HYDROGEOLOGY OF THE MANITOBA ESCARPMENT REGION

May, 1985
Winnipeg, Manitoba

Prepared by:
Hydrogeology Section

TABLE OF CONTENTS

TABLES

ILLUSTRATIONS

1. INTRODUCTION

Indications are that at some locations the groundwater flow system in the Manitoba Escarpment area could be very sensitive to engineering works that would change the existing surface water regime, (Rutulis, 1977), e.g., headwater reservoirs, diversion of streams, drainage works, flood control dykes, etc. The changes in groundwater condition caused by engineering works, of course, can be either beneficial or detrimental to groundwater resources in the affected area. In this report the hydrogeology of the study area (Figure 1), particularly those aspects of it that could be affected by engineering works and vice versa, is described.

Numerous groundwater studies and investigations including considerable field work have been carried out in the study area by the Manitoba Water Resources Branch. The first studies were groundwater availability studies for rural municipalities. (Planning Division 1970, 1971; Little, 1973 a,b). The municipal scale studies were followed by regional studies that included parts of the Manitoba Escarpment (Planning Division 1972, 1973, 1976 a,b, 1978, 1980, Little, 1981). In addition to the municipal and regional studies numerous groundwater investigations for municipal water supplies have been completed in the study area. Extensive groundwater level monitoring and other field work was carried out in the Wilson Creek Experimental Watershed Area from 1965 to 1980. A report on groundwater regime, balance, and runoff in the Experimental Watershed was completed in 1984 (Zaltsberg 1984). The present report to a great extent is based on the Water Resources Branch studies and investigations as well as on many other papers, maps and reports dealing with the Escarpment region and related maters.

2. GEOLOGICAL SETTING

2.1 Bedrock

The groundwater movement and storage that has a significant effect on groundwater resources in the study area and that can be affected by artificial modifications of natural runoff takes place in the sedimentary rocks that overlie the Precambrian basement rocks. Hence, in respect to the hydrogeology of the study area our main concern is the stratigraphy of Paleozoic and younger rocks in the Escarpment area.

The depth to the Precambrian rocks is up to 500 m in the lowland area and up to 1200 m in the upland areas. The stratigraphic column of the sedimentary rocks is shown in Table 1.

In the study area the Precambrian rocks are overlain by the Ordovician Winnipeg Formation. The Winnipeg Formation is up to 70 m thick and consists of sand, sandstone and shale beds. The sand and sandstone beds are usually porous and permeable and can store and transmit water.

The Winnipeg Formation is overlain by up to 325 m thick sequence of Paleozoic carbonate rocks. The dominant rocks in this sequence are dolomite, limestone, dolomitic limestone. Shale beds are common only in the Stonewall and Stony Mountain Formations. The carbonate rocks commonly have secondary openings such as solution channels and fractures that make certain zones in them porous and permeable.

At the end of the Paleozoic era there was a period of some 100 million years of non-deposition and erosion. During this period valleys and depressions were eroded in the carbonate rocks and, therefore, the contact between the Paleozoic and younger rocks is irregular both in vertical and horizontal planes.

Deposition of the sedimentary rocks resumed in the Jurassic period. Various kinds of shales are dominant in the Jurassic formations but beds of limestone, sandstone, sand, anhydrite and gypsum also are common. The limestone, sandstone and sand beds form permeable zones within the low permeability Jurassic shales.

In the northern half of the study area and in the Pembina Hills area the Jurassic formations are overlain by the Cretaceous Swan River

Formation. Considerable erosion took place at the end of the Jurassic period and as a result valleys and channels are common in the surface of the Jurassic rocks. Because of these irregularities in the surface of the underlying rocks the thickness of the Swan River Formation varies considerably from place to place. The Swan River Formation consists of shale, clay, sand and sandstone. The sand and sandstone beds, which are extensive and, in some parts of the study area, are thicker than the shale beds,are permeable and porous.

The Swan River Formation is overlain by up to 400 m of Cretaceous shale formations with some bentonite layers in the Vermilion River Formation, a few thin limestone beds in the upper part of the Favel Formation and some fine silty sand at the base of the Ashville Formation. In general, the shales are soft and clayey and have very low permeability. The only exception is the Odanah Member of the Riding Mountain Formation. The Odanah Member is fissile and contains fractured zones. Because of these secondary openings the Odanah shale is considerably more permeable than the soft clayey shales. The Odanah shale overlies the clayey shales in the Pembina Hills and Riding Mountain areas.

2.2 Surficial Deposits

In the upland areas the bedrock is overlain by glacial till with lenses and some more extensive sand and gravel deposits within the till or at the base of it. The till layer is generally less than 30 m thick in the Pembina Hills area, more than 65 m thick in the Riding Mountain area and more than 200 m thick in Duck Mountain and Porcupine Hills areas.

On the Manitoba Escarpment the surficial deposits generally are less than 20 m thick and comprise till, sand and gravel, and, less commonly, clay and silt. Bedrock crops are common on the Escarpment.

One of the most significant surficial deposits in the valleys between the uplands is the ancient Assiniboine Delta located between the Pembina Hills and Riding Mountain. In the study area the delta consists of thick and extensive sand deposits that cover some 1000 km^2 and are 10 m to 30 m thick. The sand generally is well sorted and clean. Consequently it is quite permeable. The sand is underlain by 40 m to 50 m of clay and up to 30 m of till.

In contrast to the thick glacial drift between the two southern uplands the surficial deposits in most of the valley between Riding and Duck Mountain are less than 10 m thick. In the Grandview-Gilbert Plains area the dominant material is till covered with a thin layer of clay. A notable exception is a deep northeasterly trending bedrock valley at Timberton which contains extensive and thick gravel deposits.

In the Swan River Valley the surficial deposits are 20 m to 50 m thick and consist of interbedded till, sand, gravel, clay and silt. The sand and gravel beds, which are permeable, are fairly common in the valley.

In the central and northern parts of the lowland (north of Neepawa) the bedrock is overlain mainly by till. In the vicinity of Dauphin Lake and at the base of Riding Mountain the till is overlain by a thin layer of clay and silt. The till contains numerous pockets and lenses of sand and gravel. Some of the sand and gravel deposits interbedded in the till or at the base of it are more than 10 km^2 in area and form major permeable zones within the surficial deposits.

In the southern lowland area the surficial deposits consist of an extensive and thick clay layer that is exposed east of the Pembina Hills and is covered by an extensive but thin sand layer from the vicinity of Carman north to the Plumas area. The clay layer commonly is more than 30 m thick and reaches a maximum thickness of about 100 m in the vicinity of St. Claude. In general, the clay layer is underlain by till. Several fairly extensive and thick buried deltaic sand and gravel deposits occur a few kilometres east of the Escarpment. The thin sand deposits that cover the clay are permeable. The extensive and thick clay layer forms a very low permeability blanket in the southern lowland area. The deltaic sand and gravel deposits usually are highly permeable and can readily store and transmit water.

Since the surficial deposits consist of materials that range from very low permeability clays to highly permeable gravels and various combinations of these materials can occur at a given location, in many areas detailed and site specific studies would be required to define groundwater conditions in the surficial deposits.

3. HYDROSTRATIGRAPHY

3.1 Introduction

Based on their hydraulic properties the geological formations that underlie the Manitoba Escarpment region can be combined or split up into the following regional hydrostratigraphic units:

1. Surficial Deposits,
2. Odanah Shale,
3. Cretaceous Clayey Shales,
4. Swan River Formation,
5. Jurassic Formations,
6. Paleozoic Carbonate Rocks.

The stratigraphic - hydrostratigraphic unit correlation is indicated in Table I and the general hydrostratigraphic setting across Manitoba Escarpment is illustrated in Figure 2. The Paleozoic rocks are underlain by Precambrian rocks which are practically impermeable and, therefore, form the base of the hydrostratigraphic units that have an effect on groundwater conditions in the study area.

3.2 Surficial Deposits

The surficial deposits hydrostratigraphic unit is a heterogeneous deposit of glacial drift comprising glacial till, glaciofluvial and glacio-lacustrine deposits, and recent deposits consisting mainly of fluvial deposits. Groundwater conditions within this unit vary considerably from place to place and with depth. Based on dominant material and other characteristics that affect the water bearing properties the surficial deposits unit can be divided into the following hydrogeological units:

1. Alluvium and alluvial fans,
2. Shallow surface sand,
3. Assiniboine Delta Sand,
4. Lowland Complex,
5. Valley Complex,

6. Escarpment Complex,
7. Clay and silt,
8. Till,
9. Buried sand and gravel.

The areal distribution of the hydrogeological units is indicated on the surficial deposits hydrogeology map (Figure 3) and their hydrogeological characteristics are summarized in Table II. Much of the groundwater development in the study area is within the surficial deposits.

3.2.1 Alluvium and Alluvial Fans

Alluvium and alluvial fan deposits are common at the base of the Escarpment. Some of the more extensive and, in respect to groundwater resources, significant alluvial deposits (including fans) are outlined in Figure 3. These deposits consist of interbedded clay, silt, sand and gravel. The thickness of the alluvial deposits is up to 15 m. At the base of Riding Mountain the alluvial fans commonly contain thick shale gravel beds, that form some of the higher yield aquifers of this hydrogeological unit. The municipal well of the Village of McCreary and a community well at the Riding Mountain settlement are completed in the shale gravel aquifers. The transmissivity of the McCreary aquifer is 190 m^2/d and potential well capacity more than 10 L/s. Since the alluvial deposits often are sandy and gravelly at surface they are fairly permeable and, consequently, form significant local recharge areas. The aquifers are also recharged by the streams that cross them.

3.2.2. Shallow Surface Sand

The shallow surface sand blankets much of the lowland in the southern part of the study area. The sand usually is less than 5 m thick but here and there it is up to 10 m thick. The sand forms an extensive but thin aquifer. Since the sand is generally underlain by a thick clay layer that contains no aquifers and water in sand and gravel aquifers interbedded in the till that underlies the clay generally is not potable, the shallow sand aquifers are the only source of potable groundwater in extensive areas of the southern lowland.

The sand aquifers are readily recharged by precipitation. Most of the recharge is from snow melt and early spring rains. Typically during spring recharge the water table rises about one metre but declines rapidly after the recharge peak. In some places the yearly average saturated thickness of the shallow sand aquifers is less than 0.5 m. Because of the minimal saturated thickness in some cases the aquifers are dewatered during the winter and in periods of groundwater drought. Studies by the Water Resources Branch (Little, 1981) indicate that in some cases the "dry wells" are the result of poor well site selection and poor well design rather than lack of groundwater.

3.2.3. Assiniboine Delta Sand

The Assiniboine Delta sand is part of the ancient Assiniboine Delta that extends southwesterly from the study area towards the Assiniboine River and a short distance south of it. In much of the study area (Figure 3) the saturated thickness of the Assiniboine Delta sand ranges from 20 m to 30 m. Because of its large areal extent, significant saturated thickness and high hydraulic conductivity the Assiniboine Delta sand forms the most extensive high yield aquifer in the study area. The Assiniboine Delta sand forms a significant groundwater recharge area and a major groundwater storage reservoir. The area of the reservoir is about 1000 km^2. Assuming an average saturated thickness of 20 m and a coefficient of storativity of 0.20 the volume of water stored in it in the study area is 4.0×10^9 m^3 (the City of Winnipeg consumption in 1978 was 0.075×10^9 m^3). The hydraulic conductivity of the sand aquifer ranges from 0.1 m/s to 1.0 m/s (Planning Division, 1970).

