HATFIELD VALLEY AQUIFER SYSTEM IN THE MELVILLE REGION, SASKATCHEWAN

by

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HATFIELD VALLEY AQUIFER SYSTEM IN THE MELVILLE REGION, SASKATCHEWAN

Volume I

(Text and Appendices A to E)

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1. INTRODUCTION

1.1 Purpose and Scope of Study

The present report concerns the second phase of a three-phase study of the Hatfield Valley Aquifer System in the Melville region. The study was commissioned to the Saskatchewan Research Council (SRC) by the Saskatchewan Department of the Environment (contract #97-80/81) under the Canada - Saskatchewan Interim Agreement on Water Development for Regional Economic Expansion and Drought Proofing.

The objective of this study is to define the aquifers involved and evaluate, both in terms of quantity and quality, the groundwater resources in the Hatfield Valley Aquifer System.

1.2 Location of Study Area

The study area is located between the Manitoba - Saskatchewan border and 104° West Longitude and 50° and 51° 15' North Latitude comprising an area of approximately 25,700 km^2 (Figure 1). The area includes the NTS map sheet Melville (62 L), the western portions of the Riding Mountain sheet (62 K) and the Duck Mountain sheet (62 N), and the southern quarter of the Yorkton sheet (62 M).

1.3 Previous Work

The geology and groundwater resources of the Melville - Yorkton region were investigated by Cherry and Whitaker (1969) and Christiansen (1960, 1971a). These publications described the surficial and bedrock geology and topography on maps and cross-sections and also showed the base of groundwater exploration, and the location of aquifers. Meneley and Christiansen (1975 a, b) discussed the hydrogeology at the Fort Qu'Appelle Fish Culture Station and in the Yorkton area, respectively.

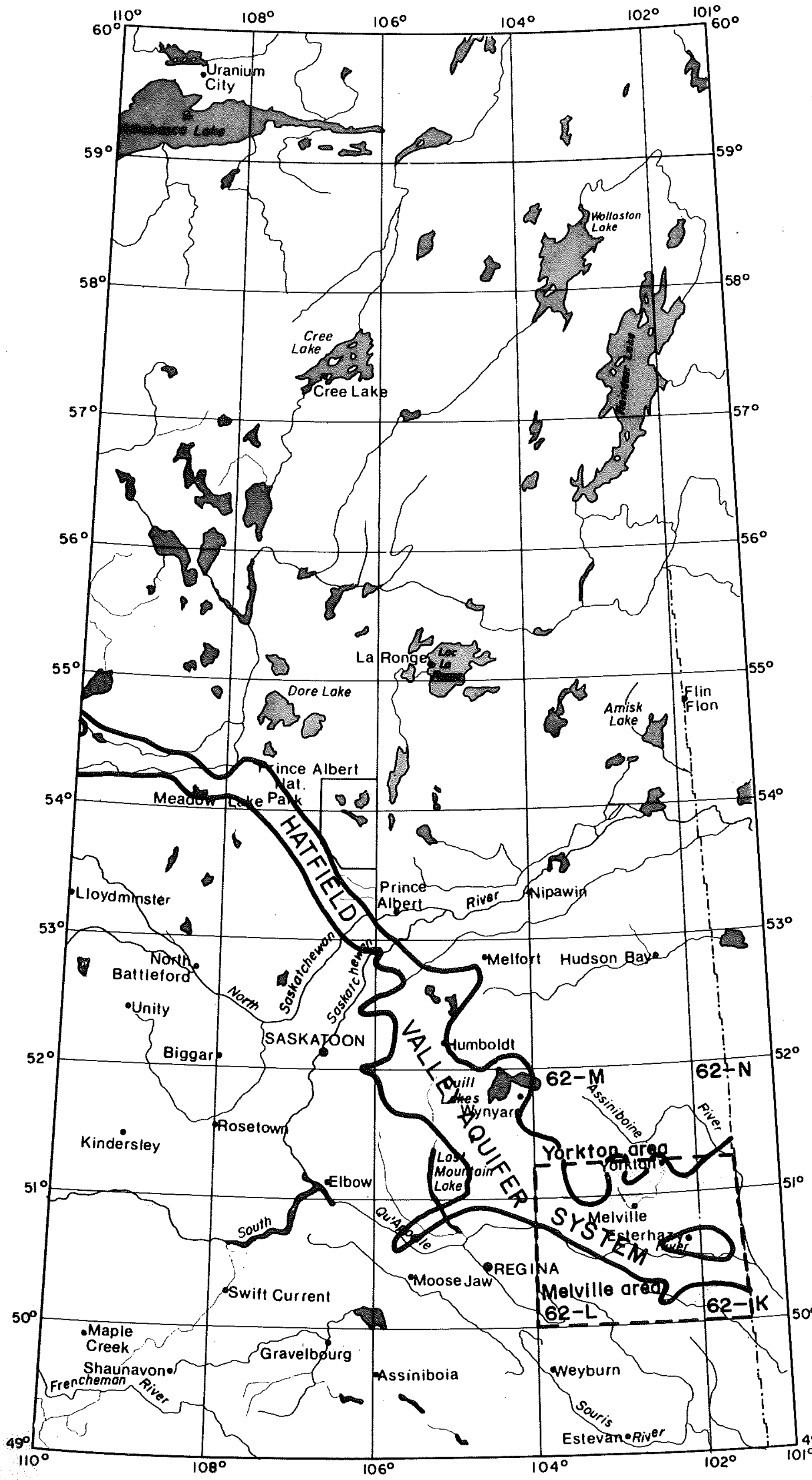


Fig. I Location map of study area and Hatfield Valley Aquifer System.

The geological units and aquifers along the western edge of the study area are described in reports on the Fort Qu'Appelle area and the Regina-Moose Jaw region (Christiansen et al., 1977 and Christiansen, 1979a).

Meneley (1972) discussed the groundwater resources in Saskatchewan and included descriptions of aquifers in the study area. Maathuis (1977) discussed the hydrogeology of the Yorkton area, which included maps and cross-sections depicting the aquifers in the area, and also included information on the water quality in these aquifers. Maathuis (1980a) described the Hatfield Valley Aquifer System in Saskatchewan. He described the system in more detail in the Fort Qu'Appelle area, which is part of this study area (Maathuis, 1980b).

Clifton and Associates Ltd. (1981) have investigated, in considerable detail, the geology and hydrogeology of the area around Bredenbury. Included in their report is work done by Christiansen (1981) which describes the geology of the area using maps and cross-sections to depict the various units. Numerous other reports concerning the geology and hydrology of the various parts of the area are available from other studies, particularly concerning potash mine development. Most of these reports are site-specific and provide detailed information for one locale. The scope of these reports makes them of limited use in this regional investigation.

1.4 Present Study

For the Phase I study of the present program all subsurface information with electric logs was compiled for the Melville region (Schreiner, 1980). These data included testhole and augerhole logs from the Saskatchewan Research Council, drill hole information from the Family Farm Improvement Branch, and oil and potash company logs. Other logs such as water well records have not been used because of the lack of electric logs which makes the data incompatible with the other logs. Also site specific data was not used since commonly it is not critical to a regional investigation such as this. Time limitations prevented extensive review of this information. This information was compiled into two maps. One map shows bedrock geology and topography. The other map delineates the area and thickness of the aquifers and drift cover thickness. Cross-sections show the stratigraphic relationship of the geologic units. These maps and sections were prepared to provide a geological framework for the area to aid in directing the subsequent test drilling program.

In addition to this information geohydrological data was also compiled which included information on water quality, water levels, flowing wells, hydraulic properties, and groundwater allocations.

During the period June 1 to August 28, 1981, a total of 56 testholes were drilled under contract to Hayter Drilling Ltd., Watrous, Saskatchewan. The total footage that was test-drilled, electric-logged, and sampled was approximately 8,000 m (26,000 ft). In addition to the test-drilling, six piezometers were installed in the Hatfield Valley Aquifer in previously drilled testholes. The total footage of piezometers was approximately 800 m (2,600 ft). The locations of these testholes and piezometers is shown on Maps A and B.

A total of 12 augerholes were drilled under contract to Don MacRae Augering, Conquest, Saskatchewan. The total footage drilled was 620 feet with samples collected at 2 to 5 foot intervals depending on materials encountered. The augerholes were concentrated along a traverse east and west of Melville in order to better define the boundaries of the Bredenbury Aquifer (Map B).

Cutting samples from the rotary holes were collected at intervals of 1.5 m (5 ft.) by the driller and were washed and placed in muffin tins by a geologist. The role of the side hole sampler was primarily to obtain precisely located samples from testholes which for various reasons did not provide adequate cutting samples. For example it was used in the Oakshela testhole where sample recovery was poor for technical reasons. In the Percival 2 testhole, where disturbed shale was suspected, more reliable samples were required.

The other proposed application was for recovering cores of sands for grain size analysis to estimate hydraulic conductivity. For technical reasons such as collapse of the hole or dropping out of the sand before the sampler reached surface, the side hole sampler could not be used for this purpose. Testholes where side hole samples were taken are marked, and the location of each sample is indicated on the testhole logs in Appendix F.

Samples from rotary drilling augering and side hole sampling were dried and samples were described by the senior geologist with the aid of dilute hydrochloric acid, a Munsell Color Chart, and a hand lens. Selected till samples were analyzed for carbonate content and grain size analyses were done on selected sand samples. Additional samples of bedrock and drift were analyzed for grain size to calibrate field descriptions. Based on these descriptions, the driller's log, and the electric log, the geologic log was compiled. All geologic logs, as well as the piezometer installation logs obtained during this program, are included in Appendix F. Carbonate contents of till units are plotted as graphs on the testhole logs which are included on the cross-sections. Results of grain size analyses are listed in tables in Appendix D along with hydraulic conductivity values based on these analyses.

Water samples and water levels were mainly taken from farm wells known to be completed in the Hatfield Valley Aquifer System and from the six piezometers installed in the present program. Also, a limited number of samples were taken from wells in aquifers composed of the Empress Group material or Bredenbury Formation. These aquifers flank the Hatfield Valley and are hydrologically connected. The chemical analyses of water samples are tabulated in Appendix G with pertinent results shown as water quality bars on the cross-sections.

The subsurface information from the testholes drilled in this program was integrated with the information previously compiled to produce two maps and 13 cross-sections (Appendix B). These maps and cross-sections show the geometry and geological setting of the Hatfield Valley Aquifer System and the member aquifers, Map A shows the bedrock geology, the surface elevations and the contours of the bedrock surface. Map B shows the distribution, depth below surface, and thickness of the sediments comprising the aquifer system as well as reported water levels and available drawdown. Six cross-sections traverse the area from south to north and six from west to east. A longitudinal section follows the Hatfield Valley through the area. The index of logs used on the cross-sections is in Appendix A.

A preliminary evaluation of the aquifer systems in terms of groundwater quantity and quality is made based on the previously available information and that collected during this program.

1.5 Acknowledgements

The cooperation and interest of the Rural Municipalities and farmers throughout the study area are gratefully appreciated.

Mr. Bryan Schreiner (SRC) compiled and interpreted the geologic information. He also supervised the test drilling, piezometer installation, sample collection and analyses as well as all other field components of this study. Mr. Harm Maathuis (SRC) interpreted the hydrologic information and also did the numerous calculations.

Test-drilling and electric logging was done by Mr. Marty Hayter, of Hayter Drilling Ltd., Watrous, Saskatchewan.

Mr. Mark Simpson, Geology Division, Saskatchewan Research Council (SRC) assisted the senior author throughout the drilling program. Mr. Edward Jaworski, Geology Division, SRC, provided valuable assistance during the installation and pumping of the piezometers. Mr. Denis Zlipko (SRC) (SRC) collected most of the water samples and compiled much of the water quality data along with Mrs. Judy Rackel. They also verified the test-hole locations and elevations.

Dr. Ralph Arnold, Head, Geology Division, SRC, and Mr. William Taylor, also of SRC, critically reviewed the manuscript.

By special request, Mr. Herb 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 and his effort is gratefully appreciated.

Carbonate analyses of till samples were done by Mr. William Ross and Ms. Terri McKay, Sedimentary Laboratory, SRC. Mr. Ross also supervised the sidehole core sampling. Water samples were analyzed according to standard methods by the Chemical Laboratory, SRC.

Mrs. Janet Campbell assisted with the preparation of the maps and cross-sections.

Drafting was done by Geology Graphics, SRC.

2. PHYSIOGRAPHY

2.1 Topography

The study area can be subdivided into the following major physiographic divisions: Assiniboine River Plain, Touchwood Hills Upland, Pheasant Hills Upland and Moose Mountain Upland (Figure 2). The Assiniboine River Plain occupies most of the area. In the Melville region, it forms a central lowland with topographic elevation ranging from 500 to 600 m ASL, and is flanked by the Touchwood Hills Upland to the northwest, and the Moose Mountain Upland to the southwest. The topographic elevation of the Touchwood Hills Upland ranges from 600 to 670 m ASL, whereas the Moose Mountain Upland ranges from 600 to 700 m ASL.

The Pheasant Hills Upland is a small highland located in the west-central part of the area and is surrounded by the Assiniboine River Plain. The topographic elevation of the Pheasant Hills Upland rises above 600 m ASL but does not exceed 670 m ASL. The Qu'Appelle Valley which crosses the central part of the area from west to east, is a striking topographic feature with its valley bottom approximately 90 m below the surrounding plain.

2.2. Surface Drainage

The major part of the area drains into the Qu'Appelle River which flows from west to east through the central part of the area and eventually flows into the Assiniboine River. The Fishing Lakes, Crooked Lake, and Round Lake which are narrow, long, bodies of water are confined within the Qu'Appelle Valley and form part of the main river system (Figure 2).

The southern part of the area drains southeast primarily by way of

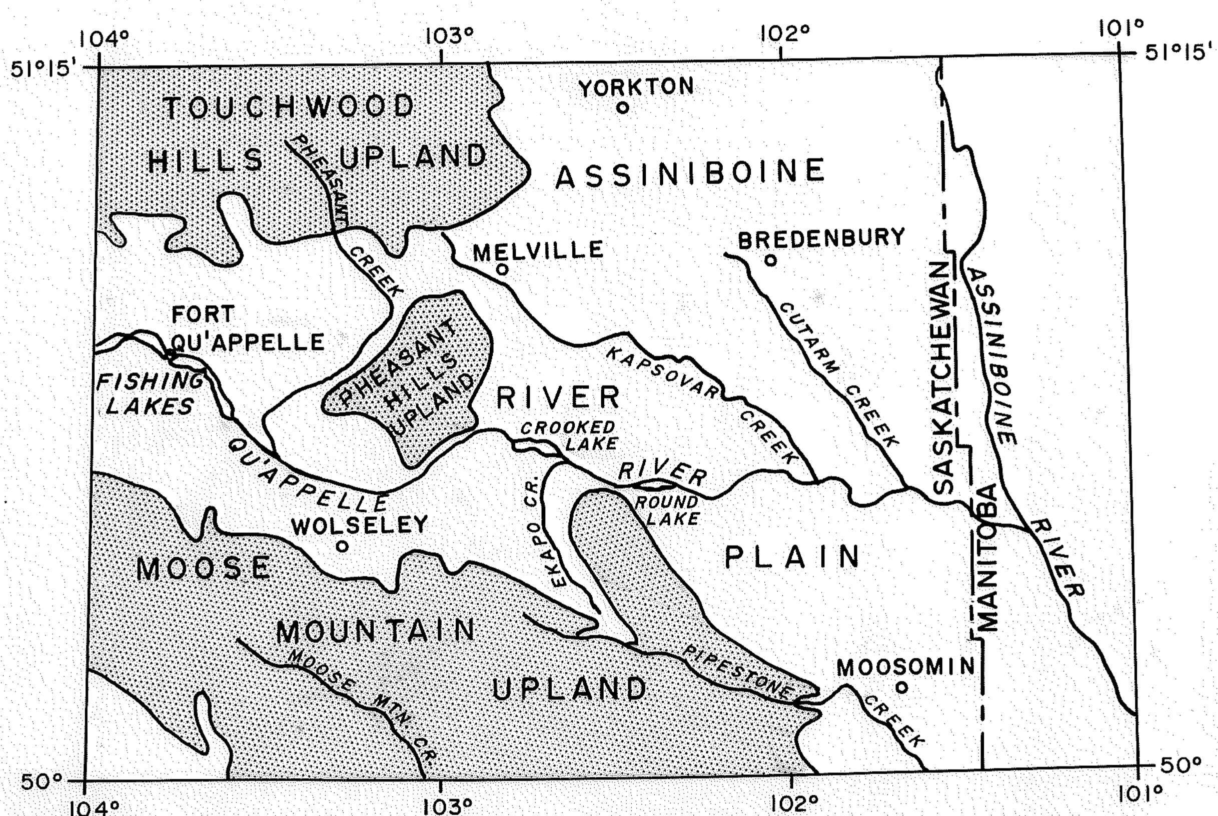


Figure 2 Physiographic divisions of the study area (after Acton et al., 1960).

Moose Mountain Creek and Pipestone Creek. The surface run-off drainage systems are generally poorly integrated and much of the area does not contribute directly to surface run-off because many topographic depressions have no outlets.

2.3 Climate

Climatological data from four meteorological stations in the study area; Yorkton A, Whitewood, Moosomin, and Indian Head CDA are taken from Bergsteinsson (1976). 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 summer of at least four months with temperatures above 10°C. The average annual precipitation (1941-1970) ranges from 418 to 435 mm/year in the northwest half of the area and between 478 and 506 mm/year in the southeast half. The average monthly precipitation is less than 30 mm/month during the winter (October-April), and above 30 - 90 mm/month in the summer (May-September). The average precipitation as snowfall is approximately 30% of the total annual precipitation.

