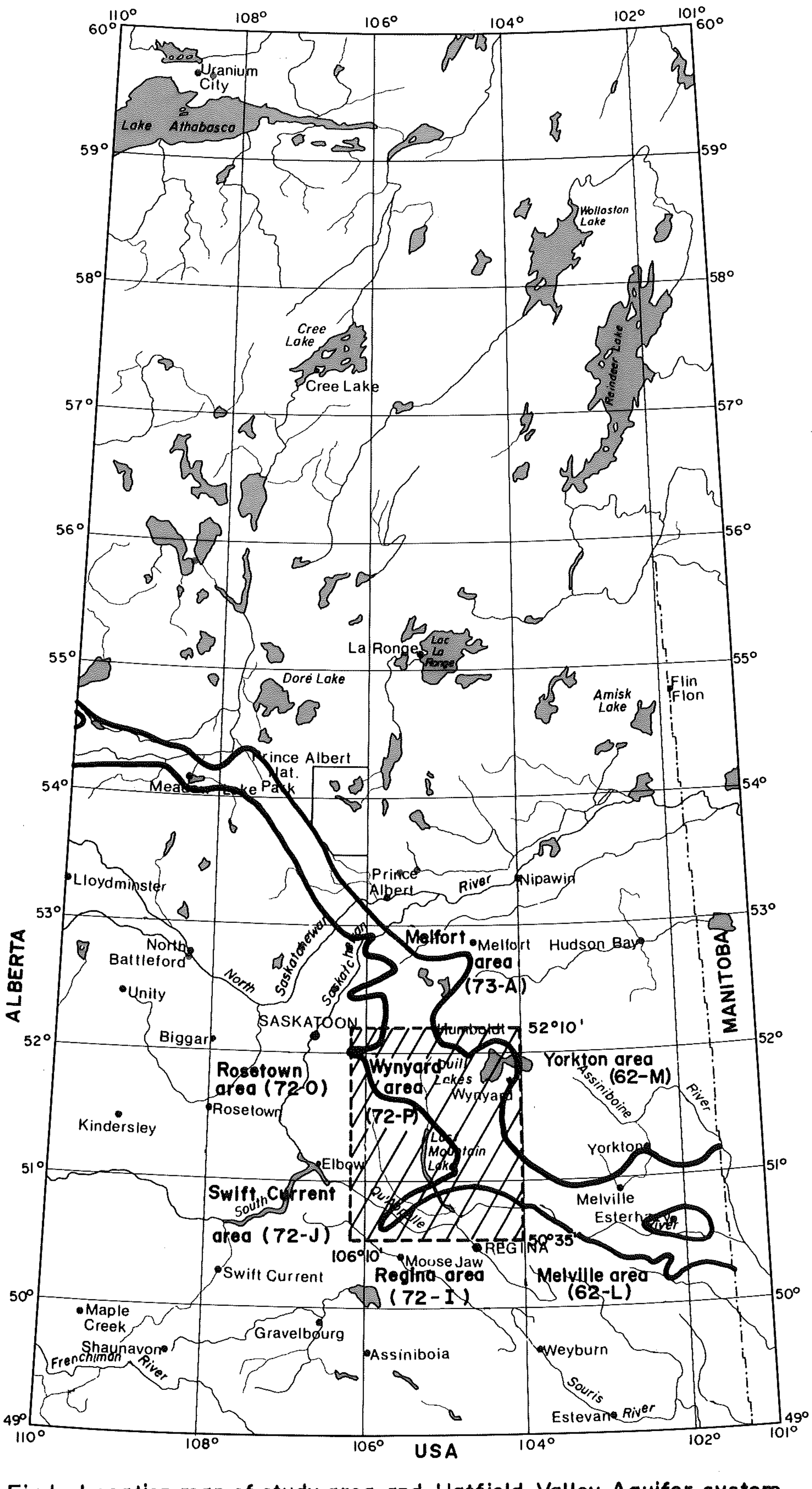


Fig. I Location map of study area and Hatfield Valley Aquifer system.

Samples from testholes were taken every 1.5 m (5 ft), dried and described according to lithologic characteristics. Selected till samples were analyzed for carbonate content, and grain size analysis were carried out on selected sand samples.

The role of the sidehole core sampler is primarily to obtain precisely located samples from testholes which for various reasons do not provide adequate cutting samples. For this purpose the sampler was only used on a few occasions (e.g. SRC Wishart). The second objective was to obtain sand samples for grain size analysis in order to estimate the hydraulic conductivity. For technical reasons, such as collapse of the hole and dropping out of the sand before the sampler reached the surface, the samples could not be used for this purpose.

Water samples were mainly taken from wells known to be completed in the Hatfield Valley Aquifer System or the Swift Current Valley Aquifer System, but also a limited number of samples were taken from wells in intertill aquifers and in the Judith River Formation Aquifer.

Testhole data and chemical analyses of water samples taken are compiled in Appendix F and G in Volume II of this report.

1.4 Data Presentation

A total of 15 cross-sections (A-A' to N-N', and a logitudinal cross-section through the Hatfield Aquifer) have been prepared showing the geometry and geological setting of the Hatfield Valley and Swift Current Valley Aquifer Systems (Appendix A). The carbonate contents of till units are plotted as graphs on the testhole logs which are included on the cross-sections. A map (Map A) has been prepared with the bedrock surface elevations and contours as well as the distribution of the units outcropping out at the bedrock surface. A second map (Map B) shows the distribution depth and thickness of the sediments comprising the aquifer systems as well as reported water levels and available drawdown (Appendix A).

The location of testholes drilled under this program and the location of the piezometer are also shown on these maps.

Water quality data are presented in the form of water quality bars on the cross-sections and in table form. Results of grain size analyses are listed in tables in Appendix D along with calculated hydraulic conductivity values based on these analyses. Testholes where side-hole core sampling was done are marked and the location of the samples is indicated on the logs.

1.5 Acknowledgements

The cooperation and interest of the Rural Municipalities and farmers within the study area are gratefully acknowledged.

Mr. Harm Maathuis (SRC) compiled and interpreted the hydrologic information in this study. He also supervised the test drilling piezometer installation, and sample collection and analyses and all other field components of the investigation. Mr. Bryan Schreiner (SRC) assisted with the interpretation of the geologic information.

Testholes were drilled by Mr. G. Gray, assisted by Messrs. O. Schnell and R. Boehr, of Hayter Drilling Limited, Watrous, Saskatchewan.

Mr. D. Zlipko (SRC), Geology Division assisted the author throughout the drilling program and also collected most of the water samples. Mr. E.J. Jaworski (SRC), Geology Division provided additional assistance when needed.

Dr. R.G. Arnold (SRC), Head, Geology Division, read the manuscript critically.

By special request, Mr. H. Martin, Family Farm Improvement Branch (FFIB), Regina, prepared FFIB logs for the study area. These logs were of importance in preparing cross sections and maps.

Messrs. R. Woodward and G. Blenchinger were in charge of obtaining sidehole core samples. Carbonate analyses on tills were done by Mr. W. C. Ross and Ms. T. McKay, SRC Sedimentary Laboratory. Water samples were analyzed according to standard methods by the SRC Chemical Laboratory.

Mrs. J. Rackel compiled all the testhole logs and, together with Mr. D. Zlipko, compiled, edited, and processed all the water quality data. Drafting was done by the SRC Graphic Section.

2 PHYSIOGRAPHY

2.1 Topography

The study area can be subdivided into the following major, physiographic divisions (Figure 2): Assiniboine River Plain, Quill Lake Plain, Touchwood Hills Upland, Allan Hills Upland, Moose Mountain Hills Upland, and Last Mountain Upland (Figure 2). The Assiniboine River Plain occupies most of the area. In the Wynyard area (72P) it forms a central lowland with a topographic elevation ranging from 490 to 595 m ASL and is flanked by the Allan Hills Upland on the west and Touchwood Hills Upland on the east. The topographic elevation of these uplands ranges from 610 to 655 m ASL, and 595 to 730 m ASL, respectively. The Last Mountain Upland area rises sharply about 180 m above Last Mountain Lake and has a topographic elevation ranging from 595 to 680 m ASL. The Moose Mountain Hills Upland area in the study area has an elevation of approximately 610 m ASL. The northeastern part of the study area is occupied by the Quill Lake Plain with elevation of 535 to 595 m ASL. The Qu'Appelle Valley which crosses the southern part of the area from west to east, is a striking topographic feature with its valley bottom approximately 90 m below the surrounding upland.

2.2 Surface Drainage

The Quill Lake drainage basin forms a closed basin in the northeastern portion of the study area. The remainder of the area drains into the Qu'Appelle River which flows from west to east and ultimately drains into Lake Winnipeg, Manitoba. The surface run-off drainage systems are generally poorly integrated and much of the area does not contribute directly to surface run-off courses because many topographic depressions have no outlets.

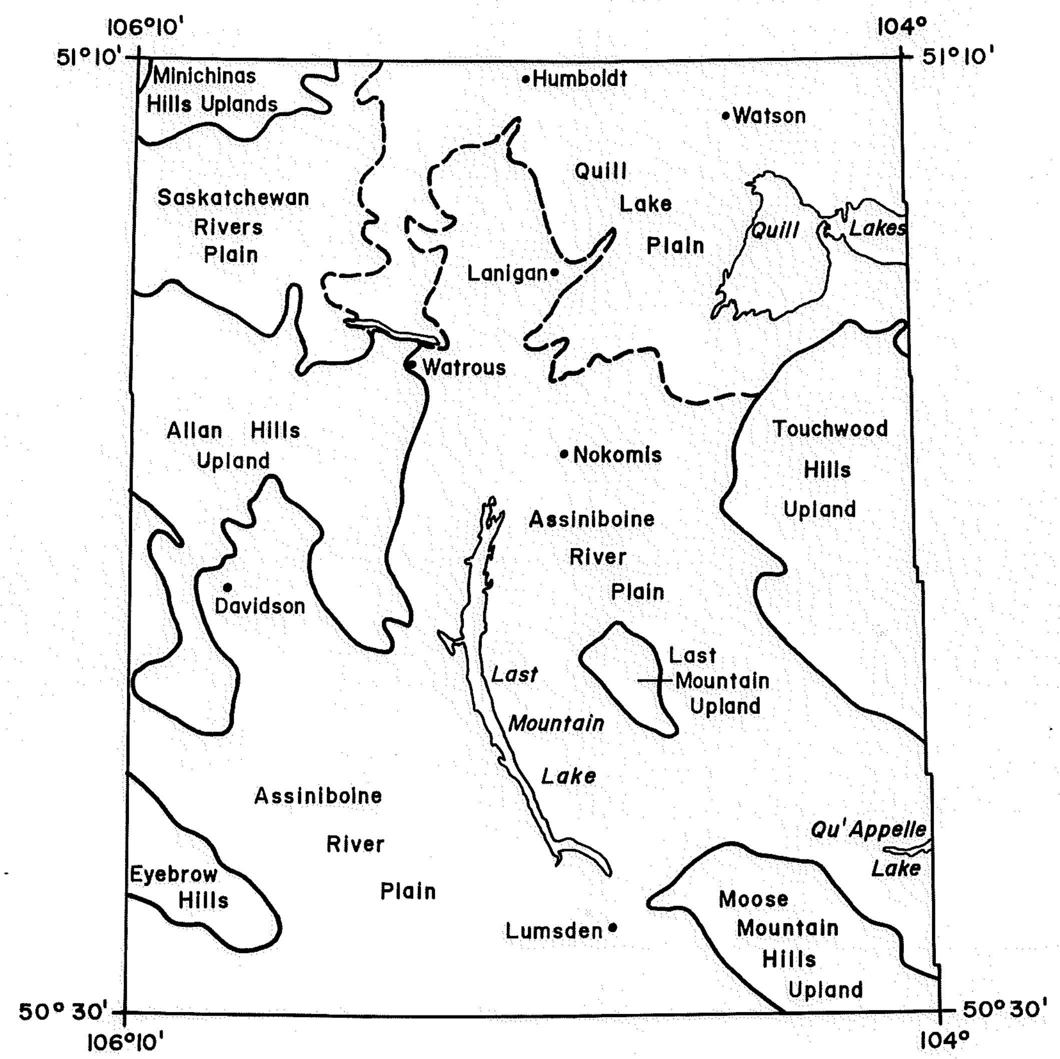


Fig.2 Physiographic divisions of study area (after Acton et al, 1960)

2.3 Climate

Climatological data from six meteorological stations in the study area are shown in Appendix B . According to the Koppen classification these stations fall under the Dfb type of climate, which is of the Boreal type, where the wettest month may have less than tenfold more precipitation than the driest month, and which has a warm summar of at least four months with temperatures above 10°C. The average annual precipitation (1941-1970) ranges from 357 mm/year in the western portion of the study area to 379 mm/year in the northern one. In the remainder of the area the average annual precipitation is in the order of 400 mm/year (Bergsteinsson, 1976). The average monthly precipitation is low (< 30 mm/month) during the winter (October - April) and high (30-80 mm/month) during the summer (May - September). The average winter precipitation is approximately 40% of the total annual precipitation.

3. BEDROCK GEOLOGY

3.1 Bedrock Stratigraphy

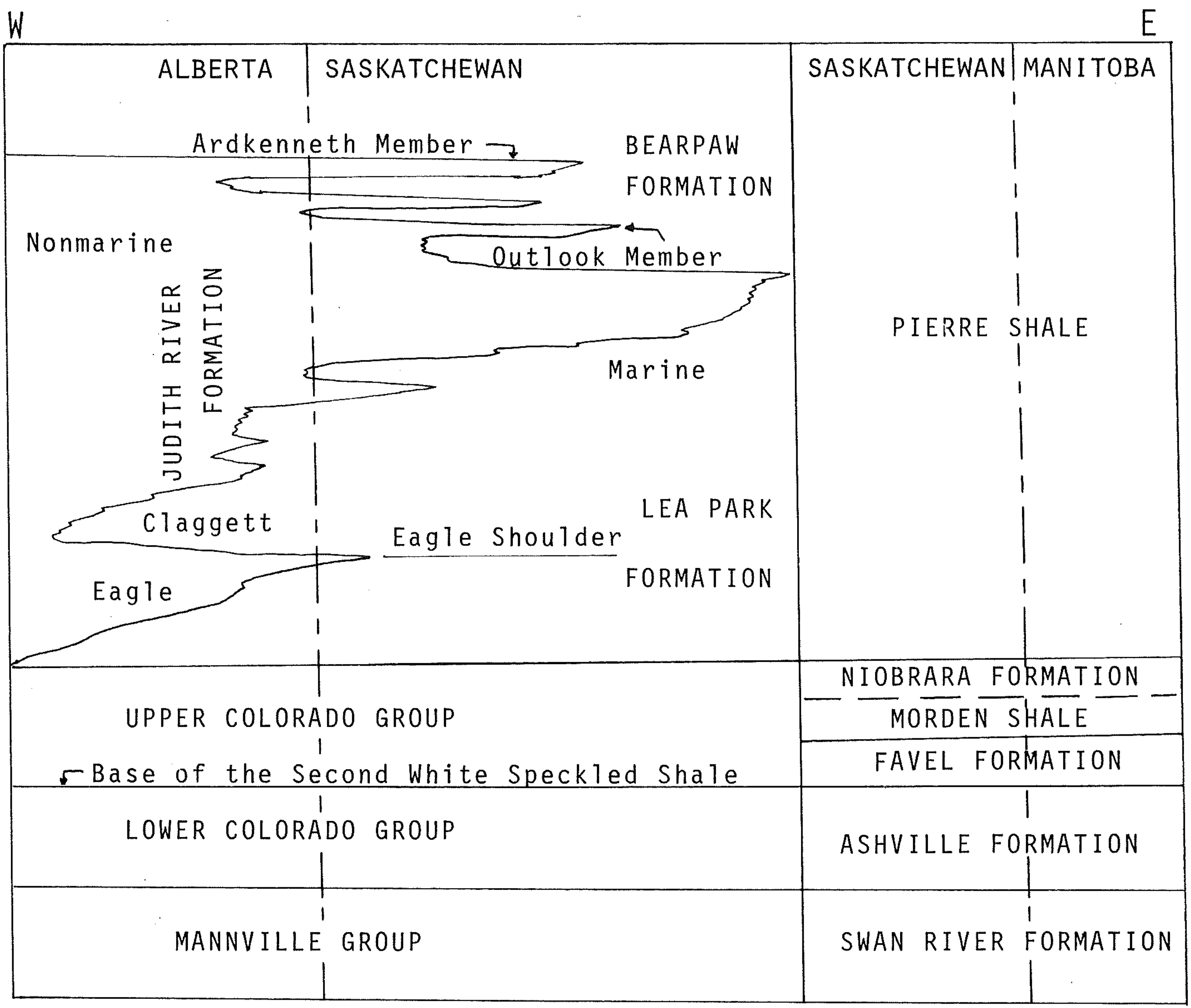
The bedrock stratigraphy in the study area is complicated by the fact that a facies and nomenclature change occurs within the area (McLean, 1971; Whitaker et al; 1972). The sequence of Cretaceous bedrock units and related nomenclatures are shown in Figure 3. In the Quill Lakes area, this sequence is overlain by the Tertiary "Wynyard" Formation.

3.2 Ashville - Lower Colorado Group and Swan River - Mannville Group

For the purpose of this report, both Groups are presented as an undifferentiated unit on the cross-sections (Appendix A). The Swan River-Mannville Group consists of locally cemented fine to medium-grained sand, and silt and clay. The Ashville-Lower Colorado Group is comprised of calcareous silt and clay. These units are described by Christiansen (1970, 1971a, 1971b) and Meneley, (1967). Neither of these Groups outcrop on the bedrock surface in the study area.

3.3 Favel Formation, Morden Shale and Niobrara Formation, and Pierre Shale

The ascending sequence of the Favel Formation, Morden Shale and Niobrara Formation, and Pierre Shale, is equivalent to the sequence of the Lea Park Formation and Upper Colorado Group, Judith River Formation and Bearpaw Formation, respectively. The Favel Formation, Morden Shale and Niobrara Formation and Pierre Shale occur east of the pinch-out of the Judith River Formation, whereas the Lea Park Formation and Upper Colorado Group, Judith River Formation, and Bearpaw Formation occur in the west (Figure 3). The lithostratigraphical division and nomenclature change



Nomenclature of Cretaceous Units of the Western Canadian Great Plains (modified from McLean, 1971)

Nomenclature of Cretaceous Formations of the Manitoba Escarpment (after McNeil and Caldwell, 1981)

FIGURE 3 CRETACEOUS NOMENCLATURES OF THE CANADIAN GREAT PLAINS

A comparison is shown between the nomenclature system for Cretaceous Units in the Western Canadian Great Plains and the nomenclature of Cretaceous Formations in the Manitoba Escarpment. This does not necessarily represent a correlation of stratigraphic units.

coincides with the actual or projected "pinch-out" of the Judith River Formation (McLean, 1971). The complicated nature of the Judith River Formation in the study area (i.e., cross section H-H' and E-E', Appendix B) indicates that this assumed boundary may not be correct. However, this study does not provide sufficient data to determine the actual boundary. Therefore, for this study, the boundary of the lithostratigraphic units as indicated by Whitaker et al. (1972) has been used (Map A, cross section E-E'). For the nomenclature of the units east of the "pinch-out", the nomenclature is adopted from McNeil et al. (1981).

The Favel Formation, ranging in thickness from 12-24 m (40-80 ft) consists of calcareous shale. The Morden Shale and Niobrara Formation, formerly known as the Vermillion Formation, are comprised of calcareous silt and clay, and non-calcareous silt and clay, respectively. Together both units comprise a thickness of 24-42 m (80-140 ft). The Pierre Shale, also known as the Riding Mountain Formation, is 150-240 m (500-800 ft) thick, and is composed of non-calcareous silt and clay. In the eastern portion of the study area, the Pierre Shale outcrops on the bedrock surface (Map A).