3.2.4. Lowland Complex

The lowland complex consists of numerous sand and gravel beach ridges and extensive outwash deposits underlain and interspersed by glacial till with pockets of sand and gravel. These conditions exist in a fairly extensive area (Planning Division, 1976b) between Duck Mountain and the eastern boundary of the study area (Figure 3). The surface sand and gravel deposits likely form numerous shallow sand and gravel aquifers and provide good local recharge conditions. The good local recharge conditions likely play a significant role in suppressing the deep saltwater flow system, which in other parts of the lowland, where recharge is retarded by low permeability materials, tends to intrude in shallow confined aquifers. The fact that water is fresh in sand and gravel aquifers interbedded in the till and at some locations even in the bedrock aquifers seem to be an evidence of good recharge conditions in the lowland complex area.

3.2.5. Valley Complex

The valley complex comprises interbedded glaciofluvial, lacustrine and till deposits, i.e., interbedded clay, silt, sand, gravel and till. Sand and gravel form the aquifers within the complex. In areal extent the aquifers range from small pockets to fairly extensive surface sand areas. Because surface sand and gravel deposits are common and there are numerous sand and gravel layers within the clay and till, recharge conditions in the valley complex areas are fairly good. The most extensive valley complex is found in the Swan River Valley and a smaller one along the Assiniboine River (Fig. 3). The sand and gravel aquifers of the Valley Complex generally provide adequate supply for domestic and farm requirements. However, some of the aquifers seem to be fairly extensive and have high transmissivity, e.g., a coarse sand and gravel aquifer just east of the Town of Swan River that is providing abundant supply for the Town and a similar aquifer at the Village of Treherne.

3.2.6. Escarpment Complex

The escarpment complex is found on the Manitoba Escarpment as indicated in Figure 3 and consists of a variety of surficial deposits including glacial till, numerous sand and gravel beach ridges, minor outwash, and alluvial deposits in the numerous valleys that cross the Escarpment. One of the major characteristics of the escarpment complex is steep slopes and numerous deep valleys. Because of the steep slopes and the valleys the sand and gravel deposits that exist on the excarpment are more often than not likely to be dry than to be saturated. Sand and gravel aquifers may be found here and there in buried valleys in bedrock or till and as pockets surrounded by till. Some of the lower beach ridges form narrow long aquifers with a minimal saturated zone.

3.2.7. Clay and Silt

The clay and silt unit consists mainly of clay with a thin layer of silt or silty clay in the upper part. The clay and silt reaches a maximum thickness of about 100 m in the vicinity of St. Claude and in extensive areas it is more than 30 m thick. The clay and silt forms the upper hydrogeological unit in an extensive area in the southeast corner of the study area and in several small areas northeast and north of the Pembina Hills (Figure 3). The clay and silt also underlies much of the shallow sand area and the Assiniboine Delta sand unit. The clay and silt forms an extensive aquitard that prevents local recharge of aquifers below it and, on the other hand, prevents deep salty water from contaminating surface sand and gravel aquifers. Because the clay and silt layer prevents local recharge, water in most aquifers below it is salty or highly mineralized and not potable.

3.2. 8. Till

Till is the most extensive overburden hydrogeological unit in the study area. It covers the uplands and extensive areas of the lowland in the northern part of the Manitoba Escarpment Region. By far the most dominant material in this unit is glacial till. Till, in general, has low permeability and acts as an aquitard. However, the till often contains sand and gravel deposits of various sizes; they range from small pockets of less than a hectare to buried outwash and valley deposits that can cover many square kilometres. The sand and gravel within the till forms the most common and often the only fresh water aquifers in the till area. In some areas the interbedded sand and gravel beds are very scarce and, if there are no bedrock aquifers, groundwater is difficult to find, e.g. these conditions exist in the Gilbert Plains - Grandview area. The till unit is up to 275 m thick in the Duck Mountain area and generally less than 30 m in the Pembina Hills area. In the lowland area the till generally is less than 50 m thick.

Since very little well drilling and test drilling has been done in the Riding Mountain, Duck Mountain and Porcupine Hills area, information about aquifers within the till unit is very limited for these upland areas. Based on data for more developed glacial till areas it is likely that some fairly extensive sand and gravel aquifers exist there. In the lowland area the sand and gravel aquifers in till, particularly near the base of it, often are contaminated by the salty water from the deep bedrock aquifers, e.g., McCreary, Glenella and Plumas areas.

3.2.9. Buried Sand and Gravel

This hydrogeological unit consists of extensive sand and gravel outwash, valley and deltaic deposits laid down on bedrock or surficial deposits and overlain by other kinds of overburden. These are major sand and gravel deposits that can be mapped on a regional scale (Fig. 3) and where saturated form major aquifers. The aquifers are important sources of groundwater in the lowland area. Several municipal wells or well fields and numerous community wells have been installed in the buried sand and gravel aquifers. Because the aquifers consist of coarse sand and gravel and the saturated thickness in places is more than 60 m their transmissivity is fairly high to very high, e.g., up to 1.5×10^3 m^2/d at Miami, up to 5.0×10^3 m^2/d east of Dauphin, up to 10.4×10^3 m^2/d at Winkler (Charron, 1964), up to 0.2×10^3 m^2/d at Rathwell. Since in the southern part of the study area these aquifers are the only major sources of potable groundwater, proper management to prevent pollution and over development is essential. It is likely that other major buried sand and gravel aquifers exist in the Manitoba Escarpment Region area but have not been discovered because very minimal groundwater development and exploration has taken place, e.g., Riding and Duck Mountains, Porcupine Hills areas and northern part of the lowland.

3.3. Odanah Shale

This hydrostratigraphic unit is formed by the hard, silicious and fissile shale of the Odanah Member of the Riding Mountain Formation (Table 1, Figure 2). The Odanah Shale usually contains one or more fractured zones. Since fractures can impart significant sectondary permeability, they increase the water bearing properties of the shale considerably. As a result the fractured zones constitute aquifers. Because the fractured zones are common, the whole area underlain by the Odanah Member is considered to be an aquifer. The fractured zones often are common in the upper part of the formation but may also occur at any depth within the Odanah Shale. The areal extent of the Odanah Shale is indicated in Figure 4. It is more than 100 m thick in the Riding Mountain area and around 50 m thick on the Pembina Hills.

The transmissivity of the fractured shale aquifers generally is low and, therefore, they are mainly a source of water for domestic and farm requirements. In general, the maximum yield of wells in the fractured shale is less than 1.0 L/s. The general regional transmissivity of the Odanah Shale seems to range from 1.5 m^2/d to 15.0 m^2/d. However, in some places the Odanah Shale contains pockets of very highly fractured shale. The transmissivity of the highly fractured shale aquifers is several orders of magnitude higher than average transmissivity, e.g., at the Villages of Strathclair and Rossburn aquifer tests at the municipal wells indicate local transmissivity of 1500 m^2/d, at Inglis and Oakburn 150 m^2/d and at Baldur and Belmont around 30 m^2/d. Although the above locations are outside the study area, they indicate that high transmissivity areas might exist in the study area. The very highly fractured shale beds seem to occur adjacent to or near buried bedrock valleys. The reason for this probably is weathering and mass movement along the ancient valleys and folding of the rock by glaciers. Based on aquifer tests carried out in the Odanah Shale at various locations in Manitoba the hydraulic conductivity of the shale aquifers ranges from 5.7×10^{-7} m/s to 8.7×10^{-4} m/s, a ratio of about 1000. The fractured shale aquifers are the most common sources of groundwater in the Pembina Hills area. In the Riding Mountain area because of sand and gravel aquifers in the thick glacial drift, the development of fractured shale aquifers is minimal.

3.4 Cretaceous Clayey Shales

The Cretaceous clayey shales comprise the Millwood Member of the Riding Mountain Formation and Vermilion River, Favel and Ashville Formations. In the Manitoba Escarpment area these formations and the Millwood Member consist mainly of soft clayey shale. The only exceptions are a few thin limestone beds in the Favel Formation and very fine silty sand beds here and there in the Ashville formation, which may yield minor quantities of highly mineralized water at a few locations. The soft clayey shales have very low permeability. Consequently the clayey shales form an extensive and very thick aquitard; in the upland areas the thickness generally is more than 200 m (Figures 2, 4). This aquitard is absent in the lowland area and is less than 60 m thick in the valleys between the uplands. Because in general the Cretaceous clay shales are not water bearing and water in the underlying aquifers generally is salty the top of this hydrostratigraphic unit is the base of exploration for fresh water aquifers. The hydraulic conductivity of shale rarely is larger than 10^{-9} m/s and commonly 10^{-10} to 10^{-12} m/s (Freeze and Cherry, 1979). Laboratory tests of Pierre Shale in North Dakota, which corresponds to Riding Mountain Formation in Manitoba, indicate hydraulic conductivity of 10^{-12} to 10^{-14} m/s (Neuzil and others, 1984). In situ pump and slug tests of Pierre shale indicated hydraulic conductivity of 10^{-10} to 10^{-11} m/s (op cit.). Although groundwater movement through the clayey shales is very slow, over large areas during a long period of time it amounts to fairly large quantities that can be significant contribution to groundwater recharge. For example 31 x 10^{3} m^{3}/a (year) would flow through a square kilometre of shale with hydraulic conductivity of 10^{-10} m/s under a head of one metre. This would sustain a pumping rate of 1.0 L/s. Of course, the actual flow could be several orders of magnitude more or less depending on the order of magnitude of the hydraulic conductivity and hydraulic head.

3.5. Swan River Formation

The Swan River Formation has numerous and often thick and extensive quartz sand and sandstone beds interbedded in shale, silt and clay. The sand and sandstone beds are more or less hydraulically connected. Consequently the Swan River Formation constitutes an extensive aquifer system that extends under much of the central plains of the continent. In the Manitoba Escarpment area it underlies the two northern uplands, and the Pembina Hills. The formation subcrops in extensive areas in the northern part of the study area and in a few small areas adjacent to the Pembina Hills (Figure 4). In the northern part of the Manitoba Escarpment Region the Swan River aquifer system is in hydraulic contact with the water bearing Paleozoic carbonate rocks and therefore it basically becomes part of carbonate aquifer system described in a following section. The thickness of the formation in the study area is up to 105 m.

The transmissivity of the Swan River sandstone aquifers generally is low. Even in the thickest and coarsest aquifers it rarely exceeds 100 m^2/d (Rutulis, 1984). In most of the Swan River aquifer system water is highly mineralized. Potable water is found locally in the northern half of the study area where the aquifers subcrop and are subject to local recharge.

The Villages of Bowsman, Ethelbert and Minitonas are the only municipalities that draw water from the Swan River aquifers. Elsewhere the aquifers are used mainly for domestic and farm requirements.

3.6. Jurassic Shale and Limestone

This hydrostratigraphic unit comprises all the Jurassic formations found in the Escarpment Region. The dominant material in the formations is shale but they also contain beds of limestone, sandstone, gypsum and anhydrite. Because the shale beds are more common than the other rocks, this unit acts mainly as an aquitard. The limestone and sandstone beds, however, are likely to act as conduits for water. Thus both vertical and horizontal movement in this zone is likely. The limestone beds are water bearing but the water generally is highly mineralized and not acceptable for use (Figures 2, 4).