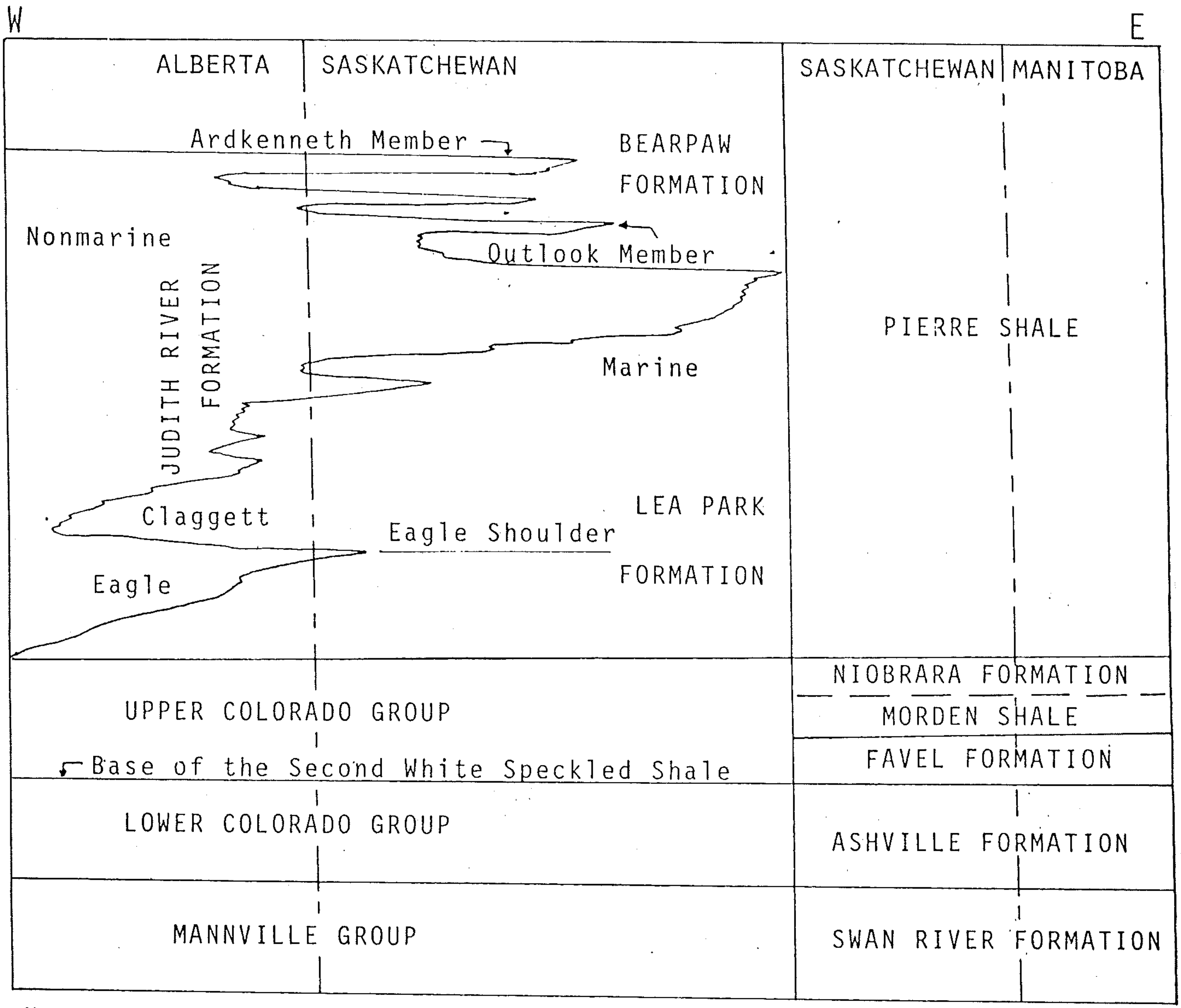
3. BEDROCK GEOLOGY

3.1 General Remarks

The bedrock geology in the Melville region is complicated by the fact that a change in nomenclature of the formations occurs within the western part of the map area. The sequence of Cretaceous bedrock units and the related nomenclature are shown in Figure 3. The Bearpaw Formation, the Judith River Formation, the Lea Park Formation and the Upper Colorado Group are found in the western part of the area as shown on the bedrock map (Map A). These formations are underlain by the Lower Colorado Group and the Mannville Group as shown in Figure 3.

In the northeast part of the study area around Bredenbury, the Cretaceous sequence is overlain by the "Bredenbury Formation", which is believed to be of Quaternary-Tertiary age (Christiansen, 1981).

In the remainder of the area the Pierre Shale is at the bedrock surface with the Odanah Member of this formation occurring in the east-central part of the area (Map A). The Niobrara Formation, the Morden Shale, and the Favel Formation underlie these units as shown in Figure 3. The Ashville Formation and the Swan River Formation, in turn, underlie the above units. In the western part of the area, the base of the Second White Speckled Shale was used as the marker bed. In the remaining area, the Favel Formation provided the marker unit. These units were used because of their conspicuous profiles on electric logs. The lithostratigraphic divisions and nomenclature change coincides with the actual or projected "pinch-out" of the Judith River Formation. The location of this "pinch-out" is based on the cross-sections, and where data were lacking it is based on the boundary as outlined by McLean (1971), and Whitaker and Pearson (1972).



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 bedrock nomenclature

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.

3.2 Bedrock Surface Topography

The bedrock surface topography as shown on the bedrock geology map (Map A) is dominated by the Hatfield Valley System. The Hatfield Valley is a fluvial valley formed by water erosion during the first glaciation (Christiansen et al., 1977). Glacial erosion by subsequent continental glaciers modified the Hatfield Valley and eroded the upland areas, producing concave upward surfaces on the bedrock.

Disturbed bedrock occurs in the eastern part of the study area on the bedrock highland above 1500 to 1600 feet,north and south of the Qu'Appelle River and also south of the Rocanville Valley (Map A). West of Hazel Cliffe (T.18, R.33) and east of Tantallon (T.18, R.32) the deformation is expressed as thrust moraine and highly folded and faulted bedrock. These features are a result of ice thrusting in the area (Christiansen 1971a).

South of the Qu'Appelle Valley as well as south of the Rocanville Valley soft, brecciated, slickensided, and mylonitic bedrock occurs (Map A) but the regional structure is unaffected. This deformation is the result of glacial overriding of the area. Glacial erosion also resulted in the large depressions in the southern wall of the Rocanville and Hatfield Valleys.

Collapse has also affected the bedrock surface in the area. A collapse structure at Crater Lake, northeast of Melville, was described by Christiansen (1971b). A good example of collapse is found just west of Kipling in the south-central part of the area. These collapse structures create bedrock depressions which are reflected in the stratigraphy at depth. Postglacial fluvial erosion formed the Qu'Appelle Valley as the last glacier retreated from the area. Locally this valley is cut deeply into bedrock.

These models of erosion were used to help define the bedrock surface topography and provided the basis for the contacts drawn in the cross-sections.

3.3 Swan River Formation - Manville Group

These two bedrock units can be considered to be equivalent and therefore here they are described together. The Swan River-Manville Group consists of locally cemented, fine-to medium-grained sand, silt, and clay. These units are described by Cherry and Whitaker (1969) and Christiansen (1971a).

In the eastern part of the area Paleozoic sediments are shown grouped with the Swan River Formation at the base of some of the cross-sections. These sediments consist of limestone and dolomites but are not differentiated for this report. None of these bedrock units are exposed on the bedrock surface.

3.4 Ashville Formation - Lower Colorado Group

These two bedrock units can be considered to be equivalent and therefore here they are described together. The Ashville Formation-Lower Colorado Group is 110 - 135 m (360 - 445 ft) thick and is composed of calcareous silt and clay. These units are further described by Cherry and Whitaker (1969) and Christiansen (1971a). Neither of these two units outcrop on the bedrock surface.

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

The Favel Formation, ranging in thickness from 15-30 m (50-100 ft), consists of calcareous shale. The Morden Shale and the Niobrara Formation, together, formerly known as the Vermillion River Formation, are comprised of calcareous silt and clay, and non-calcareous silt and clay, respectively. Together both units comprise a thickness of 45-110 m (150-360 ft). The Pierre Shale, also known as the Riding Mountain Formation, is 65-485 m (200-1600 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). This revised nomenclature as well as more detailed descriptions are given in McNeil and Caldwell (1981).

3.6 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 Upper Colorado Group are composed of 245-275 m (800-900 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).

3.7 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. The position of the Judith River Formation is uncertain due to the fact that it is extremely thin in this area and may "pinch-out" intermittently in the western part of the area. The Formation thickness may range from 0-10 m (0-35 ft) and it occurs to the north and south of the Hatfield Valley Aquifer in the western part of the area (Map A).

3.8 Bearpaw Formation

The Bearpaw Formation consists of 0-350 m (0-1150 ft) of thick gray, non-calcareous, silt and clay. The Bearpaw Formation forms the bedrock surface in most of the area north and south of the Hatfield Valley in the western part of the area.

3.9 Odanah Member

The Odanah Member of the Pierre Shale consists of 0-30 m (0-100 ft) of gray and light gray, non-calcareous, hard, siliceous shale, interbedded with gray non-calcareous clay, commonly brecciated and mylonitic. The Odanah Member outcrops at the bedrock surface north and south of the Qu'Appelle Valley in the east central part of the area. Other members of the Pierre Shale occur in the area; however, only the Odanah Member is described here since this fractured bedrock is used as a water supply in a few cases.

3.10 "Bredenbury Formation"

Extensive sands and silts occur in the Melville-Yorkton-Bredenbury area. These deposits have been informally named the "Bredenbury Formation" by Christiansen (1981). This formation which is up to 60 m (200 ft)thick is composed of fine to medium-grained sand to the north and west and interbedded fine-grained sand and silt, or silt to the south. Well preserved, soft, unlithified wood occurs commonly throughout the unit. The base of the formation is commonly marked with less than a metre of well-rounded chert, quartzite, siderite,and limestone gravel. Christiansen (1981) indicates that the "Bredenbury Formation" is preglacial and should be considered as a bedrock unit on the basis of the chert and quartzite gravel and the stratigraphic position on the upland of the Pierre Shale well above the Hatfield Valley.

4. GLACIAL AND POSTGLACIAL 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 Surficial Stratified Drift as described by Christiansen (1968) and Whitaker and Christiansen (1972). For the purpose of the 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, mainly till.

The glacial geology and history of deglaciation of the study area was described by Christiansen (1960, 1972, 1977a, b, and 1979b).

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 nonmarine Tertiary bedrock and underlies till of Quaternary age in 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 be up to 165 m (540 ft) thick in collapse structures. The common thickness in the deeper parts of the Hatfield Valley is approximately 50 m (165 ft.). The occurrence of the Empress Group is not limited to the Hatfield or Rocanville Valleys, as it is also present in the adjacent uplands (Map B).

Within the Hatfield Valley Aquifer, the Empress Group is composed of medium-to coarse-grained sand, locally with gravel layers and with minor occurrences of interbedded silt layers. The sands consist of quartz with minor amounts of limestone, dolomite, and igneous and metamorphic rock fragments. Initially, the Empress Group extended over a larger area than presently exists, but was removed by erosion. There is increasing evidence that more Empress Group material has been glacially removed than was previously assumed. The top of the Empress Group is mainly modified by glacial erosion.

Facies changes in the Hatfield Valley sediments are likely 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.

4.3 Drift

Based on carbonate content, electrical resistance, and lithologic parameters, stratigraphic units such as the Sutherland and Saskatoon Groups, along with subdivisions of the groups, such as the Floral and Battleford Formations 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. 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 these deposits determines the surface configuration and thickness of the Empress Group sediments.

On the cross-sections the glacial deposits are referred to as undifferentiated drift with thicknesses ranging from 15 to 250 metres.

4.4 Postglacial Deposits

The Qu'Appelle Alluvium is a major postglacial deposit and is composed of silt, clay, and sand (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 the Hatfield Valley Aquifer System is that the "Empress Group" sediment 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} to 8.64×10^{-6} m/day, with typical values in the 1.7×10^{-4} to 4.3×10^{-4} m/day range. The hydraulic conductivity of the till matrix is typically in the 8.64×10^{-7} to 8.64×10^{-8} m/day range (Grisak _et al._, 1976 and references therein: Grisak and Cherry,

STRATIGRAPHY		LITHOLOGY		GEOHYDROLOGIC CLASSIFICATION		GENERALIZED GEOHYDROLOGICAL SETTING & AQUIFER NAMES
POSTGLACIAL STRATIFIED DRIFT		ALLUVIUM SAND, SILT & CLAY LACUSTRINE: SILT AND CLAY		SEMI-CONFINING LAYER		SEMI-CONFINING LAYER
GLACIAL DRIFT UNDIFFERENTIATED		TILL		SEMI-CONFINING LAYER		
		STRATIFIED SAND, SILT AND GRAVEL		AQUIFER		UNNAMED INTERTILL AQUIFERS
		TILL		SEMI-CONFINING LAYER		SEMI-CONFINING LAYER
EMPRESS GROUP		SAND, SILT AND GRAVEL		AQUIFER		EMPRESS GROUP AQUIFERS: HATFIELD VALLEY, MELVILLE, BASAL, ROCANVILLE AQUIFERS
"BREDENBURY FORMATION"		SILT		SEMI-CONFINING LAYER		SEMI-CONFINING LAYER
		SAND AND GRAVEL		AQUIFER		BEDROCK AQUIFER: BREDENBURY-WILLOWBROOK
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		SEMI-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 FORMATION AND LOWER COLORADO GROUP		SILT AND CLAY		SEMI-CONFINING LAYER		

NOTE: ⟷ INDICATES HYDRAULIC CONNECTION BETWEEN AQUIFERS

Figure 4 Generalized geohydrological setting in the study area

1975; Hendry, 1982). Meneley (1972) used a value of 8.1×10^{-5} m/day in calculations of the yield from aquifers in Saskatchewan. Puodziunas (1978) assumed a bulk hydraulic conductivity value for tills in the 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 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 may 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 the 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, 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. 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 only yield 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 caution.

5.5 Water Quality Data and Interpretation

In addition to water quality data collected within the framework 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 aquifer system.

The type of water has been determined according to the method outlined by Piper (1974) but the number of water types was reduced to four.

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 (McNeely, 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 system for irrigation use can only be assessed in general terms and detailed site-specific geohydrological 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. The Adjusted Sodium Adsorption Ratio (ASAR) now generally is 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 subdivisions of the Hatfield Valley Aquifer System in the study area follow the subdivisions as reported by Meneley (1972). However, the boundaries and definition of the aquifers as well as a few of the names have been modified based on the information gained from this study. The Hatfield Valley Aquifer System consists of the Hatfield Valley Aquifer, Melville Aquifer, Basal Aquifer, Bredenbury Aquifer (formerly known as the Yorkton-Bredenbury Aquifer), Willowbrook Aquifer, and the Rocanville Aquifer. Locally, intertill aquifers may be directly hydraulically connected to the Hatfield Valley Aquifer System (Christiansen et al, 1977). The Hatfield Valley Aquifer is the major aquifer within the System to which all other aquifers are fully or partially hudraulically connected.

The geohydrological setting of the Hatfield Valley Aquifer System is shown in Figure 5 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 for the Hatfield Valley Aquifer and other aquifers are shown as water quality data bars on the cross-sections 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, locally the aquifer may also include glacial sediments where they form one geohydrological unit with the Empress

Group. The Rocanville Aquifer can be defined as the continuation of the Empress Group south of the Qu'Appelle Valley which divides this aquifer from the Hatfield Valley Aquifer. The Rocanville Aquifer boundaries nearly coincide with the 457 m (1500 foot) ASL bedrock contour and include the Rocanville bedrock valley. The Melville and Basal Aquifers are virtually completely hydraulically connected to the Hatfield Valley Aquifer, and the boundary between these aquifers has been selected as the Hatfield Valley "shoulder". For the purpose of this study, the 427 m (1400 ft) ASL bedrock contour line has been considered as the "shoulder" of the Hatfield Valley. Consequently, this contour line has been used as the boundary between the Hatfield Valley and the Melville and Basal Aquifers.

The Bredenbury Aquifer is an aquifer composed of the sediments comprising the "Bredenbury Formation" located around Yorkton and Bredenbury in the upland north of the Hatfield Valley (Map B).

The Willowbrook Aquifer is also defined as an aquifer composed of the sediments comprising the "Bredenbury Formation" but is located in the upland area around Willowbrook north of the Hatfield Valley. Although the "Bredenbury Formation" occurs in two separate but adjacent areas, the aquifers are connected hydraulically through the Melville and intertill aquifers (Map B).

The Judith River Formation Aquifer is a bedrock aquifer, composed of sand and silt of the Judith River Formation and occurs in the southwest part of the Hatfield Valley. However, in this area the Judith River Formation is silty and does not provide a useful source of groundwater. Therefore, this aquifer is not considered in detail in this study.

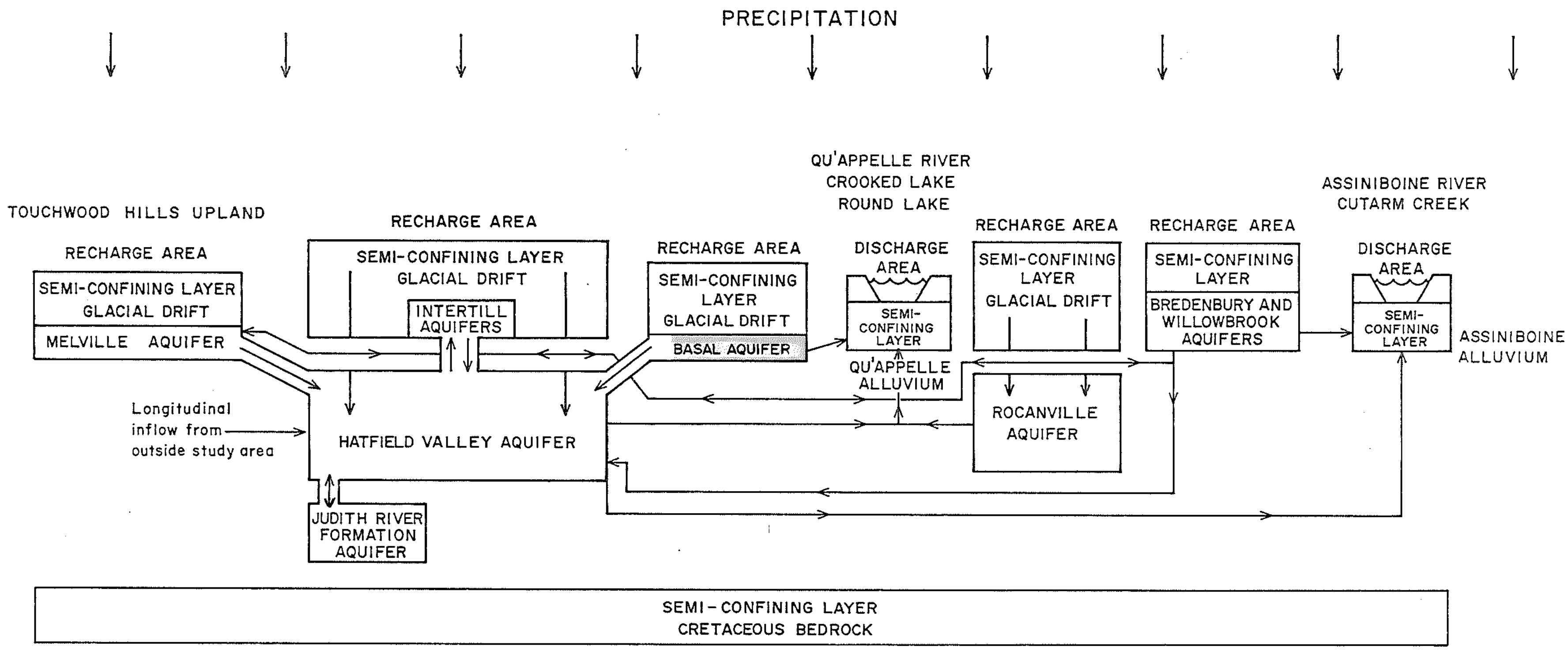


Figure 5: Geohydrological setting of the Hatfield Valley Aquifer System in the Melville Region

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 1). 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 glacier 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 then glacially eroded to a large extent and its shape was modified and much of the Empress Group was removed. During the retreat of the glacier the valley, as well as the sorrounding areas, was filled with drift: till, sands, gravels, silts and clays. During subsequent glaciations the valley continued to be eroded and the Empress Group partly removed by glacial erosion. In turn it was covered by glacial drift during glacial deposition.

6.3.2 Geohydrological Setting

The Hatfield Valley Aquifer in the study area covers an area of approximately 4600 km^2. The aquifer thickness may range from 0-80 m but typically is in the 50 m range. The semi-confining, glacial drift layer overlying the aquifer is characteristically between 25 and 225 m thick. and averages 90 m thick. The aquifer is underlain by silt and clay bedrock which can be considered "impermeable". Within the western part of the Valley the Judith River Formation underlies the Empress Group. This thin, silty bedrock aquifer is connected to the Hatfield Valley Aquifer.

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, and anisotropic buried valley aquifer, which is connected hydraulically to adjacent aquifers.

6.3.3 Groundwater Flow System

All groundwater in Saskatchewan originates 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).

In the northwestern part of the study area (Map B), the Hatfield Valley Aquifer drains into the Qu'Appelle Valley near Fort Qu'Appelle, where major discharge appears to be concentrated into the Fishing Lakes, in particular, Mission Lake (Meneley, 1972, Christiansen et al., 1977). The water level in the Hatfield Valley Aquifer declines towards the Qu'Appelle Valley, which intersects the aquifer and acts as an enormous drain.