3.4 Lea Park Formation and Upper Colorado Group

Because the Lea Park Formation cannot be separated from the Upper Colorado Group on electric logs, the two units are combined. The Lea Park Formation and the Upper Colorado Group are composed of 150-365 m (500-1200 ft) of thick gray silt and clay. The upper portion of this unit is non-calcareous. This unit only crops out on the bedrock surface in areas where overlying bedrock has been removed by erosion (e.g., Hatfield Valley Aquifer).

3.5 Judith River Formation

The Judith River Formation is comprised of interbedded, non-calcareous, gray and greenish gray, very fine to fine grained sand, and gray silt. Available data (cross-section H-H', logs 93 and 94) suggest that, at least locally, the Judith River Formation may consist of an upper and lower sand unit, separated by a silt and clay unit. The position of the Judith River Formation is uncertain due to the fact that insufficient data are available, and that is occurs in an area where many collapse structures are thought to exist. The Formation thickness may range from 12-60 m and it occurs to the west and south of the Hatfield Valley Aquifer.

3.6 Bearpaw Formation

The Bearpaw Formation consists of 0-150 m (0-500 ft) of thick, gray, non-calcareous, silt and clay. It may include the Ardkenneth sand member (cross-section H-H', logs 109 and 145), and an unknown sand member (cross-section H-H', log 130). The Bearpaw Formation forms the bedrock surface in most of the area west and south of the Hatfield Valley.

3.7 "Wynyard Formation"

The youngest bedrock deposit encountered in the study area consists of yellow, brown, and light gray silt, and clay at the top; and sand, chert, and gravel at the base. These sediments have unofficially been designated as the "Wynyard Formation" (Christiansen, 1970). These deposits occur as erosional remnants of the Tertiary bedrock, and within the study area, they occur in the Quill Lakes area.

3.8 Bedrock Surface Topography

The bedrock surface topography, as shown on the bedrock geology map (Map A, Appendix A), is dominated by the Hatfield Valley and the Swift

Current Valley. In the study area, the collapse structures affected the bedrock surface to a limited extent (cross section L-L', log 253, Appendix B). Post-glacial fluvial erosion formed the Qu'Appelle Valley as the last glacier retreated from the area. Locally, this valley was cut deeply into the bedrock.

4. GLACIAL AND POST-GLACIAL GEOLOGY

4.1 General Remarks

The glacial geology consists of a sequence of stratigraphic units which, in ascending order, may include the Empress, the Sutherland and Saskatoon Groups, and the Surficial Stratified Drift. For the purpose of this present study, only the Empress Group has been delineated and is shown on Map B and in the cross-sections. The remainder of the drift in the cross-sections is presented as undifferentiated drift.

The glacial geology and history of deglaciation of the study area was described by Meneley (1964), Greer and Christiansen (1963), Christiansen (1961), and Christiansen (1979a, 1979b, 1979c).

4.2 Empress Group

The Empress Group is composed of sand, gravel, silt, and clay of fluvial, lacustrine, and colluvial origin that overlies marine Cretaceous and non-marine Tertiary bedrock, and underlies till of Quaternary age in south southern Saskatchewan. Minor constituents include "till balls", wood, coal, and organic-rich silts and clays (Whitaker and Christiansen, 1972).

The Empress Group material is the primary fill within the Hatfield Valley. In the study area, the Empress Group may range in thickness from 2.5 to 98 m (8-325 ft). The occurrence of the Empress Group is not limited to the Hatfield or Swift Current Valleys, as it also is encountered in the adjacent uplands (Map B, cross-section E-E').

Except for the northern and southeastern portion of the Hatfield Valley Aquifer, the Empress Group is composed of medium to coarse-grained sand, locally with a gravel layer at the bottom and with minor occurrences of interbedded silt or a silt layer at the top. The sands consist of quartz with minor amounts of limestone, dolomite, igneous, and metamorphic rock fragments. In the northern and southeastern portion, the Empress Group is more silty throughout its thickness (cross-section A-A', logs 11 and 13).

Facies changes in the Empress Group sediments are liable to occur but these variations could be quite complex. The nature and detail of the present information is such that it is impossible to reliably define these variations.

Initially, the Empress Group extended over a larger area than presently exists, but was removed by erosion (cross-section K-K', logs 109 and 220: cross-section B-B', logs 27 to 33). There is increasing evidence that more Empress Group material has been glacially removed than was previously assumed (Schreiner: personal communication). The top of the Empress Group is mainly formed by glacial erosion.

4.3 Drift

Based on carbonate content, electric resistance, and lithological parameters, stratigraphic units, such as the Sutherland and the Saskatoon Groups, along with subdivisions of the groups, such as the Floral and Battleford Formation, as described by Christiansen (1968), are evident in a number of cross-sections. Locally stratified gravels, sands, and silts are found between till units in the drift (longitudinal cross-section, logs 207 to 80). However, within the framework of the present study, which was to investigate the Hatfield Valley Aquifer System, no attempt was made to subdivide the glacial deposits and delineate the intertill aquifers. Primarily, correlation of drift units was restricted to basal till units which separate the glacial deposits from the Empress Group materials. The relationship of the deposits determines the surface configuration and thickness of the Empress Group sediments.

On the cross-sections, the glacial deposits are referred to an undifferentiated drift. The thickness of the drift may range from 15 to 250 metres.

4.4 Post-Glacial Deposits

The Qu'Appelle Alluvium is a major post-glacial deposit and is composed of silt, clay, and sand (Christiansen, 1961; Christiansen, *et al.*, 1977). It is confined to the Qu'Appelle Valley in the form of valley fill and flood plains.

5. GEOHYDROLOGIC BACKGROUND

5.1 Introduction

The geohydrological setting of the study area is derived from the geological setting and is illustrated in a general way in Figure 4. A discussion of the geohydrologic terms used in the following text is provided in Appendix E.

Geohydrologic and hydraulic parameters, which are important in the preliminary assessment of groundwater flow systems and aquifer yields include parameters, such as hydraulic conductivity, storage coefficient, thickness of aquifer and overlying layers, and water level and available drawdown data. From a user's point of view, water quality data may be of equal importance.

5.2 Hydraulic Properties of Till

The basic setting of both the Hatfield and Swift Current Valley Aquifer Systems is that the "Empress Group" Aquifer is underlain by an "impermeable" base and overlain by a semi-confining layer: mainly tills (Figure 4). Consequently, both in terms of natural and induced recharge conditions, the hydraulic characteristics of the semi-confining layers are of significant importance in any assessment of yields.

In the literature, data on the hydraulic conductivity of tills are generally separated into data on fractured till and intergranular or matrix hydraulic conductivity. Bulk hydraulic conductivities for fractured tills may range from 8.64×10^{-4} - 8.64×10^{-6} m/day with typical values in the 1.7×10^{-4} - 4.3×10^{-4} m/day range. The hydraulic conductivity of the till matrix is typically in the 8.64×10^{-7} - 8.64×10^{-8} m/day range (Grisak _et al_. (1976), and references therein: Grisak and

STRATIGRAPHY		LITHOLOGY		GEOHYDROLOGIC CLASSIFICATION		GENERALIZED GEOHYDROLOGICAL SETTING & AQUIFER NAMES
POST GLACIAL		ALLUVIUM SAND, SILT & CLAY LACUSTRINE: SILT AND CLAY		SEMI-CONFINING LAYER		SEMI-CONFINING LAYER
DRIFT UNDIFFERENTIATED		GLACIAL TILL		SEMI-CONFINING LAYER		SEMI-CONFINING LAYER
		STRATIFIED SAND, SILT & GRAVEL		AQUIFER		UNNAMED INTERTILL AQUIFERS
		GLACIAL TILL		SEMI-CONFINING LAYER		SEMI-CONFINING LAYER
EMPRESS GROUP		SAND, SILT AND GRAVEL		AQUIFER		EMPRESS GROUP AQUIFER: HATFIELD VALLEY, WYNYARD MEACHAM AND SWIFT CURRENT VALLEY AQUIFERS
"WYNYARD" FORMATION		CLAY AND SILT		SEMI-CONFINING LAYER		SEMI-CONFINING LAYER
		SAND AND GRAVEL		AQUIFER		"WYNYARD FORMATION" AQUIFER
BEARPAW FORMATION	PIERRE SHALE	CLAY AND SILT	CLAY AND SILT	SEMI-CONFINING LAYER	SEMI-CONFINING LAYER	SEMI-CONFINING LAYER
JUDITH RIVER FORMATION		SAND AND SILT		AQUIFER		JUDITH RIVER FORMATION AQUIFER
LEA PARK FORMATION		CLAY AND SILT		SEMI-CONFINING LAYER		"CONFINING" LAYER
UPPER COLORADO GROUP	NIOBRARA FORMATION AND MORDEN SHALE	CLAY AND SILT	CLAY AND SILT			
BASE OF SECOND WHITE	FAVEL FORMATION		CLAY AND SILT			
SPECKLED SHALE ASHVILLE LOWER COLORADO GROUP		SILT AND CLAY		SEMI-CONFINING LAYER		

NOTE: ⟷ INDICATES HYDRAULIC CONNECTION BETWEEN AQUIFERS

FIG. 4 GENERALIZED GEOHYDROLOGICAL SETTING IN STUDY AREA

Cherry (1974); Hendry (1982)). Meneley (1972) used a value of 8.1×10^{-5} m/day in calculations of the yield from major aquifers in Saskatchewan. Puodziunas (1978) assumed a bulk hydraulic conductivity value for tills in Souris River basin area in the order of 4.3×10^{-4} m/day and considered this value as conservative.

To date, no reliable quantitative data are available on the bulk hydraulic conductivity of "thick" till layers in Saskatchewan. It is, however, suggested that fracturing in tills is more widespread than is presently assumed. This assumption is supported by the fact that deep aquifers in Saskatchewan are being recharged according to Meneley et al. (1979), and as shown by computer model studies of aquifers (Kewen and Schneider, 1979). Therefore, a bulk hydraulic conductivity of 4.3×10^{-4} m/day is assumed in this study. The specific yield of till is estimated to be 1%. This value must be considered conservative as specific yield values for clays, as quoted in the literature, may range from 1 to 10% (Walton, 1970).

5.3 Hydraulic Properties of Aquifers

The hydraulic properties of the aquifer are important in estimating the yield of individual wells, the potential of the aquifer, and consequence of local and regional development.

Hydraulic properties of aquifers (transmissivity and storage coefficient), can be determined by means of pump tests, with or without observation wells, response tests, artificial tracer tests, and by means of empirical formulae using grain-size data.

In general, it can be stated that reliable data on the hydraulic properties of the Empress Group are lacking. However, a large number of short-term, single-well, pump test data on farm and domestic wells is available. These data generally provide the pumping rate, time of pumping, and one drawdown level, taken at the end of the pump test. However, not only is the accuracy of these measurements questionable, but the methods used to analyse the pump test data are not reliable. The Jacob approximation of the Theis solution (Cooper and Jacob, 1946) is often used to analyse these type of data, but calculations yiled only an apparent transmissivity with no physical meaning (Corbet, 1982). In addition, this method of analysis does not separate drawdowns caused by hydraulic properties of the aquifer itself from drawdowns due to well construction practices (Sauveplane, 1982). Consequently, these pump test data have not been analysed. The Papadopulos-Cooper method (Papadopulos and Cooper, 1967) would provide a more realistic method of analysis, however, it requires a more frequent measurement of drawdowns during the test.

5.4 Hydraulic Head and Available Drawdown Data.

The hydraulic head data as presented on Map B (Appendix B) must be interpreted with care as both the time of measurement and accuracy may differ. Consequently, these data can be used only as a crude indication of direction of groundwater flow. Similarly, because of the nature of the hydraulic head data, available drawdown data must be interpreted with care.

5.5 Water Quality Data and Interpretation.

In addition to water quality data collected within the frame work of the present study, data from SRC's water quality data bank and selected data from Rutherford (1966) have been used in the preliminary assessment of the water quality in the aquifers systems.

The type of water has been determined according to the method outlined by Piper (1944), but the number of water types was reduced to four (Fig. 5).

Saskatchewan Environment guidelines (Appendix C) have been used to assess the water quality from the aquifer systems in terms of its suitability for municipal and domestic use. Because guidelines for industrial uses may vary widely depending on the type of industry (McNealy, et al., 1979), suitability of the groundwater for industrial purposes is not included in the assessment.

Assessment of the water quality in terms of its suitability for irrigation is complex as it not only depends on the water quality itself but also on factors, such as soil type, soil texture, drainage characteristics, climate, type of crop, and irrigation water management (Bachman et al., 1980). Consequently, the suitability of water from the aquifer systems for irrigation use can only be assessed in very general terms and detailed site-specific geohydrologic and soil investigations are required for a more precise assessment.

Although the Sodium Adsorption Ratio (SAR) used as a preliminary tool to assess the suitability of groundwater for irrigation has become less accepted in recent years, SAR values are included in the water quality data tables. Now the Adjusted Sodium Adsorption Ratio (ASAR) is generally

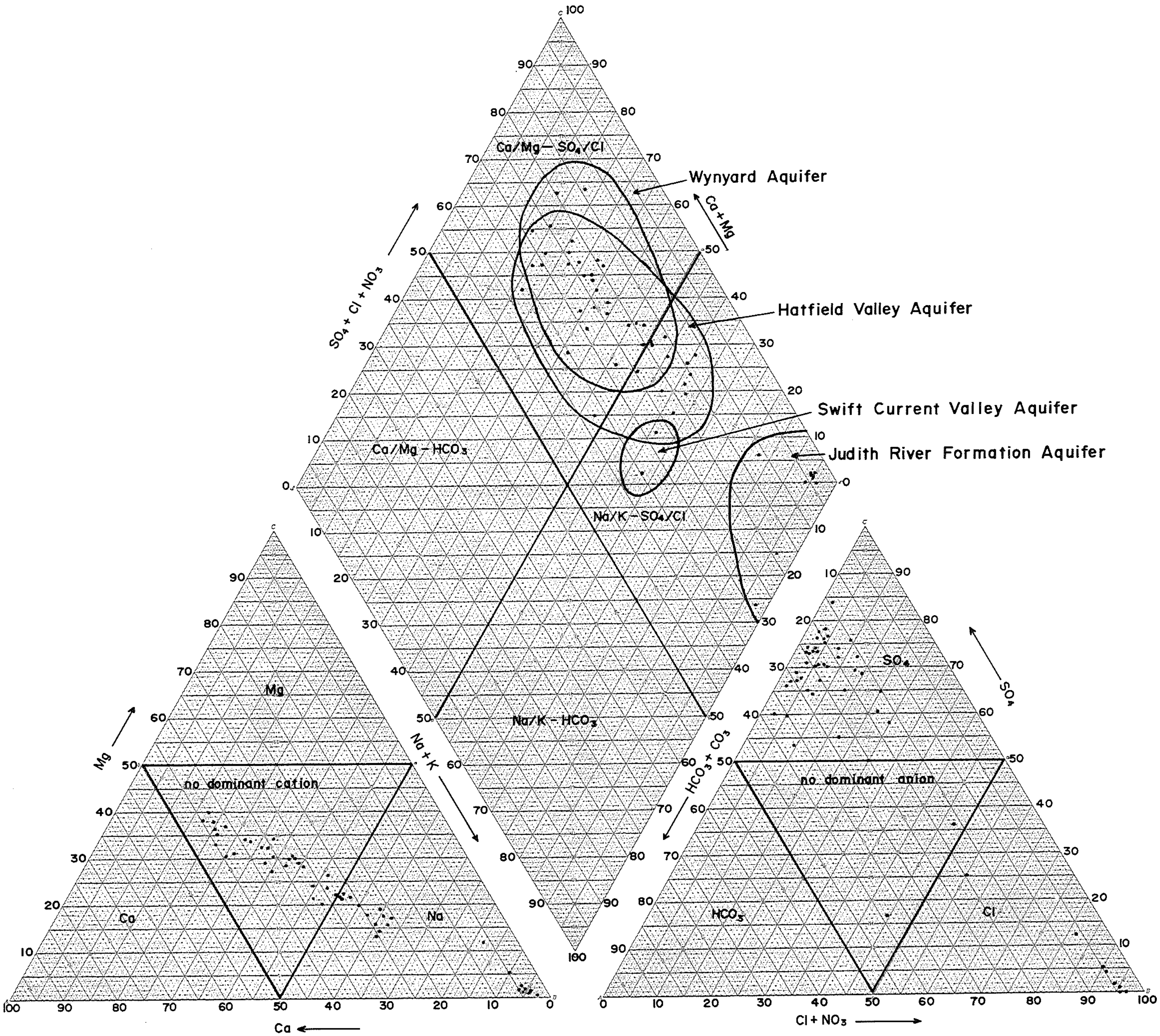


Fig. 5 Modified Piper plot of water quality data in the study area.

used to investigate irrigation suitability, as it includes added effects of precipitation and dissolution of calcium in the soil as related to concentrations of $CO_3^=$ + HCO_3^-(Bouwer, 1978 and references therein). ASAR values are also presented in the Tables. Formulae for calculation of SAR and ASAR, as well as guidelines for interpretation of water quality for irrigation use, are included in Appendix C.

6 HATFIELD VALLEY AQUIFER SYSTEM

6.1 Introduction

The following subdivisions of the Hatfield Valley Aquifer System in the study area have been taken from the literature: Hatfield Valley Aquifer, Wynyard Aquifer, Strasbourg Aquifer, and Swift Current Valley Aquifer (Meneley, 1972). Christiansen (1979b) added the Meacham Aquifer to this system. The present study indicates that the Swift Current Valley Aquifer may not be connected to the Hatfield Valley Aquifer. Locally intertill aquifers may directly be hydraulically connected to the Hatfield Valley Aquifer. The Strasbourg Aquifer as defined by Meneley (1972) may not exist as such. The Hatfield Valley Aquifer constitutes the major aquifer within this system to which all the other aquifers are fully, or partially, hydraulically connected.

The geohydrological setting of the Hatfield Valley Aquifer System is shown in Fig. 6 and is discussed below. The extent of the Empress Group is shown on Map B and in the cross-sections. Also shown on Map B are depth to the aquifer, point thickness, reported water level, and available drawdown. Water quality data are shown as water quality data bars on the cross-section and in Tables.