Since in extensive areas the Jurassic shale and limestone underlies the Swan River sandstone aquifer system and it subcrops in extensive areas in the lowland it may have an attenuating effect on salt water intrusion into the stratigraphic units that overlie it. Although highly mineralized and salt water is common in the lowland area, the problems probably would be considerably more severe without the Jurassic shale beds.

3.7. Paleozoic Carbonate Rocks

The lowest hydrostratigraphic unit that affects the groundwater conditions in the Manitoba Escarpment region is formed by a thick sequence of Paleozoic rocks consisting mainly of carbonate rocks. The oldest Paleozoic formation that subcrops in the study area is the Devonian Winnipegosis Formation (Table 1). The Paleozoic carbonate rocks subcrop in the lowland in the northern half of the Escarpment Region. The carbonate rocks form an extensive water bearing zone that extends for hundreds of kilometres outside the study area. The carbonate rocks contain fractured zones that form high transmissivity conduits for groundwater flow. The Paleozoic carbonate rock groundwater flow system originates as brine with total dissolved solids of more than 200 000 mg/L in the Williston Basin in North Dakota (Downey, 1984). It appears that by the time this deep flow reaches the Manitoba Lowland its mineral concentration has been reduced by precipitation of halite (Downey, 1984) and by recharge of less mineralized water because the total dissolved solids concentration in the lowland aquifers and brine springs usually is less than 40 000 mg/L (Little, 1973, a, b; Planning Division, 1972, 1973, 1976b, 1980; Stephenson, 1973; Wadien, 1984). In short, the Paleozoic carbonate rock hydrostratigraphic unit plays a significant role in deteriorating groundwater quality in the Manitoba Escarpment Region lowland area. In groundwater discharge areas the highly mineralized groundwater in the upper hydrostratigraphical units above the carbonate rocks can in turn cause soil salinity.

4. FLOW SYSTEMS

Two basic types of groundwater flow systems can be discerned in the Escarpment area: local flow systems and a regional flow system.

The regional flow system may originate hundreds of kilometres west of the study area (Downey, 1984). The regional flow system dominates in the deep water bearing zones under the Escarpment and it has intruded shallow aquifers in extensive areas east of the Escarpment. The main transmission zone of the regional flow system is formed by the Paleozoic carbonate rocks. The putative flow pattern of the groundwater flow system is indicated in Figures 2, and 5-11.

The local flow systems originate as precipitation, mainly snow, within the study area. The areal extent of the local flow system ranges from less than a hectare to more than a hundred square kilometres, e.g. many minor flow systems are likely to exist along the ravines on Manitoba Escarpment and, on the other hand, a single extensive flow system likely exists in the Assiniboine Delta area. Within the usual zone of groundwater development the local flow systems are dominant in the upland, Escarpment and Escarpment base areas. East of the Escarpment both types of flow systems can be present within the groundwater development zone. Depending on local conditions one or the other flow system can be dominant or there can be mixing of waters of the two systems. Consequently, in some parts of the lowland, there can be considerable variation of water quality in aquifers within short distances and with depth to aquifers.

Since in some parts of the lowland a delicate balance between the two types of flow systems may exist, it is the area where the most significant benefits could be made in groundwater quality, and consequently in soil conditions, by artificially suppressing the negative influence of the regional flow system and enhancing the dominance of the local fresh-water flow systems. On the other hand these also are the areas where the most damage could be done to groundwater resources and soil by mismanaging groundwater resources, i.e., by interferring with the existing groundwater flow systems.

5. QUALITY

Groundwater quality in the Manitoba Escarpment area varies over a wide range; it ranges from excellent in readily and locally recharged aquifers to brine in regional flow system discharge areas, e.g., the brine springs along Lake Winnipegosis (Figure 12).

In general, groundwater is acceptable for human consumption in the upland areas and highly mineralized in lowland areas, particularly in areas where the surficial deposits consist mainly of clay and till, i.e., where local recharge is minimal or absent, e.g., around Dauphin Lake and east of the Pembina Hills.

It seems that in those lowland areas where highly permeable deposits such as sand and gravel beach and outwash deposits are common and surface drainage is poor, e.g., the lowland complex area (Figure 3) the local flow system have supressed the upward movement of the regional salty water system. Consequently fresh water can be found in all sand and gravel aquifers and even in the upper part of the bedrock that underlies the area. This can be an indication that local recharge and drainage conditions have significant influence on groundwater quality and, therefore, artificially changing them could affect groundwater quality in some areas. The changes, of course, can be beneficial or detrimental to groundwater quality.

One of the typical characteristics of groundwater in most of the lowland areas and also in some parts of the valleys between the uplands is that water quality varies considerably from place to place, often within short distances, and also with depth, (Figure 12). The water in wells may range from fresh to salty depending on very local conditions.

The most extensive aquifer with good to excellent quality water almost everywhere is formed by the Assiniboine Delta. There the total dissolved solids concentration generally is less than 500 mg/L and hardness less than 200 mg/L. However, even in this area high iron concentration is a problem here and there.

6. HYDROGEOLOGICAL SUBREGIONS

Although the basic hydrogeological setting is similar throughout the Manitoba Escarpment region there are some conditions peculiar to certain areas along the Escarpment. Based on the variations in the basic physiographic and hydrogeological setting the study area can be divided into the following subregions:

(1) Porcupine Hills,
(2) Swan River Valley,
(3) Duck Mountain,
(4) Riding Mountain,
(5) Assiniboine Delta,
(6) Pembina Mountain. Figure 1.

6.1. Porcupine Hills Subregion

This subregion consists of Porcupine Hills and the area east of them to the eastern boundary of the study area. The most significant physiographic features of this subregion are steep slopes with many deep steep walled ravines on the Escarpment and an abrupt change from the Escarpment to the flat lowland.

The most significant hydrogeological aspects of this region are:

1. Absence of the Jurassic formations, which constitute a significant hydrostratigraphic unit in the southern part of the study area (see longitudinal section along the Escarpment; Figure 5). Consequently there is a direct hydraulic connection between the Swan River Formation and the Paleozoic carbonate rocks and the salty water of the Paleozoic rocks can readily intrude the sandstone aquifers.

2. The Paleozoic carbonate rocks subcrop a short distance east of the Escarpment (Figure 6). Hence in the lowland area fresh water can be found mainly in shallow sand and gravel aquifers. Several brine springs exist on or near the shore of Dawson Bay (Figure 12). Since in some places the salt water bearing Paleozoic rocks are less than 30 m below ground surface, water quality

in the lowland area likely is affected by local recharge conditions. Reducing recharge by improved drainage could result in salt-water intrusion in shallow aquifers.

3. The Odanah Member of the Riding Mountain Formation is absent and therefore there are no water bearing formations in the bedrock above the Swan River Formation.

4. Indications are that the surficial deposits thickness in the upland area is more than 150 m. The surficial deposits likely consist mainly of till with lenses of sand and gravel. Very few wells or test holes have been drilled in the upland area and therefore there is very little information about aquifers in this part of the subregion.

5. The most common fresh water aquifers at the base of the Escarpment and in the lowland area are alluvial sand and gravel, pockets of sand and gravel in the till, and sand and sandstone of the Swan River Formation. In general, in this subregion groundwater is fairly readily available but poor quality may be a common problem.

6.2. Swan River Valley Subregion

This subregion consists of the lowland between the Porcupine Hills and Duck Mountain and its extension towards Swan Lake.

The characteristic hydrogeological features of this subregion are:

1. Absence of Jurassic formations which allows direct infiltration of the Paleozoic rock salt-water into the Swan River Formation (Figures 5 and 7).

   As a result salty and highly mineralized water is common in the Swan River sandstone and sand aquifers (Figure 12).

2. The surficial deposits are quite heterogeneous; they comprise alluvial, glaciofluvial, lacustrine and glacial deposits. Consequently sand and gravel aquifers are common throughout the area.

3. Because both local fresh water flow systems and the regional salt water flow system are active within the zone of groundwater development, groundwater quality can vary considerably from place to place.

   In some parts of the valley the salt water system has intruded shallow sand and gravel aquifers, e.g. in the vicinity of Bowsman, and potable groundwater is difficult to find or is not available. On the other hand, at other locations, e.g., around the Town of Swan River, fresh water is found in the sandstone aquifers at depths of more than 60 m.

6.3. Duck Mountain Subregion

This subregion comprises the Duck Mountain upland and the area between it and Lake Winnipegosis and Dauphin Lake.

The most noticeable physiographic characteristics of this region are (1) the gently eastwared sloping transition zone between the steep slopes of the Escarpment and the almost flat lowland east of the transition zone, (2) numerous streams in the northern part of the lowland, and (3) the lack of streams in extensive parts of the southern part of the lowland.

The following hydrogeological features are characteristic of this subregion:

(1) The depth to the Paleozoic carbonate rock is greater than in the Porcupine Hills area and in the southern part of the subregion the Jurassic shale and limestone beds separate the Swan River Formation from the Paleozoic carbonate rock (Figure 4 and 7). The Jurassic formations likely have a retarding effect on salt-water movement from the Paleozoic rocks into the Swan River Formation.

(2) The Odanah Member of the Riding Mountain Formation does not occur in this area. Consequently in the upland area the till is underlain by Cretaceous soft shale formations, i.e., aquitard with a few minor exceptions.

(3) Low mineral concentrations in the Swan River Formation aquifer system in some areas at the base of the Escarpment (Figure 12) indicate good local recharge conditions, e.g., at Ethelbert and north of there.

(4) The upland area is covered by a very thick till layer that in places is more than 275 m thick. Indications are sand and gravel lenses interbedded in the till are fairly common in the upland area.

(5) In the northern part of the lowland, i.e., the lowland complex area (Figure 3) extensive surface sand and gravel deposits are common. The fact that even fairly deep wells in bedrock in this area have fresh water seems to indicate that significant local recharge takes place in this area. In other subregions salty and highly mineralized water is common in the lowland. Several brine springs, however, exist on or near the shores of Lake Winnipegosis (Figure 12).

(6) An extensive sand and gravel aquifer exists at the base of the upland in the Timberton area (Figure 3).

(7) In much of the lowland along the Valley River the bedrock consists of soft clayey shale. It is overlain by a thin till layer with very few pockets of sand and gravel. Water in the Swan River Formation that underlies the clayey shales is salty. As a result fresh groundwater is often difficult to find in the Grandview - Gilbert Plains - Ashville area.

6.4. Riding Mountain Subregion

The Riding Mountain subregion consists of the Riding Mountain upland and the area extending to Valley River to the north and to the eastern boundary of the study area to the east.

Physiographically the subregion is similar to the Duck Mountain subregion except that there are not as many streams below the Escarpment and the valley of the Whitemud River to the south is not as deep as that between Duck and Riding Mountain (Figure 5).

The most important hydrogeological features in the Riding Mountain subregions are:

1. In the upland area the surficial deposits are underlain by the Odanah Shale aquifer (Figure 9).
2. The Swan River Formation is absent in most of the subregion; it subcrops only in a small area south and southwest of Dauphin Lake (Figure 4).

3. In most of the lowland, bedrock is formed by the Jurassic limestone and shale and the Paleozoic carbonate rocks. Since the Paleozoic rocks constitute the main salt-water transmission zone and local recharge is impeded by the shale beds and till , highly mineralized and salty water is common in the lowland area.