East of the Pheasant Hills the groundwater flow is likely toward the southeast to the Qu'Appelle River. In the northeastern half of the area a groundwater divide exists within the Hatfield Valley Aquifer. West of the area around Zeneta the groundwater flow is southwest toward the Qu'Appelle River with discharge being concentrated in Crooked Lake. It is likely that the existance of Crooked Lake is in part the result of this discharge which is similar to the conditions forming the Fishing Lakes (Christiansen et al., 1977). East of Zeneta the groundwater flow is northeast toward the Assiniboine River which bisects the Aquifer resulting in heavy discharge into the Assiniboine River Valley. Lower water levels in the area adjacent to the Qu'Appelle and Assiniboine Valleys cause a greater hydraulic gradient which maximizes the vertical downward recharge to the aquifer. This is illustrated by Christiansen et al., (1977, Fig. 68) and by Sauer (1980, Fig. 8). It also indicates that adjacent to the Qu'Appelle

Valley nearly unconfined or unconfined conditions may exist.

These flow paths are based on water levels throughout the aquifer which include water levels established from piezometers installed near Shellmouth, Atwater, Stockholm, and in the Pheasant Hills area, as part of this study.

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, 1980a, b). 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; Bauwer, 1978). Based on grain-size data, the hydraulic conductivity of 26 Empress Group samples was found to range between 8 and 55 m/day but typically varied between 15 and 20 m/day (Appendix D). These values agree reasonably with those reported in the literature. However, locally, significantly higher hydraulic conductivities may occur. Maathuis and Jaworski (1979) reported a transmissivity of 915 m^2/day for the lower 10 m of the Hatfield Valley Aquifer at the Fort Qu'Appelle Fish Culture Station. This would suggest a hydraulic conductivity in the order of 100 m/day.

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. Where the Empress Group includes gravel layers, hydraulic conductivities for these layers 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 and are illustrated in Figure 6. Water in the Hatfield Valley Aquifer in the west half of the area is of calcium/magnesium-sulphate and sodium-sulphate type and has an average total concentration of 2256 ± 190 mg/ℓ (n = 12). This water is marginal to unacceptable for use as a municipal drinking water supply, because the total concentration and the sum of magnesium, sodium, and sulphate concentrations, generally exceed the recommended maximum desirable limits.

Furthermore, the manganese and iron concentrations are generally well above the desired maximum levels. For domestic use, the water quality should be classified as poor to unacceptable; however, it could 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.

In the central part of the Hatfield Valley Aquifer west of Range 2, the water is predominantly of the calcium/magnesium-bicarbonate type with a few occurrences of sodium-bicarbonate, calcium/magnesium-sulphate, and calcium/magnesium-sulphate-bicarbonate types. The average total concentration is about 1510 ± 349 mg/ℓ (n = 10).

The water is good for use as a municipal drinking water supply. For domestic use the water quality should be classified as fair to good; however, it is considered good as a water supply for most livestock. The moderate ASAR value and conductivity (or total concentration) of the water renders it as potentially usable for irrigation in this area depending on the soil type.

TABLE 1 - Water Quality Hatfield Valley and Basal Aquifers

Location	Depth	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	Total Hard.	Total Alka.	SAR	ASAR
*SE16-9-20-30-W1	182	Ca/Mg-SO_4	705	1220	52	312	113	343	19.7	8.30	0.11	0.003	0.03	0.14	<0.001	0.61	2774	2770	7.10	1245	590	4.2	12.9
*NW 7-17-20-30-W1	240	Ca/Mg-SO_4	637	1490	32	295	131	370	17	35.6	N/D	N/D	N/D	N/D	N/D	N/D	3008	2900	7.15	1275	521	4.5	13.3
*NE 5-5-21-30-W1	240	Ca/Mg-SO_4	543	1170	45	227	91	336	13	5.80	N/D	N/D	N/D	N/D	N/D	N/D	2431	2550	7.42	940	445	4.8	13.7
*NW 5-19-21-30-W1	260	Na-SO_4	416	1060	330	150	58	567	15	6.75	N/D	N/D	N/D	N/D	N/D	N/D	2603	3100	7.55	625	341	10.0	25.5
NW13-30-21-20-W1	269	Na-SO_4	511	1000	232	142	56	522	14	5.85	N/D	N/D	N/D	N/D	N/D	N/D	2483	2750	7.50	584	419	9.4	25.2
NW16-27-22-30-W1	180	Ca/Mg-SO_4	411	972	61	236	90	213	11	6.35	N/D	N/D	N/D	N/D	N/D	N/D	2000	2150	7.38	960	337	3.0	8.4
SE10-36-22-30-W1	254	Ca/Mg-SO_4	430	920	148	185	72.9	289	12.3	1.66	0.38	3.7	0.03	0.03	<0.001	0.13	2063	2150	7.81	762	350	4.6	12.3
SE 4- 2-23-30-W1	280	Na-SO_4	472	915	165	164	70	380	13	4.0	N/D	N/D	N/D	N/D	N/D	N/D	2183	2450	7.50	696	387	6.3	16.9
NW11-14-23-30-W1	240	Na-SO_4	504	1020	112	188	79	372	14	2.9	N/D	N/D	N/D	N/D	N/D	N/D	2292	2400	7.20	792	413	5.7	16.0
SE 2-34-23-30-W1	224	Na-SO_4	553	956	174	138	74	462	15	4.25	N/D	N/D	N/D	N/D	N/D	N/D	2376	2600	7.50	649	453	7.9	21.9
*NE13-27-20-31-W1	282	Na-SO_4	492	1180	424	233	78	567	21	0.98	N/D	12	N/D	N/D	N/D	N/D	3008	3550	7.42	903	403	8.2	23.3
*NE 5-31-20-31-W1	185	Na-SO_4	370	1610	337	290	88	600	19	4.5	N/D	N/D	N/D	N/D	N/D	N/D	3319	3850	7.50	1086	303	7.9	21.7
*SW 5-33-20-31-W1	180	Na-SO_4	397	1410	567	247	81	720	26	1.80	N/D	N/D	N/D	N/D	N/D	N/D	3450	4200	7.50	950	325	10.2	27.6
SE 7-21-21-31-W1	296	Na-SO_4	482	1050	261	130	44	615	14	5	N/D	N/D	N/D	N/D	N/D	N/D	2601	3100	7.50	506	395	11.9	30.5
*SW 1- 1-20-32-W1	160	Na-Cl	391	227	1520	92	23	1050	16	4.02	N/D	N/D	N/D	N/D	N/D	N/D	3323	5100	7.50	327	321	25.4	56.3
*NW15-28-20-32-W1	146	Na-SO_4/Cl	546	642	287	128	46	465	22	12.45	N/D	N/D	N/D	N/D	N/D	N/D	2149	2600	7.45	506	447	9.0	24.2
*NW 4-34-20-32-W1	140	Na-SO_4/Cl	543	660	246	113	38	473	15	1.53	N/D	N/D	N/D	N/D	N/D	N/D	2090	2550	7.36	437	445	9.8	24.6
*NW13-34-20- 1-W2	285	Na-Cl	755	440	1715	155	55.1	1249	26.5	1.11	0.04	0.007	0.11	0.20	<0.001	0.44	4398	5550	8.15	614	630	21.9	61.0
SE 8- 6-21- 2-W2	320	Na-SO_4	615	690	126	156	61.4	350	23.1	2.30	0.22	0.002	0.03	0.46	<0.001	0.44	2025	2150	7.30	643	510	6.0	16.8
NE12- 9-21- 2-W2	221	Ca/Mg-SO_4	635	580	30	203	77.3	117	14.0	4.86	0.29	0.002	0.02	0.24	<0.001	0.14	1662	1660	7.15	825	530	1.8	5.2
SE 4-10-20- 3-W2	406	Ca/Mg-HCO_3	610	310	4	195	66.4	42	11.0	5.84	0.16	0.003	0.02	0.18	<0.001	0.20	1245	1130	7.75	760	510	0.7	2.0
NE11-15-21- 3-W2	200	Ca/Mg-HCO_3	660	330	47	113	48	203	10	3	N/D	N/D	N/D	N/D	N/D	N/D	1414	1400	7.40	478	541	4.0	11.1
NE11-15-21- 3-W2	216	Ca/Mg-HCO_3	641	319	57	113	45	197	10	3.1	N/D	1	<0.01	0.03	N/D	N/D	1386	1624	7.64	465	525	4.0	10.9
NE12-18-21- 3-W2	197	Ca/Mg-HCO_3	543	338	49	137	45	161	8	10.8	N/D	7	<0.01	0.04	N/D	N/D	1299	1577	7.31	527	445	3.1	8.1
NW15-22-21- 3-W2	117	Ca/Mg-HCO_3	600	400	7	168	69	75	11.7	0.33	0.77	5.5	<0.02	0.24	<0.001	0.24	1338	1200	6.91	703	492	1.2	3.5
NW 5-24-21- 3-W2	200	Ca/Mg-HCO_3	628	943	19	295	118	128	12	34	N/D	<1	<0.01	0.01	N/D	N/D	2177	2360	7.45	1220	515	1.6	4.8
SW 1-28-21- 3-W2	208	Ca/Mg-HCO_3	630	159	20	105	42	107	8	1.99	0.32	<0.005	<0.02	0.21	<0.001	0.29	1070	1000	7.11	424	516	2.2	6.0

TABLE 1 - Water Quality Hatfield Valley and Basal Aquifers (Continued)

Location	Depth	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	Total Hard.	Total Alka.	SAR	ASAR
NW 5-22-19- 5-W2	420	Ca/Mg-SO_4 HCO_3	589	480	27	176	77	120	7.1	11	0.15	13	0.07	0.16	<0.001	0.32	1490	1570	7.55	758	483	1.9	5.6
NE 1- 2-20- 7-W2	457	Na-HCO_3	440	238	31	65	31	158	10.6	8.69	0.16	8.4	0.38	0.13	<0.001	0.21	992	1120	7.40	289	361	1.1	3.1
NE 9-10-19- 8-W2	533	Na-SO_4	576	914	74	157	78	370	16	5.4	0.56	20	0.05	0.23	<0.001	0.47	2210	2400	7.60	717	472	6.0	17.5
NE14-20-19- 8-W2	519	Ca/Mg-SO_4	580	1180	79	205	108	337	17.8	2.31	0.41	5.1	0.09	0.10	<0.001	0.48	2515	2600	7.53	956	480	4.7	14.1
SE16-22-19- 9-W2	596	Ca/Mg-SO_4	480	1080	34	210	103	250	22.1	1.03	0.16	4.9	0.03	0.05	<0.001	0.44	2186	2190	7.75	949	390	3.5	10.2
NE15- 2-19-11-W2	430	Na-SO_4	510	824	67	116	54	388	18	4.8	0.22	14	0.09	0.26	<0.001	0.52	1990	2230	7.57	513	418	7.5	19.4
NW11-12-20-12-W2	481	Na-SO_4	578	944	146	124	62	507	17	5.1	0.11	16	0.21	0.15	<0.001	0.46	2390	2690	7.82	566	474	9.3	25.8
NW16-23-20-12-W2	505	Na-SO_4	580	1120	145	175	89	440	21.7	4.29	0.08	18	0.12	0.09	<0.001	0.50	2574	2850	7.50	753	475	6.8	19.5
NW15-27-20-12-W2	510	Na-SO_4	580	870	98	115	54	423	13.1	3.56	0.07	16	0.02	0.08	<0.001	0.42	2160	2400	7.58	476	475	8.2	22.0
SW 9- 6-21-12-W2	543	Ca/Mg-SO_4	537	891	67	180	94	288	7.5	7.7	0.18	17	0.07	0.15	<0.001	0.34	2080	2240	7.74	840	440	4.3	12.1
NW12-12-21-13-W2	530	Na/SO_4	530	930	108	146	88	339	13.6	8.36	0.13	16	0.02	0.11	<0.001	0.45	2180	2410	7.45	726	434	5.5	15.3
SE 8-15-21-13-W2	431	Ca/Mg-SO_4	530	1030	47	199	103	267	13.2	4.06	0.11	15	0.07	0.01	<0.001	0.43	2186	2010	7.40	863	434	3.8	11.1
NE 2-22-21-14-W2	314	Na-SO_4	522	972	249	130	75	519	21	<0.01	0.15	11	<0.02	0.24	<0.001	0.54	2500	2860	7.71	634	428	9.0	24.0
SW 9-15-22-14-W2	574	Ca/Mg-SO_4	530	900	74	177	86	301	12.8	3.53	0.12	14	0.10	0.13	<0.001	0.44	2099	2320	7.50	795	434	4.6	13.0

Note: 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

* - Water quality for the Basal Aquifer

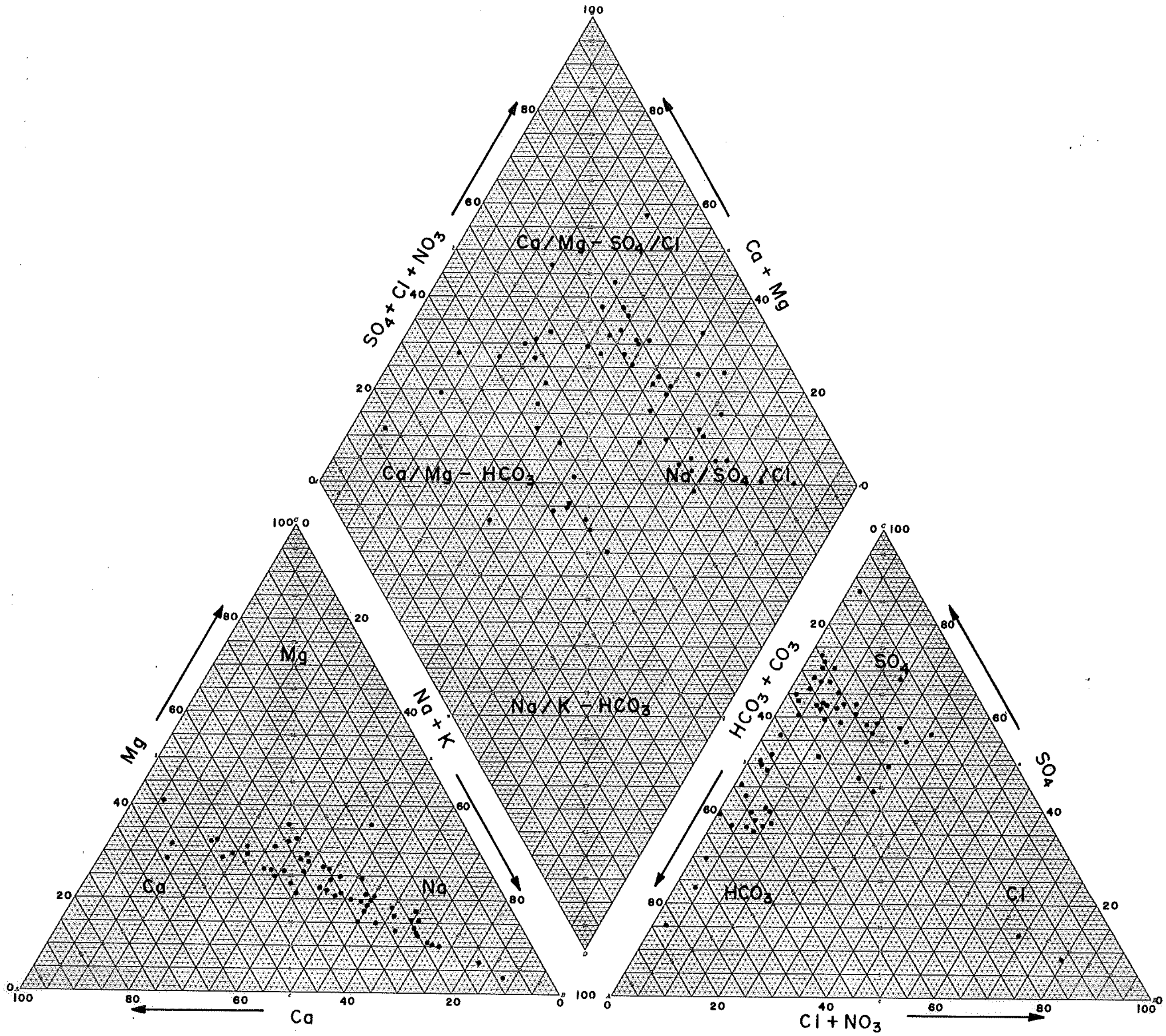


Figure 6 Water quality diagram of Hatfield Valley and Basal Aquifers

In the eastern part of the Hatfield Valley Aquifer, the water is predominantly of the sodium-sulphate type with some calcium/magnesium-sulphate and calcium/magnesium-bicarbonate types occurring as well. The average total concentration is approximately 2427 ± 237 mg/ℓ (n = 7).

This water is marginal to unacceptable as a municipal drinking water supply because the total concentrations and the sum of magnesium, sodium and sulphate concentrations, generally exceed the recommended maximum desirable limits. Furthermore, the manganese and iron concentrations are generally well above the desired maximum levels. For domestic use, the water quality should be classified as poor; however, it could be used for livestock. The combination of high ASAR and conductivity (or total concentration) renders it unfit for irrigation use in this area.

The selenium concentrations throughout the Hatfield Valley Aquifer are systematically below the detection limit while boron concentrations may range up to 0.6 mg/ℓ which is well below the maximum acceptable concentration of 5.0 mg/ℓ.

The nitrate (NO_3 + NO_2) concentrations, expressed as NO_3, may vary widely. In the eastern half of the aquifer the nitrate values are commonly less than 1 mg/ℓ. In the western half the nitrate values are generally greater than 1 mg/ℓ. Based on known nitrate concentrations in deep aquifers in Saskatchewan it was anticipated that nitrate values would be below this limit. To date, no explanation can be provided as to why the observed concentrations are above 1 mg/ℓ, but an investigation is presently underway (Maathuis, in progress). Repeated sampling of wells in the Hatfield Valley Aquifer along the Qu'Appelle Valley revealed no detectable amounts of coliforms.

Although the water may be classified as unacceptable for drinking supplies or other uses according to the guidelines (Appendix C), where the aquifer is the only available and reliable water supply it is often used for these purposes. In some cases, simple treatments can alleviate the major problems of high iron and manganese concentrations.

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.

The 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 inter-till 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), A is the area of the aquifer (m^2).

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 im-

Table 2 Average Geohydrological Parameters of the Hatfield Valley Aquifer

- thickness of semi-confining layer:	$m^1 = 90$ m
- bulk hydraulic conductivity of semi-confining layer:	$K_v^1 = 4.3 \times 10^{-4}$ m/day
- specific yield of semi-confining layer:	S = 0.01
- vertical hydraulic resistance of semi-confining layer:	c = 209000 days
- thickness of aquifer:	m = 50 m
- hydraulic conductivity of aquifer	K = 15 - 25 m/day
- storage coefficient (confined) of aquifer	$S = 2.0 \times 10^{-4}$
- specific yield (unconfined) of aquifer	S = 0.1
- surface area of aquifer	$A = 4625 \times 10^6$ m^2
- average annual precipitation	P = 410 mm/year

plies that a new dynamic equilibrium with the climate will be 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 additional recharge is 3, 5 or 10% of the annual precipitation, a lowering of the hydraulic head of the aquifer of 7, 12, and 23 m, respectively, would be required. The average available drawdown in the western part of the area is about 30 m while in the eastern part it is about 15 m. Taking into account the draining effect of the Qu'Appelle and Assiniboine Rivers, a conservative estimate of the average available drawdown is approximately 15 m.