6.2 Aquifer Boundaries

The Hatfield Valley Aquifer is defined as constituting the Empress Group deposits within the boundaries of the Hatfield Valley. In addition to Empress Group sediments, the aquifer locally may also include glacial sediments where they form one geohydrological unit with the Empress Group (cross-section B-B^1, logs 27-33). The western and southern extent of the aquifer can be well defined as the limit of the Empress

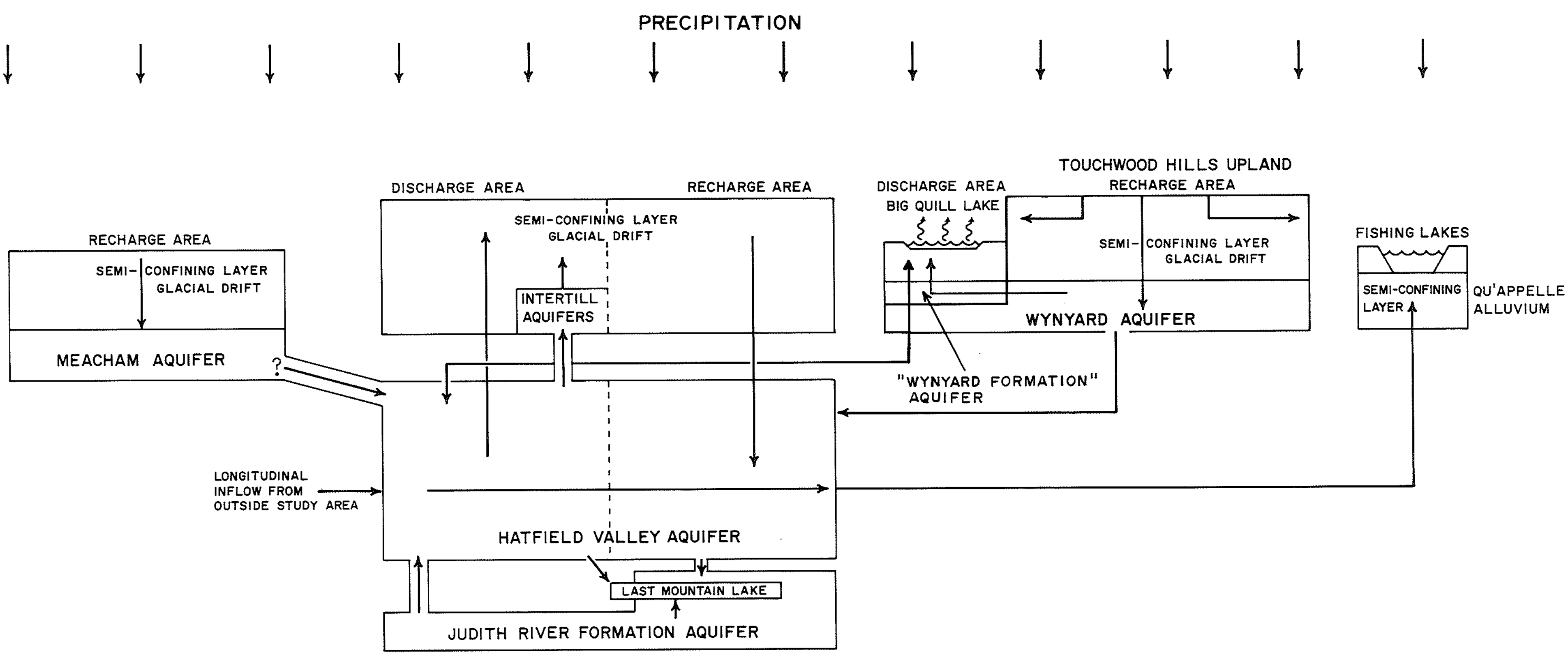


Fig. 6 Schematic diagram of the Hatfield Valley Aquifer System in the Humbolt-Fort Qu'Appelle area.

Group. However, because the Wynyard Aquifer is virtually completely hydraulically connected to the Hatfield Valley Aquifer, the boundary between these two aquifers has been selected arbitrarily. For the purpose of this study, the 427 m (1400 ft) ASL bedrock contour line has been considered as the eastern shoulder of the Hatfield Valley. Consequently, this contour line has been used as the arbitrary boundary between the Hatfield Valley and Wynyard Aquifers.

The Wynyard Aquifer is defined as the Empress Group deposits located in the upland east of the Hatfield Valley (Map B).

The Meacham Aquifer, composed of the Empress Group and the intertill stratified deposits, is defined as an aquifer, located in the upland area west of the Hatfield Valley in the northwestern part of the study area (Map B).

The Judith River Formation Aquifer is a bedrock aquifer, composed of sand and silt of the Judith River Formation and occurs to the west and south of the Hatfield Valley (Map B).

6.3 Hatfield Valley Aquifer

6.3.1 Origin and Filling of the Hatfield Valley

The Hatfield Valley extends from the Manitoba border in the southeast to the Cold Lake area in northwestern Saskatchewan (Figure 7). According to Christiansen et al. (1977), the Hatfield Valley was cut into bedrock by fluvial erosion during the advance of the first continental glaciation. The Valley carried meltwater from the advancing glacier to the north and extra glacial water from the south. During the glacial advance stratified deposits known as the Empress Group were deposited in the Valley. The ice continued to advance and eventually overrode the Valley which was glacially eroded to a large extent and its shape was

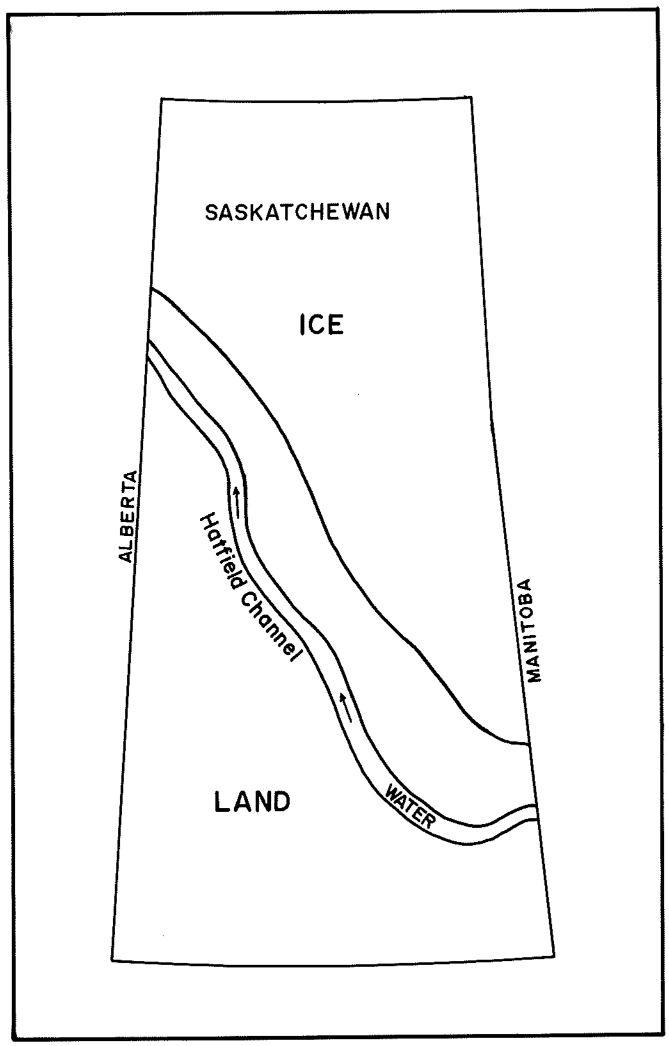


Fig. 7 Location of the Hatfield Valley.
(From Christiansen, 1977)

modified and much of the Empress Group was removed. During the retreat of the glacier, the Valley as well as the surrounding area was filled with drift: till, sands, gravels, silts and clays. During subsequent glaciations the Valley continued to be eroded and the Empress Group was partly removed by glacial erosion. In turn was covered by glacial drift during glacial depositions.

6.3.2 Geohydrological Setting

The Hatfield Valley Aquifer in the study area covers an area of approximately 6090 km^2. The aquifer thickness may range from 0-99m but typically is in the 30-60m range. The semi-confining, glacial drift layer overlying the aquifer characteristically is between 90 and 150 m thick. The aquifer is underlain by silt and clay bedrock which can be considered as "impermeable".

Based on the description of the Empress Group sediments and the geohydrological setting, the Hatfield Valley Aquifer can be described as an extensive, continuous, heterogeneous, anisotropic, buried valley aquifer which is connected hydraulically to adjacent aquifers.

6.3.3 Ground Water Flow Systems

All groundwater in Saskatchewan originated from precipitation that infiltrates to the water-table, moves downward and laterally under influence of gravity, and eventually discharges back to the surface at some point of lower elevation (Meneley et al., 1979).

Outside the study area, in the Melfort (73A) area, a groundwater divide occurs in the Hatfield Valley Aquifer (Meneley, 1972). North of this divide, groundwater is discharged into the South Saskatchewan River, whereas to the south of the divide, groundwater moves longitudinally into the study area. According to cross-section $A\text{-}A^1$, the Hatfield Valley Aquifer in the northern portion of the study area may receive lateral inflow from the Judith River Formation Aquifer.

Available water-level data in the Lanigan-Sinnett-Jansen area suggest that lateral outflow may take place from the Hatfield Valley Aquifer into the Wynyard Aquifer. However, in the Touchwood Hills Upland area, water moves vertically downward into the Wynyard Aquifer and then laterally in a radial pattern. Consequently, along most of its eastern boundary the Hatfield Valley Aquifer receives lateral inflow from the Wynyard Aquifer. Although the Allan Hills Upland area is a recharge area in which water moves vertically downward into the Judith River Formation Aquifer, this aquifer is likely to discharge into Last Mountain Lake (cross sections F-F' and G-G') and only locally may recharge the Hatfield Valley Aquifer (cross-section C-C'). To date, insufficient information exists about the Hatfield Valley Aquifer southwest of Watrous and relationship of this part to the main Hatfield Valley Aquifer remains unclear. Although cross-section H-H' (logs 164-167) suggests that the Meacham Aquifer is connected to part of the Hatfield Valley Aquifer, insufficient data are available to define the nature of this connection.

In the Lanigan-Nokomis area, flow within the aquifer is longitudinal, but water levels in this area are near or above ground surface. A vertically upward groundwater flow from the aquifer exists, which makes this area a significant groundwater discharge area. Although the topographic elevation is relatively low, disruptions in the longitudinal flow path must occur in order for the groundwater levels to be this high. Meneley (1972) suggested that the interruption of longitudinal flow was caused by glacial erosion and solution-collapse. In this study, however, no evidence was found that bedrock lows within the Valley, such as occurring at the Village of Hatfield, are related to solution-collapse.

Cross-sections C-C^{1} to F-F^{1} indicate that the cross-sectional area of the Hatfield Valley Aquifer may change significantly within relatively short distances due to removal of aquifer sediment by glacial erosion. In addition, cross section F-F^{1} (log 124) and the longitudinal cross section through the aquifer suggest that glacial erosion at this site and subsequent filling of the depression with glacial till, may well be the most significant structure blocking, or at least drastically inhibiting, longitudinal flow. The combination of changes in cross-sectional area and this "blocking" are presently considered as the major reasons for interruption of longitudinal flow and for the high water-level in the aquifer in the Lanigan-Nokomis area.

Flow conditions in the Hatfield Valley Aquifer can be very complex and are best illustrated by investigating the geohydrological setting in the Andora-Nokomis area. In this area, the Hatfield Valley Aquifer is overlain by glacial drift in which significant intertill aquifers have been encountered (cross-sections D-D^{1}, E-E^{1}, and J-J'). Under natural conditions, vertically upward groundwater flow exists in both the Hatfield Valley and the intertill aquifers. Under development conditions, a direct connection between these aquifers becomes apparent. An irrigation well, completed in an intertill aquifer (cross-section D-D' log 79), clearly influences the hydraulic head in the Hatfield Valley Aquifer at the site of observation well SRC Nokomis. This well is completed in the upper portion of the Hatfield Valley Aquifer, at a distance of approximately 11 km from the irrigation well. The "steep" declines in the water level during the summers of 1979-1981 are attributed to pumpage from this irrigation well (Fig. 8).

Based on the similarities between the water quality in Last Mountain Lake (cross-section N-N^{1}, water quality near log 287) and in the northern portion of the Hatfield Valley Aquifer, a hydraulic connection between the Aquifer and the Lake has been assumed (Meneley, 1972). However, the nature of this connection remains unclear.

South of the "blockage" (coss-section F-F^{1}, log 124) groundwater in the Hatfield Valley Aquifer is composed of water which has passed the blockage, water which flowed laterally into the aquifer from the Wynyard Aquifer, and water derived from vertical downward groundwater flow through the overlying semi-confining layer.

The Strasbourg Aquifer, which according to Meneley (1972) includes a sand deposit at the base of the drift as well as the Judith River Formation Aquifer, does not appear to exist as such. The Judith River Formation may form a pathway for Hatfield Valley Aquifer water to be discharged into Last Mountain Lake as the water level in the aquifer is likely higher than the lake level (± 1610 ft ASL). Pertinent data on this system does not exist. The present study also indicates (cross-section N-N^{1}, Map B) that no connection may exist between the Swift Current Valley Aquifer System and the Hatfield Valley Aquifer.

In the southeastern portion of the study area, the Hatfield Valley Aquifer drains into the Qu'Appelle Valley near Fort Qu'Appelle, where major discharge appears to be concentrated in Mission Lake (Meneley, 1972, Christiansen <u>et al</u>; 1977). The water level in the Hatfield Valley Aquifer will decline towards the Qu'Appelle Valley, which intersects the

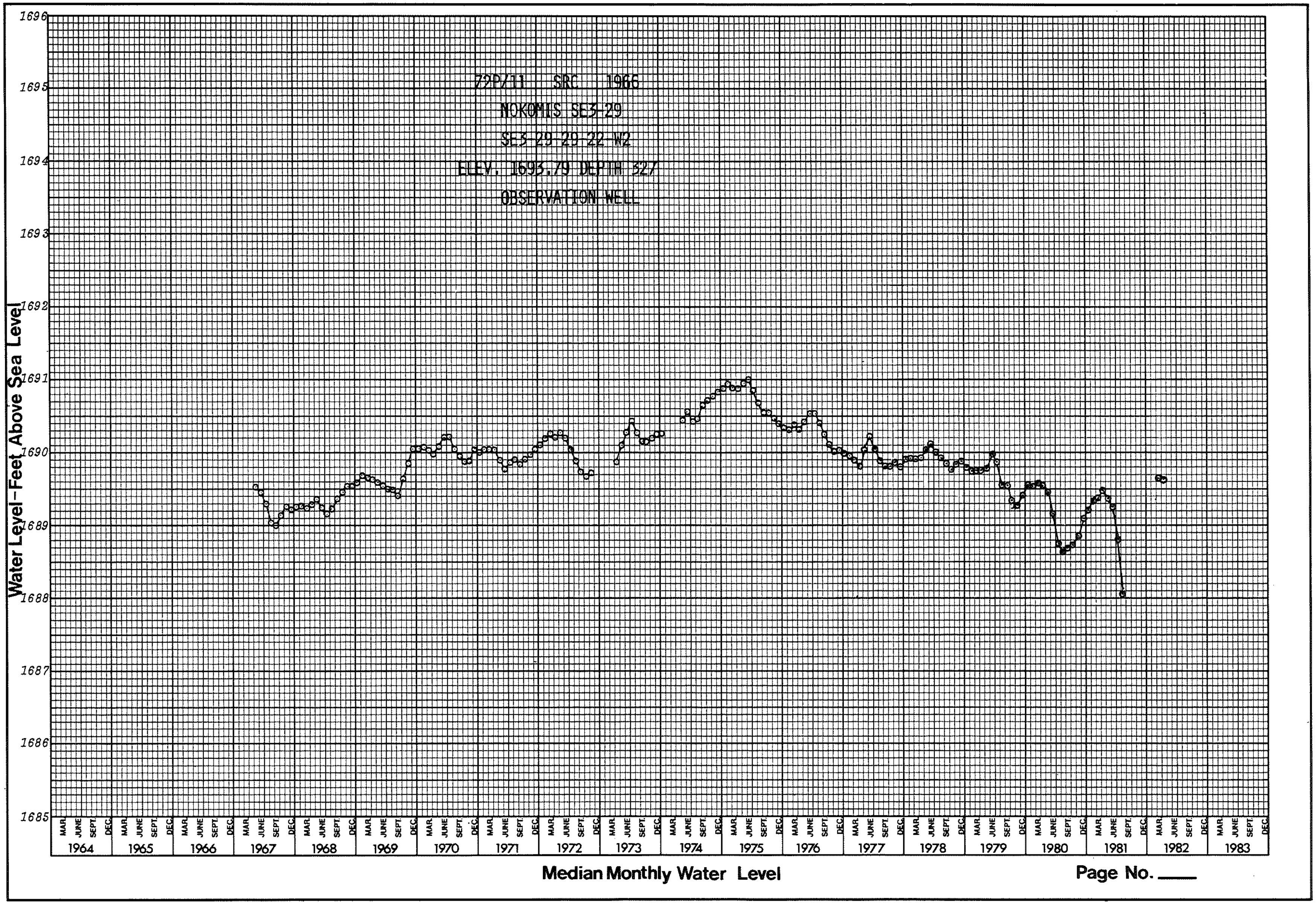


Fig. 8 Hydrograph from observation well SRC Nokomis

aquifer and acts as an enormous drain. Consequently, lower water levels in the area adjacent to the Qu'Appelle Valley cause a greater vertical hydraulic gradient which maximizes the vertical downward recharge to the aquifer.

6.3.4 Hydraulic Properties

A review of available data on the hydraulic properties of the Hatfield Valley Aquifer System in the study area concluded that a hydraulic conductivity in the order of 15-25 m/day could be considered as representative for the fine to medium and medium to coarse grained sands of the Empress Group (Maathuis, 1980). These values fall well within the range of hydraulic conductivities for these type of sands as reported in the literature (Kruseman and de Ridder, 1970; Meneley, 1972; Bouwer, 1978)

Hydraulic conductivities calculated from grain-size data are found to range between 10 and 70 m/day but are typically in the 10-20 m/day range (Appendix D). The calculated values are compatible with the values reported in the literature.

A pump test carried out in the Village of Drake deep well No. 2 indicated a transmissivity of about 305 m^2/day (Meneley, 1978). Based on an aquifer thickness of 12.8 m, this suggests a hydraulic conductivity of about 23 m/day which agree reasonably with the values above.

Assuming that silt layers within the Empress Group do not contribute to the transmissivity of the aquifer, the transmissivity can be estimated by multiplying the hydraulic conductivity by the thickness of the sand in each testhole. In testholes where the Empress Group includes gravel layers, hydraulic conductivities for such layers as reported in the literature should be used to estimate the transmissivity. Based on the testhole logs and lithological descriptions, the transmissivity of the Hatfield Valley Aquifer is estimated to range from less than 200 m^2/day to 2500 m^2/day. The storage coefficient of the aquifer is estimated to be in the order of 2.0×10^{-4}.

6.3.5 Water Quality

The water quality data in the Hatfield Valley Aquifer are summarized in Table 1. Water in the Hatfield Valley Aquifer north of Nokomis generally is of the sodium-sulphate type and has a total concentration of 2770 ± 205 mg/l (n=9). This water is less desirable for use as a municipal drinking water supply, because the total concentration and the sum of magnesium, sodium and sulphate concentrations, generally greatly exceed the recommended maximum desirable limits. Furthermore, the manganese and iron concentrations are generally well above the desired maximum levels. In some cases, as for the Village of Drake, the aquifer may be the only available and reliable water supply source and a simple treatment can alleviate the problems related to high iron and manganese concentrations. For domestic use, the water quality should be classified as poor to unacceptable, but again in many places the aquifer may be the only reliable water source. In any case, the water can be used for livestock. The combination of high ASAR and conductivity (or total concentration) of the water renders it unfit for irrigation use in this area, unless favorable soil and drainage conditions exist.