4. Alluvial fan aquifers are common at the base of the Escarpment. Some of the more extensive alluvial fans are indicated on Figure 3. The alluvial fan aquifers are recharged mainly by infiltration of precipitation over the alluvial fans and by infiltration from streams that cross them. Consequently, water in these aquifers is of good to excellent quality and they are significant sources of water in the subregion, e.g., municipal well at the Village of McCreary, community well at Riding Mountain settlement.

5. In an up to five km wide belt just east of the alluvial fans very few aquifers occur within the surficial deposits, the bedrock is soft clayey shale that contains no aquifers, and water in deeper water bearing zones is highly mineralized (Figure 9). Consequently potable water is difficult to impossible to find in this area.

6.5. Assiniboine Delta Subregion

The Assiniboine Delta subregion includes part of the Assiniboine Delta and the area east of it to the study boundary and southeasterly to the Assiniboine River. This subregion is located in a fairly extensive low area between two "mountains". Basically it consists of an upland plain formed by the Assiniboine Delta Sand and a lake plain lowland. (Figure 10)

The most prominent hydrogeological features in this subregion are:

1. The sand of the Assiniboine Delta forms the most extensive high yield fresh water aquifer in the study area. In the central part of it the saturated thickness ranges from 20 m to 30 m (Pedersen, 1970) and potential pumping rates of high capacity wells are likely to exceed 100 L/s at some locations. Groundwater quality is good to excellent in the Assiniboine Delta Aquifer area.

2. The bedrock in the area consists of the Cretaceous clayey shales that are underlain by the Jurassic shale and limestone hydrostratigraphic unit. Consequently the deep regional groundwater flow system is dominant in the bedrock formations and water in bedrock aquifers is salty.

3. In the lowland part of the subregion east of the Assiniboine Delta Aquifer groundwater conditions are quite different. In most of the lowland the only aquifers are formed by thin sand deposits at surface which often have a very minimal saturated thickness.

4. Water in sand and gravel interbedded in the surfical deposits often is salty, particularly in deep aquifers near the base of the overburden. A few exceptions occur here and there, e.g. in the vicinity of Rossendale (Figure 3).

5. In a few small areas in the lowland the surface sand is absent (Figure 3).

6. In general, groundwater supply is abundant in the upland (Assiniboine Delta Aquifer) area and minimal in the lowland area.

6.6. Pembina Hills Subregion

The Pembina Hills subregion occupies the study area south of the Assiniboine River. It comprises part of the Pembina Hills and part of the Red River Valley.

The Pembina Hills are the lowest of the "mountains" along the Manitoba Escarpment and the Escarpment topography is not as rugged as below the other uplands. This subregion differs from the other "mountain" subregions in that most of the upland is cultivated in contrast to the extensive forests of the northern areas.

The following are the more significant hydrogeological and groundwater conditions in the subregion:

1. In the upland area the surficial deposits generally are thin and are only a fraction of those found on the other three uplands (Figure 11).

2. In most of the upland the surficial deposits are underlain by the Odanah shale aquifer.

3. Because of the thin overburden the shale aquifer, in general, is readily recharged by infiltration from the surface.

4. The Odanah shale is underlain by the Cretaceous clayey shales, i.e., by a thick aquitard. The clayey shale beds subcrop and outcrop along the escarpment.

5. The Swan River Formation subcrops in a few narrow zones along the base of the Escarpment (Figure 4).

6. East of the Escarpment the bedrock is formed by Jurassic formations that are underlain by Paleozoic rocks.

7. In much of the lowland the upper layer of the surficial deposits consist of a thick clay (Figure 3). The clay layer also underlies much of the shallow surface sand area. Since the clay is an aquitard and groundwater in the aquifers below the clay layer is salty, practically no potable water is available in the clay and silt areas shown in Figure 3.

8. Because of the thick and extensive aquitards local recharge of the Swan River Formation and the deeper water bearing hydro-stratigraphic units seems to be minimal. Consequently water in the deep bedrock and even in most sand and gravel aquifers in the lowland area is salty.

9. In much of the shallow surface sand area deep sand and gravel aquifers do not exist or they yield only highly mineralized water.

10. In respect of fresh water supply, the most significant aquifers in the area are formed by buried sand and gravel aquifers at the base or a short distance east of the Escarpment (Figure 3). These aquifers have been developed for municipal supply and water supply for the surrounding area, e.g. municipal supply for the Town of Winkler and the Villages of Miami and St. Claude.

7. GROUNDWATER PROBLEM AREAS

Several groundwater problem areas that are significant on a regional scale exist in study area. In groundwater problem areas one or more of the following conditions exist: fresh water aquifers do not exist, fresh water aquifers are very scarce, well yields are very minimal, quality is very poor, the aquifers often dry up in late winter even under normal recharge conditions. Most of the problem areas are in the lowland of the study area.

In the southern part of the study area in one fairly extensive and several smaller areas which correspond to the clay and silt hydrogeological unit shown on Figure 3, fresh groundwater in general is not available because the upper layer of the surficial deposits consists of clay and water in the aquifers underneath the clay is highly mineralized and not acceptable for human consumption or for livestock.

In the Riding Mountain subregion groundwater supply problems are common in a narrow belt extending from Laurier to McCreary and from there south to the vicinity of Neepawa. In this belt sand and gravel aquifers are scarce and those that exist often yield only highly mineralized water and water in bedrock aquifers generally is salty. A fairly extensive groundwater problem area more or less corresponds to the Valley River valley from the vicinity of Grandview to Dauphin and vicinity. In much of this area the surficial deposits consist of clayey till with very few minor gravel deposits and the bedrock consists of the Cretaceous clayey shales. Water in the Swan River sandstone aquifers that underlie the clayey shale beds is salty. Consequently groundwater is difficult to impossible to find in the area and the water supply for most farms seems to be far from satisfactory.

In the area east of Duck Mountain groundwater problem areas exist along the west shore of Lake Winnipegosis and in a belt along the base of the Manitoba Escarpment extending from Ethelbert to Ashville. In the Lake Winnipegosis area the main problem is salt water in bedrock aquifers and its intrusion into shallow overburden aquifers. In the groundwater problem belt below the Escarpment the situation is similar to that in the Valley River area, i.e., very few shallow aquifers outside the beach ridge along Hwy. 10 and salty water in the Swan River sandstone and deeper aquifers.

North of Duck Mountain scattered groundwater problem areas exist in the lower reach of the Swan River Valley and in the lowland along Swan Lake and Dawson Bay. The main problems there are salty water in bedrock and its intrusion into shallow aquifers.

In addition to the groundwater problem areas in the lowland the Manitoba Escarpment areas shown as Escarpment Complex in Figure 3 also can be considered as groundwater problem areas. The main reasons for lack of groundwater on the Escarpment are steep slopes and numerous ravines that drain permeable deposits on the Escarpment. Since much of the Escarpment area is underlain by the Cretaceous clayey shales, deep aquifers that would not be affected by the drainage do not exist and water below the clayey shales is salty.

Nearly all the groundwater problems in the study area are not related to lack of groundwater but are caused by the fact that salt water is common in the bedrock aquifers that underlie the area and usually are within the usual depth for groundwater exploration.

8. ARTIFICIAL RECHARGE

Not all headwater storage has to be in man-made storage reservoirs above ground. In areas where suitable conditions exist, an alternate possibility is to divert headwaters into aquifers, i.e. to artificially recharge aquifers. The artificial recharge could be accomplished directly by diverting water into pits or wells excavated or installed in an aquifer or indirectly by enhancing existing natural recharge conditions.

For ideal artificial recharge conditions of unconfined aquifers the following general conditions should exist.

1. The aquifer must be at least partially exposed.
2. The aquifer must be highly permeable, e.g., it should consist of clean sand and gravel or highly fractured rock.
3. The static level must be below ground level.

For ideal artificial recharge conditions of confined aquifers the piezometric surface must be well below ground surface and the permeability high to permit recharge by gravity flow in recharge wells.

The least expensive sites for artificial recharge would be gravel pits or rock quarries already excavated in aquifers or natural depressions in the surface of aquifers providing they are near a stream or drain that can be readily diverted into the recharge area. At some locations it might be possible to enhance natural aquifer recharge, e.g., by reservoirs on streams that cross aquifers, spreading of runoff over an aquifer. Some of the alluvial fan aquifers at the base of the Escarpment seem to be suitable for recharge enhancement.

Another variation of headwater storage could be artificial recharge of salt water aquifers with fresh water or enhancement of natural recharge in salty groundwater areas to improve groundwater quality.

Although artificial recharge is a possibility for some headwater storage, several problems are likely to hinder implementation of recharge projects. A major restriction of widespread use of artificial aquifer recharge is likely to be lack of suitable sites. Acceptable recharge water quality could be another serious problem; tests at one experimental recharge project (Elie) indicate that agricultural chemical levels in stream waters can occasionally be above acceptable levels. This of course, would also be a problem for waters stored in above-ground reservoirs, if used as source of potable water. A serious problem could also be the impact of artificial recharge on groundwater levels in surrounding area, e.g., high levels may have detrimental effect on crops, soils, buildings and other structures.

No doubt extensive studies and experimental work would be required to determine whether or not artificial recharge and recharge enhancement to store headwaters is practical and economically feasible and to determine locations of acceptable recharge sites in the study area. A study of agricultural chemicals in runoff and possible attenuation of their concentration by sorbsion and dilution in aquifers would be a good starting point; if water quality were not acceptable and it were not possible to improve it by attentuation other recharge studies would not be justified.

9. POTENTIAL EFFECT OF HEADWATER STORAGE RESERVOIRS ON GROUNDWATER

The raised hydraulic heads at the boundary of a reservoir would cause a reversal of flow directions and an influx of water from the reservoir into the groundwater system (Freeze and Cherry, 1979). The groundwater and surface water also could be affected by reservoirs because "leakage from reservoirs at points distant from the dam is not uncommon" (op. cit.). As has been indicated elsewhere in this report, headwater storage can also affect groundwater regime and flow systems considerable distances downstream from a reservoir by changing natural stream regime below the dam that, in turn, can affect groundwater recharge. The changes in groundwater conditions resulting from headwater storage reservoirs can be either beneficial or detrimental to the surrounding area depending mainly on the hydrogeological setting and land use.

Assuming that the reservoirs would be built in the Manitoba Escarpment and upland areas the sites will be within the following four hydrogeological and hydrostratigraphic units, in order of increasing hydraulic conductivity; the Cretaceaous clayey shales, glacial till, Odanah Shale and Assiniboine Delta sand and gravel. In the following discussion of storage reservoirs in the four main hydrogeological settings the main concern is reservoir - groundwater interaction without any consideration of aspects related to site suitability for dam construction.

From the viewpoint of causing the least effect on groundwater in the surrounding area the most desirable hydrostratigraphic unit for reservoir sites would be the Cretaceous clayey shales. Because of the very low permeability of this unit, reservoirs within this hydrostratigraphic unit are not likely to change groundwater conditions for any significant distance around them and there would be only minimal seepage to aquifers below the shale, i.e ., significant piping through highly permeable zones to distant points would not be possible.

For the same reasons as the Cretaceous clayey shales and almost equally acceptable for minimum effect on groundwater would be reservoirs in the massive till deposits on Riding and Duck Mountain and Porcupine Hills. The main difference between reservoirs within the till and the

Cretaceous clayey shales is that the till may contain pockets and layers of sand and gravel, i.e., sand and gravel aquifers, that could be strongly affected by raised hydraulic heads and also could result in groundwater transmission for long distances, i.e., piping. In contrast the clayey shales are uniform over extensive areas and do not contain aquifers. The only exception is the Favel Formation, which may contain a few thin permeable limestone beds.