Meneley (1972) assumed a value of 10% of the precipitation as the arbitrary upper limit of the additional percentage of precipitation which can be withdrawn. The 10% value may be too high in this case as this amount might reduce water levels below the available drawdown levels.

Based on ΔR values of 5% and 3%, respectively, the net groundwater yield is calculated to be in the order of 7.5×10^7 and 4.5×10^7 m^3/year, respectively. These values, however, must be considered as maximums as no attempt has been made to calculate the number of wells and the production rates 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 of 4.5×10^7 m^3/year is the more realistic estimate.

The sustained yield of the aquifer will be larger than the net groundwater yield as discharge to the Qu'Appelle and to the Assiniboine Valleys will decrease as a consequence of developing the aquifer.

Under "drought: conditions recharge to the aquifer decreases and the water stored in the aquifer and in the overlying semi-confining layers and aquifers is "mined". Initially the yield from wells comes from storage within the aquifer itself, but when large vertical hydraulic gradients are created it is derived from storage in the overlying semi-confining layers and aquifers. Consequently, the water table and hydraulic heads in overlying aquifers decreases systematically as drought conditions continue. Ultimately, the overlying layers are dewatered and the aquifer becomes unconfined. When average or above average precipitation conditions return, however, the propensity for recharge has increased as the vertical hydraulic gradient increases 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 3.3×10^9 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 additional yield from the aquifer. This maximum additional yield is the volume of water which can be withdrawn from the aquifer in addition to the natural recharge. Consequently, the maximum additional yield is governed by the amount of available drawdown. Inspection of the available drawdown data suggests a significant difference between the western and eastern part of the Hatfield Valley Aquifer. In the western part, the average available drawdown would be in the order of 30 m, whereas in the eastern part, 15 m is more representative. At the present time insufficient data are available to separate these areas and therefore, the maximum additional yield for the aquifer at large has to be based on the lower value. This yield would be 9.7×10^7 m^3/year and implies that it would take 34 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. Furthermore, during "drought" periods precipitation will not be zero and, therefore, 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 sediments, it can be calculated [Equation 4] that under unconfined conditions, 3.7×10^8 m^3 would become available per one metre head decline over the aquifer. It is assumed that 50% of the aquifers could be dewatered, a total volume of 9.3×10^3 m^3 could be withdrawn. However, this calculation of the total unconfined yield is of a hypothetical nature because due to development the transmissivity and available drawdown would decrease and, consequently an extremely large number of wells would be needed 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 5450 m^3/day could be withdrawn from a well or well field. This estimated production rate is a crude-indication of the yield which can 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 5% of the precipitation can be withdrawn without creating undesirable effects, it is estimated that the continuous yield of a well or well field also would be 5450 m^3/day. Generally, the available drawdown is greater than the increase in hydraulic head difference which would be required to additionally induce the precipitation up to 10%. However, in this particular case, to withdraw an additional 5% of the precipitation would require an increase in the head difference between the water table and piezometric level of about 15 m. This increase is virtually equal to the available drawdown, and consequently, the continuous yield is equal to the maximum yield in this case. It is estimated that individual wells would have to be spaced at 15 km intervals to avoid drawdown interferences.

6.3.8 Consequences of Development

A large scale development of the aquifer, such as that of withdrawing the estimated net groundwater yields, will result in a decrease of discharge to the Qu'Appelle and the Assiniboine Valleys. However, by lowering the water level in the Hatfield Valley Aquifer the lateral inflow from the Melville and Bredenbury Aquifers will increase. In particular large scale developments adjacent to the Qu'Appelle Valley should be carefully planned and managed. Such a development will tend to "intercept" discharge to this Valley. Since the natural conditions are nearly or completely unconfined, development may critically affect the water level adjacent to the Valley. However, it has been demonstrated (Meneley and Christiansen, 1975a; Maathuis and Jaworski, 1979) that large scale development is locally possible provided produced water is returned to the Qu'Appelle Valley system in order to maintain the natural water balance. The Hatfield Valley Aquifer discharges large quantities of water to the Qu'Appelle Valley (Meneley, 1972). Withdrawing water from the aquifer reduces discharge and thereby lowers water levels in the Qu'Appelle River. This effect could be reduced by returning pumped water to the River.

6.4 Melville Aquifer

6.4.1 Geohydrological Setting

The Melville Aquifer in the study area covers an area of approximately 3700 km^2. The aquifer is composed of Empress Group materials, usually sand with some gravel and silt interbeds. The average aquifer thickness is about 30 m and it may range from 5 to 60 m in thickness. The semi-confining layer overlying the aquifer averages about 125 m and ranges from 20 to 180 m in thickness. This thickness is due to the fact that the aquifer is primarily overlain by the Touchwood Hills Upland. The aquifer is underlain by silt and clay bedrock which is considered to be "impermeable". The Melville Aquifer can be considered as an extensive heterogeneous, and anisotropic blanket aquifer, which is hydraulically connected to the Hatfield Valley Aquifer to the south and to the Willowbrook and Bredenbury Aquifers to the east in the study area.

The Melville Aquifer has a similar stratigraphic position as the Wynyard Aquifer to the west. The Melville Aquifer consists of Empress Group stratified material and may contain minor occurrences of Tertiary sediments between bedrock shale and the overlying glacial till. The

Wynyard Aquifer also occurs between bedrock shale and the glacial till and is composed of Empress Group stratified deposits (Maathuis and Schreiner, 1982). These two aquifers may be connected in the western part of the area, however, the paucity of information prevents any proper definition of the geologic and hydrologic extent and setting of the Melville Aquifer and therefore the interrelationship of the two aquifers remains in doubt.

6.4.2 Groundwater Flow System

The Touchwood Hills constitutes a major groundwater recharge area. Water infiltrating to the water table moves vertically downward into 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 will move vertically downward from intertill aquifers into the Melville Aquifer.

In the Melville Aquifer itself, flow is horizontal and directed to the Hatfield Valley Aquifer in the south. In the eastern portion the aquifer receives lateral inflow from the Willowbrook and Bredenbury Aquifers.

6.4.3 Hydraulic Properties

Because the Melville Aquifer is mainly composed of Empress Group sediments, it is assumed that the hydraulic conductivity will be in the same range as for the Hatfield Valley Aquifer: 15-25 m/day. Consequently, the transmissivity may range from less than 100 m^2/day to 1500 m^2/day. The storage coefficient is estimated to be in the order of 1.0×10^{-4} to 2.0×10^{-4}.

TABLE 3 - Water Quality Melville Aquifer

Location	Depth	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	Total Hard.	Total Alka.	SAR	ASAR
NW15- 4-24-2-W2	151	Ca/Mg-SO_4	448	1180	693	314	121	577	13	1.3	.87	3.5	.10	.18	N/D	N/D	3352	4270	7.20	1280	367	7.0	19.8
NW 8-34-24-2-W2	168	Ca/Mg-SO_4	576	425	25	176	59	113	7.8	3.9	.10	5.5	.09	.27	N/D	N/D	1392	1450	7.42	681	472	1.9	5.4
NW 2- 4-25-2-W2	141	Ca/Mg-SO_4	539	978	111	185	84	355	10	10.3	.26	4.4	<0.05	.20	N/D	N/D	2277	2540	7.18	804	442	5.4	15.1
SW 1- 2-24-3-W2	183	Na-Cl	494	500	658	163	29	619	10	4.8	.30	2.1	.18	.11	N/D	N/D	2481	3540	7.35	526	405	11.7	30.0
SE 1-11-25-4-W2	131	Ca/Mg-SO_4	504	1010	111	202	75	358	9.6	9.0	.12	<0.05	<0.5	.14	N/D	N/D	2279	2460	7.42	815	413	5.5	15.2
SE16-11-25-4-W2	265	Ca/Mg-SO_4	437	813	31	176	72	234	11	5.6	.10	7	<0.05	.11	N/D	N/D	1787	1950	7.75	733	358	3.8	10.6
NE16-20-25-4-W2	265	Na/SO_4																					
NE16-20-25-4-W2	222	Na/SO_4	513	2710	295	338	167	927	16	16.0	.99	<0.5	<0.05	.33	N/D	N/D	4983	5130	7.45	1530	421	10.3	28.7
SW13-28-25-4-W2	102	Mg-HCO_3	559	274	Nil	108	104	15	9	2.2	N/D	2	<0.01	.26	N/D	N/D	1073	1078	7.33	702	458	0.3	0.7
NE14-28-25-4-W2	112	Ca/Mg-SO_4/HCO_3	588	497	14	179	107	43	11	4.6	1.16	<0.5	<0.05	.24	N/D	N/D	1445	1400	7.20	887	482	0.6	1.9
SW12-20-21-5-W2	206	Na-SO_4	551	718	140	153	61	335	13	4.3	N/D	13	<0.01	.03	N/D	N/D	1988	2453	7.47	632	552	5.8	16.2
NW14-22-21-5-W2	209	Mg/Ca-SO_4	745	733	171	200	211	202	21	2.4	N/D	300	<0.01	.04	N/D	N/D	2785	3000	7.79	1363	611	2.4	7.3
NW13-30-21-6-W2	207	Ca/Mg-SO_4	570	1130	20	288	131	147	13.3	.23	1.82	14	<0.02	.21	<0.001	.42	2316	2230	6.98	1208	467	1.8	5.4
SW16-16-22-6-W2	233	Ca/Mg-SO_4	451	1170	261	227	102	446	8.3	10.9	.46	11	<0.05	.18	N/D	N/D	2687	3040	7.68	986	370	6.2	17.7
SE 4-29-22-6-W2	264	Ca/Mg-SO_4	510	1035	152	114	134	375	13	3.0	N/D	4	<0.01	.21	N/D	N/D	2340	2570	7.62	845	418	5.6	15.7
NW 2-15-24-6-W2	230	Na-SO_4/Cl	449	617	353	140	51	419	7.1	6.9	.24	13	.07	.28	N/D	N/D	2057	2560	7.60	561	368	7.7	20.0
NE 1-16-24-6-W2	235	Na-SO_4/Cl	436	574	285	115	49	386	6.3	15.9	.24	9.3	<0.05	.29	N/D	N/D	1877	2350	7.52	487	357	7.6	19.9
SW 4026-24-6-W2	373	Na-Cl/SO_4	551	499	679	56	12	775	5.9	1.5	.18	9.3	.05	.34	N/D	N/D	2589	3570	7.65	192	452	24.5	55.4
SE16-29-24-6-W2	240	Na-SO_4	461	702	159	114	43	383	6.8	4.6	.37	9.3	<0.05	.31	N/D	N/D	1883	2280	7.35	460	378	7.8	20.3
2-31-21-9-W2	361	Ca/Mg-SO_4	560	820	20	169	92	223	10.6	14.7	.39	11	.05	.11	<0.001	.35	1910	1770	7.37	750	459	3.4	10.0
SW 1-24-22-9-W2	367	Ca/Mg-SO_4	630	516	17	157	78	145	9.1	.13	.91	10	<0.02	.12	<0.001	.29	1536	1580	7.21	645	517	2.4	6.9
SE 2- 7-23-11-W2	587	Ca/Mg-SO_4	580	790	34	178	107	212	10.9	1.04	.05	.001	.03	.20	<0.001	.39	1914	1980	8.00	885	480	3.1	9.1

Note: 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

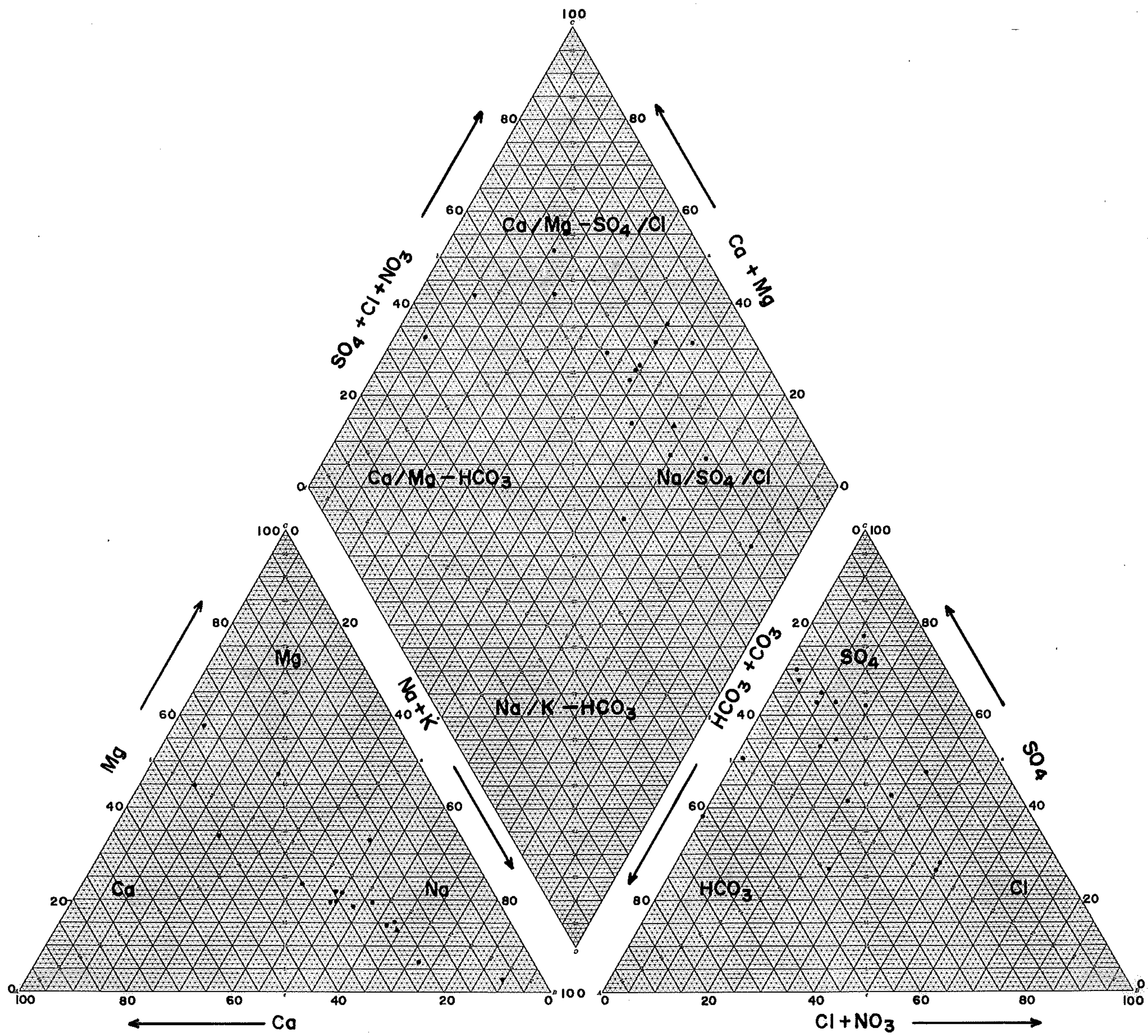


Figure 7 Water quality diagrams of the Melville Aquifer

6.4.4 Water Quality

Water in the Touchwood Hills area is of the calcium/magnesium-sulphate type. To the east, south of the Bredenbury Aquifer the water is of both the calcium/magnesium-sulphate and sodium-sulphate types (Table 3, Figure 7). Although the total concentration may range from 1400 to 5000 mg/ℓ, its average total concentration is 2236 ± 820 mg/ℓ (n - 21). The total concentration and sum of magnesium, sodium and sulphate generally renders the water undesirable as a municipal drinking water supply. In addition, iron and maganese are above the desirable maximum concentration. The water must be classified as poor for use as a 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 boron concentration is commonly also less than the detection limit of 0.10 mg/ℓ, however the values may be as high as 0.39 in a few cases.

6.4.5 Assessment of Yields

Assessment of the net groundwater yield is difficult as the thickness of the semi-confining layer varies significantly. The net groundwater yield calculation (Equation 1 to 3, section 6.3.6) has been based on the general geohydrological setting of the area (Table 4). It has been estimated that the groundwater yield is 1.5×10^8, 7.7×10^7 and 4.6×10^7 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 125 m represents the average thickness of the semi-confining layer overlying the aquifer, approximately 4.7×10^9 m^3 could be withdrawn from this layer under drought conditions when dewatering takes place. Insufficient data are available on the available drawdown but assuming a value of 60 m as a reasonable gross estimate, the maximum additional yield is calculated to be 2.8×10^8 m^3/year. When the aquifer becomes unconfined, 3.7×10^8 m^3 of water will become available per metre of head decline. A total volume of 5.6×10^9 m^3 would become available if 50% of the aquifer thickness could be dewatered.

6.4.6 Assessment of Single Well Yields

Based on the average aquifer characteristics, an estimated average available drawdown,and assuming that up to 50% of the drawdown in a well may be due to well losses, it is estimated that up to 11,000 m^3/day could be withdrawn from a well or well field.

If an additional 10% of the precipitation could be withdrawn without creating undesirable effects, it is estimated that in the order of 6800 m^3/day could be withdrawn on a continuous basis. Again it has been assumed that up to 50% of the drawdown in the well may be caused by well losses. In both cases it is estimated that individual wells or well fields would have to be spaced at 13 km intervals to avoid drawdown interference.

Table 4 Average Geohydrologic Properties of the Melville Aquifer

average thickness of semi-confining layer	m^1 = 125 m
bulk hydraulic conductivity of semi-confining layer	$K_v^1 = 4.3 \times 10^{-4}$ m/day
Specific yield of semi-confining layer	S = 0.1
vertical hydraulic resistance of semi-confining layer	c = 289350 days
thickness of aquifer	M = 30 m
hydraulic conductivity of aquifer	K = 15 - 25 m/day
storage coefficent (confined) of aquifer	$S = 1.5 \times 10^{-4}$
specific yield of aquifer	S = 0.1
surface area of aquifer	$A = 3730 \times 10^6$ m^2
average annual precipitation	P = 410 mm/year

6.5 Basal Aquifer

6.5.1 Geohydrological Setting

This aquifer, herein informally called the Basal Aquifer, is a subdivision of the Hatfield Valley Aquifer which was not differentiated by Meneley (1972). The aquifer which occurs in the east half of the study area parallels the Hatfield Valley to the southeast. It forms an apron which borders the bedrock upland to the south and extends from the Qu'-Appelle Valley around to the town of Welby (Map B). This aquifer has a similar stratigraphic position and may be connected to the buried valley aquifer described in the Welby area by Beckie and Balzer (1970).

The aquifer occurs above the "shoulder" of the Hatfield Valley at about 427 m (1400 ft.) ASL on the bedrock surface and extends to about 457 m (1500 ft.) ASL bedrock contour line. The aquifer is composed of Empress Group sand, gravel, and some silt but may contain some glacial stratified deposits as well. This aquifer appears to have a similar stratigraphic position to the Melville Aquifer. The area of the aquifer is approximately 950 km^2 with an average thickness of about 20 m but it may range from 5 to 90 m. The average thickness of the semi-confining layer overlying the aquifer is about 50 m but it may range from 20 to 75 m.

The aquifer is underlain by silt and clay bedrock which is considered to be "impermeable". The Basal Aquifer can be considered as a heterogeneous, anisotropic, blanket aquifer, which is hydraulically connected to the Hatfield Valley Aquifer to the north.

6.5.2 Groundwater Flow System

The aquifer is recharged by precipitation particularly in the area of the Welby Sand Plain which acts as a significant recharge area. Water infiltrating to the water table will move vertically downward into the intertill aquifers and then laterally, or it may directly recharge the aquifer.

In the Basal Aquifer itself, flow is horizontal and directed to the Hatfield Valley Aquifer to the north. The Aquifer discharges directly to the Qu'Appelle Valley in the south near Welby and to the southwest at Round Lake. Some discharge may occur toward the Assiniboine Valley to the east, however, the extention of the aquifer east to the valley is not evident with the present information (Map B).