The water in the Hatfield Valley Aquifer south of Nokomis is generally of the calcium/magnesium-sulphate type and has a total concentration of 2215 ± 315 mg/l (n=6). The fact that this water is of a different type and is less mineralized is partly due to the location where the sample was taken, that is locations where the Wynyard Aquifer discharges into the

Table 1 Water Quality Hatfield Valley Aquifer

Location	Depth Feet	Water Type	$HCO_3 + CO_3$	SO_4	Cl	Ca	Mg	Na	K	Fe	Mn	NO_3	PO_4	F	SE	B	CONC.	COND.	pH	T.H.	T.A.	SAR	ASAR
SW12-8-23-16-W2	454	Na/Ca-SO_4	622	746	91	176	65	295	12	3.3	0.25	12	N/D	0.16	N/D	N/D	2023	2207	7.26	706	510	4.8	14.75
4-3-26-16-W2	665	Ca/Mg-SO_4	526	1360	39	336	138	208	13	9.6	0.29	5.5	<0.02	0.12	<0.001	0.52	2630	2690	7.51	1410	431	2.4	6.9
SE1-36-23-17-W2	690	Ca/Mg-SO_4	573	728	22	229	111	120	8.9	15	0.28	1.8	<0.02	0.15	<0.001	0.37	1809	1880	7.60	992	470	1.6	4.9
SE8-10-24-17-W2	755	Ca/Na-SO_4	520	926	54	215	111	228	10	20	0.43	10	<0.002	0.10	<0.001	0.37	2074	2280	7.58	992	426	3.14	9.1
NE9-19-25-18-W2	535	Ca/Mg-SO_4	464	1110	22	271	120	181	12	24	0.35	11	N/D	0.13	N/D	N/D	2215	2280	7.20	1170	380	2.30	6.7
NW12-6-26-18-W2	556	Ca/Na-SO_4	543	1230	68	270	121	287	8.2	6.4	0.58	0.21	<0.02	0.48	<0.001	0.32	2535	2280	7.40	1160	445	3.75	10.5
SE4-5-30-21-W2	482	Na-SO_4	489	1460	192	214	80	596	8.6	3.4	0.12	20	0.26	0.05	<0.001	0.50	3060	3530	7.46	860	401	8.82	24.2
NE-7-7-32-21-W2	350	Na-SO_4	428	1370	215	208	98	510	17	0.3	N/D	<1	<0.03	0.08	N/D	N/D	2846	3450	7.95	921	351	7.30	20.2
NW-16-22-33-21-W2	400	Na/Ca-SO_4	479	1560	40	242	117	438	11	3.3	0.58	8.0	<0.02	0.11	<0.001	0.70	2900	3010	7.52	1080	393	5.88	16.5
SE3-29-29-22-W2	327	Na-SO_4	460	1173	300	171	83	577	8.3	6.7	0.16	16.3	0.07	0.13	N/D	N/D	2796	3393	7.73	769	377	9.15	25.00
NW2-17-31-22-W2	417	Na-SO_4	400	1310	288	198	73	570	11	6.8	0.23	15	0.11	0.12	N/D	N/D	2870	3230	7.49	797	328	8.8	23.49
SE10-14-32-22-W2	500	Na-SO_4	478	1110	160	177	77	466	9.0	7.9	0.40	13	0.10	0.19	<0.001	0.42	2490	2830	7.48	763	392	10.63	29.1
NW9-36-34-22-W2	500	Mg/Ca-SO_4	521	1590	24	279	170	295	15	22	0.75	4.3	0.08	0.12	<0.001	0.70	2900	2900	7.52	1390	437	3.44	9.8
SE9-34-23-W2	520	Na-SO_4	570	1380	95	190	80	610	7	0.03	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	7.95	803	467	9.34	
SE8-5-36-23-W2	462	Na-SO_4	426	1057	328	195	60	523	13	2.85	0.32	8.64	<0.01	0.20	N/D	N/D	2616	3220	7.41	732	349	8.48	22.4
SW4-33-32-26-W2	284	Na/Ca-SO_4	407	1270	44	217	86	351	8.7	5.1	0.18	14	0.11	0.21	<0.001	0.79	2400	2500	7.39	899	334	5.10	14.28
NE13-24-31-27-W2	398	Na/Ca-SO_4	607	1060	82	202	112	371	12	5.1	0.17	12	0.33	0.19	<0.001	0.66	2460	2780	7.57	1067	498	5.29	15.5

Notes: All values in mg/ℓ (ppm), except for conductivity which is in μS/cm and pH
N/D means not determined; Nil means below detection limit
SAR means sodium adsorption ratio; ASAR means adjusted sodium adsorption ratio

Hatfield Valley Aquifer. Also the water quality in the aquifer will improve in the direction toward the discharge area as the amount of vertical recharge into the aquifer will increase towards the point of discharge (see section 6.3.3). The water quality is less desirable for municipal drinking water and of poor quality for domestic supplies, but in some places the aquifer is the only reliable water supply source. The water can be used for livestock. The data suggest that in terms of ASAR values the groundwater locally could be fit for irrigation; however, from a total concentration point of view it is not desirable. The selenium concentrations in both sections of the Hatfield Valley Aquifer are systematically below the detection limit, while boron concentrations may range from 0.3 to 0.7 mg/l.

The $(NO_3 + NO_2)$ $-NO_3$ concentrations may vary widely but are generally greater than 1 mg/l whereas concentrations less than 1 mg/l were anticipated based on what is known about the nitrate concentration in deep aquifers in Saskatchewan. To date, no explanation can be provided as to why the observed concentrations are above the 1 mg/l level, but an investigation is presently underway (Maathuis, in progress).

6.3.6 Qualitative Assessment of Yields.

In the present study, yields can only be assessed in a global and qualitative way, based on the generalized geohydrological parameters of the Hatfield Valley Aquifer as listed in Table 2.

A yield of an aquifer under development conditions is the amount of water that can be withdrawn from the aquifer without creating undesirable side effects. This takes into account the amount of additional recharge from precipitation which occurs due to the development. Undesirable effects may include lowering the water-table and the dewatering of intertill aquifers (Meneley, 1972).

The yield can be calculated according to the following equations:

$$Q_A = \frac{\Delta H \times A \times 365}{c} \qquad \text{[Equation 1]}$$

and

$$\Delta H = \Delta R \times c \qquad \text{[Equation 2]}$$

which combines to $Q_A = \Delta R \times A \times 365$ [Equation 3]

where Q_A is groundwater yield (m^3/year), c is vertical hydraulic resistance (days), ΔH is allowable drawdown (m), and ΔR is percentage of annual precipitation (m/day).

Table 2 Average Geohydrological Parameters of the Hatfield Valley Aquifer

- thickness of semi-confining layer:	m^1 = 120 m
- bulk hydraulic conductivity of semi-confining layer:	K_v^1 = 4.3 x 10^{-4} m/day
- specific yield of semi-confining layer:	S = 0.01
- vertical hydraulic resistance of semi-confining layer.	c = 279100 days
- thickness of aquifer	m = 45 m
- hydraulic conductivity of aquifer	K = 15 - 25 m/day
- average tranmissivity of aquifer	T = 900 m^2/day
- storage coefficient (confined) of aquifer	S = 2.0 x 10^{-4}
- specific yield (unconfined) of aquifer	S = 0.1
- surface area of aquifer	A = 6090 x 10^6 m^2
- average annual precipitation	P = 400 mm/year

This estimate of the yield, called net groundwater yield, does not take the hydraulic properties of the aquifer and semi-confining layer into account, but only the estimate of additional recharge. It also implies that a new dynamic equilibrium with the climate is established and that the yield of wells is derived only from induced recharge from precipitation. The additional amount of vertical hydraulic head difference required to create the additional recharge can be calculated from Equation 2. Assuming the additional recharge is between 3 and 10% of the annual precipitation, a lowering of the hydraulic head of the aquifer in the range of 10 to 31 metres would be required. These values are much less than the average available drawdown of 76 m.

Meneley (1972) assumed a value of 10% of the precipitation as the arbitrary upper limit of the additional percentage of precipitations which can be withdrawn. Although a 10% value may be on the high side, to date, there is insufficient information to select a more realistic figure.

Based on ΔR values of 10%, 5% and 3%, respectively, the net ground water yield is calculated to be in the order of 2.4×10^8, 1.2×10^8 and 0.7×10^8 m^3/year, respectively. These values must be considered maximums, as no attempt has been made to calculate the number of wells and the production rate which are required to withdraw this amount. Boundary effects and the superposition of well drawdowns would result in the total production from these wells being less than the calculated net groundwater yield. Induced lateral inflow has the effect of a local increase in the net groundwater yield. Because of these effects it is estimated that a net groundwater yield in the order of 1.0×10^8 m^3/year is a more realistic estimate.

The sustained yield of the aquifer is larger than the net groundwater yield as discharge to Last Mountain Lake and the Qu'Appelle Valley decreases as a consequence of developing the aquifer.

Under "drought" conditions recharge to the aquifer decreases and water stored in the aquifer and in the overlying semi-confining layers and aquifers will be "mined". Initially the yield from wells comes from storage within the aquifer itself, but when larger vertical hydraulic gradients are created it is derived from storage in the overlying semi-confining layers and aquifers. Consequently, the water table and hydraulic head in overlying aquifers systematically decreases as drought conditions continue. Ultimately, the overlying layers are de-watered and the aquifer becomes unconfined. When average or above average precipitation conditions return, the propensity for recharge has increased as the vertical hydraulic gradient is increased during the drought period.

The total volume of usable storage in the semi-confining layer can be calculated from:

$$V_W = A \times S \times m^1 \qquad \text{[Equation 4]}$$

where V_W is volume of water (m^3); A is surface area (m^2); S is specific yield of semi-confining layer; and m^1 is saturated thickness of confining layer (m). This volume is calculated to be 7.3×10^9 m^3, assuming a conservative value for the specific yield of the semi-confining layer of 1%. Equation 1 also can be used to calculate the maximum yield of the aquifer when the potentiometric surface is at the top of the aquifer. This yield would be 6.1×10^8 m^3/year and implies that it would take 12 years to drain the semi-confining layer at this rate, assuming no recharge during this period. It is obvious that because of aquifer geometry, variations in transmissivity, and bulk vertical hydraulic conductivity, the calculated maximum yield is not achieved and could be an order of magnitude less. During "drought" periods, precipitation may not be zero and some recharge may occur. Therefore, the time required to drain the semi-confining layer is at least an order of magnitude longer.

If the water level in the aquifer drops below the top of the aquifer, it becomes unconfined. Much more water becomes available as the specific yield of an unconfined aquifer is much larger than the specific storage coefficient of a confined or semi-confined aquifer.

Assuming a conservative value for the specific yield of 10% for the Empress Group sediment it can be calculated [Equation 4] that under unconfined conditions, 6.1×10^8 m^3 would become available per one metre head decline over the aquifer.

If it is assumed that 50% of the aquifer thickness could be de-watered, a total volume in the order of 1.4×10^{10} m^3 could be withdrawn. The above calculation of the total volume is of a hypothetical nature as due to a decrease in transmissivity and available drawdown as a result of development, an extremely large number of wells would be required to withdraw this amount.

6.3.7 Assessment of Single Well Yields

Single well yields can be estimated based on the available drawdown or on the additional percentage of precipitation which can be withdrawn.

Based on the available drawdown average aquifer characteristics, and assuming that up to 50% of the drawdown in a well may be due to well losses, it is estimated that up to 22,000 m^3/day (appr. 3000 Igpm) could be withdrawn from a well or well field. At this production rate, the recharge to the water table is less than the induced recharge to the aquifer and some de-watering of the semi-confining layer occurs. The estimated production rate is a crude indication of the yield which could be obtained for a limited period of time in case of an emergency such as a drought. It essentially represents the maximum pumping rate from a well or well field without creating unconfined conditions near the well site.

If it is assumed that an additional 10% of the precipitation could be withdrawn without creating undesirable effects, it is estimated that up to 9500 m^3/day (appr. 1750 Igpm) could be withdrawn from a well or well field on a continuous basis. Again, this estimate is based on average aquifer characteristics and on well losses accounting for up to 50% of the drawdown in a well.

In both cases it is estimated that individual wells or well fields would have to be spaced at 16 km intervals to avoid drawdown interferences. This distance of 16 km represents the cone of influence of any well completed in the aquifer, regardless of the production rate.

6.3.8 Consequences of Development

A large scale development of the aquifer, such as that of withdrawing the estimated net groundwater yields, results in a decrease of discharge to Last Mountain Lake and Qu'Appelle Valley. However, by lowering the water level in the Hatfield Valley Aquifer the lateral inflow from the Wynyard aquifer increases.

In the Lanigan-Nokomis area the existing upward hydraulic gradient is likely to be reversed. This may benefit agriculture in the long-term as salinity problems in this area decrease.

6.4 Wynyard Aquifer

6.4.1 Geohydrological setting

The Wynyard Aquifer as indicated by Meneley (1972, Fig. 130) can be interpreted as including material of the Empress Group and the sands and gravels of the "Wynyard Formation". However, the sands and gravels of the "Wynyard Formation" can be uniquely defined and, consequently, it appears to be justified to consider these sands and gravels as a separate aquifer. In this report, this aquifer is referred to as the "Wynyard Formation" Aquifer. The parentheses are required as the name Wynyard Formation has not been formally recognized. The Wynyard Aquifer is now defined as the aquifer formed by sediments of the Empress Group in the upland east of the Hatfield Valley.

The Wynyard Aquifer in the study area covers an area of approximately 3400 km^2. The thickness of the aquifer may range from 0-45 m, but typically is in the 23-28 m range. The semi-confining layer overlying the aquifer may range from 50-150 m in the Touchwood Hills to 45-75 m in the "lowland" north of the Hills. The aquifer is underlain by silt and clay bedrock which is considered "impermeable".

The Wynyard Aquifer can be described as an extensive, heterogeneous and anisotropic, blanket aquifer, which is hydraulically connected to the Hatfield Valley Aquifer and the "Wynyard Formation" Aquifer.

The "Wynyard Formation" Aquifer covers an area of approximately 750 km^2 and is typically 6 metres thick. The aquifer is overlain by Tertiary silts and clays and glacial deposits which form a semi-confining layer and underlain by "impermeable" bedrock. The aquifer is hydraulically connected to the Wynyard Aquifer.

In the vicinity of the Town of Wynyard, the aquifer was studied in detail to determine whether or not it could serve as a water supply source for the Town of Wynyard (PFRA, 1981). This study indicated a probably complex geohydrological setting, but an ample supply of relatively fresh water. However, within its context, which deals with the Hatfield Valley and the Empress Group, the "Wynyard Formation" Aquifer is not discussed in detail.

6.4.2 Groundwater Flow System

The Touchwood Hills constitutes a mjaor groundwater recharge area. Water infiltrating to the water table moves vertically downward into the intertill aquifers, and then laterally, or it may directly recharge the aquifer. In addition, because of the prevailing vertical downward hydraulic gradient in the area, groundwater moves vertically downward from the intertill aquifers into the Wynyard Aquifer.

In the Wynyard Aquifer itself, flow is horizontal and directed to the north toward the topographically lower discharge area which includes Big Quill Lake (Whiting, 1977). Groundwater moves laterally toward the Hatfield Valley Aquifer in the west and south. In the northern portion, the aquifer receives lateral inflow from the Hatfield Valley Aquifer.

6.4.3 Hydraulic Properties

Because the Wynyard Aquifer is mainly composed of the Empress Group sediments, it is assumed that the hydraulic conductivity is in the same range as for the Hatfield Valley Aquifer: 15-25 m/day. Consequently, the transmissivity may range from less than 350 m^2/day to 950 m^2/day. The storage coefficient is estimated to be in the order of 1.0×10^{-4} to 2.0×10^{-4}.

6.4.4 Water Quality

Water in the Touchwood Hills area is of the calcium/magnesium sulphate type, whereas in the discharge area, probably under the influence of the lateral inflow from the Hatfield Valley Aquifer, water is of the sodium-sulphate type (Table 3). Although the total concentration may range from 1600 to 2900 mg/l, its average total concentration is 2460 ± 300 mg/l. The total concentration and sum of magnesium, sodium and sulphate generally renders the water less desirable for a municipal drinking water supply. In addition, iron and manganese are above the desirable maximum concentration. However, locally the water may be the only reliable water supply source. The water must be classified as poor for domestic supply, but it is acceptable for livestock.

Although the ASAR values range widely and suggest that locally the water could be used for irrigation, salinity problems can be expected as the water is too mineralized. The selenium concentration is below the detection limit of 0.001 mg/l, and the average boron concentration is 0.49 mg/l.

6.4.5 Assessment of Yields

Assessment of the net groundwater yield is complex as the thickness of the semi-confining layer outside in the Touchwood Hills area varies significantly.

The net groundwater yield calculation (Equation 1 to 3, section 8.3.5) has been based on the general geohydrological setting of the area outside the Touchwood Hills (Table 4). It has been estimated that the groundwater

Table 3 Water Quality in The Wynyard Aquifer

LOCATION	DEPTH FEET	WATER TYPE	HCO_3 + CO_3	SO_4	Cℓ	Ca	Mg	Na	K	Fe	Mn	NO_3	PO_4	F	SE	B	Conc.	Cond.	pH	T.H.	T.A.	SAR	ASAR
SE1-21-29-15-W2	544	Ca/Mg-SO_4	526	1220	17	295	154	147	10.0	34	0.49	3.5	< 0.02	0.13	< 0.001	0.43	2370	2430	7.43	1370	431	1.7	5.0
NE16-23-29-16-W2	574	Ca/Mg-SO_4	589	1080	36	254	132	233	9.7	2.2	0.42	6.7	< 0.02	0.14	< 0.001	0.43	2340	2460	7.63	1180	483	3.0	8.8
SW12-4-35-16-W2	129	Na-SO_4	384	1615	152	184	99	595	8	0.80	N/D	Nil	N/D	N/D	N/D	N/D	3038	3250	7.30	865	314	8.89	23.24
NE13-8-30-17-W2	700	Na/Mg-SO_4	581	1210	100	261	131	316	11.0	7.3	0.80	6.9	< 0.02	0.14	< 0.001	0.52	2620	2850	7.53	1190	476	4.0	11.8
NW4-8-3$_2$-17-W2	260	Ca/Mg-SO_4	581	932	16	255	131	133	9.5	4.5	0.94	4.9	< 0.02	0.15	< 0.001	0.40	2060	2170	7.53	1180	476	1.7	5.1
NE8-14-27-18-W2	548	Ca/Mg-SO_4	587	1050	67	295	143	161	9.9	7.6	0.56	5.6	0.16	0.12	< 0.001	0.35	2320	2380	7.46	1320	481	1.9	5.7
NE14-30-30-18-W2	380	Na/Mg-SO_4	506	1240	90	239	134	322	11.0	27	0.77	9.2	< 0.02	0.14	< 0.001	0.56	2550	2840	7.43	1150	415	4.1	11.8
GE9-30-31-18-W2	260	Ca/Mg-SO_4	556	1340	43	301	159	251	12.0	15	1.5	0.12	< 0.02	0.17	< 0.001	0.58	2660	2810	7.65	1400	456	2.9	8.6
NE6-34-31-18-W2	280	Ca/Mg-SO_4	584	1110	23	307	155	128	12.0	14	0.71	3.6	< 0.02	0.14	< 0.001	0.38	2320	2670	7.56	1400	479	1.5	4.4
NW13-10-32-18-W2	272	Ca/Mg-SO_4	587	1010	24	258	139	152	10.0	5.5	0.43	3.7	< 0.02	0.17	< 0.001	0.44	2180	2290	7.42	1210	481	1.9	5.7
NW4-4-30-19-W2	267	Ca/Mg-SO_4	377	1140	20	265	149	118	11.0	5.3	0.73	6.0	0.19	0.12	< 0.001	0.45	2090	2240	7.33	1270	309	1.4	4.0
SW4-14-30-19-W2	353	Ca/Na-SO_4	445	1290	104	281	132	284	11.0	5.4	0.66	5.9	< 0.02	0.14	< 0.001	0.48	2550	2800	7.61	1240	365	3.5	10.0
NW16-21-30-19-W2	350	Na/Ca-SO_4	471	1350	86	269	130	325	11.0	4.4	0.56	6.7	< 0.02	0.14	< 0.001	0.49	2650	2950	7.48	1210	386	4.1	11.6
NE16-24-31-19-W2	270	Ca/Na-SO_4	538	1360	50	277	147	278	12.0	6.8	0.90	3.9	< 0.02	0.15	< 0.001	0.50	2670	2830	7.58	1300	441	3.4	9.6
NE13-2-32-19-W2	284	Ca/Na-SO_4	573	1440	47	298	145	295	14.0	N/D	N/D	NIL	N/D	N/D	N/D	N/D	2812	2900	7.15	1340	470	3.5	10.4
NW3-1-33-19-W2	235	Na-SO_4	425	1280	88	190	96	406	11.0	3.1	0.11	6.6	< 0.02	0.12	< 0.001	0.45	2500	2800	7.60	869	348	6.0	16.1
SE11-15-33-19-W2	287	Na-SO_4	515	1140	62	190	87	392	9.6	8.4	0.15	1.6	< 0.02	0.12	< 0.001	0.51	2400	2760	7.86	828	422	5.9	16.4
SE7-33-33-19-W2	280	Na/Ca-SO_4	572	1030	30	206	109	258	9.2	3.0	0.11	5.5	< 0.02	0.09	< 0.001	0.55	2220	2360	7.57	960	469	3.6	10.0
SW12-11-34-19-W2	264	Na/Ca-SO_4	473	640	19	141	76	208	6.9	0.29	0.30	0.92	< 0.02	0.22	< 0.001	0.55	1566	1620	7.67	660	387	3.5	9.6
SE14-34-28-20-W2	260	Ca/Mg-SO_4	348	1580	24	344	151	185	12.0	12.60	N/D	< 1	< 0.03	0.15	N/D	N/D	2657	2880	7.30	1477	286	2.1	5.8
NW13-36-28-20-W2	273	Ca/Mg-SO_4	524	1150	36	265	138	200	14.0	1.70	N/D	< 1	< 0.03	0.07	N/D	N/D	2329	2560	7.40	1228	430	2.5	7.2
SE4-1-32-20-W2	276	Na-SO_4	419	1460	178	234	115	526	10.0	3.30	0.31	1.6	< 0.02	0.20	< 0.001	0.40	2948	2850	7.47	1050	343	7.0	19.3
NE13-11-32-21-W2	267	Na/Ca-SO_4	486	1360	33	26	104	362	14	0.03	1.8	5.5	< 0.02	0.14	< 0.001	0.47	2590	2700	7.53	90	398	5.0	14.4
SE16-11-32-21-W2	306	Na-SO_4	473	1370	58	221	95	416	11	2.8	0.31	6.0	< 0.02	0.14	< 0.001	0.52	2650	3020	7.56	943	388	5.0	16.9
NW13-24-33-21-W2	272	Na-SO_4	484	1540	62	228	106	467	10	3.8	0.26	6.6	0.17	0.09	< 0.001	0.59	2900	2960	7.51	1000	397	6.4	18.3
SW1-30-33-21-W2	290	Na/Ca-SO_4	554	1340	27	234	127	326	11	4.1	0.26	0.04	< 0.002	0.09	< 0.001	0.64	2620	2680	7.67	1110	454	4.3	12.7