The Odanah shale forms an extensive aquifer and at some locations it may be fairly highly permeable. Consequently placing headwater storage reservoirs within this hydrostratigraphic unit could have a significant effect on groundwater regime in the surrounding area, if there is no significant clay or till lining of the reservoir. The effect could be beneficial or detrimental depending on local circumstances. For example, in some areas it may result in better water supply from wells because of higher water levels and better quality water. In other areas increased groundwater flow could cause wet fields and increased soil salinity. The same reservoir, of course, could be beneficial to some parts of the surrounding area and detrimental to others. Because the Odanah shale may contain some fairly extensive highly fractured shale beds with fairly high hydraulic conductivity, the effects on groundwater flow systems may be significant considerable distance from the reservoir.

The maximum effect of headwater storage reservoirs on groundwater conditions can be expected in the Assiniboine Delta area. Since the valleys there are cut through sand that, in general, has high hydraulic conductivity, significant seepage from reservoirs into the surrounding area seems to be inevitable. The flow from the reservoir into the sand could have considerable beneficial effect on the water resources in the surrounding area. It would increase considerably the volume of water in storage in the sand aquifer, i.e., part of the headwater storage would be in the aquifer. Higher water levels in the aquifer would increase stream discharge and would improve water supply downstream. The quantities of water stored in a relatively small area of a sand aquifer can be significant. For example, raising water level 5 m over an area of one square kilometre of sand with storage coefficient of 0.20 would put 1×10^6 m^3 of water in storage, which would be enough to supply a town of 10 000 for one year. On the other hand, storing water in the valleys in the Assiniboine Delta area could have severe detrimental effects in the surrounding area, particularly below a reservoir, e.g., high water table where it is not acceptable, seepage in drains, flooded basements, etc.

10. SUMMARY

The basal hydrostratigraphic unit that has a significant influence on groundwater conditions in the Manitoba Escarpment area consists of Paleozoic carbonate rocks. The Paleozoic rocks form an extensive aquifer system that underlies the whole study area and extends for hundreds of kilometres west of it. In general, water in this aquifer system is salty and it is the main source of the highly mineralized water in lowland area.

The carbonate rocks are overlain by Jurassic shale formations that are overlain by a thick sequence of Cretaceous clayey shales which form an extensive aquitard that underlies the uplands and form bedrock in Duck Mountain and Porcupine Hills area.

In the Pembina Hills and Riding Mountain uplands the upper bedrock hydrostratigraphic unit is the Odanah shale of the Cretaceous Riding Mountain Formation. In contrast to the other Cretaceous shales this shale is hard and forms an extensive aquifer.

The upper hydrostratigraphic unit consists of surficial deposits. It contains numerous small sand and gravel aquifers and some extensive sand and gravel aquifers. The ancient Assiniboine Delta, part of which is in the study area, forms the most extensive sand aquifer in the study area. In extensive areas the surficial deposits consist mainly of till and clay aquitards.

The uplands, the Manitoba Escarpment and the Assiniboine Delta areas are groundwater recharge areas where, in the upper strata, local groundwater systems are dominant. The deep regional groundwater flow systems that originate west of the study area and are at considerable depth in the upland area are at or near ground surface in the lowland area. The lowland is the potential discharge area of the deep flow systems and intrusion of the highly mineralized water into surface and near surface aquifers is common. If it were not for the counteracting influence of local flow systems and low permeability strata retarding upward movement of the deep waters in some parts of the lowland, the intrusion of salt water in aquifers and in soil in the lowland area would have been much more widespread. Thus one of the most important things to keep in mind when modifying water regime in the lowland area is that reduction of local recharge could result in salt water intrusion in fresh water aquifers and non-saline soils.

Headwater storage reservoirs will have the least effect on groundwater in areas underlain by Cretaceous clayey shales and massive thick glacial till. The most severe affect of storage reservoirs on groundwater regime can be expected in the Assiniboine Delta area. Reservoirs in the Odanah shale areas could affect groundwater conditions in the Odanah shale aquifer. The effect of storage reservoirs on aquifers could be beneficial, detrimental, or both depending on local groundwater conditions.

REFERENCES

CHARRON, J.E., 1964. Two aquifer tests in Winnipeg and Brandon Map-Areas, Manitoba. G.S.C., Paper 63-43.

DAVIES, J.F., B.B. Bannatyne, G.S. Barry, and H.R. McCabe. 1962. Geology and mineral resources of Manitoba. Man. Dept. Mines and Nat. Res. Mines Branch.

DOWNEY, Joe, S. 1984. Geohydrology of the Madison and associated aquifers in parts of Montana, North Dakota, South Dakota, and Wyoming. U.S. Geol. Survey Professional Paper 1273-G.

EHRLICH, W.A., L.E. Pratt, E.A. Poyser and F.P. Leclaire. 1958. Reconnaissance soil survey of West-Lake map sheet area. Manitoba Soil Survey, Soils Report No. 8.

EHRLICH, W.A., L.E. Pratt, and F.P. Leclaire. 1962. Detailed reconnaissance soil survey of Swan River map sheet area. Manitoba Soil Survey, Soils Report No. 13.

FREEZE, R., Allan, John A. Cherry, 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

LITTLE, J. 1973 a, Groundwater availability in the Dauphin Area. Man. Dept. of Mines, Res. and Environmental Management, Water Res, Branch, Groundwater Availability Studies Report No. 10.

LITTLE, J. 1973 b. Groundwater availability in the Ochre River - Ste. Rose Area. Dept. Mines, Res. and Environmental Management, Water Res. Branch, Groundwater Availability Studies Report No. 7.

LITTLE, J. 1981. Groundwater availability in the Almasippi soils area of South-Central Manitoba. Manitoba Dep. Nat. Res. Water Res. Branch, Groundwater Availability Study Report No. 18.

MANITOBA MINERAL RESOURCES DIVISION. 1979. Geological map of Manitoba, scale 1:1000 000. Map 79-2.

MANITOBA MINERAL RESOURCES DIVISION. 1981. Surficial geological map of Manitoba, scale 1:1000 000. Map 81-1.

NEUZIL, C.E., J.D. Bredehoft and R.G. Wolff. 1984. Leakage and fracture permeability in the Cretaceous shales confining the Dakota Aquifer in South Dakota. In Jorgensen, D.G. and D.C. Signor, eds. Geohydrology of the Dakota aquifer. Nat. Water Well Assoc.

Worthington, Ohio.

PLANNING DIVISION. 1979. Groundwater availability in the Carberry area. Man. Dept. Mines, Res. and Environmental Management Water Res. Branch, Groundwater Availability Studies Report No. 2.

PLANNING DIVISION. 1971. Groundwater availability in the Ethelbert area. Man. Dept. Mines, Res. and Environmental Management. Water Res. Branch, Groundwater Availability Studies Report No. 3.

PLANNING DIVISION. 1972. Neepawa Map Sheet, 72-J. Man. Dept. Nat. Res. Water Res. Branch, Groundwater Availability Study Report No. 11.

PLANNING DIVISION. 1973. Swan Lake Map sheet 63-C. Nat. Res. Water Res. Branch, Groundwater Availability Studies Report No. 12.

PLANNING DIVISION. 1976a. Brandon map sheet, 62-G. Man. Dept. Nat. Res. Water Res. Branch, Groundwater Availability Study Report No. 14.

PLANNING DIVISION. 1976 b. Duck Mountain map sheet, 62-N. Man. Dept. Nat. Res. Water Res. Branch. Groundwater Availability Study Report No. 15.

PLANNING DIVISION. 1978. Riding Mountain Map Sheet 62-K. Man. Dept. Nat. Res. Water Res. Branch, Groundwater Availability Study Report No. 16.

PLANNING DIVISION. 1980. Winnipeg map sheet, 62-H. Man. Dept. Nat. Res. Water Res. Branch, Groundwater Availability Study Report No. 13.

RUTULIS, M. 1977. Groundwater resources in the Turtle River watershed Man. Dept. Nat. Res. Water Res. Branch.

RUTULIS, M. 1979. Groundwater resources in the Morden, Stanley, Thompson, Winkler (M.S.T.W.) Planning District. Man. Dept. Nat. Res. Water Res. Division.

RUTULIS, M. 1984. Dakota aquifer system in the Province of Manitoba. Jorgensen, D.G. and D.C. Signor, eds. Geohydrology of the Dakota aquifer. Nat. Water Well Assoc. Worthington, Ohio.

Stephenson, J.F. 1973. Geochemical studies - Mineral spring sampling. In summary of geological field work, 1973. Man. Dept of Mines, Res. and Env. Management, Mines Branch. Geological Paper 1/73.

Van Everdingen, R.O. 1968. Studies of formation waters in Western Canada - Geochemistry and hydrodynamics. Canadian Journal Earth Sci., V. 5, pp. 523 - 543.

WADIEN, Rita, 1984. The geochemistry and hydrogeology of saline spring waters of the Winnipegosis area, south western Manitoba. Unpublished B. Sc. thesis, Dept. Earth Science, Univ. Manitoba.

ZALTSBERG, E. 1984. Groundwater regime, balance and runoff in the Wilson Creek Experimental basin (1965 - 1980). Man. Dept. Nat. Res., Water Res. Branch.

TABLE I

STRATIGRAPHIC-HYDROSTRATIGRAPHIC UNIT CORRELATION CHART IN THE MANITOBA ESCARPMENT AREA

STRATIGRAPHY						HYDROSTRATIGRAPHY		
		STRATIGRAPHIC UNIT						
ERA	PERIOD	FORMATION	MEMBER	MAXIMUM THICKNESS METRES	BASIC LITHOLOGY	HYDROSTRATIGRAPHIC UNIT	MAXIMUM THICKNESS METRES	GEOHYDROLOGIC CHARACTERISTICS
CENOZOIC	RECENT			15	Alluvium, sanddunes, peat	Surficial deposits	275	Forms aquifers and aquitards. Main fresh water zone in much of the area (See Table II).
	PLEISTOCENE			275	Glacial deposits			
	EOCENE TO PALEOCENE NOT PRESENT		UNCONFORMITY					
MESOZOIC	CRETACEOUS	RIDING MOUNTAIN	ODANAH	200	Hard, siliceous shale	Odanah Shale	200	Fractured zones in the shale form aquifers. Fresh water zone.
			MILLWOOD	130	Soft, clayey shale	Cretaceous clayey shales	375	Extensive and thick aquitard.
		VERMILION RIVER	PEMBINA	30	Shale, bentonite beds			
			BOYNE	50	Calcareous shale			
			MORDEN	45	Calcareous shale, concretions			
		FAVEL		40	Shale, limestone bands			
		ASHVILLE		80	Silty, clayey shale			
		SWAN RIVER		105	Sand, sandstone, shale, clay	Swan River Formation	105	Sand and sandstone aquifer zone. Fresh and salty water.
		EROSIONAL	DISCONTINUITY					
	JURASSIC	MELITA		65	Shale, limestone, sandstone	Jurassic shale and limestone	145	Limestone beds form aquifers. Shale aquitards. Fresh and salty water.
		RESTON		30	Limestone and shale			
		AMARANTH	EVAPORITES		Anhydrite, gypsum, shale, dolomite			
			RED BEDS	50	Dolomitic, shale to siltstone			
		TRIASSIC TO MISSISSIPPIAN NOT PRESENT.		UNCONFORMITY				
PALEOZOIC	DEVONIAN	SOURIS RIVER		50	Limestone, evaporite, shale	Paleozoic carbonate rock	400	Major aquifer system. Main salt-water transmission zone.
		DAWSON BAY		35	Limestone, anhydrite, shale			
		WINNIPEGOSIS *		60	Dolomite, reef and inter-reef			
		ELM POINT		15	High calcium limestone			
		ASHERN		15	Dolomite and shale			
	SILURIAN	INTERLAKE GROUP: CEDAR LAKE, EAST ARM, ATIKAMEG, MOOSE LAKE, INWOOD, FISHER BRANCH		75	Mainly dolomite			
	ORDOVICIAN	STONEWALL		15	Dolomite			
		STONY MOUNTAIN	WILLIAM	35	Dolomite			
			GUNTON					
			PENITENTIARY		Calcareous shale, limestone, dolomite.			
			GUNN					
		RED RIVER	FORT GARRY	125	Mottled dolomitic limestone, limestone, dolomite			
			SELKIRK		Dolomitic limestone, dolomite			
			CAT HEAD		Mottled limestone, dolomite			
			DOG HEAD					
		WINNIPEG		60	Sandstone, shale	Winnipeg sandstone	60	Major aquifer system. Mainly brine.
		NONCONFORMITY						
PROTEROZOIC ARCHEAN		PRECAMBRIAN ROCKS			Igneous and metamorphic rocks	Precambrian rock		Aquitard. Base of significant groundwater movement.