6.5.3 Hydraulic Properties

Because the Basal Aquifer is mainly composed of Empress Group sediments, it is assumed that the hydraulic conductivity will be in the same range as for the Hatfield Valley Aquifer: 15 - 25 m/day. Consequently, the transmissivity may range from less than 100 m^2/day to 2500 m^2/day. The storage coefficent is estimated to be in the order of 1.0×10^{-4} to 2.0×10^{-4}.

6.5.4 Water Quality

Water quality in the Basal Aquifer is variable with sodium-sulphate, calcium/magnesium-sulphate, sodium-chloride and sodium-sulphate-chloride types occurring within the area (Table 1). The total concentration may range from about 2100 to 4400, and the average total concentration is 2960 ± 666 mg/ℓ (n = 11). The water is generally unfit for a municipal drinking water supply, and it is classified as very poor for domestic use, and as poor but usable as a water supply for livestock.

The ASAR values are commonly over 20 which indicates that the water is not usable for irrigation. Selenium concentration is below the detection limit and the boron concentrations are commonly not detectable but they may be as high as 0.6 mg/ℓ.

6.5.5 Assessment of Yields

Since the thickness of the aquifer and semi-confining layer is variable, the assessment of net groundwater yield calculation (Equation 1 to 3, section 6.3.6) has been based on the general geohydrological setting of the area (Table 5). It is estimated that the net groundwater yield is 4.3×10^7, 2.1×10^7, and 1.3×10^7 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 50 m represents the average thickness of the semi-confining layer overlying the aquifer, approximately 4.8×10^8 m^3 could be withdrawn from this layer under drought conditions when dewatering takes place. Available data suggest the available drawdown is in the order of 15 m, therefore, the maximum additional yield would be in the order of 4.5×10^7 m^3/year. When the aquifer becomes unconfined 9.5×10^7 m^3 of water becomes available per metre of head decline. The aquifer would yield 9.5×10^8 m^3 of water if 50% of the aquifer thickness could be dewatered.

6.5.6 Assessment of Single Well Yields

Based on the available drawdown, average aquifer characteristics, and assuming that up to 50% of the drawdown in the well is caused by well losses, it is estimated that the maximum yield of a well or well field is in the order of 2200 m^3/day.

It is estimated that on a continuous basis, without creating undesirable effects, up to 2200 m^3/day could be obtained from a well or well field. Because the estimated available drawdown virtually equals the amount of additional vertical head difference which would be required to

Table 5 Average Geohydrologic Properties of the Basal Aquifer

average thickness of semi-confining layer	m^1 = 50 m
bulk hydraulic conductivity of semi-confining layer	$K_v^1 = 4.3 \times 10^{-6}$ m/day
specific yield of semi-confining layer	S = 0.1
vertical hydraulic resistance of semi-confining layer	c = 115740 days
thickness of aquifer	M = 20 m
hydraulic conductivity of aquifer	K = 15 - 25 m/day
storage coefficient (confined) of aquifer	$S = 1.5 \times 10^{-4}$
specific yield of aquifer	S = 0.1
surface area of aquifer	$A = 950 \times 10^6\ m^2$
average annual precipitation	P = 450 mm/year

induce an additional amount of 10% of the precipitation, the continuous yield does not differ from the maximum single well yield. It is estimated that wells or well fields would have to be spaced at 7 km intervals to avoid drawdown interferences.

6.6 Bredenbury Aquifer

6.6.1 General Remarks

This extensive aquifer, which extends from the Yorkton area to around Bredenbury to the south, was termed the Yorkton-Bredenbury Aquifer by Meneley (1972). In this study, the aquifer is considered to be restricted to the "Bredenbury Formation" and, therefore, the name Bredenbury Aquifer is adopted (Map B). The aquifer system in this area has been dealt with in a number of reports such as: Meneley and Christiansen (1975b) and Maathuis (1977). Recently the aquifer was reported on in an environmental impact study of the Bredenbury area (Clifton Associates Ltd., 1981). These studies along with the information gained from the present investigation form the basis for describing the Bredenbury Aquifer in this report.

Augering of 12 holes along the traverse of cross-section D-D' was done as an attempt to better define the areal extent and depth to the Bredenbury Aquifer (Map B). Preliminary work indicated that the "Bredenbury Formation" may be near enough to surface to be reached by augering. Commonly, the auger holes did not penetrate the aquifer either due to thick drift or the presence of intertill sands which prevented deep drilling in a few cases. This information provides minimum thickness of the drift cover as well as better definition of the boundaries of the aquifer.

6.6.2 Geohydrological Setting

The Bredenbury Aquifer in the study area is composed of the "Bredenbury Formation" sands and silts which extend from the Yorkton area south and east to Bredenbury and cover an area of about 2600 km^2. The aquifer thickness is about 25 m on average and ranges from 10 - 60 m in thickness. The semi-confining layer overlying the aquifer may range from 10 - 50 m but averages about 30 m in thickness. The aquifer is underlain by silt and clay bedrock which is considered "impermeable". The Bredenbury Aquifer can be considered as an extensive, heterogeneous, and anisotropic, blanket aquifer which is hydraulically connected to the Hatfield Valley and Melville Aquifers and to the coarse-grained glacial deposits around the cities of Yorkton and Melville.

6.6.3 Groundwater Flow System

No definite recharge areas are evident in the Bredenbury Aquifer area. Generally, recharge conditions are presumed to be favourable because the semi-confining layer is relatively thin or even absent. The largest propensity for recharge is along the rivers and creeks which cut into the "Formation" and act as drains which reduce the hydraulic head and thereby improve the recharge potential. Where the rivers and creeks input water to the aquifer the hydraulic head is high and recharge is not enhanced.

Discharge from the aquifer is to the Assiniboine River, to Cutarm Creek, as well as toward the topographic low south of Yorkton. The Hatfield Valley and Melville Aquifers receive the flow from the Bredenbury Aquifer particularly where they are in direct contact in the north central part of the area (Map B).

6.6.4 Hydraulic Properties

Virtually no hydraulic property data are available from the Bredenbury Aquifer (Clifton Associates Ltd., 1981). It is estimated that the hydraulic conductivity of the aquifer may range from less than 1 m/day where it is silty to 5-10 m/day where it is sandy. Because of the nature and distribution of the sediments it is difficult to estimate transmissivity but this likely will range from less than 10 m^2/day to 250 m^2/day. The storage coefficient is estimated to be in the order of 1.0×10^{-4} (dimensionless).

6.6.5 Water Quality

The water quality data from the study by Clifton Associates Ltd. (1980), as well as the data obtained in this study, indicate that the water quality and type are variable (Table 6, Figure 8). The water quality may be a function of the sampling location taking into account nearness to discharge or recharge areas and flow conditions. In the area of Ranges 5 - 6 and Townships 24 - 25, which is northeast of Melville, the water is of the sodium-sulphate type. In the remainder of the area the water is of the calcium/magnesium-sulphate or calcium/magnesium-bicarbonate type. The total concentration ranges from 650 to 3350 mg/ℓ with an average of about 1880 ± 703 mg/ℓ (n = 42).

Water usage is difficult to specify because of the variability of the type and quality. In general terms, the water is acceptable for municipal drinking water supplies but iron and manganese problems are to be expected. The water is from satisfactory to poor for domestic use but can be used for livestock without any foreseeable problems.

TABLE 6 - Water Quality Bredenbury and Willowbrook Aquifers

Location	Depth	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	Total Hard.	Total Alka.	SAR	ASAR
SE 9-26-23-31-W1	278	Ca/Mg-SO_4	492	1080	128	217	84	351	12	11.4	N/D	N/D	N/D	N/D	N/D	N/D	2375	2500	7.48	886	403	5.1	14.3
SW13-32-23-31-W1	218	Ca/Mg-SO_4/ Cl	752	702	198	238	203	99	36	1.43	N/D	N/D	N/D	N/D	N/D	N/D	2229	2500	7.35	1425	616	1.1	3.5
NW11-36-22- 1-W2	169	Ca-HCO_3	544	317	17	167	55	58	9	1.52	N/D	N/D	N/D	N/D	N/D	N/D	1169	1250	7.50	646	446	1.0	2.9
14-36-22- 1-W2	174	Ca-HCO_3	594	116	4	142	45	24	8	3.37	N/D	N/D	N/D	N/D	N/D	N/D	936	940	7.18	539	487	0.5	1.3
SE12- 5-24- 1-W2	179	Ca-SO_4/ HCO_3	521	435	4	176	79	46	10	7.9	0.17	7.5	0.16	0.22	N/D	N/D	1287	1330	7.55	765	427	0.7	2.1
SE 3- 8-24- 1-W2	149	Ca-HCO_3	455	164	4	132	40	17	5.2	4.9	0.22	3.5	<0.05	0.34	N/D	N/D	826	877	7.39	496	373	0.3	0.9
24-25- 1-W2	can't	find																					
SW 3- 5-26- 1-W2	157	Ca-Mg-SO_4	577	763	60	182	107	198	8.5	10.9	0.28	9.3	<0.05	0.35	N/D	N/D	1916	2030	7.22	894	473	2.9	8.7
NE14-28-26- 1-W2	106	Ca-Mg-SO_4/ HCO_3	604	588	18	210	89	96	8.7	6.1	0.49	12.4	<0.05	0.37	N/D	N/D	1633	1700	7.18	884	495	1.4	4.1
NE14-27-22- 2-W2	180	Ca-Mg-SO_4	350	1450	299	291	106	475	15	17	N/D	<1	<1	N/D	N/D	N/D	3003	3900	7.10	1160	28	6.1	16.6
NE16-13-22- 3-W2	129	Ca/Mg-SO_4	637	808	31	271	93	132	11	2.9	N/D	<1	<1	N/D	N/D	N/D	1986	2200	7.50	1060	522	1.8	5.3
SW13-22-22- 3-W2	188	Ca/Mg-SO_4	626	939	60	310	116	168	10	35.3	0.64	4.4	<0.05	0.22	N/D	N/D	2309	2330	7.08	1250	513	2.1	6.2
SE 3-26-22- 3-W2	164	Mg/Ca-SO_4	234	1250	35	179	181	155	11	72.3	0.61	3.5	<0.05	0.08	N/D	N/D	2122	2240	6.92	1190	192	2.0	5.1
SW12-29-22- 3-W2	108	Ca-HCO_3	721	398	18	270	77	18	9.2	0.7	1.9	22	<0.05	0.19	N/D	N/D	1536	1590	7.32	992	591	0.3	0.8
NW 5-10-21- 4-W2	162	Ca/Mg-SO_4	576	700	32	167	68	239	6.0	14.9	0.12	3.1	<0.05	0.22	N/D	N/D	1806	1840	7.20	693	472	3.9	11.1
NW16-22-21- 4-W2	184	Na-HCO_3	610	333	51	89	36	236	7.7	1.60	0.10	11	<0.02	0.13	<0.001	0.36	1368	1430	7.30	350	500	5.3	14.2
SW 4-12-22- 4-W2	198	Ca/Mg-SO_4	660	820	24	242	104	139	11.8	7.25	0.24	12	<0.02	0.07	<0.001	0.29	2012	1810	6.99	1009	541	1.9	5.7
NW14-25-22- 4-W2	226	Ca/Mg-SO_4	570	887	107	194	70	340	7.4	11.4	0.32	24	<0.05	0.19	N/D	N/D	2211	2370	7.28	773	467	5.3	15.4
NE 8- 2-23- 4-W2	135	Na-HCO_3	2120	180	128	28	14	860	18	N/D	N/D	NIL	NIL	N/D	N/D	N/D	3348	3500	7.90	127	1735	33.1	78.2
NE 8- 2-23- 4-W2	143	Na-HCO_3	2080	178	117	30	13	850	18	N/D	N/D	NIL	NIL	N/D	N/D	N/D	3286	3500	7.90	127	1705	32.6	77.0
NE 9- 9-23- 4-W2	123	Ca/Mg-HCO_3	480	216	3	115	50	44	9.1	1.95	0.30	1.3	<0.02	0.22	<0.001	0.11	921	880	7.09	492	393	0.9	2.3
1-14-23- 4-W2	132	Ca/Mg-SO_4/ HCO_3	500	450	10	132	61	153	12.2	3.38	0.13	5.5	<0.02	0.18	<0.001	0.25	1328	1170	7.10	580	410	2.8	7.6
SE 4- 1-25- 4-W2	87	Ca/Mg-SO_4	469	754	56	188	72	201	9	21.2	0.15	4.4	<0.05	0.17	N/D	N/D	1775	1970	7.15	764	384	3.3	8.9
SW 1- 3-25- 4-W2	118	Mg/Ca-HCO_3	562	346	66	79	104	128	10	0.3	N/D	4	<0.1	0.23	N/D	N/D	1300	1390	7.73	630	461	2.2	6.4

TABLE 6 - Water Quality Bredenbury and Willowbrook Aquifers (Continued)

Location	Depth	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	Total Hard.	Total Alka.	SAR	ASAR
NE16- 7-25- 4-W2	78	Ca/Mg-SO_4	545	1410	362	312	150	433	12	6.4	1.46	0.4	<0.05	0.20	N/D	N/D	3232	3670	7.16	1394	447	5.0	14.9
SE16-23-25- 4-W2	94	Ca/Mg-SO_4	646	903	14	286	128	103	8.3	4.6	1.19	<0.5	<0.05	0.19	N/D	N/D	2094	2030	7.01	1240	530	1.3	3.8
NW 1-26-25- 4-W2	50	Ca/Mg-SO_4	583	258	11	152	67	44	7.3	0.9	0.29	3.5	<0.05	0.29	N/D	N/D	1127	1140	7.28	653	478	0.8	2.2
NE16-27-25- 4-W2	74	Ca/Mg-SO_4	442	51	7	78	46	16	3.4	<0.10	0.23	8.0	<0.05	0.29	N/D	N/D	652	682	7.40	385	363	0.4	0.9
NW 2-35-25- 4-W2	55	Mg/Ca-HCO_3	509	272	7	78	104	39	7	2.8	N/D	1.0	<0.1	0.22	N/D	N/D	1020	1075	7.03	629	417	0.7	1.9
NW11-35-25- 4-W2	69	Mg/Ca-HCO_3	520	370	53	129	81	80	7	2.2	N/D	<1	<0.01	0.21	N/D	N/D	1242	1330	7.33	659	427	1.4	3.8
SW 4- 3-26- 4-W2	58	Ca-HCO_3	586	317	7	200	53	36	7.1	3.7	0.71	<0.5	<0.05	0.24	N/D	N/D	1211	1220	7.13	717	481	0.6	1.7
SE 3- 4-26- 4-W2	73	Mg-HCO_3	575	226	NIL	93	99	23	10	3.8	N/D	3.3	<0.01	0.25	N/D	N/D	1033	1047	7.32	644	471	0.4	1.2
3-28-22- 5-W2	188	Ca/Mg-SO_4	510	1050	66	228	98	246	12.7	3.06	0.34	7.7	<0.02	0.21	<0.001	0.39	2207	1210	7.11	934	410	3.4	10.0
NW15-31-23- 5-W2	167	Na-SO_4	473	892	110	135	62	380	7.1	3.3	0.34	7.0	<0.05	0.26	N/D	N/D	2070	2380	7.35	592	387	6.8	18.3
NW13- 4-24- 5-W2	150	Na-SO_4	475	848	141	151	63	369	7.5	2.5	0.73	3.5	<0.05	0.33	N/D	N/D	2062	2380	7.40	636	389	6.4	17.2
SE 1- 8-24- 5-W2	267	Na-SO_4	475	1110	351	201	104	506	8.4	8.3	0.24	12	<0.05	0.24	N/D	N/D	2776	3310	7.21	927	390	7.2	20.6
SW 4-15-24- 5-W2	109	Ca-SO_4	677	654	28	251	87	115	7.8	10.5	0.91	2	<0.05	0.29	N/D	N/D	1834	1860	7.10	986	555	1.6	4.8
NE16- 2-25- 5-W2	73	Ca/Mg-SO_4	549	710	42	200	92	167	8.1	18.4	0.37	3.1	<0.05	0.22	N/D	N/D	1790	1860	7.65	828	450	2.5	7.2
NW 4-13-25- 5-W2	60	Na-SO_4	614	530	56	116	61	265	9.0	3.0	0.79	<0.5	<0.05	0.22	N/D	N/D	1655	1820	7.40	539	503	5.0	13.6
SW 4-12-21- 6-W2	205	Na-SO_4	830	950	41	191	93	391	12.1	6.56	0.47	10	0.09	0.16	<0.001	0.39	2526	2610	7.01	858	680	5.8	17.3
NE16- 2-23- 6-W2	192	Na-SO_4	499	1070	63	175	78	392	8.0	10.1	0.56	7.1	<0.05	0.21	N/D	N/D	2303	2520	7.50	758	409	6.2	17.2
5- 4-23- 6-W2	211	Na-SO_4	470	1120	67	172	78	375	12.7	0.16	0.49	13	<0.02	0.14	<0.001	0.51	2309	2550	7.10	750	385	6.0	16.7
SE 8-13-23- 6-W2	192	Na-SO_4	442	1170	134	176	72	447	8.1	6.8	0.51	13	<0.05	0.23	N/D	N/D	2470	2820	7.25	735	363	7.2	19.9
*NW12-33-25- 6-W2	160	Na-SO_4/ HCO_3	378	307	21	36	45	175	5.7	4.15	0.15	4.0	0.06	0.11	N/D	N/D	976	1070	7.11	275	310	4.6	10.6
*SE 1- 2-25- 7-W2	250	Ca/Mg-SO_4	614	590	18	194	87	119	6.6	3.8	0.20	3.1	<0.05	0.26	N/D	N/D	1636	1690	7.45	840	503	1.8	5.2

Note: 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

*Willowbrook Aquifer

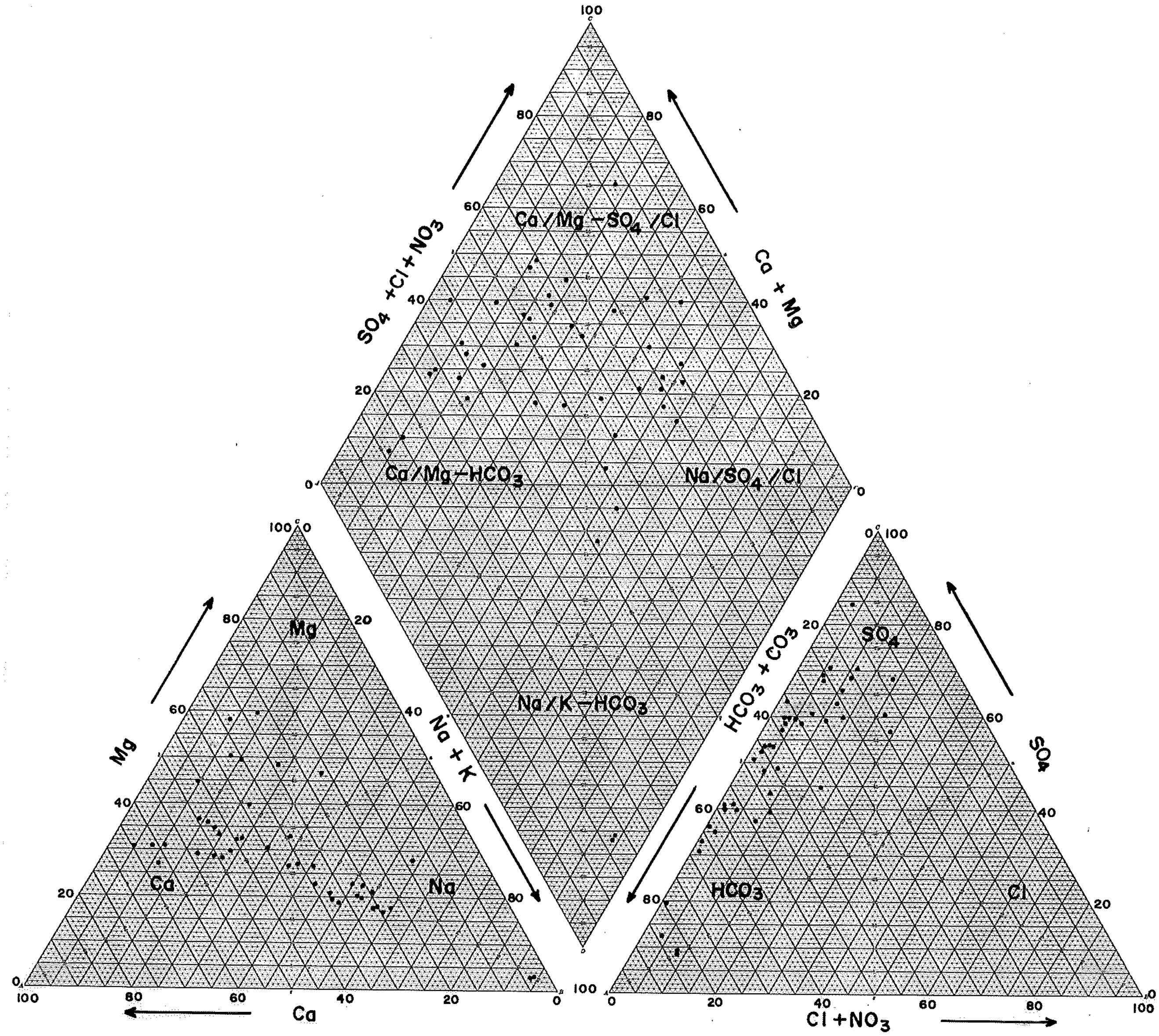


Figure 8 Water quality diagram of the Bredenbury and Willowbrook Aquifers

Although the ASAR values indicate that in some areas the water may be usable for irrigation, each site would have to be assessed individually because of the high variability in these values.