Notes: All values in mg/ℓ (ppm), except for conductivity which is in μS/cm and pH
N/D means not determined; NIL means below detection limit
SAR means sodium adsorption ratio; ASAR means adjusted sodium adsorption ratio

Table 4 Average Geohydrologic Properties of the Wynyard Aquifer

thickness of semi-confining layer outside Touchwood Hills area	m^1	= 60 m
average thickness of semi-confining layer Touchwood Hills area	m^1	= 120 m
bulk hydraulic conductivity of semi-confining layer	K^1_v	= 4.3×10^{-6} m/day
Specific yield of semi-confining layer	S	= 0.1
vertical hydraulic resistance of semi-confining layer	c	= 139500 -279100 days
thickness of aquifer	m	= 25 m
hydraulic conductivity of aquifer	K	= 15-25 m/day
average tranmissivity of aquifer	T	= 500 m^2/day
storage coefficient (confined) of aquifer	S	= 1.5×10^{-4}
specific yield of aquifer	S	= 0.1
surface area of aquifer	A	= 3400×10^6 m^2
average annual precipitation	P	= 400 mm/year

yield is 1.4×10^8, 6.8×10^7 and 4.1×10^7 m^3/year, respectively, assuming that 10%, 5% and 3% of the annual precipitation can be withdrawn in addition to the natural recharge. The sustained yield is greater as development causes decreases in discharge and lateral flow to the Hatfield Valley Aquifer.

Assuming a thickness of 120 m represents the average thickness of the semi-confining layer overlying the aquifer, approximately 4.9×10^9 m^3 could be withdrawn from this layer under drought conditions when de-watering takes place. When the aquifer becomes unconfined, 4.1×10^8 m^3 of water becomes available per metre of head decline, and $5.1 \times 10^9 m^3$ if 50% of the aquifer could be de-watered.

6.4.6 Assessment of single well yields

Based on the available drawdown and average aquifer characteristics it is estimated that up to 11,000 m^3/day (appr. 1650 Igpm) could be withdrawn from a well or well field completed in the aquifer beneath the Touchwood Hills. In the area surrounding the Touchwood Hills, this yield would be in the order of 8200 m^3/day (appr. 1250 Igpm).

On a continuous basis, a well or well field beneath the Touchwood Hills could yield up to 5450 m^3/day (appr. 800 Igpm) and up to 2750 m^3/day (appr. 400 Igpm) in the surrounding area.

In the Touchwood Hills area, wells should be spaced at 12 km intervals and outside this area at 8 km intervals to avoid drawdown interference.

6.4.7 Consequences of Development

Assuming the net groundwater yield is withdrawn from the aquifer, the whole area, including Big Quill Lake, through the "Wynyard Formation" Aquifer, acts as a recharge area. Consequently, wells near Big Quill Lake experience a drastic decrease in water quality as Big Quill Lake is saline (Whiting, 1977). In the discharge area, groundwater development may have a beneficial long-term effect as salinity problems should decrease with time.

6.5 Meacham Aquifer

The Meacham Aquifer is an aquifer approximately 1215 km^2 in area and is located in the western upland. It forms the northwestern portion of the Hatfield Valley Aquifer System (Map B). Insufficient information is available for this aquifer, which in part may consist of the Empress Group sediments (cross-section H-H^1, log 5). It is also known to include intertill aquifers (cross-section B-B^1, log 24 to 26).

In most of the aquifer area, water reaching the water table moves vertically downward into the aquifer. The aquifer may discharge through the Judith River Formation Aquifer into the Hatfield Valley Aquifer (cross-section A-A^1), but also directly into the Hatfield Valley Aquifer near Watrous (cross-section G-G^1). Absence of data makes yield calculations impossible at the present time and no water quality data are available.

7. SWIFT CURRENT VALLEY AQUIFER SYSTEM

7.1 Introduction

The Swift Current Valley Aquifer System consists of the Swift Current Valley Aquifer which is connected hydraulically to the Judith River Formation Aquifer. The Swift Current Valley Aquifer is also hydraulically connected to Last Mountain Lake, and possibly, to Buffalo Pound Lake. Although the Swift Current Valley Aquifer has been known for a long time (Christiansen, 1961, 1971), the aquifer is still poorly understood as test hole data and data on hydraulic properties are scarce. The extent of the aquifer is shown on Map B which also shows the depths to the aquifer and point thickness of the Empress Group. Cross-sections G-G[1] to I-I[1] and N-N[1] show the lateral and vertical distribution of the aquifer as well as available water quality data.

7.2 Swift Current Valley Aquifer

7.2.1 Origin and Filling of Swift Current Valley

The Swift Current Valley originally is believed to have been a preglacial valley which drained to the northeast. During the initial advance of the glacier, the valley was truncated by the Hatfield Valley which drained to the northwest. The valley was filled with sediments of the Empress Group. Subsequent glaciations resulted in glacial erosion of the Empress Group, which locally has been totally removed (cross-section N-N', log 289) and covering of the valley with glacial drift, mainly till.

7.2.2 Geohydrological Setting

The Swift Current Valley Aquifer covers an area of approximately 890 km^2. The aquifer is predominantly made up of sediments of the Empress Group and its thickness may range from 15 to 30 metres. The overlying glacial deposits range in thickness from 60-90m and consists mainly of glacial till, although significant intertill aquifers are known to occur (cross-section N-N[1], log 285). The aquifer sediments are laterally connected to the Judith River Formation, which underlies the aquifer over a considerable area. The bedrock silts and clays underlying the Judith River Formation form an "impermeable" base.

The present study indicates that the Swift Current Valley Aquifer may not be connected to the Hatfield Valley Aquifer (cross-section N-N').

7.2.3 Groundwater Flow Systems

There is no evidence at the present time that suggests that there are discharge areas other than Last Mountain Lake and Buffalo Pound Lake. Water infiltrating into the water table moves vertically downward into the aquifer and then laterally toward these lakes. In addition, the aquifer receives lateral inflow from the Judith River Formation Aquifer. A piezometer was installed near Last Mountain Lake (cross-section N-N[1], log 287) and initial, relative water level data indicate that the piezometric surface in the aquifer, east of the lake, is approximately 7.5 m above the lake level.

The geological setting near Buffalo Pound Lake remains unclear but assuming that the aquifer underlies the lake, upward groundwater flow into the lake takes place.

7.2.4 Hydraulic Properties

At the present time no data are available on the hydraulic properties of the Swift Current Valley Aquifer. The sediments in the aquifer appear to be similar to those of the Empress Group in the Hatfield Valley Aquifer. Therefore a hydraulic conductivity of 15-25 m/day and a storage coefficient of 1.0 x 10^{-4} are assumed.

7.2.5 Water Quality

Only two water analysis are available at the present time (Table 5) and they indicate that the water is of the sodium-sulphate type. This water is less desirable for municipal drinking water supply and is of poor quality for domestic use. The ASAR value and total concentration make it unfit for irrigation use.

As anticipated, the water quality of Last Mountain Lake is quite similar to that in the piezometer, which is adjacent to the lake.

7.2.6 Assessment of Yields

Due to the hydraulic connections with surface water bodies, the approach used to calculate the net groundwater yield cannot be applied to this aquifer. Furthermore, the direct connection to the Judith River Formation complicates calculation of a yield.

7.2.7 Consequences of Development

Under aquifer development conditions, the water produced comes mainly from induced recharge, but also from induced inflow from the Judith River Formation Aquifer. In addition, wells near the lakes short-circuit the groundwater flow systems and receive most of their water from induced recharge from the lakes, through the lake bottoms.

Table 5 Water Quality in the Judith River Formation, Swift Current Valley System, Meacham and Tertiary Aquifers

Location	Depth Feet	Water Type	HcO_3 + CO_3	SO_4	Cl	Ca	Mg	Na	K	Fe	Mn	NO_3	PO_4	F	SE	B	CONC.	COND.	pH	T.H.	T.A.	SAR	ASAR
Judith River Formation Aquifer																							
NE3-17-22-22-W2	400	Na-Cl/SO_4	510	933	905	61	73	985	12	9.2	N/D	16	<0.01	0.26	N/D	N/D	3504	4520	7.86	456	418	20.2	50.77
SE10-4-29-25-W2	459	Na-Cl	173	52	2778	40	11	1840	11	3.8	N/D	50	<0.01	0.34	N/D	N/D	4950	7680	7.40	143	142	66.4	103.6
NE14-26-30-26-W2	420	Na-Cl	422+42	534	854	20	8	950	7	0.9	N/D	30	<0.01	0.52	N/D	N/D	2868	4200	8.50	85	346	45.3	78.98
NWr-7-24-27-W2	494	Na-Cl	215	234	3270	82	20	2195	8	3.2	N/D	0.4	<0.01	0.22	N/D	N/D	6028	9520	7.93	286	177	59.8	105.38
NE3-28-24-27-W2	540	Na-Cl	201	11	3430	67	16	2050	8.4	2.5	0.08	4.4	<0.02	0.35	<0.001	3.4	5780	8260	7.49	233	165	58.4	102.87
SEZ-16-25-28-W2	556	Na-Cl	195	<1	4200	89	15	2460	11	1.3	0.08	0.01	<0.02	0.27	<0.001	3.1	6970	9910	8.00	281	160	63.5	118.2
SW1-18-29-28-W2	620	Na-Cl	510+100	244	487	9	2	678	3.1	0.41	<0.001	0.13	<0.02	0.43	<0.001	2.2	2036	2730	8.36	30	584	53.4	85.41
13-36-29-28-W2	592	Na-Cl	266	491	2330	58	21	1680	8.8	0.77	0.07	0.02	0.09	0.27	<0.001	2.8	4850	6630	7.95	233	218	48.1	89.49
NW4-33-32-28-W2	480	Na-Cl	222	99	3374	82	19	2200	14	0.7	N/D	50	<0.01	0.25	N/D	N/D	6061	9870	7.28	286	182	56.9	111.5
NW13-16-33-28-W2	417	Na-Cl	208	8	3248	64	14	2080	13	2.9	N/D	30	<0.01	0.22	N/D	N/D	5668	9440	7.85	219	173	61.49	101.90
Swift Current Valley Aquifer																							
NW13-34-22-23-W2	283	Na-SO_4	650	885	47	130	56	428	9.8	1.8	0.17	25	0.15	0.18	N/D	N/D	2233	2470	7.69	550	530	7.9	21.3
SE16-9-21-25-W2	318	Na-SO_4	650	1040	235	169	83	552	8.3	6.1	0.26	2.4	<0.02	0.24	<0.001	0.94	2747	2850	7.83	758	533	8.7	24.9

Notes: All values in mg/ℓ (ppm), except for conductivity which is in μS/cm and pH
N/D means not determined
SAR means sodium adsorption ratio; ASAR means adjusted sodium adsorption ratio

8. CONCLUSIONS

1. The Hatfield Valley Aquifer System includes the Hatfield Valley and the Wynyard Aquifers, which are comprised of sediments of the Empress Group. In addition, the Meacham Aquifer, which in part consists of the Empress Group sediments, the "Wynyard Formation" Aquifer, the Judith River Aquifer (bedrock aquifer) and the intertill aquifers may be affected to a variable extent when the Hatfield Valley Aquifer System is developed.
2. The Swift Current Valley Aquifer may not be hydraulically connected to the Hatfield Valley Aquifer.
3. Major discharge areas of the Hatfield Valley Aquifer System are: the Lanigan-Nokomis area, the topographical low north of the Touchwood Hills Upland, and the Qu'Appelle Valley near Fort Qu'Appelle. Groundwater from the Hatfield Valley is assumed to discharge into Last Mountain Lake, but the nature of the connection between the aquifer and the lake remains unknown.
4. Significant differences in the cross-sectional area of the Hatfield Valley Aquifer and the existence of a major blockage near Govan are the likely causes of the high potentiometric head in the aquifer in the Lanigan - Nokomis area.
5. In the discharge areas of the Hatfield Valley and the Wynyard Aquifers, groundwater is of the sodium-sulphate type. In the recharge area a calcium/magnesium-sulphate type of water is encountered. In the Hatfield Valley Aquifer water quality improves in the direction toward the Qu'Appelle Valley because of the accumulative addition of water from vertically downward recharge.

6. Groundwater from the Hatfield Valley Aquifer System is less desirable for municipal drinking water supplies and is classified as poor for domestic use. In some cases, it is the only reliable water supply source. It can be used for livestock, however, unless extremely favourable soil and drainage conditions exist, it is unsuitable for irrigation purposes.

7. The bulk hydraulic conductivity of till is assumed to be 4.3×10^{-4} m/day. The Empress Group sediments, fine to medium and medium to coarse-grained sands, have an estimated hydraulic conductivity in the order of 15-25 m/day. The storage coefficient of the Hatfield Valley and the Wynyard Aquifers is in the order of 1.0×10^{-4}.

8. The net groundwater yield of the Hatfield Valley Aquifer may range from 0.7×10^{8} -1.2×10^{8} m^3/year. The net groundwater yield of the Wynyard Aquifer is in the order of 4.1×10^{7} -6.8×10^{7} m^3/year. The yield is derived from additional recharge from precipitation.

9. Under "drought" conditions water produced from the aquifers is derived from storage in the overlying semi-confining layer. It is estimated that 7.3×10^{9} of water would be available from the semi-confining layer overlying the Hatfield Valley Aquifer. The semi-confining layer above the Wynyard Aquifer could produce 4.9×10^{9} m^3.

10. The Swift Current Valley Aquifer System consists of the Swift Current Valley and the Judith River Formation Aquifers. This aquifer system discharges into Last Mountain Lake and, and probably into Buffalo Pound Lake. Water is of the sodium sulphate type and less desirable for municipal and domestic uses, and unfit for irrigation.

11. Geologic and hydrogeologic data on the Swift Current Valley Aquifer System and Meacham Aquifer are inadequate for proper description of the geohydrology and estimation of yields.

9. CONSIDERATIONS FOR FUTURE WORK

1. Based on the presently available data, an attempt should be made to model the Hatfield Valley Aquifer System or portions of this system (i.e., Hatfield Valley and Wynyard Aquifers). The model should be of a simplistic nature and should be used to determine whether the estimated net groundwater yield can be produced from the aquifers. The model can be made more sophisticated as more data become available.
2. For further refinement of aquifer geometry and understanding of connections between aquifers, additional testholes are required in: the central portion of the Hatfield Valley Aquifer and along its shoulders, in the area southwest of Watrous, in the southwestern portion of the Wynyard Aquifer, and in the Meacham Aquifer. Additional testholes are required to further define the Swift Current Valley Aquifer System.
3. The bulk hydraulic conductivity of "thick" till layers should be further investigated because of the important role the hydraulic conductivity of such layers plays in estimating yields.

10 REFERENCES

Acton, D.F., Clayton, J.S., Ellis, J.G., Christiansen, E.A., and Kupsch, W.O., 1960. Physiographic divisions of Saskatchewan. Map prepared by Saskatchewan Soil Survey, Saskatchewan Research Council, Geology Division, and University of Saskatchewan, Geology Department.

Bachman, M., Cameron, D., Jame, Y., and Nicholaichuk, W. Use of groundwater for irrigation in Saskatchewan. A Cooperative study by Agriculture Canada and Saskatchewan Environment, Saskatchewan Environment, 60 p.

Bergsteinsson, J.L., 1976. Precipitation and temperature characteristics for southern arable Saskatchewan. Saskatchewan Research Council, Physics Division (unpublished map).

Bouwer, H., 1978. Groundwater Hydrology. McGraw-Hill Book Company, New York, 480 p.

Christiansen, E.A., 1960. Geology and groundwater resources of the Qu'Appelle area, Saskatchewan. Saskatchewan Research Council, Geology Division, Report No. 1, 53 p.

Christiansen, E.A., 1961. Geology and groundwater resources of the Regina area, Saskatchewan. Saskatchewan Research Council, Geology Division, Report No. 2, 72 p.

Christiansen, E.A., 1968. Pleistocene stratigraphy of the Saskatoon area, Saskatchewan, Canada. Canadian Journal of Earth Sciences, Volume 15, No. 5, pp. 1167-1173.

Christiansen, E.A., 1970. Geology and groundwater resources of the Wynyard area (72 p), Saskatchewan. Saskatchewan Research Council, Geology Division, map No. 10.

Christiansen, E.A., 1971. Geology and groundwater resources of the Regina area (72 I), Saskatchewan. Saskatchewan Research Council, Geology Division, Map No. 13.

Christiansen, E.A., 1977. Engineering properties of glacial deposits in southern Saskatchewan. Thirtieth Canadian Geotechnical Conference, Saskatoon, 30 p.

Christiansen, E.A., 1979a. Geology of the Regina-Moose Jaw region, Saskatchewan. E.A. Christiansen Consulting Ltd., Report 0016-003. Unpublished report prepared for Saskatchewan Municipal Affairs, 67 p.

Christiansen, E.A., 1979b. Geology of the Saskatoon region, Saskatchewan. E.A. Christiansen Consulting Ltd., Report 0016-002. Unpublished report prepared for Saskatchewan Municipal Affairs, 62 p.

Christiansen, E.A., 1979c. The Wisconsinan deglaciation of southern Saskatchewan and adjacent areas. Canadian Journal of Earth Sciences Volume 16, No. 4, pp. 913-938.