TABLE 1

80-1-7-1038

* LOWEST FORMATION SUBCROPPING IN STUDY AREA.

REFERENCES: PLANNING DIVISION, 1972, 1973, 1976a, 1976b, 1978
DAVIES AND OTHERS, 1979
MANITOBA MINERAL RESOURCES DIVISION, 1979

TABLE II

SURFICIAL DEPOSIT HYDROGEOLOGICAL UNITS

UNIT	MATERIAL	MAX. THICK. METRES	HYDROGEOLOGICAL CHARACTERISTICS AND SIGNIFICANCE
ALLUVIUM AND ALLUVIAL FANS	Clay, silt, sand, gravel	20	Numerous small and some fairly extensive aquifers.
SHALLOW SURFACE SAND	Sand	10	Extensive but thin aquifers.
ASSINIBOINE DELTA SAND	Sand, fine to coarse.	35	Extensive and thick high yield aquifer. High transmissivity.
LOWLAND COMPLEX	Sand and gravel underlain by till.	50	Numerous shallow aquifers and till aquitard. Groundwater conditions vary considerably from place to place.
VALLEY COMPLEX	Clay, silt, sand, gravel and till.	50	Interbedded aquifers and aquitards; very variable.
ESCARPMENT COMPLEX	Till, sand, gravel, clay, silt shale rubble.	30	Minor scattered aquifers. Well drained because of steep slopes and rough topography.
CLAY AND SILT	Clay and silt.	100	Extensive aquitard. Underlies much of the shallow surface sand. Forms low permeability barrier between fresh and salty groundwater flow systems.
TILL	Till with lenses of sand and gravel.	275	Extensive aquitard. Contains numerous small and some fairly extensive aquifers. In some areas contains practically no aquifers.
BURIED SAND AND GRAVEL	Sand and gravel	70	Major buried sand and gravel aquifers. Significant sources of fresh water. May occur at various stratigraphic positions within the surficial deposits.

80-1-7-1038

Manitoba

Memorandum

Date March 25, 1986

To L. Gray, P. Eng.
Head of Hydrogeology Section

From M. Rutulis, P. Eng.
Aquifer Data Geologist

FILE: 7.8.

Telephone

Subject MANITOBA ESCARPMENT - HEADWATER STUDY - GROUNDWATER IMPLICATIONS.

In response to the March 18, 1986 request by Mr. L.J. Whitney, P. Eng., Chairman, Manitoba Escarpment Headwater Storage Study, Steering Committee an office review of the hydrogeological setting of the proposed dam sites was carried out. As most of the sites are in relatively remote areas where well drilling and aquifer investigations are non-existent or very minimal at best, the comments had to be based on very general hydrogeological information.

Consequently only the general hydrogeological setting for each site could be outlined and based on it the affect of the proposed reservoir on groundwater indicated. A list of the proposed storage reservoir sites with the pertinent comments is attached.

M. Rutulis, P. Eng.

MR:dlm

Attachment.

GROUNDWATER IMPLICATIONS AT PROPOSED STORAGE RESERVOIR SITES ON MANITOBA ESCARPMENT

SITE: No. 19

LOCATION: North Duck River, NW20-35-34W

HYDROGEOLOGICAL SETTING: The bedrock at this site is Millwood shale of the Riding Mountain Formation. The shale is overlain by 60 m to 100 m of glacial drift; mainly glacial till. The till may contain pockets of sand and gravel. The pockets of sand and gravel form the only aquifers in the surrounding area.

GROUNDWATER IMPLICATIONS: Because the reservoir would be surrounded and underlain by low permeability materials and there are no wells in the immediate vicinity, no significant effect on groundwater conditions or wells can be expected.

SITE: No. 25A

LOCATION: Minitonas Creek, NE3-35-26W

HYDROGEOLOGICAL SETTING: The area is underlain by the Millwood Member of the Riding Mountain Formation. The surficial deposits consist mainly of glacial till. The only aquifers in the immediate vicinity likely are formed by scattered pockets of sand and gravel in the till.

GROUNDWATER IMPLICATIONS: Because only minor aquifers are likely to exist in the vicinity of the reservoir, the reservoir is not likely to cause significant changes in the groundwater regime at this site.

SITE: No. 26B

LOCATION: East Favel River, 30-35-25W

HYDROGEOLOGICAL SETTING: The bedrock at this site is Vermilion Formation shale. At the southwest corner of the section 5 m of surface sand and gravel underlain by till to a depth of 18 m have been reported. In SW31-35-25W the shale has been reported at 1.5 m below ground surface.

GROUNDWATER IMPLICATIONS: Since the bedrock at this site is an aquitard, no significant effect on groundwater conditions in the surrounding area can be expected. If the dam is placed near the north end of the section, there might be some seepage into the thin limestone beds of the Favel Formation.

SITE: No. 29B

LOCATION: Pine River, NE35-32-23W

HYDROGEOLOGY SETTING: The bedrock at this site is shale of the Vermilion River Formation. It is overlain by about 100 m of glacial till with minor deposits of sand and gravel. The materials underlying and surrounding the reservoir are aquitards.

GROUNDWATER IMPLICATIONS: Because there are no extensive aquifers in the surrounding area, no significant effect on groundwater conditions can be expected.

SITE: No. 30

LOCATION: Berlinski Creek, NE16-32-23W

HYDROGEOLOGICAL SETTING: The bedrock at this location is Vermillion Formation shale, which is an aquitard. The shale is overlain by a thin till layer.

GROUNDWATER IMPLICATIONS: The reservoir is not likely to cause a significant affect on groundwater conditions in the surrounding area.

SITE: No. 37

LOCATION: Shanty Creek, NE22-29-23W

HYDROGEOLOGICAL SETTING: The bedrock consists of shales of the Millwood Member of the Riding Mountain Formation and Vermilion River Formation. The shales are overlain by up to 6 m of glacial till. Consequently there are practically no aquifers at this site.

GROUNDWATER IMPLICATIONS: The reservoir is not likely to cause any groundwater related problems in the surrounding area.

SITE: No. 38A

LOCATION: Fishing River, SW26-28-23W

HYDROGEOLOGICAL SETTING: The area is underlain by shale of the Vermilion River Formation. The shale is overlain by up to 130 m of glacial till. No significant water bearing zones indicated in the immediate vicinity.

GROUNDWATER IMPLICATIONS: Because the area is underlain by low permeability materials, a reservoir at this site is not likely to have a significant effect on groundwater resources in the vicinity.

SITE: No. 39A

LOCATION: Drifting River, SE21-27-23W

HYDROGEOLOGICAL SETTING: The bedrock at this site is shale of the Vermilion River Formation which constitutes an aquitard. The shale is overlain by up to 130 m of glacial till with some sand and gravel deposits form the only aquifers at this location.

GROUNDWATER IMPLICATIONS: A reservoir at this location is not likely to cause groundwater problems in the surrounding area.

SITE: No. 47

LOCATION: West Wilson River, NW31-23-23W

HYDROGEOLOGICAL SETTING: The bedrock at this site is shale of the Millwood Member of the Riding Mountain Formation. The shale is overlain by a few metres of till. No significant water bearing zones exist at this location.

GROUNDWATER IMPLICATIONS: The effect on groundwater of a reservoir at this site would be insignificant.

SITE: No. 48

LOCATION: East Wilson River, E 1/2 33-23-23W

HYDROGEOLOGICAL SETTING: The conditions at his site are basically the same as at site No. 47.

GROUNDWATER IMPLICATIONS: -

SITE: No. 77

LOCATION: Tobacco(?) Creek, SW17-6-7W

HYDROGEOLOGICAL SETTING: The area is underlain by shale of the Vermillion River Formation. The shale is overlain by a thin glacial till layer that, in places, is overlain by sand and gravel beach deposits. Lenses of sand and gravel may overlie the shale in the floodplain area.

GROUNDWATER IMPLICATIONS: A reservoir at this site would not have a significant effect on the general groundwater conditions in the vicinity.

SITE: No. 91

LOCATION: Tobacco Creek, SW2-5-7W

HYDROGEOLOGICAL SETTING: The site is underlain by shale of the Vermilion River Formation. Shale outcrops are common and the drift is less than 10 m thick.

GROUNDWATER IMPLICATIONS: The reservoir likely would not cause significant groundwater problems in the surrounding area.

SITE: No. 122

LOCATION: Squirrel Creek, NW18-11-11W

HYDROGEOLOGICAL SETTING: The bedrock at this site consists of Jurassic Formations. The shale is overlain by more than 120 m of drift comprising thick clay, silty clay, sand and glacial till beds. Sand layers are common in the upper part of the surficial deposits and form the most common aquifers at the site and in the vicinity.

GROUNDWATER IMPLICATIONS: The reservoir likely would cause rise of water levels in shallow wells in the immediate vicinity, i.e., within one kilometre or so. The reservoir also could cause higher water table in the Almasippi sand areas north and northeast of the reservoir site.

SITE: No. 123

LOCATION: Spring Creek, NE15-15-14W

HYDROGEOLOGICAL SETTING: The bedrock in the area consists of Jurassic Formations comprising shale, limestone and gypsum beds. The depths to bedrock ranges from 65 m to 100 m. The surficial deposits consist of a thin silty and sandy layer at surface underlain by up to 35 m of glacial till that, in turn, is underlain by thick clay, silty clay and silt beds. The only potable water aquifers in the area are pockets of sand and gravel in the till.

GROUNDWATER IMPLICATIONS: The reservoir likely would cause rise of water levels in wells located less than 500 m from it. Some shallow pockets of dry sand and gravel near the reservoir may become water bearing.