6.6.6 Assessment of Yields

The limiting factor in the aquifer yield calculations is the thickness of the semi-confining layer overlying the Bredenbury Aquifer. Meneley (1972) indicates that because of the limited thickness of this layer an available drawdown of 3 m would be an appropriate value to use. The net groundwater yield calculations are based on the general geohydrological setting of the area (Table 7). With the available drawdown limited to 3 m a maximum value of 5% of annual precipitation can be withdrawn. Therefore it is estimated that the groundwater yield is 5.8×10^8 and 3.5×10^7 m^3/year assuming that 5% and 3% of annual precipitation can be withdrawn in addition to the natural recharge. The sustained yield is once again larger as development causes decreased dicharge and lateral outflow.

Assuming a thickness of 30 m, which represents the average thickness of the semi-confining layer approximately 7.9×10^8 m^3 could be withdrawn from this layer under drought conditions when dewatering takes place. When the aquifer becomes unconfined, 2.6×10^8 m^3 of water becomes available per metre of head decline and a total volume of 3.3×10^9 m^3 if 50% of the aquifer thickness could be dewatered.

6.6.7 Assessment of Single Well Yields

The limiting factor in estimating yields of single wells is the available drawdown which is estimated to be in the order of 3 metres. If the aquifer is to be kept contained, it is estimated that the maximum yield of a well is in the order of 135 m^3/day. Because the available

Table 7 Average Geohydrologic Properties of the Bredenbury Aquifer

average thickness of semi-confining layer	$m^1 = 30$ m
bulk hydraulic conductivity of semi-confining layer	$K_v^1 = 4.3 \times 10^{-4}$ m/day
specific yield of semi-confining layer	$S = 0.01$
vertical hydraulic resistance of semi-confining layer	$c = 69400$ days
thickness of aquifer	$M = 25$ m
hydraulic conductivity of aquifer	$K = 1 - 10$ m/day
storage coefficient (confined) of aquifer	$S = 1.0 \times 10^{-4}$
specific yield of aquifer	$S = 0.1$
surface area of aquifer	$A = 2640 \times 10^6$ m^2
average annual precipitation	$P = 435$ mm/year

drawdown is virtually equal to the additional vertical head difference which would have to be created to induce an additional 3% of the precipitation, the continuous well yield is also in the order of 135 m^3/day. It is estimated that wells would have to be spaced at approximately 3 km intervals in order to avoid drawdown interferences.

6.7 Willowbrook Aquifer

6.7.1 Geohydrological Setting

The Willowbrook Aquifer covers an area of approximately 760 km^2 in the north part of the study area (Map B). This aquifer is composed of "Bredenbury Formation" material similar to the Bredenbury Aquifer. The Willowbrook Aquifer is a heterogenous and anisotropic blanket aquifer, which is hydraulically connected to the Melville Aquifer, which in turn connects it to the Bredenbury Aquifer. The average thickness of the aquifer is about 20 m with a range of 20 - 25 m. The semi-confining layer ranges from 75 - 150 m thick but is typically about 130 m in thickness. The aquifer is underlain by silt and clay bedrock which is considered to be "impermeable".

6.7.2 Groundwater Flow System

The Touchwood Hills to the west constitutes a major recharge area. Water infiltrating to the water table will move vertically downward into the intertill aquifers and then laterally, or it may directly recharge the aquifer. A number of flowing wells have been encountered in this aquifer particularly in the southern part (Map B). These wells indicate a vertical upward hydraulic gradient in these areas which is likely induced by the high hydraulic heads in the Touchwood Hills resulting in discharge at the base of the Hills. At the present time, however, insufficient data is available to adequately explain the cause of these flowing wells.

The flow within the aquifer is not well defined because of the paucity of water well data. It is assumed that water flows southeast to the Melville Aquifer and north toward the low topographic areas.

6.7.3 Hydraulic Properties

Because the Willowbrook Aquifer is composed of "Bredenbury Formation" material,it is assumed that the hydraulic conductivity will be in the same range as for the Bredenbury Aquifer: 1 - 10 m/day. The transmissivity should be approximately 100 m^2/day. The storage coefficient is estimated to be in the order of 1.0×10^{-4} to 2.0×10^{-4} (dimensionless).

6.7.4. Water Quality

Only two water samples are available for the Willowbrook Aquifer and these are listed at the bottom of Table 6. One sample is of the sodium-sulphate/bicarbonate type and has a total concentration of 976 mg/ℓ. The second sample is of the calcium/magnesium-sulphate type and has a total concentration of 1636 mg/ℓ. These samples indicate that the water may be fit as a municipal drinking water supply and is generally good as a domestic supply. The water would be good for livestock and maybe useful for irrigation although the ASAR values vary from 10.6 to 5.2 in the two samples. More samples are required to determine the actual nature of the water in the aquifer.

6.7.5 Assessment of Yields

The net groundwater yield calculation (Equation 1 to 3, section 6.3.6) has been based on the general geohydrological setting of the area (Table 8). It is estimated that the groundwater yield is 3.3×10^7, 1.7×10^7, and 1.0×10^7 m^3/year, respectively, assuming that 10%, 5% and 3% of the annual precipitation can be withdrawn in addition to the natural recharge.

Table 8 Average Geohydrologic Properties of the Willowbrook Aquifer

average thickness of semi-confining layer	m^1 = 130 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 = 0.1
vertical hydraulic resistance of semi-confining layer	c = 300925 days
thickness of aquifer	M = 20 m
hydraulic conductivity of aquifer	K = 1 - 10 m/day
storage coefficient (confined) of aquifer	S = 1.5 x 10^{-4}
specific yield of aquifer	S = 0.1
surface area of aquifer	A = 760 x 10^6 m^2
average annual precipitation	P = 435 mm/year

Development causes a decrease in discharge resulting in a higher sustained yield.

Assuming a thickness of 130 m which represents the average thickness of the semi-confining layer, approximately 9.9×10^8 m^3 could be withdrawn from the layer when dewatering takes place. The aquifer, when unconfined, makes available 7.6×10^7 m^3 of water per metre of head decline and 7.6×10^8 m^3 if 50% of its thickness could be dewatered.

Insufficient data are available at the present time, in particular with regard to the available drawdown, to estimate single well yields.

6.8 Rocanville Aquifer

6.8.1 General Remarks

The Rocanville Aquifer includes the sediments of the Empress Group in the Rocanville Valley, which extend to the northwest to the Qu-Appelle River Valley (Map B). In the western part, these sediments may have been deposited in the Hatfield Valley and were disconnected from the main aquifer by the Qu'Appelle River. The stratified deposits to the south of the main part of the aquifer were deposited on the bedrock highland which had been previously eroded by the advancing glacier. Although the Rocanville Aquifer has been known for a long time (Christiansen, 1971a, and Meneley, 1972), the aquifer is still poorly understood as testhole data and data on hydraulic properties are scarce.

6.8.2 Origin and Filling of the Rocanville Valley

The Rocanville Valley is believed to have a similar origin as the Hatfield Valley and was likely connected to 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 and covered with glacial drift, mainly till.

6.8.3 Geohydrological Setting

The Rocanville Aquifer covers an area of approximately 1450 km^2. The aquifer is predominantly made up of sediments of the Empress Group and its thickness may range from 10 to 125 metres. The overlying glacial deposits range in thickness from 70 - 150 m and consist mainly of glacial till. The bedrock silts and clays underlying the aquifer form an "impermeable" base.

The present study indicates that the Rocanville Aquifer is not connected to the Assiniboine Valley to the west.

6.8.4 Groundwater Flow Systems

There is no evidence at the present time to suggest that there are discharge areas other than along the Qu'Appelle River, particularly at Crooked Lake and Round Lake. Water infiltrating into the water table moves vertically downward into the aquifer and then laterally toward the river. A piezometer (SAKIMAY I-SW1-27-18-7-W2) was installed about 10 km south of the Qu'Appelle Valley and initial relative water level data indicate that the piezometric surface in the aquifer is below the top of the aquifer creating unconfined conditions in this area.

6.8.5 Hydraulic Properties

At the present time no data are available on the hydraulic properties of the Rocanville 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 2.0×10^{-4} are assumed.

6.8.6 Water Quality

Only two water analyses are available at the present time and they indicate that the water is of the calcium/magnesium-sulphate type. This water with total concentration values of 1335 and 1595 mg/ℓ , respectively, is fit as a municipal drinking water supply and is of good quality for domestic use. The ASAR values of about 5 suggest that it is usable for irrigation.

6.8.7 Assessment of Yields

The net groundwater yield calculation (Equations 1 to 3, section 6.3.6) has been based on the general geohydrological setting of the area (Table 9). It is estimated that the net groundwater yield is 6.3×10^7, 3.1×10^7, and 1.9×10^7 m^3/year, respectively, assuming that 10%, 5% and 3% of the annual precipitation can be withdrawn in addition to natural recharge. The sustained yield is greater as development causes decreases in discharge and lateral outflow.

Assuming a thickness of 125 m represents the average thickness of the semi-confining layer, approximately 1.8×10^9 m^3 could be withdrawn when dewatering of the aquifer occurs. If the aquifer becomes unconfined 1.5×10^8 m^3 of water would become available per metre of head decline and 3.4×10^9 m^3 if 50% of the aquifer thickness could be dewatered.

Insufficient data are available at the present time, in particular, regarding the available drawdown to estimate single well yields.

Table 9 Average Geohydrological Parameters of the Rocanville Aquifer

thickness of semi-confining layer	m^1 = 125 m
bulk hydraulic conductivity of semi-confining layer	$K_v^1 = 4.3 \times 10^{-4}$ m/day
specific yield of semi-confining layer	S = 0.01
vertical hydraulic resistance of semi-confining layer	c = 289350 days
thickness of aquifer	m = 45 m
hydraulic conductivity of aquifer	K = 15 - 25 m/day
storage coefficient (confined) of aquifer	$S = 2.0 \times 10^{-4}$
specific yield (unconfined) of aquifer	S = 0.1
surface area of aquifer	$A = 1450 \times 10^6$ m^2
average annual precipitation	P = 430 mm/year

7. CONCLUSIONS

1. The Hatfield Valley Aquifer System includes the Hatfield Valley, Melville, Basal, and Rocanville Aquifers which are comprised of sediments of the Empress Group. In addition, it includes the Bredenbury and Willowbrook Aquifers which consist of "Bredenbury Formation" deposits. The Judith River Formation Aquifer (bedrock aquifer) is not considered as a usable aquifer in the study area.
2. The Hatfield Valley Aquifer is the most significant aquifer in the area. The Melville and Basal Aquifers are hydraulically connected to the Hatfield Valley Aquifer. The Judith River Formation Aquifer and, locally, intertill aquifers are in part hydraulically connected to the Hatfield Valley Aquifer. A connection between the Bredenbury and Willowbrook Aquifers and Hatfield Valley Aquifer is direct or through the Melville Aquifer.
3. The Rocanville Aquifer is not hydraulically connected to the Assiniboine Valley.
4. Major discharge areas of the Hatfield Valley Aquifer System are: the Assiniboine River and the Qu'Appelle Valley, particularly, at the Fishing Lakes, Crooked Lake, and Round Lake.
5. Flowing artesian conditions exist in the southern part of the Willowbrook Aquifer.
6. Water quality and type are very variable throughout the Hatfield Valley Aquifer System. In the Hatfield Valley Aquifer water quality improves toward the Qu'Appelle Valley and Assinboine Valley because of the accumulative addition of water from vertically downward recharge.

7. Groundwater from the Hatfield Valley Aquifer System generally cannot be recommended for municipal drinking water supplies and is classified as poor for domestic use. However, when this aquifer is the only available and reliable water supply it is often used for these purposes and it could be used for livestock. Furthermore, unless extremely favourable soil and drainage conditions exist, it is unsuitable for irrigation purposes in most areas.

8. The bulk hydraulic conductivity of till is assumed to be 4.3×10^{-4} m/day. Empress Group sediments, fine to medium- and medium to coarse-grained sand, have an estimated hydraulic conductivity in the order of 15 - 25 m/day. "Bredenbury Formation" sand has an assumed hydraulic conductivity of 1 - 10 m/day. The storage coefficient of the Hatfield Valley, Melville, Basal and Rocanville Aquifers is in the order of 1.0 to 2.0×10^{-4}. The storage coefficient of the Bredenbury and Willowbrook Aquifers is about 1.5×10^{-4}.

9. The net groundwater yield of the aquifers is as follows:

Hatfield Valley Aquifer	7.5×10^7 to 4.5×10^7 m^3/year
Melville Aquifer	1.5×10^8 to 4.6×10^7 m^3/year
Basal Aquifer	4.3×10^7 to 1.3×10^7 m^3/year
Bredenbury Aquifer	5.8×10^8 to 3.5×10^7 m^3/year
Willowbrook Aquifer	3.3×10^7 to 1.0×10^7 m^3/year
Rocanville Aquifer	6.3×10^7 to 1.9×10^7 m^3/year

This production is derived from additional recharge from precipitation.

10. Under "drought" conditions water produced from the aquifers will be derived from storage in the overlying semi-confining layer.

The estimated water available from the semi-confining layer over the aquifers is as follows:

Hatfield Valley Aquifer	3.3×10^9 m^3
Melville Aquifer	4.7×10^9 m^3
Basal Aquifer	4.8×10^8 m^3
Bredenbury Aquifer	7.9×10^8 m^3
Willowbrook Aquifer	9.9×10^8 m^3
Rocanville Aquifer	1.8×10^9 m^3

11. It must be emphasized that the values of hydraulic conductivity and groundwater yield from the aquifer and semi-confining layers, as summarized in 8, 9, 10 above, are very generalized estimates. These values are based on estimated hydraulic properties and average thickness values. The resulting figures are only provided as a guideline. More precise evaluations can be made as more data, especially on aquifer properties, becomes available.

12. Testdrilling done in this study has refined the definition of the bedrock surface and the extent and dimensions of the major aquifers. Preliminary cross-sections and evaluation of existing data were a necessity in this program to indicate the proper location of testholes to resolve problems and questions raised by the preliminary work. Each testhole, when properly sampled and logged, provides valuable data which aids in the present interpretation but will also contribute to any future investigations.

8. 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, Melville, Basal or Bredenbury, Willowbrook, Melville Aquifers). Because of the limited data available the model should be simple 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 and geohydrological data are required in the central portion of the Hatfield Valley Aquifer and along its shoulders, in the northwestern portion of the Melville Aquifer, and in the Willowbrook Aquifer. Additional testholes would be required to further define the Rocanville 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.

4. The six piezometers installed in the Hatfield Valley Aquifer System in this study should be developed to continuous recording stations. The data would provide regional geohydrological information on the Hatfield Valley Aquifer System which to date is not adequate for proper evaluation of the aquifer.

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APPENDIX A

INDEX OF LOGS USED IN CROSS SECTIONS

APPENDIX A. INDEX OF LOGS USED IN CROSS SECTIONS

The testholes drilled in this study are marked by an asterisk.