Christiansen, E.A., Acton, D.F., Lang, A.J., Meneley, W.A., and Sauer, E.K., 1977. Fort Qu'Appelle Geolog. The Valleys-past and present. The Saskatchewan Museum of Natural History, Saskatchewan Culture and Youth, Interpretive Report 2, 83 p.

Christiansen, E.A., and Meneley, W.A., 1971. Geology and groundwater resources of the Rosetown area (720), Saskatchewan. Saskatchewan Research Council, Geology Division, Map No. 14.

Cooper, H.H., and Jacob, C.E., 1946. A generalized graphical method for evaluating formation constants and summarizing well field history. American Geophysical Union Transactions, Volume 33, pp. 526-534.

Corbet, T.F., 1982. Definition of hydrostratigraphic units in the Tertiary and Upper Cretaceous of central Alberta using the statistical distribution of apparent transmissivities, in Proceedings, G. Ozoray (ed.) pp. 2-91, Second National Hydrogeological Conference, Winnipeg, Manitoba, Canada, 155 p.

Greer, J.E., and Christiansen, E.A., 1963. Geology and groundwater resources of the Wynyard area (72 p), Saskatchewan. Saskatchewan Research Council, Geology Division, Report No. 3, 55 p.

Grisak, G.E., Cherry, J.A., Vonhof, J.A., and Blumele, J.P. Hydrogeologic and hydrochemical properties of fractured till in the interior plains region, in Glacial Till, Legget, R.F. (ed.), pp 304-345. Royal Society of Canada, Ottawa, 412 p.

Grisak, G.E., and Cherry, J.A., 1975. Hydrologic characteristics and response of fractured till and clay confining a shallow aquifer. Canadian Geotechnical Journal, Volume 12, pp. 23-43.

Hendry, J.T., 1982. Hydraulic conductivity of glacial till in Alberta. Groundwater, Volume 20, No. 2, pp. 162-169.

Kewen, T.J., and Schneider, A.T., 1979. Hydrogeologic evaluation of the Judith River Formation Aquifer in west central Saskatchewan. Saskatchewan Research Council, Geology Division. Report prepared for Saskatchewan Environment, 76 p.

Kruseman, G.P. and de Ridder, N.A., 1970. Analysis and evaluation of pumping test data. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. Bulletin 11, 200 p.

Maathuis, H., 1980a. Hatfield Valley Project - Phase I. Preliminary study of the Hatfield Valley Aquifer System in the Lanigan-Fort Qu'Appelle area. Report prepared for Saskatchewan Environment, 43 p.

Maathuis, H., 1980b. Hatfield Valley Aquifer System in Saskatchewan. Report prepared for Saskatchewan Environment, 43 p.

Maathuis, H., (in progress). Nitrate concentrations in deep aquifers in Saskatchewan. Saskatchewan Research Council, Geology Division.

McNeely, R.N., Neimanir, V.P. and Dwyer, L., 1979. Water quality source book. A guide to water quality parameters. Inland Waters Directorate, Water Quality Branch, Ottawa, Canada, 89 p.

McNeil, D.H., Caldwell, W.G.E., 1981. Cretaceous rocks and their Foraminifera in the Manitoba Escarpment. The Geological Association of Canada, Special Paper Number 21, 429 p.

McLean, J.R., 1971. Stratigraphy of the Upper Cretaceous Judith River Formation in the Canadian Great Plains. Saskatchewan Research Council, Geology Division. Report No. 11, 96 p.

Meneley, W.A., 1964. Geology of the Melfort area (73A) Saskatchewan. Ph.D Thesis, University of Illinois, 147 p.

Meneley, W.A., 1962. Geology and groundwater resources of the Melfort area (73A) Saskatchewan. Saskatchewan Research Council, Geology Division, Map No. 6.

Meneley, W.A., 1972. Groundwater resources in Saskatchewan, in water supply for the Saskatchewan-Nelson Basin, Appendix 7, Section F, pp. 673-723. Saskatchewan-Nelson Basin report, Ottawa.

Meneley, W.A., 1978. Water supply - Village of Drake, Evaluation of deep well No. 2. W.A. Meneley Consultants Ltd., Saskatoon, 5 p.

Meneley, W.A., Maathuis, H., Jaworski, E.J., and V.F. Allen, 1979. SRC Observation wells in Saskatchewan Canada: Introduction, Design and Discussion of Accumulated Data 1964-1977: Accumulated Data for Observation wells, Volume 1, Atton's Lake - Hearts Hill, Volume 2, Lilac-Yorkton 519. Saskatchewan Research Council, Geology Division. Report No. 19.

Papadopulos, I.S., and Cooper, H.H., 1967. Drawdown in a well of large diameter. Water Resources Research, Volume 3, pp. 241-244.

PFRA, 1981. Town of Wynyard, Wynyard Groundwater Study. Final Phase report. Prairie Farm Rehabilitation Administration, Geology and Air Surveys Division, Regina, Saskatchewan, 37 p.

Piper, A.M., 1974. A graphic procedure in the geochemical interpretation of water analyses. American Geophysical Union, Transactions, volume 25, pp. 914-923.

Puodziunas, P.P., 1978. Souris River Basin Study. Groundwater study - Saskatchewan, in Souris River Basin Study, Souris River Basin Study Board, Canada-Manitoba-Saskatchewan, Supplement 3, Water Supply Study, Volume 2 of 2, C, 66 p.

Rutherford, A.A., 1966. Water quality survey of Saskatchewan groundwaters Saskatchewan Research Council, Chemistry Division, 267 p.

Sauveplane, C., 1982. Skin-effect and well losses evaluation: a critical review of concepts and methods, in Proceedings, G. Ozoray (ed.), pp. 100-107, Second National Hydrogeological Conference, Winnipeg, Manitoba, Canada, 155 p.

Walton, W.C. 1970. Groundwater resources evaluation. McGraw-Hill, New York, 664 p.

Whitaker, S.H., and Christiansen, E.A., 1972. The Empress Group in southern Saskatchewan. Canadian Journal of Earth Sciences, Volume 9, No. 4, pp. 353-360.

Whitaker, S.H., Pearson, D.E., 1972. Geological Map of Saskatchewan. Saskatchewan Department of Mineral Resources, Geological Sciences Branch, and Saskatchewan Research Council, Geology Division.

Whiting, J.M., 1977. The hydrological and chemical balance of the Big Quill Lake Basin. Final report. Saskatchewan Research Council, Engineering Division, 96 p.

APPENDIX A

MAPS, CROSS-SECTIONS AND LOG INDEX

Cross Section Log Index

Testholes drilled under the program are marked with an *

1.	SRC Prud'Homme 1964	NW12-7-37-28-W2
2.	Imperial Oil South Bend	1-4-37-28-W2
3.	Canadian Oil Whiterose Etal Trojan 16-36	16-36-36-28-W2
4.	Imperial Oil Meacham	16-32-36-27-W2
5.	SRC Meacham 1971	SW4-30-36-27-W2
6.	FFIB Leo Callaghan	SW13-22-36-26-W2
7.	Sunland Refining Backes #1	1-30-36-26-W2
8.	FFIB Arnold Pheil	SE8-29-36-25-W2
9.	FFIB Desmond Koffing	NE13-34-36-25-W2
10.	Atlantic Richfield Pheas Arco S Bruno	16-34-36-25-W2
11.	SRC Carmel 1963	NE16-12-37-25-W2
12.	B.A. Carmel Pappenfoot	5-11-37-24-W2
13.	SRC Dixon 1963	SE16-33-36-23-W2
14.	SRC Humboldt 1963	SE9-5-37-22-W2
15.	Honolulu Oil Gregor	6-2-37-21-W2
16.	FFIB Tom Vidak	SW34-36-20-W2
17.	FFIB Schmidtkamp Bros.	SW3-29-36-19-W2
18.	SRC Watson SW11-20	SW11-20-36-18-W2
19.	Hayter Quill Lake #1	NE13- 9-36-16-W2
20.	FFIB Peter Breckner	SE13-35-33-28-W2
21.	FFIB Lawrence Breckner	NW 1-26-33-28-W2
22.	Shell Young	10-22-33-27-W2
23.	Shell Young	12-18-33-26-W2

24. GSC Plunkett	NE16- 8-33-26-W2
25. FFIB Austin Farago	NE8-12-33-26-W2
*26. SRC Plunkett 81-1	SW13-3-33-25-W2
27. FFIB Jacob Dyck	SE6-4-33-24-W2
28. FFIB James Bowman	5-1-33-24-W2
29. Alwinsal Beaver	1-12-33-24-W2
30. Hayter Guernsey	SW2-18-33-23-W2
31. Alwinsal Sarcee	4-28-33-23-W2
32. SRC Alwinsal	NW10-28-33-23-W2
33. DTRR Lanigan	SW5-29-33-22-W2
34. Duval Guernsey	1-29-33-22-W2
35. FFIB William Funk	SW1-30-33-21-W2
36. Kerr McGee Sinnett	14-22-33-21-W2
37. U of S Farm Lanigan	NW16-22-33-21-W2
38. PW Lanigan #2	SW13-24-33-21-W2
39. Kerr McGee Esk 8-20	8-20-33-20-W2
40. Kerr McGee Esk 8-22	8-22-33-20-W2
41. FFIB Mervin Arnst	SE1-24-33-20-W2
42. FFIB Armond Holfeld	SE11-15-33-19-W2
43. Quill Lake	NW13-18-33-18-W2
44. SRC Wynyard	SE1-28-33-16-W2
45. FFIB John Allingham	1-8-32-27-W2
46. SRC Young	NW13-12-32-27-W2
47. SRC Xena	NE16-2-32-26-W2
48. FFIB Norman Hutchinson	NW12-3-32-25-W2
49. C.S. Watrous No. 1	4-2-32-25-W2

50.	Campana Sth #8 (2680S/10E)	NW5-36-31-25-W2
51.	Campana Sth #20 (10E/1440N)	SW5-8-32-24-W2
52.	Campana Sth #23 (46N/21W)	SE1-9-32-24-W2
53.	FFIB Richard Neufield	SW4-10-32-24-W2
* 54.	SRC Watrous 81	SW1-10-32-24-W2
55.	SRC Drake	NE16-34-31-23-W2
56.	SRC Drake	SE2-6-32-22-W2
57.	SRC Drake	SW4-3-32-22-W2
58.	SRC Drake	NW13-32-31-21-W2
59.	FFIB Bob Burns	NE13-11-32-21-W2
60.	SRC Jansen	SW3-4-32-20-W2
61.	FFIB George Schinkel	SW4-1-32-20-W2
62.	SRC Dafoe	NE13-2-32-19-W2
63.	FFIB Agnes Traquair	NE1-3-32-18-W2
64.	FFIB C.B. Crawford	NW4-8-32-17-W2
65.	SRC Kandahar	SW8-17-32-17-W2
66.	SRC Kandahar	NE5-21-32-17-W2
67.	SRC Kandahar	NW13-23-32-17-W2
68.	SRC Kandahar	SW2-25-32-17-W2
69.	SRC Wynyard	SE1-16-32-16-W2
70.	SRC Mozart	SW13-25-32-15-W2
71.	FFIB Elmer Thoner	NE15-1-31-28-W2
72.	Kerr McGee Horseshoe 16-36	16-36-30-28-W2
* 73.	SRC Renown 81	NW13-35-30-26-W2
74.	Hayter Renown	NW13-36-30-26-W2

75.	FFIB W.H. Penrose	NW13-3-31-25-W2
*76.	SRC Venn 81	NE9 -6-31-24-W2
77.	FFIB Raymond Harding	SE16-22-30-24-W2
78.	S.W.P. Boulder Lake	12-20-30-23-W2
79.	FFIB Con Borshein	SE21-30-23-W2
*80.	SRC Bank Lake 81	NW13-20-30-22-W2
81.	Gen. Petro. Kutawagon	SW4-17-30-20-W2
82.	FFIB Borden Beeler	NW12-18-30-20-W2
83.	SRC Kutawagon	SW4-17-30-20-W2
84.	Socony Sohio Copeland #1	6-13-30-20-W2
85.	FFIB Walter Davidson	SE8-17-30-19-W2
86.	FFIB Allan Kirstein	SW4-14-30-19-W2
87.	FFIB Mike Korsak	NE13-8-30-17-W2
88.	FFIB Barry Nelson	NE16-23-29-16-W2
89.	FFIB Arnold Hall	SE1-21-29-15-W2
*90.	SRC Wishart	SW1-20-29-14-W2
91.	FFIB Ernest Boucher	SE8-12-29-29-W2
92.	FFIB John R. McJannet	SW1-18-29-28-W2
93.	FFIB George Crawford	SW14-13-29-28-W2
94.	GSC Kenaston	NE16-19-29-27-W2
95.	FFIB John Karmark	1-27-29-27-W2
96.	FFIB Ralph More	SE16-19-29-26-W2
97.	GSC Amazon	NW-23-29-26-W2
98.	GSC Amazon	SW-4-30-29-25-W2
99.	GSC Simpson	NW16-21-29-24-W2
100.	GSC Simpson	NW14-20-29-24-W2

101.	GSC Simpson	NE16-23-29-24-W2
102.	GSC Nokomis	NE16-19-29-23-W2
103.	GSC Nokomis	NE16-22-29-23-W2
104.	GSC Nokomis	NE16-24-29-23-W2
105.	SRC Nokomis	SE3-29-29-22-W2
106.	SRC Nokomis	SE2-27-29-22-W2
107.	GSC Nokomis	NE16-24-29-22-W2
108.	FFIB Eureka Breeding Ent.	SE4-5-30-21-W2
*109.	SRC Semans 81	NE16-9-29-20-W2
110.	FFIB George Merkel	16-6-29-18-W2
111.	SRC Punnichy	SE2-16-28-16-W2
*112.	SRC Wynot	NE16-4-28-14-W2
113.	SRC Davidson	NW5-19-27-28-W2
114.	FFIB David Shapson	NW4-20-27-28-W2
115.	FFIB Guy Sampson	SE1-20-27-28-W2
116.	FFIB Laurrie Lockwood	SE8-24-27-27-W2
117.	FFIB Alex Thompson	SW1-19-27-27-W2
118.	FFIB William Steckler	S-1-2-27-26-W2
119.	FFIB Lawrence Klenk	NE9-16-27-25-W2
120.	FFIB Marvin Code	CSW26-27-25-W2
*121.	SRC Govan	NE14-16-27-23-W2
122.	FFIB Malcom Campbell	SW10-22-27-23-W2
123.	SRC Govan	SE1-29-27-22-W2
124.	SRC Govan	SE1-28-27-21-W2
125.	SRC Semans	SE1-1-28-20-W2
126.	FFIB William Plohr	NE8-14-27-18-W2

127.	Pyramid Gordan #1	3-28-26-16-W2
128.	FFIB George Macza	4-26-26-15-W2
*129.	SRC Leross	SE1-27-26-14-W2
130.	SRC Craik	NE8-35-23-29-W2
131.	FFIB Wayne Dixon	NE3-28-24-27-W2
132.	SRC Penzance	SW3-28-24-26-W2
133.	Augerhole	SW4-35-24-25-W2
134.	SRC Last Mountain Lake	NW15-36-24-24-W2
135.	SRC Strasbourg	NW4-33-24-22-W2
136.	Socony Sohio Duval	9-20-25-21-W2
137.	SRC Last Mountain	NE15-21-25-21-W2
138.	FFIB Melvin Hoffman	NE14-24-25-21-W2
*139.	SRC Last Mountain 81	NW13-33-25-20-W2
140.	SRC Serath	SW4-3-26-19-W2
141.	FFIB Ralph Wasylyniak	NW12-6-26-18-W2
142.	FFIB Harold Weber	SW3-30-25-17-W2
143.	TW Bryce Lake #1	1-14-25-16-W2
144.	FFIB Lane Wright	SW9-12-18-27-W2
145.	Dillman Marquis	4-14-19-27-W2
146.	SRC Marquis	NE8-16-19-27-W2
147.	SRC Marquis	SW12-25-19-28-W2
148.	SRC Marquis	NW4-35-19-28-W2
149.	SRC Keeler Augerhole	NW4-34-20-28-W2
150.	Dillman Keeler	4-34-20-28-W2
151.	SRC Keeler	NW12-16-21-28-W2
152.	SRC Keeler	SW4-21-21-28-W2

153. FFIB Charles Smith	N16-8-22-28-W2
154. GSC Aylesbury	1-35-22-28-W2
155. FFIB Harvey Millar	NE9-22-23-28-W2
156. FFIB J.K. White	SE2-16-25-28-W2
157. FFIB Frank Andreas	SE4-27-25-28-W2
158. FFIB Steven Gust	15-36-26-28-W2
159. FFIB Roy Kenny	SW4-6-28-27-W2
160. FFIB Art Morrison	NW4-1-29-28-W2
161. FFIB Dale Weisner	13-36-29-28-W2
162. Hudson Bay Watrous	6-24-30-28-W2
163. SRC Bultel	NW12-35-30-28-W2
164. Sohio Watrous	11-15-31-27-W2
165. FFIB Stan Keffer	NE13-24-31-27-W2
166. FFIB Stuart Rowen	N1-2-32-27-W2
167. SRC Young	SW1-26-32-27-W2
168. Shell Young	9-2-33-27-W2
169. Noranda Neely A-10	4-10-34-27-W2
170. Cons. Morrisson	9-20-34-27-W2
171. Cons. Morrisson Colonsay	5-33-34-27-W2
172. FFIB Don Franson	SE21-35-27-W2
173. Imp. Saxby	4-19-36-26-W2
174. SRC Buffalo Pound Lake	NE4-9-19-25-W2
175. Sohio Findlater #2	9-20-20-25-W2
176. Sohio Findlater	2-4-21-25-W2
177. FFIB Lloyd Hills	SE16-9-21-25-W2
178. U of S Findlater	NE13-32-21-25-W2

179.	U of S Findlater	SE 9-6-22-25-W2
180.	SRC Holdfast	NE16-31-22-25-W2
181.	SRC Holdfast	SE3-18-23-25-W2
182.	Hayter Holdfast	1-30-23-25-W2
183.	FFIB Alfred Schrapp	NE8-5-24-25-W2
184.	FFIB Rm of Big Arm	CSW 5-26-25-W2
185.	FFIB Rm of Big Arm	CSE17-26-25-W2
186.	FFIB Don Powers	CSW21-26-25-W2
187.	FFIB Gerrard Cool	SW10-21-26-25-W2
188.	FFIB Marvin Gullacher	SE2-2-28-25-W2
189.	FFIB Harold Quennell	SE3-6-29-25-W2
190.	FFIB Phil Westby	W12-23-30-26-W2
191.	FFIB Allan Miettinen	SE14-28-31-25-W2
192.	Sohio Plunkett #4	12-21-23-25-W2
*193.	SRC Plunkett 81-2	SW4-26-34-25-W2
194.	Dafoe Wolverine	4-16-35-25-W2
195.	FFIB Richard Seidlitz	NW2-14-21-23-W2
196.	SRC Silton	NW7-17-22-22-W2
197.	FFIB Aden Wilcox	NE3-3-23-22-W2
198.	FFIB Alf Nordal	SE6-15-23-22-W2
199.	FFIB Harold Young	CS3-27-23-22-W2
200.	FFIB Gilles Fontaine	NW15-34-25-22-W2
201.	FFIB Fred Kelln	NE6-14-26-22-W2
202.	Socony Sohio Cymric 4-29	4-29-26-21-W2
203.	Socony Sohio Hatfield	14-11-28-22-W2
204.	FFIB Lorne Lee	NE16-16-28-22-W2