- -

M. RUTULIS, P. ENG.
March 27, 1986

APPENDIX G

HYDROGEOLOGY

TABLE IA
LITHOSTRATIGRAPHIC NOMENCLATURE

For the Cretaceous Geology of the Manitoba Escarpment

Traditional (Used in Appendix G)

Klassen, Wyder and Bannatyne (1970)

Boissevain Fm.	
Riding Mountain Fm.	Coulter mbr.
Riding Mountain Fm.	Odanah mbr.
Riding Mountain Fm.	Millwood mbr.
Vermilion River Fm.	Pembina mbr.
Vermilion River Fm.	Boyne mbr.
Vermilion River Fm.	Morden mbr.
Favel Fm.	Assiniboine mbr.
Favel Fm.	Keld mbr.
Ashville Fm.	Upper
Ashville Fm.	Lower (Ash Sand)
Swan River Fm.	

Revised (Used in Appendix D)

McNeil & Caldwell (1981)

Boissevain Fm.		
Pierre Shale		Unnamed Coulter mbr.
Pierre Shale		Odanah mbr.
Pierre Shale		Millwood mbr.
Pierre Shale		Pembina mbr. *
Niobrara Fm.		
Morden Shale		
Favel Fm.		Assiniboine mbr.
Favel Fm.		Keld mbr.
Ashville Fm.	Upper	Belle Fourche Shale
Ashville Fm.	Lower	Westgate mbr.
Ashville Fm.	Lower	Newcastle Sst.
Ashville Fm.	Lower	Skull Creek Shale
Swan River Fm.		

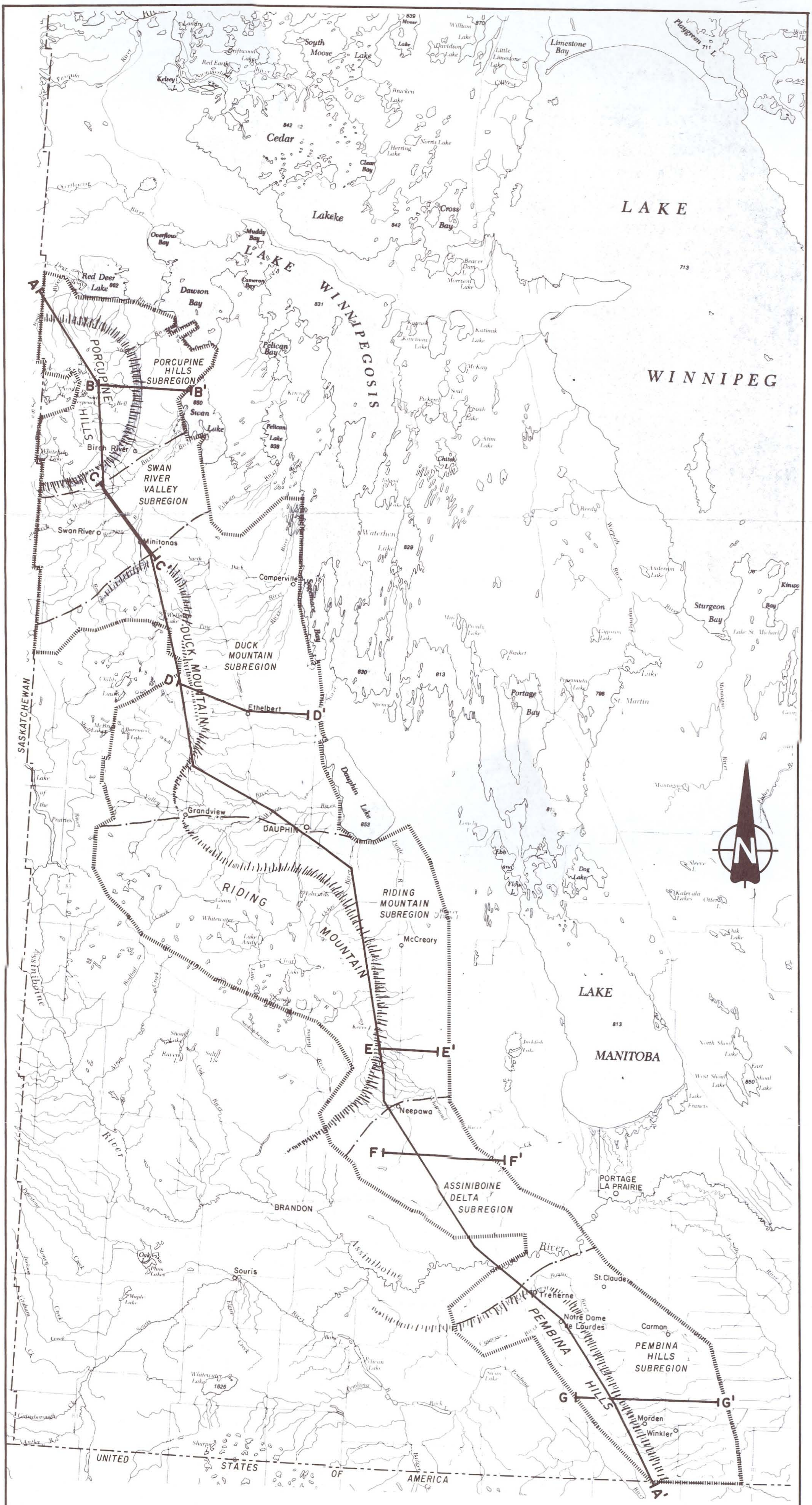
STRATIGRAPHIC-HYDROSTRATIGRAPHIC UNIT CORRELATION CHART
IN THE MANITOBA ESCARPMENT AREA

STRATIGRAPHY						HYDROSTRATIGRAPHY		
ERA	PERIOD	STRATIGRAPHIC UNIT: FORMATION	STRATIGRAPHIC UNIT: MEMBER	MAXIMUM THICKNESS METRES	BASIC LITHOLOGY	HYDROSTRATIGRAPHIC UNIT	MAXIMUM THICKNESS METRES	GEOHYDROLOGIC CHARACTERISTICS
CENOZOIC	RECENT			15	Alluvium, sanddunes, peat	Surficial deposits	275	Forms aquifers and aquitards. Main fresh water zone in much of the area (See Table II).
	PLEISTOCENE			275	Glacial deposits			
	EOCENE TO PALEOCENE NOT PRESENT			UNCONFORMITY				
MESOZOIC	CRETACEOUS	RIDING MOUNTAIN	ODANAH	200	Hard, siliceous shale	Odanah Shale	200	Fractured zones in the shale form aquifers. Fresh water zone.
			MILLWOOD	130	Soft, clayey shale	Cretaceous clayey shales	375	Extensive and thick aquitard.
		VERMILION RIVER	PEMBINA	30	Shale, bentonite beds			
			BOYNE	50	Calcareous shale			
			MORDEN	45	Calcareous shale, concretions			
		FAVEL		40	Shale, limestone bands			
		ASHVILLE		80	Silty, clayey shale			
		SWAN RIVER		105	Sand, sandstone, shale, clay	Swan River Formation	105	Sand and sandstone aquifer zone. Fresh and salty water.
		EROSIONAL DISCONTINUITY						
	JURASSIC	MELITA		65	Shale, limestone, sandstone	Jurassic shale and limestone	145	Limestone beds form aquifers. Shale aquitards. Fresh and salty water.
		RESTON		30	Limestone and shale			
		AMARANTH	EVAPORITES RED BEDS	50	Anhydrite, gypsum, shale, dolomite Dolomitic, shale to siltstone			
	TRIASSIC TO MISSISSIPPIAN NOT PRESENT.			UNCONFORMITY				
PALEOZOIC	DEVONIAN	SOURIS RIVER		50	Limestone, evaporite, shale	Paleozoic carbonate rock	400	Major aquifer system. Main salt-water transmission zone.
		DAWSON BAY		35	Limestone, anhydrite, shale			
		WINNIPEGOSIS *		60	Dolomite, reef and inter-reef			
		ELM POINT		15	High calcium limestone			
		ASHERN		15	Dolomite and shale			
	SILURIAN	INTERLAKE GROUP: CEDAR LAKE, EAST ARM, ATIKAMEG, MOOSE LAKE, INWOOD, FISHER BRANCH		75	Mainly dolomite			
	ORDOVICIAN	STONEWALL		15	Dolomite			
		STONY MOUNTAIN	WILLIAM	35	Dolomite			
			GUNTON					
			PENITENTIARY		Calcareous shale, limestone, dolomite.			
			GUNN					
		RED RIVER	FORT GARRY	125	Mottled dolomitic limestone, limestone, dolomite			
			SELKIRK		Dolomitic limestone, dolomite			
			CAT HEAD		Mottled limestone, dolomite			
			DOG HEAD					
		WINNIPEG		60	Sandstone, shale	Winnipeg sandstone	60	Major aquifer system. Mainly brine.
	NONCONFORMITY							
PROTEROZOIC ARCHEAN		PRECAMBRIAN ROCKS			Igneous and metamorphic rocks	Precambrian rock		Aquitard. Base of significant groundwater movement.

80-1-7-1038

* LOWEST FORMATION SUBCROPPING IN STUDY AREA.

REFERENCES: PLANNING DIVISION, 1972, 1973, 1976a, 1976b, 1978
DAVIES AND OTHERS, 1979
MANITOBA MINERAL RESOURCES DIVISION, 1979