Log No.	Name	Location
1	FFIB George and Mike Macza	4-26-26-15W2
2	*SRC Leross 1981	SE1-27-26-14W2
3	FFIB Ernest Kokoski	11-8-26-13W2
4	FFIB David Johnson	NE8-9-26-13W2
5	Tidewater Ituna Crown #4	1-29-25-12W2
6	Tidewater Ituna Crown #2	4-32-25-11W2
7	Tidewater Bon Accord Cr #1-29	1-29-25-10W2
8	FFIB Matt Oscienny	SE8-35-25-9W2
9	FFIB Dave Perley	SE3-5-26-8W2
10	FFIB Ken Hull	SE9-25-25-8W2
11	FFIB Joe Kruda	NE9-21-25-7W2
12	FFIB Bruce Schurko	NW-25-25-7W2
13	FFIB Jim Coulter	NE8-32-25-6W2
14	DOE Yorkton 522	SW11-33-25-6W2
15	FFIB Alan Hamilton	NW13-31-25-5W2
16	DOE Yorkton 512	SW4-2-26-5W2
17	Yorkton 65-009	NW1-6-26-4W2
18	DOE Yorkton No. 513	SW4-3-26-4W2
19	DOE Yorkton No. 509	SE2-1-26-4W2
20	SWP Yorkton	14-10-26-3W2
21	DOE Yorkton No. 526	SE1-18-26-2W2
22	DOE Yorkton No. 527	SE1-20-26-1W2
23	RIO PRADO Wroxton #8-13	8-13-26-33W1
24	RIO-TINTO Alberta Oils Ltd. STH No. 4	SW4-18-26-32W1
25	FFIB Joe Soloninko	SE9-10-26-32W1
26	RIO PRADO Calder #1-9	1-9-26-31W1

Log No.	Name	Location
27	Tidewater Bryce Lake Cr #1	1-14-25-16W2
28	BA Beckett #8-11	8-11-25-15W2
29	FFIB George Frey	12-12-25-15W2
30	Tidewater Headlands Crown #4-34	4-34-24-14W2
31	FFIB Roger Miller	9-22-24-14W2
32	FFIB Anton Petrichuk	NE14-7-24-12W2
33	FFIB Steve Karkut	NE11-9-24-12W2
34	FFIB Mike Tyminski	SE3-6-24-11W2
35	FFIB Andrew Mandziak	SW5-10-24-10W2
36	SRC Goodeve	SW6-10-24-9W2
37	FFIB M. Yanush	SW4-18-24-8W2
38	FFIB Elmer Dohms	SE3-9-24-7W2
39	Texas Gulf Melville	4-10-24-7W2
40	FFIB Peter Wassell	SE1-10-24-6W2
41	Alwinsal McKim 11-6	11-6-24-5W2
42	DOE Yorkton No. 516	NW1-9-24-5W2
43	SRC McKIM	SE1-12-24-5W2
44	Duval Sulphur & Potash, Yorkton #16-6	16-6-24-4W2
45	DOE Yorkton No. 505	SE4-9-24-4W2
46	SRC Crescent Lake	SW7-3-24-4W2
47	DOE Yorkton No. 502	SW4-1-24-4W2
48	SRC Leech Lake 2	NE10-32-23-3W2
49	Trans Era Oils Ltd. STH No. 9	1-2-24-3W2
50	DOE Yorkton 529	SE1-1-24-3W2
51	SRC Saltcoats	SW1-4-24-2W2
52	DOE Yorkton 530	SW3-1-24-2W2
53	SRC Saltcoats 2	SE2-9-24-1W2
54	SRC Calder	NE9-9-24-32W1
55	FFIB Les Thies	1-19-24-31W1
56	Amerada Crown "S-AH" #16-22	16-22-24-31W1

Log No.	Name	Location
57	GSC Roblin 17-66	NW13-21-24-29W1
58	GSC Roblin 18-66	NW13-26-24-29W1
59	GSC Roblin 16-66	SE1-1-25-29W1
60	FFIB Ron Hromeck	7-17-23-15W2
61	SRC Lipton 1967	NE15-36-22-15W2
62	FFIB Gary Gibson	NE15-22-14W2
63	DTRR Echo Lake No. 4 1974	NW4-36-21-14W2
64	FFIB John Leigh	NE5-30-21-13W2
65	SRC Lebret	SE8-15-21-13W2
66	FFIB Don McDougall	NW12-12-21-13W2
67	FFIB Frank Davies	SW9-6-21-12W2
68	FFIB David McIsaac	NW15-27-20-12W2
69	FFIB Keith Stephens	NW16-23-20-12W2
70	FFIB Garry E. Dick	NW14-17-20-11W2
71	*SRC Pheasant Creek 1981	NW14-5-20-10W2
72	*SRC Pheasant Hills 1981	SE16-22-19-9W2
73	FFIB Kenneth Bender	SW5-16-19-8W2
74	FFIB Ron Bender	NE9-10-19-8W2
75	FFIB Raymond Piller	SE3-1-19-8W2
76	SRC Hyde 1967	SE6-4-19A-7W2
77	*SRC Sakimay 1 1981	SW1-27-18-7W2
78	Imperial Cowessess #2-2	2-2-19A-6W2
79	*SRC Marieval 1 1981	NW12-6-19A-5W2
80	SRC Marieval 1970	NE12-4-19A-5W2
81	*SRC Marieval 2 1981	SW4-3-19-5W2
82	Hayter Cotham 1971	SW1-10-19-5W2
83	Triton-Tidewater Debuc #15-22	15-22-19-4W2
84	*SRC Dubuc 1981	SE4-26-19-4W2
85	*SRC Stockholm 2 1981	SE4-10-20-3W2
86	*SRC Stockholm 1981	SW12-9-20-2W2
87	Riddle Tidewater Atwater #4-16	4-16-20-2W2
88	IWB Zeneta No. 1, 1968	SW4-33-20-1W2
89	*SRC Atwater 1981	NW13-34-20-1W2
90	IWB Zeneta No. 2, 1968	SE1-3-21-33W1

Log No.	Name	Location
91	FFIB Gordon Bily	NW15-11-21-33W1
92	International Yarbo #6	13-12-21-33W1
93	International Yarbo #21	13-15-21-32W1
94	IWB Churchbridge No. 3 1968	SE1-21-21-32W1
95	*SRC Langenburg/2 1981	NE1-1-22-32W1
96	Canberra Langenburg	2-16-22-31W1
97	IWB Langenburg No. 1 1968	SW13-10-22-31W1
98	Canberra Langenburg	2-14-22-31W1
99	FFIB Lowenberger Dairy	SE16-18-22-30W1
100	Canberra Langenburg	16-29-22-30W1
101	*SRC Shellmouth 1981	SE10-36-22-30W1
102	GSC Roblin 21-66	SE1-27-23-29W1
103	GSC Roblin 20-66	SW9-36-23-29W1
104	GSC Roblin 22-66	NE16-5-24-28W1
105	BA Qu'Appelle Hornung	2-4-22-15W2
106	DTRR Echo Lake No. 5	SW5-29-21-14W2
107	FFIB Cal Mohl	NW26-21-13W2
108	FFIB Lawrance Onrait	SE2-20-21-12W2
109	CDR Patrick R/A	4-28-21-12W2
110	FFIB Joe Onrait	NE13-28-21-12W2
111	*SRC Balcarres 1981	SW4-26-21-12W2
112	FFIB Larry Waznesensky	13-30-21-11W2
113	*SRC Gillespie 1981	SE1-26-21-11W2
114	*SRC Finnie 1981	SW4-20-22-9W2
115	CDR Pheasant Creek	4-20-22-9W2
116	FFIB Ray Stafford	SW1-24-22-9W2
117	*SRC Colmer 1981	NW12-24-22-8W2
118	B.A. Husky Phillips Colmer #5-28	5-28-22-7W2
119	FFIB Leonard Dales	NE11-28-22-7W2
120	FFIB Peter Temple	SE16-26-22-7W2
121	SRC Melville	SE1-30-22-6W2
122	Dome Steelman Mobil Melville #6-29	6-29-22-6W2
123	FFIB Murry Patron	SW16-16-22-6W2

Log No.	Name	Location
124	*SRC Melville 1981	NW13-14-22-6W2
125	Sohio Melville #1	11-14-22-6W2
126	FFIB William Martin	2-16-22-5W2
127	SRC Waldron	SW4-17-22-4W2
128	FFIB William Martin	SE8-16-22-4W2
129	Socony Sohio Waldron #1	5-11-22-4W2
130	FFIB William Powell	4-12-22-4W2
131	Duval Bredenbury	16-18-22-3W2
132	Sohio Waldron	13-16-22-3W2
133	SRC Bangor #3	NE16-13-22-3W2
134	Duval Atwater	1-18-22-2W2
135	Socony Sohio Bangor #1	14-11-22-2W2
136	*SRC Bredenbury 1981	NW13-12-22-2W2
137	*SRC Cutarm Creek 1981	NW13-26-21-1W2
138	SRC Churchbridge No. 1	NE13-35-21-33W1
139	SRC Churchbridge No. 2	SW4-4-22-32W1
140	Canberra Langenburg	13-29-21-31W1
141	SRC Langenburg	SW8-26-21-31W1
142	SRC Langenburg No. 2	NE16-29-21-30W1
143	*SRC Marchwell 2 1981	SE2-24-21-30W1
144	*SRC Edgeley 1981	SE1-25-19-15W2
145	FFIB Carl Wolff	NE19-19-14W2
146	FFIB Charles Geis	NE1-26-19-14W2
147	Dillman Indian Head #6-32A	6-32-19-13W2
148	SRC Katepwa Beach 06 1976	NW13-34-19-13W2
149	SRC Katepwa Beach 05 1976	SW13-32-19-12W2
150	SRC Katepwa Beach 04 1976	SW1-8-20-12W2
151	SRC Katepwa Beach 03 1976	SW4-9-20-12W2
152	SRC Katepwa Beach 01 1976	NW4-15-20-12W2
153	FFIB Arthur Fitch	NW11-12-20-12W2

Log No.	Name	Location
154	SRC Abernethy 1969	SW12-6-20-11W2
155	Indian Head Slim Hole #20	5-20-11W2
156	FFIB Ron Englot	NE16-18-20-9W2
157	*SRC Lemberg 1981	SE1-24-20-9W2
158	BA Husky Phillips Neudorf 6-20	6-20-20-8W2
159	FFIB Larry Schutz	NW20-20-7W2
160	FFIB Raymond Rogalski	NE1-2-20-7W2
161	*SRC Grayson 1981	NW13-7-20-5W2
162	FFIB Ron Zimmer	NW1-25-19-5W2
163	SRC Stockholm No. 4 1968	NE13-22-19-3W2
164	SRC Stockholm No. 1 1968	SW4-30-19-2W2
165	Hudson Esterhazy	3-29-19-2W2
166	SRC Stockholm No. 2 1968	NW13-21-19-2W2
167	SRC Stockholm No. 3 1968	NW13-22-19-2W2
168	SRC Esterhazy 1968	SW13-25-19-2W2
169	FFIB Leonard Boukal	SW4-32-19-1W2
170	SRC Esterhazy 1967	NE12-26-19-1W2
171	IWB Yarbo No. 1 1968	SW5-36-19-33W1
172	IWB Gerald No. 3 1968	NW13-34-19-32W1
173	IWB Gerald No. 1 1968	NE15-33-19-31W1
174	IWB Spy Hill 1968	NE16-36-19-31W1
175	IWB Millwood 1968	NW13-34-19-30W1
176	H.K. Riddle Binscarth	14-28-19-28W1
177	Agro Hurd. #10-9	10-9-17-15W2
178	FFIB Edward Staudt	13-3-17-15W2
179	FFIB Leonard Pelzar	SE1-11-17-15W2
180	*SRC Squirrel Hill 1981	NW16-7-17-13W2
181	FFIB J. Ron Rose	SE10-17-13W2
182	FFIB Jack Serson	SE10-26-17-12W2

Log No.	Name	Location
183	SRC Sintaluta, 1967	NE8-6-18-11W2
184	FFIB Tony Gaetz	SW5-35-17-11W2
185	*SRC Wolseley 1981	NW15-1-17-10W2
186	*SRC Summerberry 1981	NE16-22-17-8W2
187	FFIB Fred Dunk	6-19-17-7W2
188	Sohio Grenfell #13-14	13-14-17-7W2
189	FFIB John Knox	6-14-17-7W2
190	*SRC Cowessess 1981	NW13-35-17-6W2
191	Sohio Grenfell	16-20-17-5W2
192	Faford Acres Ltd.	SE28-17-5W2
193	*SRC Kahkewistahaw 1981	SW4-29-17-4W2
194	HB Ochapowace	2-36-17-4W2
195	California Standard Oil Co. STH 60A-760E	7-33-17-3W2
196	EMR GSC 18-67 Whitemud	SW29-17-2W2
197	SRC St. Lukes	SE1-27-17-2W2
198	FFIB Archie Urzado	SW16-17-1W2
199	Riddle Tidewater Clayridge #16-14	16-14-17-1W2
200	*SRC Bear Creek 1981	SE2-18-17-32W1
201	FFIB Don Green	SE16-6-17-31W1
202	*SRC Ste. Marthe #1 1981	NW13-7-17-30W1
203	Tombill Mines Marthe 10-12	10-12-17-30W1
204	*SRC Ste. Marthe #2 1981	NE8-12-17-30W1
205	BA Husky Phillips Vibank #1	5-29-15-14W2
206	Phillips Odessa #1	5-12-16-13W2
207	Crawford E. Smith & Sadkota Petroleum Co.	16-14-16-12W2
208	*SRC Moffat 1981	SW3-5-16-9W2
209	*SRC Brown Hill 1981	NE16-12-16-8W2
210	Sohio Grenfell #4-13	4-13-16-7W2
211	*SRC Weed Hills 1981	NW5-19-15-5W2

Log No.	Name	Location
212	FFIB Ray Cope	NE9-36-15-5W2
213	*SRC Percival 1981	NW5-1-16-4W2
214	FFIB William R. Domres	SW6-16-3W2
215	FFIB Daniel Oshowy	SE4-16-3W2
216	*SRC Whitewood 1981	SW4-28-15-2W2
217	Triton Tidewater South Whitewood Crown 16-28	16-28-15-2W2
218	*SRC Burrows 1981	NW15-16-15-1W2
219	SRC Wapella 1967	SW4-9-15-33W1
220	SRC Red Jacket 1967	SW1-17-15-32W1
221	FFIB Lloyd Stanhope	NE7-24-15-32W1
222	SRC Red Jacket 1967	SE3-30-15-31W1
223	SRC Rocanville	SW4-33-15-31W1
224	Rocan Rocanville	7-27-15-31W1
225	Tenneco Jordan Welwyn	2-29-15-30W1
226	BA Husky Phillips Tyvan #1	9-11-13-13W2
227	FFIB Lawrence Schastian	SW13-18-13-12W2
228	FFIB Creigton Nagel	NE11-36-13-13W2
229	FFIB Stewart MacDougall	NW6-3-14-13W2
230	SRC Wascana Creek	NW4-16-14-13W2
231	Balmer Oil Manybone #3-16	3-16-14-13W2
232	FFIB Karl Van Fartar	SE6-33-14-13W2
233	FFIB W.G. Nelson	NW13-3-15-13W2
234	FFIB John Halzapfel	NE6-10-15-13W2
235	FFIB Leo Reise	SW5-25-15-13W2
236	BA Husky Phillips Strawberry Lake	5-29-16-13W2
237	FFIB Alex Kattler	1-7-17-13W2
238	FFIB Scott Horsman	NE8-5-18-13W2
239	FFIB H.C. McDonald	SE1-8-19-13W2
240	FFIB K.H. McDonald	NW10-17-19-13W2

Log No.	Name	Location
241	FFIB Stan Sinclair	NE15-13-20-14W2
242	FFIB Malcolm Sinclair	SE7-24-20-14W2
243	Tidewater Strat No. 1	NE1-25-20-14W2
244	DTRR Fort Qu'Appelle	SW12-30-20-13W2
245	Tidewater Strat No. 2	SE9-36-20-14W2
246	DTRR Fort Qu'Appelle	NE8-1-21-14W2
247	SRC Fort Qu'Appelle	NW14-7-21-13W2
248	SRC Fort Qu'Appelle	NW11-17-21-13W2
249	BA Husky Phillips Qu'Appelle #2-29	2-29-22-13
250	*SRC Lipton 1981	SW4-29-22-13W2
251	*SRC Lipton 1981	SW13-20-23-13W2
252	FFIB Harold Parker	12-3-26-14W2
253	BA Swenson #3-36	3-36-26-14W2
254	FFIB John Vollman	NE2-1-27-14W2
255	*SRC Wynot 1981	NE16-4-28-14W2
256	Tidewater Wynot Crown No. 1	16-18-28-14W2
257	*SRC Wishart	SW1-20-29-14W2
258	Pure Texas Gooseberry Lake #6-29	6-29-12-9W2
259	FFIB Ross Wright	NE8-13-9W2
260	SRC Candiac 1967	SE1-2-14-10W2
261	FFIB Mike Florek	NE7-14-9W2
262	FFIB John Muchowski	NW20-14-9W2
263	FFIB John Mish	NE-10-15-9W2
264	*SRC Adair Creek 1981	SW4-30-16-9W2
265	FFIB Edwin Banbury	SW8-13-17-10W2
266	FFIB Robert Banbury	SW5-24-17-10W2
267	*SRC Ellisboro 2 1981	NE16-6-18-9W2
268	SRC Ellisboro 1970	SE15-18-18-9W2
269	FFIB Barry Garden	7-30-18-9W2
270	*SRC Ellisboro 1981	SW4-31-18-9W2
271	FFIB James Mann	NE3-20-9W2

Log No.	Name	Location
272	FFIB John J. Cyca	SW26-20-9W2
273	CDR Pheasant Creek	13-20-21-9W2
274	FFIB Don Fenwick	2-31-21-9W2
275	FFIB Ken Best	Sw13-34-24-9W2
276	T.G.S. Hubbard	7-24-25-9W2
277	Tidewater Beaver Hills Cr. #1-5	1-5-26-9W2
278	FFIB Alex Smuk	9-7-26-9W2
279	FFIB Alex Smuk	9-18-26-9W2
280	IOE Parkerview	1-4-27-9W2
281	Champlin T.W. Kossuth #4-30	4-30-12-5W2
282	FFIB Gordon Kish	16-2-13-6W2
283	SRC Kipling 1967	SE1-25-13-6W2
284	FFIB Grant Ferch	SW2-1-14-6W2
285	FFIB Brett Ferch	7-2-14-6W2
286	FFIB Lorne Ryah	NW2-14-14-6W2
287	Triton Tidewater Dalzall-Crown #4-22	4-22-14-6W2
288	FFIB E. Dash and Sons	SE16-22-14-6W2
289	FFIB Ray Trithart	1-4-15-6W2
290	Tidewater Imperial Hillesden Crown #1	5-30-15-5W2
291	FFIB Raymond Peterson	SE1-16-6W2
292	Triton Tidewater Marston Lake Cr. #16-2	16-2-16-6W2
293	FFIB Wayne Belon	SE24-16-6W2
294	Imp. Tidewater Oakshela #13-25	13-25-16-6W2
295	*SRC Oakshela 1981	SE1-35-16-6W2
296	Sohio Grenfell #9-24	9-24-17-6W2
297	Imperial Cowessess	4-13-18-6W2

Log No.	Name	Location
298	Melville Beach (Hall Drilling: DOH)	SW14-12-19-6W2
299	Melville Farm Junction (Hall Drilling: DOH)	SE1-13-19-6W2
300	FFIB A. Krupi	SW6-20-5W2
301	Sohio #1	4-29-20-5W2
302	FFIB Dennis H. Mucha	SW4-12-21-6W2
303	Socony Sohio Killaly 11-14	14-11-21-6W2
304	FFIB Sig Hanowski	SE9-22-21-6W2
305	FFIB George Schmidt	NW2-22-6W2
306	FFIB Larry Hanowski	NW27-22-6W2
307	City of Melville No. 2	4-3-23-6W2
308	SRC Yorkton 520 1975	SW4-18-23-5W2
309	FFIB Mark Weisgerber	SW30-23-5W2
310	FFIB Norman Klingspon	SE7-20-24-5W2
311	FFIB Harvey Kunellis	NW34-24-5W2
312	SRC Yorkton No. 515 1974	SE1-4-25-5W2
313	FFIB C. Pratz	SE3-17-25-5W2
314	Flint Forehill #1	13-29-25-5W2
315	FFIB Ron Popowich	NE5-26-5W2
316	FFIB Maurice McKen	NW21-26-5W2
317	Amerada Crown S.D. #1-29	1-29-26-5W2
318	FFIB Harold Kriger	NW5-27-5W2
319	*SRC Langbank 1981	NW5-13-13-3W2
320	Tidewater Langbank Crown #1	16-14-13-3W2
321	*SRC St. Hubert Mission	NE14-19-14-2W2
322	FFIB Ed Teannot	NE16-30-14-2W2
323	Sohio St. Hubert #9-36	9-36-14-3W2
324	Sohio St. Hubert #14-1	14-1-15-3W2
325	BA Silverwood Hoggarth	4-20-15-2W2
326	Lake Echo Whitewood	11-15-16-2W2
327	SRC Whitewood	NE16-19-16-2W2
328	*SRC Percival 2 1981	NW4-10-17-3W2