205.	FFIB Ester Larson	SW 3-25-28-22-W2
206.	SRC Hatfield	SE 1-2-29-22-W2
207.	FFIB Theo. J. Dekoning	SW 8-10-29-22-W2
208.	FFIB Robert Halstead	SE 2-18-30-22-W2
209.	FFIB Jerry Wiens	NW2-17-31-22-W2
210.	Can. Oil Whiterose	4-29-32-22-W2
211.	Alwinsal Cree	13-18-33-22-W2
212.	Dominion Potash Attica 12-24	12-24-34-23-W2
213.	SRC Burr	SW4-3-35-23-W2
214.	Dominion Burr 4 - 18	4-18-35-23-W2
215.	FFIB Mike Sawicki	SE-23-25-24-W2
216.	SRC Burr	NE10-9-36-24-W2
217.	FFIB John Flasko	NE16-36-24-W2
*218.	SRC Southey 81-2	NE13-26-21-19-W2
*219.	SRC Southey 81-1	NE16-34-21-19-W2
220.	FFIB Edward Glass	SE4-10-22-19-W2
*221.	SRC Earl Grey 81-1	NW13-19-22-19-W2
*222.	SRC Earl Grey 81-2	NW13-20-23-19-W2
223.	SRC Earl Grey	NE9-12-24-20-W2
224.	Socony Sohio	5-11-25-20-W2
225.	FFIB Edward Lofgren	SW12-16-25-20-W2
226.	Socony Sohio Last Mountain	8-29-25-20-W2
227.	FFIB Grant Swanson	E8-11-27-20-W2
228.	GSC Lockwood	NW11-31-21-W2
229.	SRC Esk	SE11-5-33-20-W2
230.	Kerr McGee Esk	8-36-33-21-W2

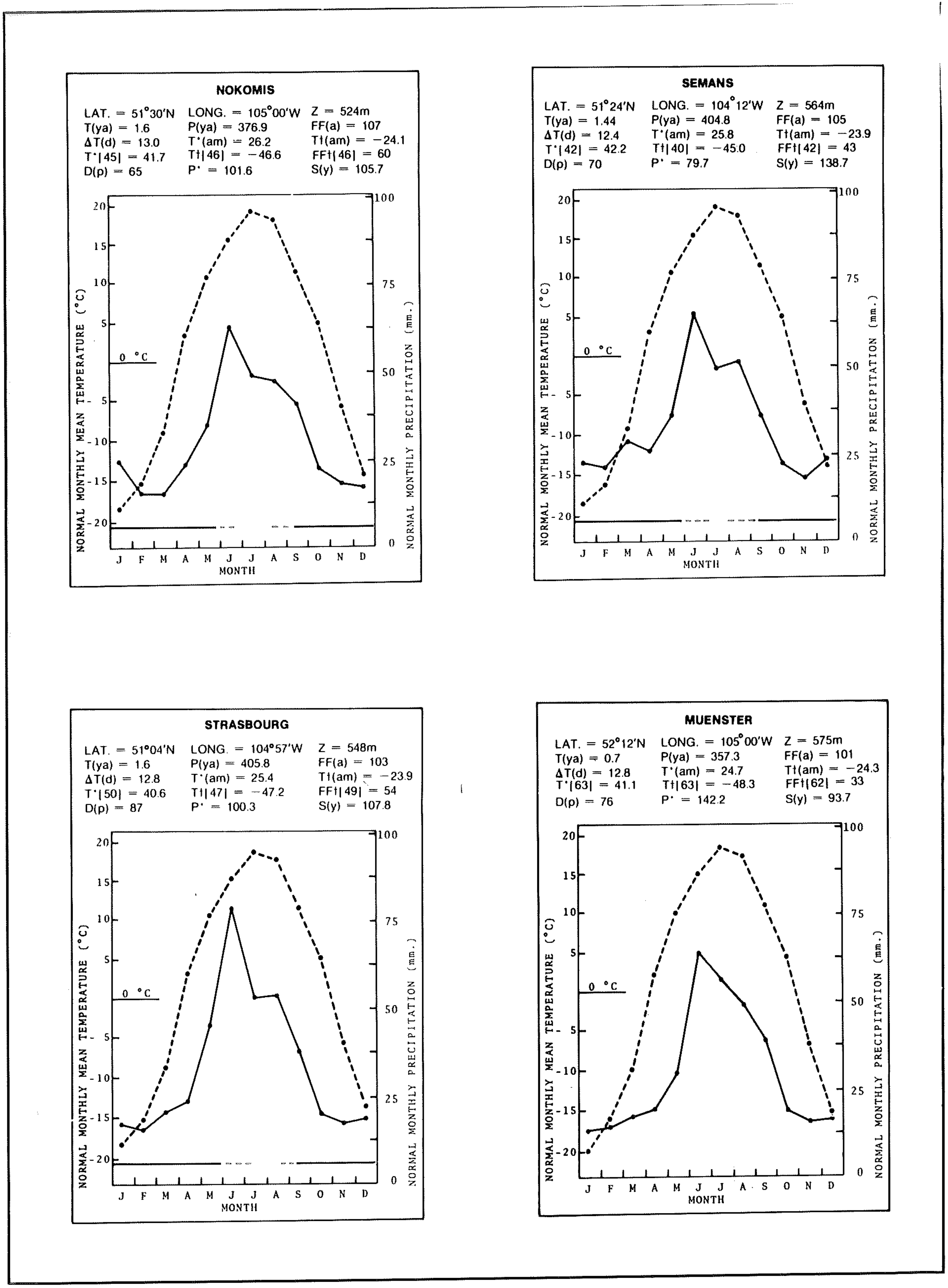
231.	Kerr McGee Jansen Lake	16-12-34-21-W2
232.	SRC Sinnett	SW4-2-35-21-W2
232A.	Winsal Sinnett	7-11-35-21-W2
233.	Alwinsal Potash	13-16-35-21-W2
234.	FFIB Leo Harder	SE30-35-21-W2
235.	FFIB John Benning	NE10-36-22-W2
236.	FFIB Walt Zowislake	SW5-36-22-18-W2
237.	FFIB Mike Zurowski	NW13-31-22-18-W2
238.	FFIB Garry Leippi	SE8-27-23-19-W2
239.	FFIB Albert Weber	CE4-19-24-18-W2
240.	SRC Gregherd	NW4-31-24-18-W2
240A.	FFIB Arnold Weber	SW2-7-25-18-W2
241.	FFIB Robert Fisher	NE9-19-25-18-W2
242.	FFIB Donald Potts	4-19-29-18-W2
243.	SRC Raymore	NW4-30-29-18-W2
244.	FFIB Clifford Currall	NW16-21-30-19-W2
245.	FFIB John Doidge	NE16-24-31-19-W2
246.	FFIB Terry Hankewich	NE15-17-32-18-W2
247.	SRC Dafoe	SW15-30-32-18-W2
248.	FFIB Mierke Bros. Ent.	NW3-1-33-19-W2
249.	FFIB Mierke Bros. Ent.	NW2-12-33-19-W2
250.	FFIB Gus Kotschoreck	SE7-33-33-19-W2
251.	FFIB George Arnest	SW12-11-34-19-W2
252.	SRC Lampard	SW4-24-34-19-W2
253.	SRC Ironspring Creek	SW4-16-35-18-W2
254.	FFIB Gerald Sager	SE14-26-20-16-W2

255.	Tw. Ft. Qu'Appelle	NE16-32-20-16-W2
255A.	102 MuscowPetung	1-9-21-16-W2
*256.	SRC Cupar 81-2	NE1-24-21-17-W2
*257.	SRC Cupar 81-1	SW13-19-21-16-W2
258.	Tw Ft. Qu'Appelle	SE8-25-21-17-W2
259.	Tw Ft. Qu'Appelle	9-6-22-16-W2
260.	SRC Cupar	NW14-31-22-16-W2
261.	FFIB Katalin Tusa	NE16-12-23-17-W2
262.	FFIB Glen Hard	SE1-36-23-17-W2
263.	FFIB Walter Ermel	SE8-10-24-17-W2
264.	Tw Cupar	4-28-24-16-W2
265.	FFIB Sid Mihalisz	4-3-26-16-W2
266.	FFIB Art Hillman	SW3-12-29-16-W2
267.	FFIB George Perry	NW13-12-29-16-W2
268.	SRC Touchwood Hills	SW1-2-31-17-W2
269.	Dominion Kandahar	1-27-31-16-W2
270.	FFIB Harry Bashutsky	SE5-10-32-16-W2
271.	DREE Wynyard #3	NE3-26-32-16-W2
272.	SRC Wynyard	NE1-4-33-16-W2
273.	SRC Quill Lake	SE4-9-34-16-W2
274.	SRC Quill Lake	SE6-17-34-16-W2
275.	SRC Quill Lake	NE14-20-34-16-W2
277.	SRC Quill Lake	NE11-32-34-16-W2
278.	SRC Quill Lake	SW12-4-35-16-W2
279.	FFIB Gerald Leiske	SW-17-35-16-W2
280.	SRC Quill Lake	SE9-20-35-16-W2

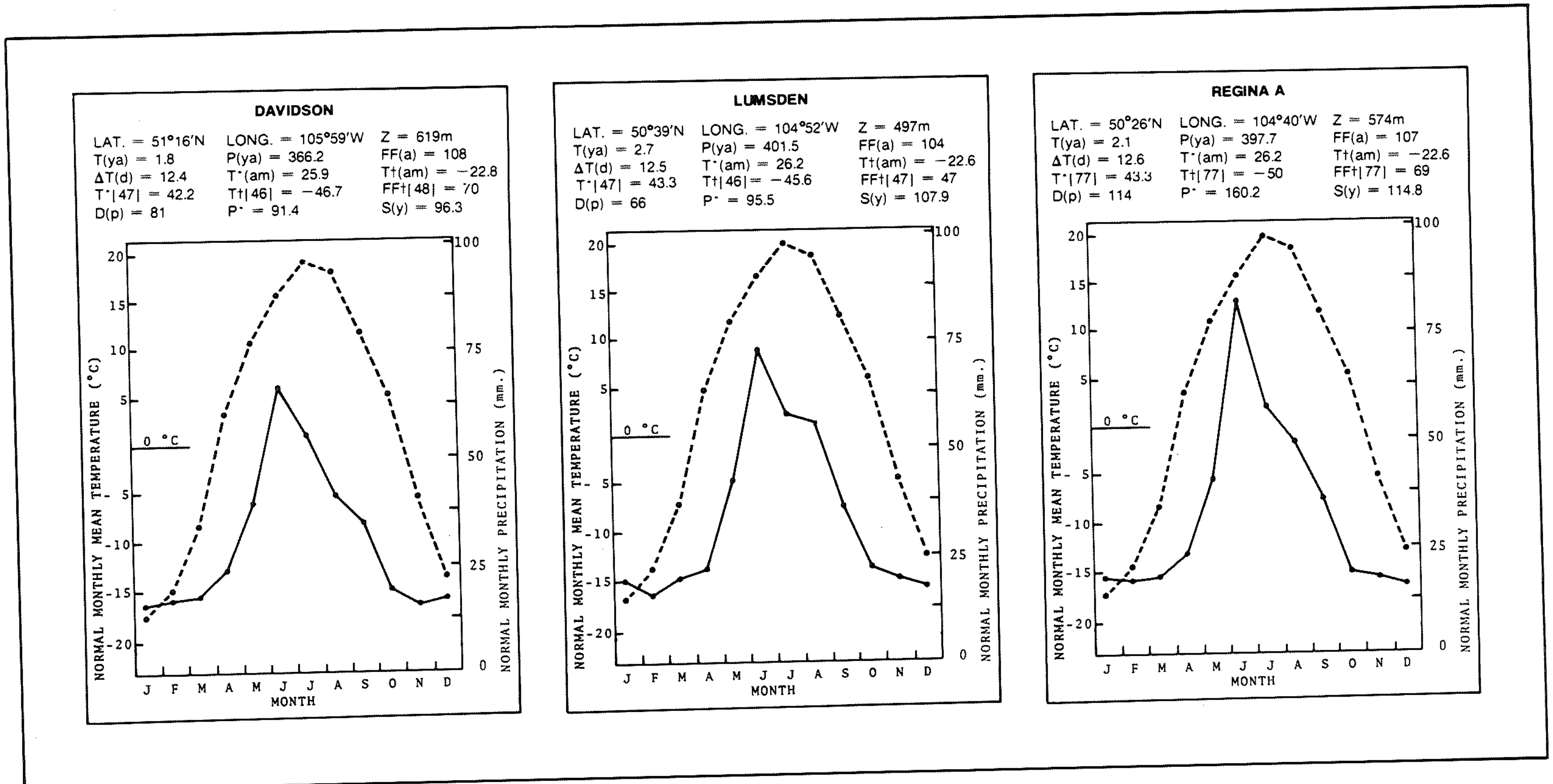
281.	FFIB Frank Mercer	SE8-35-18-29-W2
282.	Socony Marquis	12-28-19-28-W2
283.	FFIB Warman Valgardsson	NE1-33-20-27-W2
*284.	SRC Buffalo Pound Lake	NE16-30-20-26-W2
285.	SRC Dilke	SW5-15-22-24-W2
286.	FFIB R.A. Jones	SW2-30-22-23-W2
*287.	SRC Last Mountain Lake	NW13-34-22-23-W2
288.	FFIB Gerald Cameron	14-35-22-22-W2
289.	Socony Bulyea	8-30-23-20-W2
290.	FFIB Ken Gellner	SW4-26-24-19-W2
291.	FFIB Ed Schira	NW2-18-26-20-W2
292.	FFIB Carl Voeple	SW12-22-24-18-W2
293.	FFIB Ron Hrameck	7-17-23-15-W2

APPENDIX B

CLIMATIC DATA



Climatological data from stations within study area (after Bergsteinsson, 1976)



Climatological data from stations within study area (after Bergsteinsson, 1976)

CLIMATOGRAM CODE

Station Name	Usually, the climatological station name corresponds to the post office employed by the observer. The latitude and longitude shown describe the actual instrument site which may be on an outlying farm, air port or special field site.
LAT.	Latitude of the instrument site.
LONG.	Longitude of the instrument site.
Z	Elevation of the instrument site referenced to mean sea level.
T(ya)	Mean annual temperature in degrees Celsius, based on the standard period 1941-1970.
P(ya)	Mean annual precipitation in millimeters, based on the standard period 1941-1970.
FF(a)	Mean frost free season in days, based on the first and last occurrences of 0 C in a thermometer shelter, during the standard period 1941-1970.[1]
ΔT(d)	Mean diurnal temperature range, degrees Celsius.
T*(am)	Mean maximum temperature of the warmest month, in degrees Celsius, based on the standard period 1941-1970.
T†(am)	Mean minimum temperature of the coldest month, in degrees Celsius, based on the standard period 1941-1970.
T*[ii]	Extreme maximum temperature in ii years of record, degrees Celsius.
T†[jj]	Extreme minimum temperature in jj years of record, degrees Celsius.
FF†[kk]	Shortest frost free season in days over kk years of record.[1]
D(p)	Average number of days per year with precipitation equal to or greater than 0.3 MM, standard period 1941-1970.
P*	Greatest 24-hour precipitation amount, in millimeters, over the total period of station record.
S(y)	Mean annual winter snowfall in centimeters over the standard period 1941-1970.

APPENDIX C

WATER QUALITY GUIDELINES

MUNICIPAL DRINKING WATER QUALITY OBJECTIVES (SASKATCHEWAN ENVIRONMENT, 1980)

1. Bacteriological

(i) Total Coliforms	At least 90 per cent of the samples in any consecutive 30-day period should be negative for total coliform organisms and no one sample should contain more than 10 total coliform organisms per 100 ml. Properly operated municipal waterworks should be free of coliform bacteria.
(ii) Fecal Coliforms	None of the coliform organisms detected should be fecal coliforms.
(iii) Nuisance Biological Organisms	Biological organisms in concentrations which may produce objectionable colour, taste, odour and turbidity, or which may release toxic metabolites, or which may harbour pathogens are undesirable in drinking water and should be kept below such concentrations as to prevent any undesirable effects.

2. Physical

Water should not contain impurities that would be offensive to the sense of sight, taste or smell.

Parameter	Maximum
Colour	15 units
Temperature	15°C
Turbidity	5 units

3. Chemical — General

Constituent	Maximum Desirable (Concentration in mg/L)
Alkalinity (as $CaCO_3$)	500*
Chloride	250
Copper	1.0
Fluoride	1.5
Iron	0.3
Hardness (as $CaCO_3$)	800*
Magnesium	200*
(Magnesium and Sodium) plus Sulphate	1,000*
Manganese	0.05
Methylene Blue Active Substances	0.5*
Phenolics	0.002
Sodium	300*
Sulphate	500
Sulphide as H_2S	0.05
Total Dissolved Solids (sum of dissolved ions)	1,500*
Zinc	5.0

The pH range of the water should not fall outside the range of 7.0 to 9.5*

4. Chemical-Health and Toxicity Related

Constituent	Maximum Acceptable (Concentration in mg/L)
Arsenic	0.05
Barium	1.0
Boron	5.0
Cadmium	0.005
Chromium	0.05
Cyanide (free)	0.2
Lead	0.05
Mercury	0.001
Nitrates as NO_3	40*
Nitrilotriacetic Acid	0.05
Nitrites as N	1.0
Polychlorinated Biphenyls [Note (a)]	0.003*
Selenium	0.01
Silver	0.05
Total Trihalomethanes [Note (b)]	0.35
Uranium	0.02

Note:

(a) Polychlorinated Biphenyls (PCBs) should not be detectable in drinking water (i.e., less than 0.00002 mg/L). The above level of 0.003 mg/L is intended for short-term situations and should not continue for more than six to eight months in a given supply.

(b) The maximum total trihalomethane (i.e., comprised of chloroform, bromodichloromethane, chlorodibromomethane, and bromoform) concentration of 0.35 mg/L applies to actual concentrations, as determined by the purge equivalent, gas sparge or similar method acceptable to the department.

5. Biocides

Constituent	Maximum Acceptable (Concentration in mg/L)
Aldrin & Dieldrin	0.0007
Carbaryl	0.07
Chlordane (total isomers)	0.007
DDT (total isomers)	0.03
Diazinon	0.014
Endrin	0.0002
Heptachlor & Heptachlor Epoxide	0.003
Lindane	0.004
Methoxychlor	0.1
Methyl Parathion	0.007
Parathion	0.035
Toxaphene	0.005
2, 4-D	0.1
2, 4, 5-TP	0.01
Total of individual biocides	0.1

6. Radioactivity

Radionuclide [Notes (d,e,f)]	Maximum Desirable (Concentration in Bq/L) [Note (c)]
Cesium — 137	5
Iodine — 131	1
Radium — 226	0.1
Strontium — 90	1
Tritium	4,000

Note:

(c) One Becquerel (Bq)/L corresponds to approximately 27 Picocuries (pCi)/L.

(d) The objectives for the radiological characteristics of water are based on dose — response relationships as recommended by the ICRP in publication 26 and reviewed in the 1978 Guidelines for Canadian Drinking Water Quality.

(e) Where the concentration exceeds the value in the maximum desirable column, the acceptablility would have to be considered by the department.

(f) Other radionuclides not specified herein should not exceed concentrations as established by the department. Reference will be made to one per cent of the ICRP recommended annual occupational dose equivalent limit for 50 years of continuous exposure in the case of short-term maximum acceptable concentrations and to 0.1 per cent of this dose equivalent limit in the case of long-term acceptable concentrations.