Log No.	Name	Location
329	California Standard Oil Co., STH 64-730E	11-2-18-3W2
330	SRC Ochapowace 1970	SE6-15-18-3W2
331	SRC Ochapowace 1970	SE5-14-18-3W2
332	SRC Ochapowace 1970	SW10-14-18-3W2
333	SRC Camp MacKay 1973	NW16-14-18-3W2
334	SRC Stockholm 1973	SE1-26-18-3W2
335	FFIB Barry Griffith	SE8-6-21-2W2
336	IWB Atwater 1968	SW4-18-21-2W2
337	IWB Bangor 1968	NE16-30-21-2W2
338	FFIB Rick Stephens	12-6-22-2W2
339	FFIB Robert Morris	4-18-22-2W2
340	FFIB Katie Thompson	NW4-19-22-2W2
341	Duval Corp. Bredenbury	5-30-22-2W2
342	Duval Corp. Bredenbury	16-6-23-2W2
343	Trans Era Oil Ltd., S.T.H. No. 3	SE1-13-24-3W2
344	DOE Yorkton 528	SW13-36-24-3W2
345	FFIB Elsie Vargo	SW4-11-25-3W2
346	SWP Tonkin	12-30-25-2W2
347	FFIB George Woloschuk	SW1-1-26-3W2
348	DMTS TH. No. 39b S-63	SW19-12-32W1
349	Central Del Rio Red Jacket #6-19	6-19-13-32W1
350	BMG Red Jacket Crown #8-36	8-36-13-33W1
351	Tidewater East Wapella Crown #4-6	4-6-15-32W1
352	*SRC Wapella 1981	SW5-7-16-32W1
353	Triton-Tidewater Carnoustie Crown #9-12	9-12-17-33W1
354	SRC Hazel Cliffe 1970	SE1-33-17-33W1
355	SRC Hazel Cliffe 1970	SE8-9-18-33W1
356	FFIB William Bangers	SW1o-10-18-33W1
357	SRC Hazel Cliffe 1974	SE1-33-18-33W1
358	SRC Gerald No. 2 1968	NE15-16-19-32W1
359	IMC Gerald #3	7-27-19-32W1

Log No.	Name	Location
360	Tidewater CSIF Cutarm #1	1-4-20-32W1
361	International Yarbo #2	13-16-20-32W1
362	SRC Yarbo No. 2 1968	SE1-21-20-32W1
363	SRC Yarbo No. 3 1968	NW13-34-20-32W1
364	Placid Churchbridge	4-10-22-32W1
365	Sohio North Churchbridge #12-22	12-22-22-32W1
366	*SRC Churchbridge 1 1981	NW13-22-22-32W1
367	DMTS T.H. No. 49 5-63	SW1-23-32W1
368	*SRC Churchbridge 2 1981	NW16-7-23-31W1
369	Socony Sohio Kessock #1	8-11-25-33W1
370	FFIB Adam Rogalsky	3-30-25-32W1
371	FFIB Walter Strutynski	NW15-30-26-32W1
372	*SRC Fleming 1981	NE16-1-13-31W1
373	DMTS TH No. 36	4-13-13-31W1
374	BMGR Cr #16-22	16-22-13-31W1
375	FFIB L.H. Sweet	NW4-26-13-31W1
376	Riddle-Tidewater N Moosomin Crown 5-24	5-24-14-31W1
377	Riddle Tidewater Cailmont #2-4	2-4-15-30W1
378	*SRC Welwyn 1981	SW4-15-15-30W1
379	Rio Palmer Welwyn #16-17	16-17-15-30W1
380	FFIB R.H. Swanston	SE13-33-15-30W1
381	Sylvite Ste. Marthe	1-14-17-30W1
382	Sylvite Welby	SW5-34-17-30W1
383	Tombill Welby #16-4	16-4-18-30W1
384	SRC Welby	NW12-9-18-30W1
385	*SRC Spy Hill 1981	SE4-1-19-30W1
386	Canberra Spy Hill #9-14	9-14-19-30W1
387	Canberra Spy Hill #11-2	11-2-20-30W1
388	Canberra Marchwell	8-14-20-30W1
389	*SRC Marchwell 1	NW13-24-20-30W1

Log No.	Name	Location
390	Canberra Marchwell 4-25	4-25-20-30W1
391	FFIB Rody Loewen	9-12-21-30W1
392	Canberra Marchwell 9-24	9-24-21-30W1
393	FFIB Allan Dietrich	SE2-36-23-30W1

APPENDIX B

CROSS SECTIONS AND MAPS

1 plastic
water quality explanation
2 plastic

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/l	100-1500	1500-3000	3000-4000	over 4000	a
TOTAL HARDNESS, mg/l as $CaCO_3$	50- 500	500-1000	1000-2000	over 2000	b
TOTAL ALKALINITY, mg/l as $CaCO_3$	50- 500	500-1000	1000-1500	over 1500	
CHLORIDE, mg/l	up to 250	250- 500	500-1000	over 1000	
SODIUM, mg/l	up to 300	300- 500	500-1000	over 1000	c
SULPHATE, mg/l	up to 400	400- 800	800-1200	over 1200	d
NITRATE, mg/l	up to 40	40- 300	over 300		e
IRON, mg/l	up to 0.3	0.3-1.0			f
MANGANESE, mg/l	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/l 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/l 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/l is regarded as unsuitable for infant feeding.

(e) Nitrate in excess of 40 mg/l 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/l may result in staining of laundry and plumbing. Domestic units for removal are available. Iron in excess of 7 mg/l 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.

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.

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* 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.

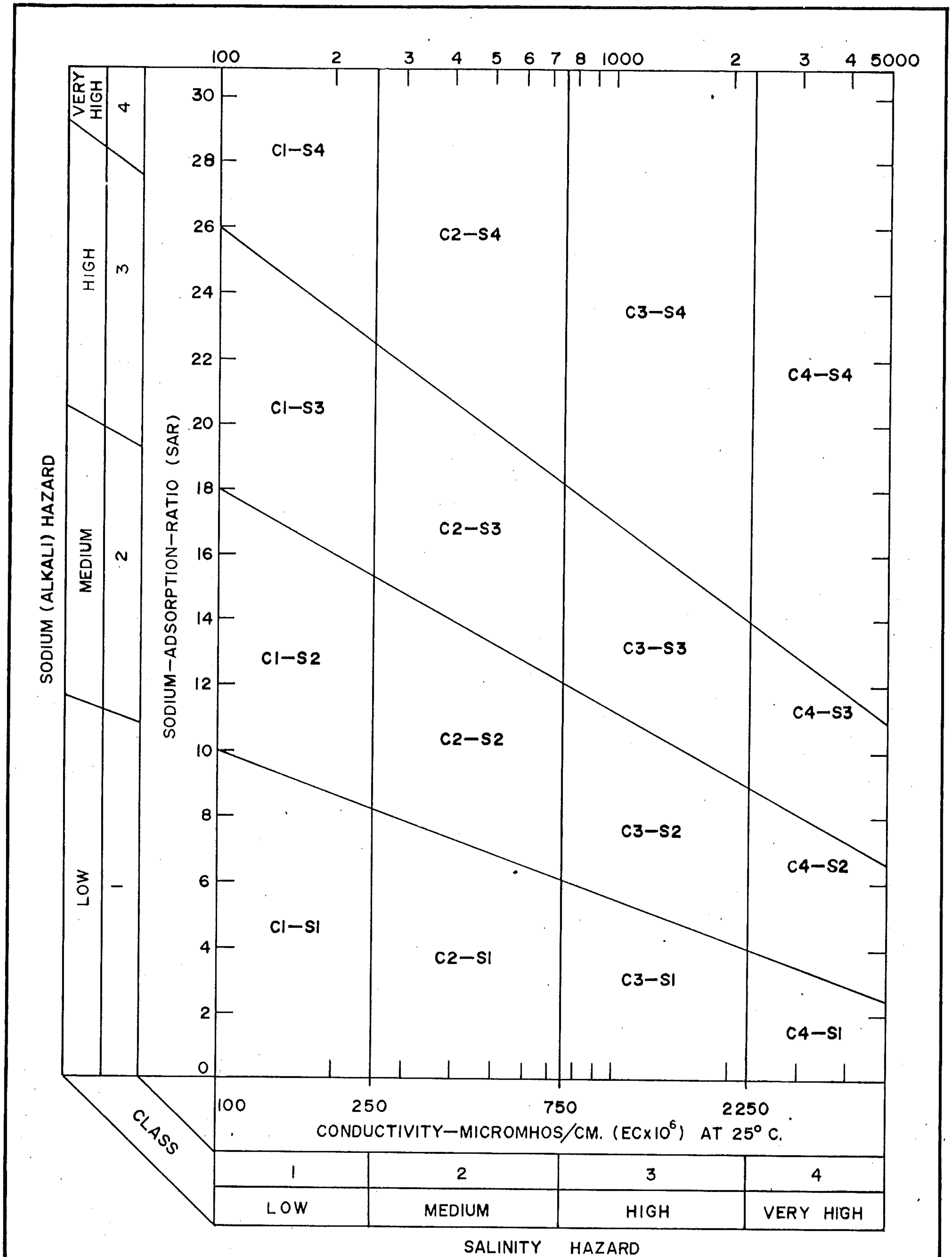
Class S4: very high sodium hazard, SAR greater than 26, in generally unsatisfactory for irrigation except under special circumstances.

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.



(THE MEAN VALUE OF EACH AQUIFER IS PLOTTED)

APPENDIX D

GRAIN SIZE ANALYSIS AND HYDRAULIC CONDUCTIVITY VALUES

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 Shellmouth	220	0.125	$156X10^{-2}$	13
SE10-36-22-30-W1	240	0.140	$1.96X10^{-2}$	17
	260	0.230	$5.29X10^{-2}$	46
SRC Langenburg/2	380	0.130	$1.69X10^{-2}$	15
NE1-1-22-32-W1	400	0.270	$7.29X10^{-2}$	63
	415	0.130	$1.69X10^{-2}$	15
SRC Atwater	300	0.140	$1.96X10^{-2}$	17
NW-13-34-20-W1				
SRC Stockholm	260	0.130	$1.69X10^{-2}$	15
SW12-9-20-2-W2	300	0.250	$6.25X10^{-2}$	54
	325	0.200	$4.0X10^{-2}$	35
	340	0.250	$6.25X10^{-2}$	54
SRC Stockholm/2	280	0.096	$9.22X10^{-2}$	8
SE4-10-20-3-W2	300	0.170	$2.89X10^{-2}$	25
	440	0.110	$1.21X10^{-2}$	10
SRC Moffat	420	0.135	$1.82X10^{-2}$	16
SW2-5-10-9-W2	460	0.170	$2.89X10^{-2}$	25
	500	0.140	$1.96X10^{-2}$	17
	540	0.115	$1.32X10^{-2}$	11
SRC Lipton	725	0.110	$1.21X10^{-2}$	10
SW4-29-22-13-W2	820	0.135	$1.82X10^{-2}$	16

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 Lemberg	630	0.115	1.32×10^{-2}	11
SE1-24-20-9-W3	650	0.125	1.56×10^{-2}	13
	660	0.118	1.39×10^{-2}	12

Notes:

1. The D_{10} was taken from grain-size gradation curves as determined by sieve analysis using ½ ϕ sieves. It is the grain-size diameter at which 10% of the soil particles are finer and 90% are coarser.
2. $K = 1.0\ (D_{10})^2$ D_{10} is millimetres. K is cm/s.
3. K(m/day) = 864 K (cm/s)

APPENDIX E

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^1_v of this layer. (Kruseman and de Ridder, 1970).

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

The Sustained Yield: 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 = 4.07×10^{-2} m/day

1 I gal/day x ft^2 = 4.89×10^{-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 = 1.24×10^{-2} m^2/day

1 I gal/day x ft = 1.49×10^{-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 $mile^2$

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Piezometer Completion Data
SRC 62K/13 1981
Shellmouth
SE-10-36-22-30W1
14:323300E, 5646100N

Bottom of washdown valve to bottom of screen	0.45 ft.
Bottom of washdown valve to bottom of screen slots	0.66 ft.
Bottom of washdown valve to top of screen slots	2.49 ft.
Bottom of washdown valve to top of screen	2.70 ft.
Bottom of washdown valve to top of reducing bushing	2.84 ft.
Bottom of washdown valve to bottom of coupling	23.67 ft.
Bottom of washdown valve to top of coupling	23.93 ft.
Subtract for glueing to coupling	-0.08 ft.
	23.85 ft.

Eleven lengths x 20.15 ft.		
(Bottom of pipe to top of coupling)		221.65 ft.
Subtract for each coupling glued	(11 x 0.08 ft.)	- .88 ft.
		220.77 ft.

Last length	
(Bottom of pipe to top of coupling)	6.57 ft.
Subtract for glueing to coupling	- 0.08 ft.
	6.49 ft.

Total measured length to bottom of screen	250.66 ft.
Piezometer above ground	- 1.60 ft.
Bottom of piezometer	249.06 ft. below ground surface

Piezometer installed in same testhole. Frac-sand pack (1 bag - 50 lb) around screen. Bentonite seal (half pail pellets) above pack. Annulus back filled with cuttings and sand. See file for pumping record and other development details. Water sample taken for analysis.

July 23, 1982 - water level is 118.6 ft. (36.15 metres) below top of piezometer, 117.0 ft. (35.85 m) below ground level.

Piezometer Completion Data
SRC 62L/16 1981
Atwater
NW13-34-20-1W2
13:706400E, 5627800N

Bottom of washdown valve to bottom of screen	0.45 ft.
Bottom of washdown valve to bottom of screen slots	0.66 ft.
Bottom of washdown valve to top of screen slots	2.49 ft.
Bottom of washdown valve to top of screen	2.70 ft.
Bottom of washdown valve to top of reducing bushing	2.84 ft.
Bottom of washdown valve to bottom of coupling	23.67 ft.
Bottom of washdown valve to top of coupling	23.93 ft.
Subtract for glueing to coupling	- 0.08 ft.
	23.85 ft.
Thirteen lengths x 20.15 ft.	
(Bottom of pipe to top of coupling)	261.95 ft.
Subtract for each coupling glued (13 x 0.08 ft).	- 1.04 ft.
	260.91 ft.
Last length	
(Bottom of pipe to top of coupling)	2.98 ft.
Subtract for glueing to coupling	- .08 ft.
	2.90 ft.

Total measured length to bottom of screen	286.90 ft.
Piezometer above ground	2.40 ft.
Bottom of piezometer	284.50 ft. below ground surface

Piezometer installed in same testhole. Hole back filled with sand and gravel to 280'. Frac-sand (1 bag) added with circulation for pack (top of pack 265'). Bentonite seal (one third pail pellets) top at 258'. Air lift for 3 hrs. at ≃ 1 gal./ min. Water clear, stable, sampled for analysis.

July 23, 1982 - water level is 120.18 ft. (36.63 metres) below top of piezometer, 117.78 ft. (35.90 m) below ground level.

Piezometer Completion Data
SRC 62L/9 1981
Stockholm 2
SE4-10-20-3W2
13:687200E, 5619000N

Bottom of washdown valve to bottom of coupling	0.46 ft.
Bottom of washdown valve to top of coupling	0.67 ft.
Bottom of washdown valve to bottom of screen slots	0.99 ft.
Bottom of washdown valve to top of screen slots	3.39 ft.
Bottom of washdown valve to bottom of coupling	3.72 ft.
Bottom of washdown valve to top of coupling	3.92 ft.
Bottom of washdown valve to top of reducing bushing	3.98 ft.
Bottom of washdown valve to top of coupling	25.09 ft.
Eighteen lengths x 21.08 ft. (Bottom of pipe to top of coupling)	379.44 ft.
Last Length (Bottom of pipe to top of coupling)	4.95 ft.

Total measured length to bottom of screen	409.48 ft.
Piezometer above ground	2.50 ft.
Bottom of piezometer	406.98 ft. below ground surface

Piezometer installed in testhole. Back fill hole with sand and gravel to 415'. Frac-sand pack (2 bags - 50 lb) and back fill hole more to 250' in clay. Bentonite seal (half pail pellets). Back fill hole with cuttings and sand. See file for pumping record. Water sample taken for analysis.

July 23, 1982 - water level is 155.4' (47.36 metres) below top of piezometer, 152.9 ft. (46.62 m) below ground level.

Piezometer Completion Data
SRC 62L/10 1981
Sakimay 1
SW1-27-18-7W2
13:650150E, 5600900N

Bottom of washdown valve to bottom of coupling	0.46 ft.
Bottom of washdown valve to top of coupling	0.66 ft.
Bottom of washdown valve to bottom of screen slots	0.93 ft.
Bottom of washdown valve to top of screen slots	3.40 ft.
Bottom of washdown valve to bottom of coupling	3.70 ft.
Bottom of washdown valve to top of coupling	3.90 ft.
Bottom of washdown valve to top of reducing bushing	3.96 ft.
Bottom of washdown valve to bottom of coupling	24.86 ft.
Bottom of washdown valve to top of coupling	25.04 ft.

Twenty-four lengths x 21.09 ft. = 506.16 ft.
(Bottom of pipe to top of coupling)

Last length
(Bottom of pipe to top of coupling) 14.50 ft.

Total measured length to bottom of screen =	546.23 ft.
Piezometer above ground	2.20 ft.
Bottom of piezometer	544.03 ft. below ground surface

Piezometer installed in testhole. Back fill hole with sand and gravel to 550'. Frac-sand pack (2 bags - 50 lb) to 535'. Bentonite seal half pail pellets. Back fill hole to surface with cuttings and sand. See file for pumping record and other development details. Water sample taken for analysis.

July 23, 1982 - water level is 387.56 ft. (118.13 metres) below top of piezometer, 385.36 ft. (117.49 m) below ground level.

Piezometer Completion Data
SRC 62L/11 1981
Pheasant Hills
SE16-22-19-9W2
13:629500E, 5612000N

Bottom of washdown valve to bottom of coupling	0.46 ft.
Bottom of washdown valve to top of coupling	0.66 ft.
Bottom of washdown valve to bottom of screen slots	0.95 ft.
Bottom of washdown valve to top of screen slots	3.40 ft.
Bottom of washdown valve to bottom of coupling	3.71 ft.
Bottom of washdown valve to top of coupling	3.91 ft.
Bottom of washdown valve to top of reducing bushing	3.99 ft.
Bottom of washdown valve to top of coupling on pipe	25.07 ft.

Twenty-seven lengths x 21.09 ft. = 569.43 ft.
(Bottom of pipe to top of coupling)

Last length
(Bottom of pipe to top of coupling) 2.90 ft.

Total measured length to bottom of screen	599.57 ft.
Piezometer above ground	2.60 ft.
Bottom of piezometer	596.97 ft. below ground surface

Piezometer installed in testhole. Back fill hole with sand and gravel to approximately 500'. Pack with sand and gravel. Bentonite seal (half pail pellets). Back fill hole to surface with cuttings and sand. See file for pumping record and more development details. Water sample taken for analysis.

July 23, 1982 - water level is 391.53 ft. (119.34 metres) below top of piezometer, 388.93 ft. (118.5 m) below ground level.

Piezometer Completion Data
SRC 62L/13 1981
Star Blanket
SE2-7-23-11W2
13:60300E, 5646200N

Bottom of washdown valve to bottom of coupling	0.46 ft
Bottom of washdown valve to top of coupling	0.67 ft.
Bottom of washdown valve to bottom of screen slots	0.93 ft.
Bottom of washdown valve to top of screen slots	3.39 ft.
Bottom of washdown valve to bottom of coupling	3.67 ft.
Bottom of washdown valve to top of coupling	3.86 ft.
Bottom of washdown valve to top of reducing bushing	3.93 ft.
Bottom of washdown valve to top of coupling	25.03 ft.

Twenty-six lengths x 21.09 ft. = 548.34 ft.
(Bottom of pipe to top of coupling)

Last length
(Bottom of pipe to top of coupling) 15.11 ft.

Total measured length to bottom of screen =	588.94 ft.	
Piezometer above ground	2.35 ft.	
Bottom of piezometer	586.59 ft.	below ground surface

Piezometer installed in testhole. No sand pack used. Air lift pumping collapsed sand around screen. Back fill hole to surface with cuttings and sand. Air lift rate at about 6 gal/min. See file for pumping record and more development details. Water sample taken for analysis.

July 23, 1982 - water level is 217.98 ft. (66.44 metres) below top of piezometer, 215.63 ft (65.74 m) below ground level.

HATFIELD VALLEY AQUIFER SYSTEM IN THE MELVILLE REGION, SASKATCHEWAN

Volume II

(Appendices F and G)

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