SASKATCHEWAN DEPARTMENT OF THE ENVIRONMENT
Water Quality Division

CHEMICAL WATER QUALITY GUIDELINES

FOR

PRIVATE WATER SUPPLIES

Constituent	Range of Concentrations				Refer To Note No.
	Satisfactory Quality	Poor Quality	Not Recommended For Consumption	Unsuitable For Use	
TOTAL DISSOLVED SOLIDS, mg/1	100-1500	1500-3000	3000-4000	over 4000	a
TOTAL HARDNESS, mg/1 as $CaCO_3$	50- 500	500-1000	1000-2000	over 2000	b
TOTAL ALKALINITY, mg/1 as $CaCO_3$	50- 500	500-1000	1000-1500	over 1500	
CHLORIDE, mg/1	up to 250	250- 500	500-1000	over 1000	
SODIUM, mg/1	up to 300	300- 500	500-1000	over 1000	c
SULPHATE, mg/1	up to 400	400- 800	800-1200	over 1200	d
NITRATE, mg/1	up to 40	40- 300	over 300		e
IRON, mg/1	up to 0.3	0.3-1.0			f
MANGANESE, mg/1	up to 0.05	0.05-0.5			f
pH, units	7.0-9.5	6-7 and 9.5-10		less than 5.5 more than 10.5	

NOTES:

(a) Total dissolved solids (dissolved mineral salts) are picked up by the water in passing through or over the earth. They can only be removed by demineralizing units. A water softener will not reduce the total dissolved solids.

(b) Hardness of water relates to the difficulty of producing a lather with soap. "Hard waters" waste soap and cause bathtub ring, hard-to-remove scale in boilers, kettles, or electric irons. Waters with more than 200 mg/1 of hardness are generally considered "hard." Hardness can be reduced by use of a water softener. To determine the hardness in grains per gallon, divide the value in mg/1 by 14.3

(c) Persons on a sodium restricted (salt-free) diet should consult their physician with respect to the suitability of water used for consumptive purposes.

(d) Due to laxative effects, sulphate in excess of 400 mg/1 is regarded as unsuitable for infant feeding.

(e) Nitrate in excess of 40 mg/1 is considered UNSAFE for consumption by infants up to 6 months of age.

(f) Iron and manganese cause yellowing or browning of water. Amounts above 0.5 mg/1 may result in staining of laundry and plumbing. Domestic units for removal are available. Iron in excess of 7 mg/1 may not be practical to remove.

(g) Livestock. Livestock, depending on species, may tolerate water quality slightly above the limits suggested under "not recommended for consumption." However, if a "poor quality" water is to be used for intensive livestock or poultry production, consult the Provincial Veterinary Laboratory or your veterinarian.

(h) Irrigation. In general, water of "poor quality" for drinking is unsuitable for irrigation of fine-textured clay lands that have low permeability. Such water may occasionally be used on sand or loam soils that are more permeable. Waters with high sodium and alkalinity contents may cause problems, especially if they greatly exceed the total hardness. For specific information on the suitability of water for irrigation consult the Soils Department, University of Saskatchewan, Saskatoon.

(i) Bacteriological Safety. This can only be assessed for a completed water supply by submitting a sample in a special sterile bottle obtainable from your district public health inspector or the Provincial Laboratory.

$$\text{Adjusted SAR} = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}[9.4 - p(K'_2 - K'_c) - p(Ca + Mg) - pAlk]$$

Values of $p(K'_2 - K'_c)$, $p(Ca + Mg)$, and $pAlk$ for calculation of the adjusted SAR with Eq. (10.1)

Concentration Ca + Mg + Na, meq/l	$p(K'_2 - K'_c)$	Concentration Ca + Mg, meq/l	$p(Ca + Mg)$	Concentration $CO_3 + HCO_3$, meq/l	pAlk
0.5	2.11	0.05	4.60	0.05	4.30
0.7	2.12	0.10	4.30	0.10	4.00
0.9	2.13	0.15	4.12	0.15	3.82
1.2	2.14	0.2	4.00	0.20	3.70
1.6	2.15	0.25	3.90	0.25	3.60
1.9	2.16	0.32	3.80	0.31	3.51
2.4	2.17	0.39	3.70	0.40	3.40
2.8	2.18	0.50	3.60	0.50	3.30
3.3	2.19	0.63	3.50	0.63	3.20
3.9	2.20	0.79	3.40	0.79	3.10
4.5	2.21	1.00	3.30	0.99	3.00
5.1	2.22	1.25	3.20	1.25	2.90
5.8	2.23	1.58	3.10	1.57	2.80
6.6	2.24	1.98	3.00	1.98	2.70
7.4	2.25	2.49	2.90	2.49	2.60
8.3	2.26	3.14	2.80	3.13	2.50
9.2	2.27	3.90	2.70	4.0	2.40
11	2.28	4.97	2.60	5.0	2.30
13	2.30	6.30	2.50	6.3	2.20
15	2.32	7.90	2.40	7.9	2.10
18	2.34	10.00	2.30	9.9	2.00
22	2.36	12.50	2.20	12.5	1.90
25	2.38	15.80	2.10	15.7	1.80
29	2.40	19.80	2.00	19.8	1.70
34	2.42				
39	2.44				
45	2.46				
51	2.48				
59	2.50				
67	2.52				
76	2.54				

Source: From Ayers, 1975; National Academy of Sciences and National Academy of Engineering, 1972; and references therein.

Guidelines for interpretation of water quality for irrigation

Problems and quality parameters	No problems	Increasing problems	Severe problems
Salinity effects on crop yield:			
Total dissolved-solids concentration (mg/l)	< 480	480–1 920	> 1 920
Deflocculation of clay and reduction in K and infiltration rate:			
Total dissolved-solids concentration (mg/l)	> 320	< 320	< 128
Adjusted sodium adsorption ratio (SAR)	< 6	6–9	> 9
Specific ion toxicity:			
Boron (mg/l)	< 0.5	0.5–2	2–10
Sodium (as adjusted SAR) if water is absorbed by roots only	< 3	3–9	> 9
Sodium (mg/l) if water is also absorbed by leaves	< 69	> 69	
Chloride (mg/l) if water is absorbed by roots only	< 142	142–355	> 355
Chloride (mg/l) if water is also absorbed by leaves	< 106	> 106	
Quality effects:			
Nitrogen in mg/l (excess N may delay harvest time and adversely affect yield or quality of sugar beets, grapes, citrus, avocados, apricots, etc.)	< 5	5–30	> 30
Bicarbonate as HCO_3 in mg/l (when water is applied with sprinklers, bicarbonate may cause white carbonate deposits on fruits and leaves)	< 90	90–520	> 520

Source: From Ayers, 1975.

(source Bouwer, 1978)

Suitability of Groundwaters for Irrigation

The suitability of a water for irrigation depends upon; 1) the salinity hazard, which is related to the electrical conductivity of the water, 2) the sodium hazard, which is a relative measure of sodium to calcium and magnesium in the water, 3) the hydraulic conductivity of the soil and drainage, and 4) the bicarbonate content.

The following classifications are taken from Richards (1954)*.

Salinity hazard classification:

Class C1: low salinity water, up to 250 μS conductivity, can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop.

Class C2: medium salinity water, conductivity between 250 and 750 μS, can be used if a moderate amount of leaching occurs.

Class C3: high salinity water, conductivity between 750 and 2250 μS, cannot be used on soils with restricted drainage.

Class C4: very high salinity, conductivity greater than 2250 μS, can be used only where soils have high hydraulic conductivities and good drainage. Must be applied in excess to provide considerable leaching and only very salt-tolerant crops should be used.

Sodium hazard:

Sodium, when present in irrigation water in excess of calcium and magnesium, may reduce the hydraulic conductivity and cause hardening of the soil by replacement of calcium and magnesium by sodium ions on the soil clays. The sodium absorption ratio (SAR) is an estimate of the extent of replacement.

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \quad \text{(concentration in epm)}$$

Sodium hazard classification:

Class S1: low sodium water, SAR 0-10, can be used for irrigation on almost all soils with little danger of sodium exchange.

Class S2: medium sodium water, SAR 10-18, will present appreciable sodium hazard in fine textured soils having high cation-exchange-capability, especially under low leading conditions.

---

* Richards, LA. 1954. Diagnosis and improvement of saline and alkaline soils. U.S. Dept. of Agric. Handbook No. 60. U.S. Gov. Printing Office, Washington, D.C. 160 p.

Class S3: high sodium water, SAR 18-26, may produce harmful levels of exchangeable sodium in most soils and will require good drainage, high leaching and organic matter additions.

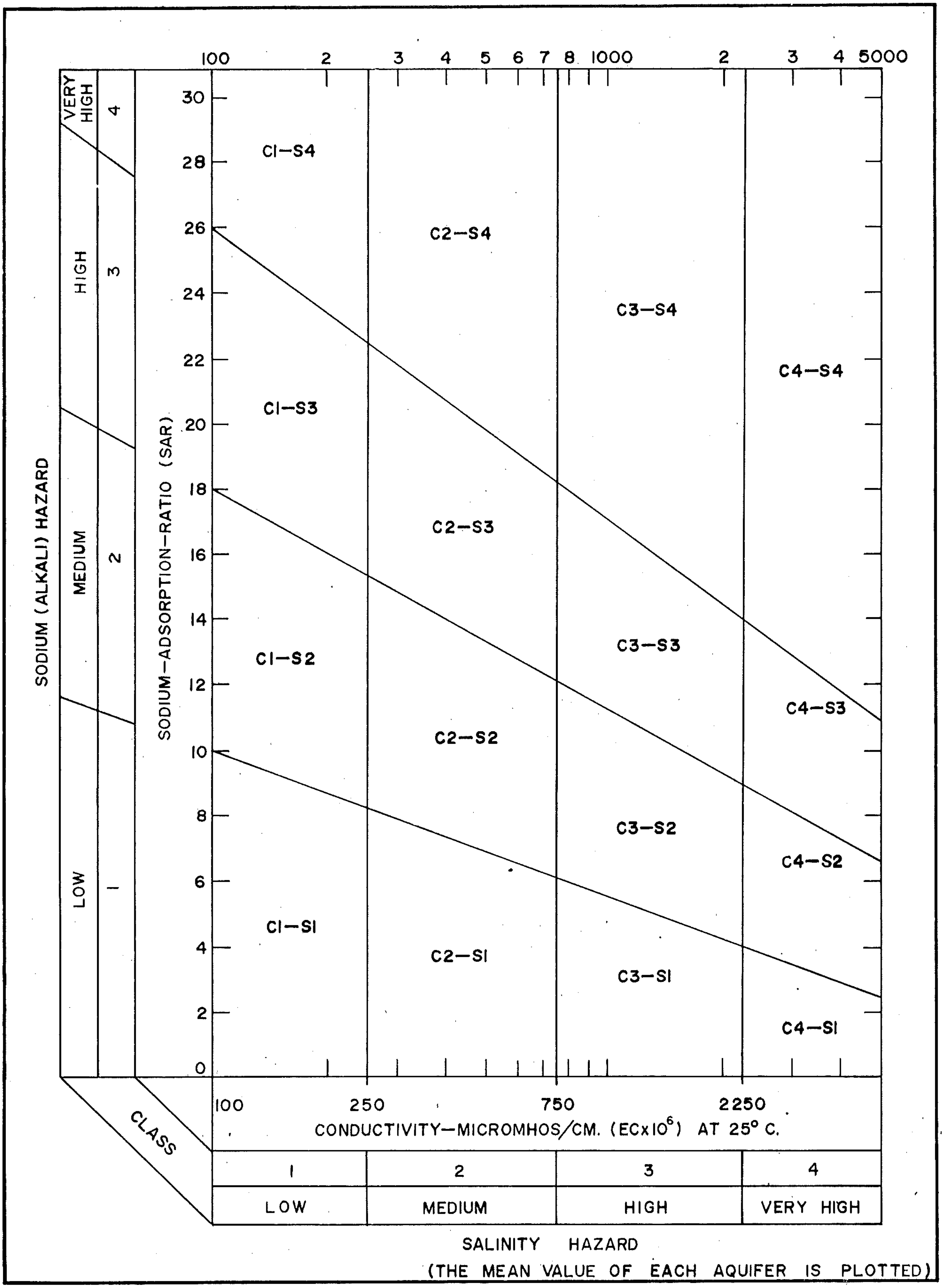
Class S4: very high sodium hazard, SAR greater than 26, in generally unsatisfactory for irrigation except under special circumstances.

Bicarbonate content: residual sodium carbonate

When much bicarbonate is present in the water, Ca^{++} and Ma^{++} tend to precipitate as carbonates if evapotranspiration causes the soil solution to become more concentrated. The relative concentration of sodium increases and, as a result, absorption of sodium to the soil complex is likely to increase. The equation expressing the residual sosium carbonate reads:

$$\text{residual } Na_2CO_3 = (CO_3^{=} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

where the concentration is expressed in milliequivalents per litre. When the residual sodium carbonate exceeds the 2.5 value, water is not suitable for irrigation. Waters with values between 1.25 and 2.5 are marginal, and those having a value less than 1.25 are probably safe.



100
2
3
4
5
6
7
8
1000
2
3
4
5000
SODIUM (ALKALI) HAZARD
VERY HIGH
HIGH
MEDIUM
LOW
4
3
2
1
SODIUM-ADSORPTION-RATIO (SAR)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
CI-S4
C2-S4
C3-S4
C4-S4
CI-S3
C2-S3
C3-S3
C4-S3
CI-S2
C2-S2
C3-S2
C4-S2
CI-SI
C2-SI
C3-SI
C4-SI
CLASS
100
250
750
2250
CONDUCTIVITY-MICROMHOS/CM. (ECx10^6) AT 25° C.
1
2
3
4
LOW
MEDIUM
HIGH
VERY HIGH
SALINITY HAZARD
(THE MEAN VALUE OF EACH AQUIFER IS PLOTTED)

APPENDIX D

GRAIN-SIZE DATA AND HYDRAULIC CONDUCTIVITY

Grain-size data and hydraulic conductivity

Testhole name Land location	Depth ft.	D_{10}[1] mm	K[2] cm/s	K[3] m/day
SRC Leross	560	0.190	$3.6x10^{-2}$	31
SE1-27-26-14-W2	580	0.125	$1.56x10^{-2}$	13
	600	0.105	$1.10x10^{-2}$	9.5
	620	0.110	$1.21x10^{-2}$	10
	640	0.120	$1.44x10^{-2}$	12
	660	0.110	$1.21x10^{-2}$	10
	680	0.115	$1.32x10^{-2}$	11
SRC Wynot	705	0.140	$1.96x10^{-2}$	17
NE16-4-28-14-W2	720	0.135	$1.82x10^{-2}$	16
	740	0.130	$1.69x10^{-2}$	15
	760	0.29	$8.4\ x10^{-2}$	73
SRC Wishart	540	0.15	$2.25x10^{-2}$	19
SW1-20-29-14-W2	580	0.13	$1.69x10^{-2}$	15
SRC Gregherd	510	0.145	$2.10x10^{-2}$	18
NW4-31-24-18-W2	540	0.120	$1.44x10^{-2}$	12
	560	0.130	$1.69x10^{-2}$	15
	590	0.160	$2.56x10^{-2}$	22
	630	0.110	$1.21x10^{-2}$	10

Grain-size data and hydraulic conductivity

Testhole name Land location	Depth ft.	D_{10}[1] mm	K[2] cm/s	K[3] m/day
SRC Last Mountain 81	400	0.108	1.17×10^{-2}	10
NW13-33-25-20-W2	420	0.115	1.32×10^{-2}	11
	440	0.110	1.21×10^{-2}	10
	460	0.110	1.21×10^{-2}	10
	500	0.130	1.69×10^{-2}	15
	520	0.140	1.96×10^{-2}	17
	540	0.145	2.10×10^{-2}	18
SRC Bank Lake	400	0.140	1.96×10^{-2}	17
NW13-20-30-22-W2	420	0.150	2.25×10^{-2}	19
	440	0.110	1.21×10^{-2}	10
	460	0.135	1.82×10^{-2}	16
	480	0.130	1.69×10^{-2}	15
	500	0.140	1.96×10^{-2}	17
	520	0.150	2.25×10^{-2}	19
SRC Last Mountain Lake	290	0.140	1.96×10^{-2}	17
NW13-33-23-23-W2	310	0.250	6.25×10^{-2}	54

Notes: 1. The D_{10} was taken from grain-site gradation curves as determined by sieve analysis using 1/2Q sieves. It is the grain-size diameter at which 10% of the soil particles are finer and 90% coarser.

2. $K = 1.0\ (D_{10})^2$ D_{10} in millimetres, K in cm/s.

3. $K(\text{m/day}) = 86_4\ K\ (\text{cm/s})$

APPENDIX E

DISCUSSION OF TERMINOLOGY AND LIST OF CONVERSIONS

APPENDIX E

DISCUSSION OF TERMINOLOGY

An Aquifer: is a zone in which a well can be constructed which will yield water at a sufficient rate for the need intended (Meneley, 1972).

A Semi-confining Layer: is a layer which has a low, though measurable, hydraulic conductivity and in which the horizontal flow component can be neglected (Kruseman and de Ridder, 1970).

An Aquifer System: includes one or more aquifers and related semi-confining layers, which functions as one geohydrologic unit under development conditions (Meneley, 1972).

A "Confining" Layer: is a layer in which the hydraulic resistance to vertical flow is so large that for all practical purposes the layer can be considered as impervious.

A Semi-confined Aquifer: or leaky aquifer, is a completely saturated aquifer that is bounded above by a semi-confining layer and below by a layer that is either confining or semi-confining (Kruseman and de Ridder, 1970).

Hydraulic Resistance (c): also called reciprocal leakage coefficient or resistance against vertical flow, is the ratio of the saturated thickness m^1 of the semi-confining layer to the vertical hydraulic conductivity K_v^1 of this layer. (Kruseman and de Ridder, 1970).

<u>The Net Groundwater Yield</u>: is the additional amount of water resource available that is derived by increasing the average rate of groundwater recharge by groundwater development (Meneley, 1972).

<u>The Sustained Yield</u>: of an aquifer is the amount of groundwater which can be withdrawn continuously without lowering water levels to critical stages or causing undesirable changes in water quality (Walton, 1970). Meneley (1972) considered the sustained yield as the sum of the net groundwater yield and the amount of water which becomes available as result of a decrease in groundwater discharge which inevitably must occur as a result of groundwater development and which cannot be credited as a net increase.

List of Conversion

1 U.S. gallon (gal) = 3.785 litres

1 Imperial gallon (I gal) = 4.546 litres

1 gal = 0.8327 I gal

1 I gal = 1.2011 gal

1 gal/day x ft^2 = 4.07 x 10^{-2} m/day

1 I gal/day x ft^2 = 4.89 x 10^{-2} m/day

1 m/day = 24.57 gal/day x ft^2

= 20.45 I gal/day x ft^2

1 I gal/day x ft = 1.24 x 10^{-2} m^2/day

1 I gal/day x ft = 1.49 x 10^{-2} m^2/day

1 m^2/day = 80.65 gal/day x ft

= 67.11 I gal/day x ft

1I gal/min = 5.45 m^3/day

1 gal/min = 6.55 m^3/day

1 m^3/day = 0.18 gal/min

= 0.15 I gal/min

1 acre-feet = 1234 m^3

1 mile = 1609 m = 1.609 km

1 km = 0.62 mile

1 $mile^2$ = 2.59 km^2

1 km^2 = 0.39 $mile^2$

HATFIELD VALLEY AQUIFER SYSTEM IN THE WYNYARD REGION, SASKATCHEWAN.

Volume II

(Appendices F and G)

H. Maathuis
B.T. Schreiner
Geology Division
Saskatchewan Research Council

Prepared for Saskatchewan Environment under the Canada-Saskatchewan Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing

May, 1982

SRC Publication No. G-744-4-E-82

TABLE OF CONTENTS

<u>Appendix</u>

A P P E N D I X F-1

TESTHOLE LOGS YORKTON AREA (62M)

A P P E N D I X F-2

TESTHOLE LOGS REGINA AREA (72I)

A P P E N D I X F-3

TESTHOLE LOGS WYNYARD AREA (72P)

A P P E N D I X G-1

WATER QUALITY DATA REGINA AREA (72I)

A P P E N D I X G-2

WATER QUALITY DATA WYNYARD AREA (72P)