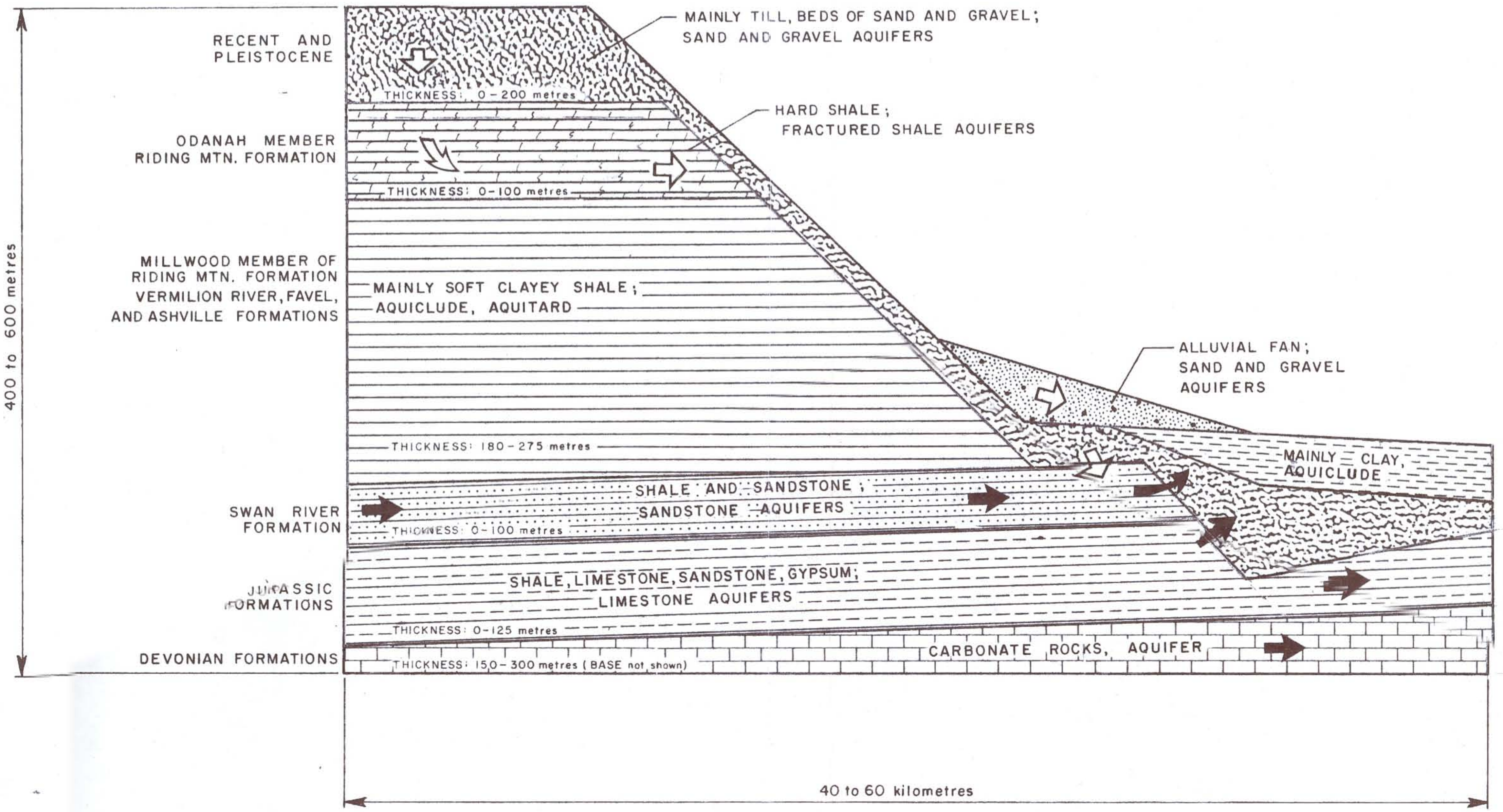
LEGEND

- STUDY AREA BOUNDARY
- SUBREGION BOUNDARY
- A—A' SECTION LINE
- MANITOBA ESCARPMENT

0 10 20 30 40 50 60
Scale In Kilometres

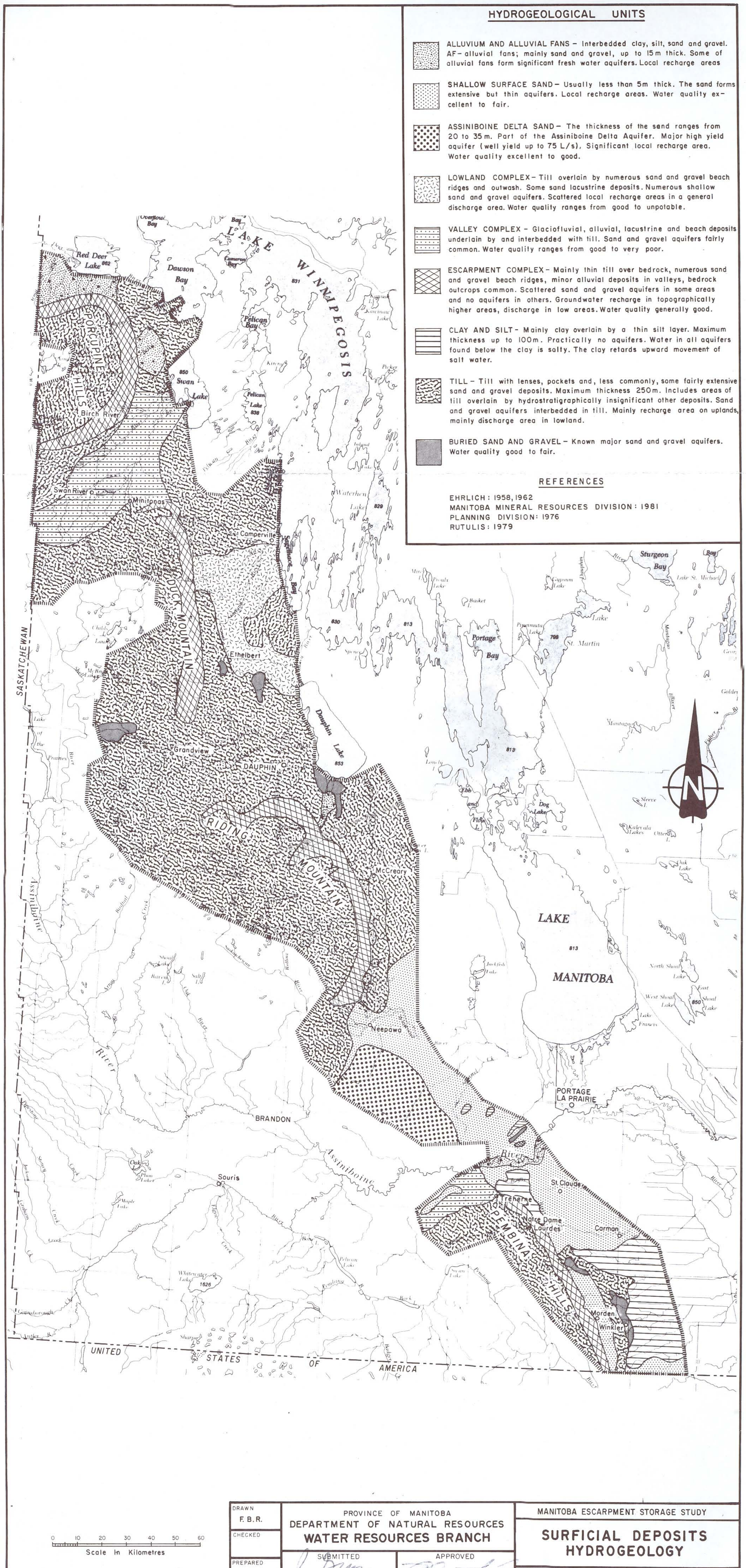
DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH		MANITOBA ESCARPMENT STORAGE STUDY			
CHECKED			STUDY AREA			
PREPARED M. Rutulis	SUBMITTED [signature]	APPROVED [signature]	SCALE AS SHOWN	DATE 85 06 14	SHEET 1 OF 12	FILE NO. 80-1-7-1038

FIGURE 1



DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES **WATER RESOURCES BRANCH**	MANITOBA ESCARPMENT STORAGE STUDY
CHECKED		SCHEMATIC HYDROGEOLOGICAL CROSS-SECTION OF MAN. ESCARPMENT & ADJACENT AREA
PREPARED M. Rutulis	SUBMITTED / APPROVED	SCALE: AS SHOWN · DATE: 85 06 14 · SHEET: 2 OF 12 · FILE NO.: 80-1-7-1038

FIGURE 2



DRAWN F.B.R.	PROVINCE OF MANITOBA	MANITOBA ESCARPMENT STORAGE STUDY		
CHECKED	DEPARTMENT OF NATURAL RESOURCES	SURFICIAL DEPOSITS		
	WATER RESOURCES BRANCH	HYDROGEOLOGY		
PREPARED M. Rutulis	SUBMITTED	APPROVED		
	SCALE AS SHOWN	DATE 85 06 14	SHEET 3 OF 12	FILE NO. 80-1-7-1038

FIGURE 3

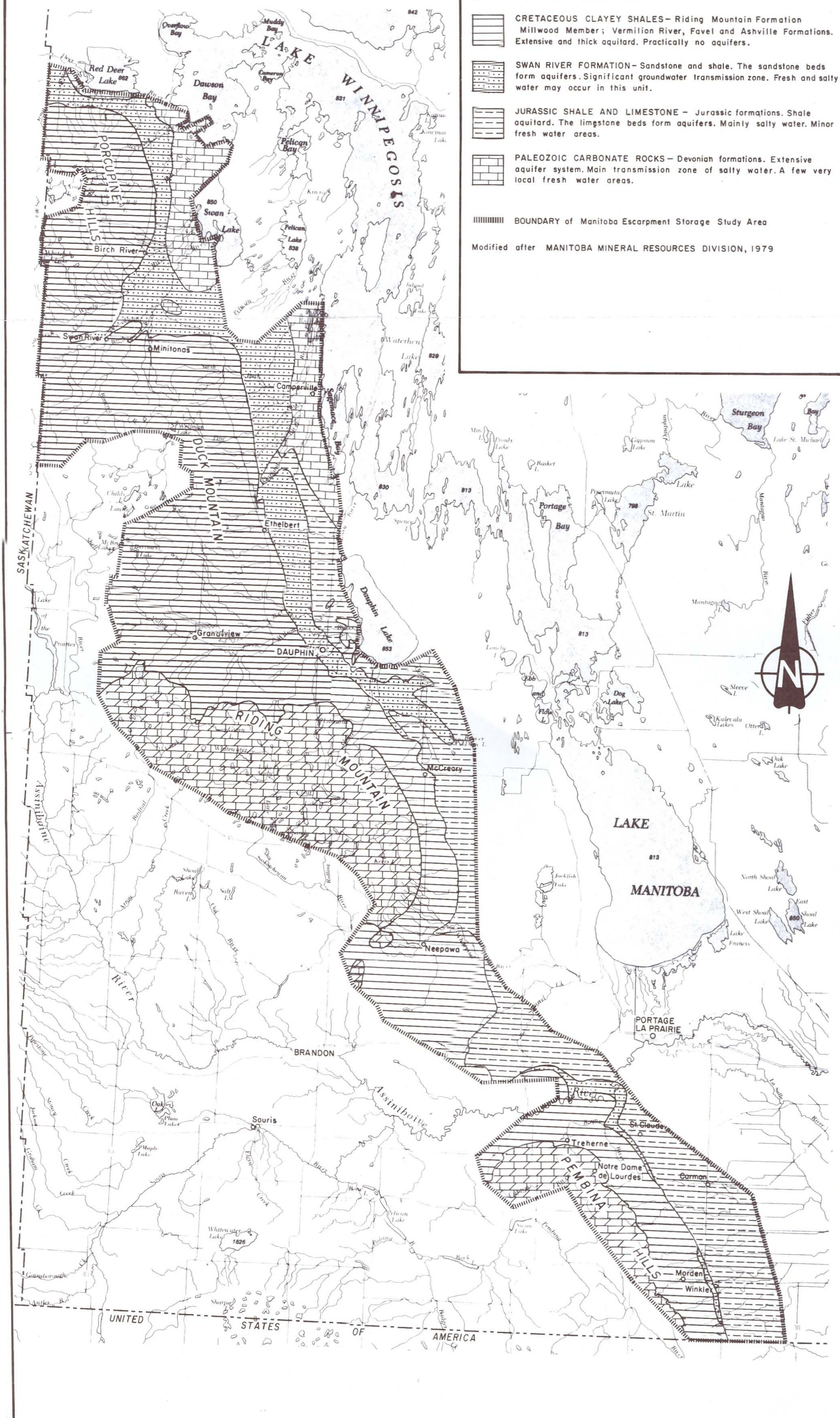
LEGEND

HYDROSTRATIGRAPHIC UNITS

- ODANAH SHALE - Odanah Member of Cretaceous Riding Mountain Formation. Hard, fractured; extensive low yield fresh water aquifer. Good to poor quality water.
- CRETACEOUS CLAYEY SHALES - Riding Mountain Formation Millwood Member; Vermilion River, Favel and Ashville Formations. Extensive and thick aquitard. Practically no aquifers.
- SWAN RIVER FORMATION - Sandstone and shale. The sandstone beds form aquifers. Significant groundwater transmission zone. Fresh and salty water may occur in this unit.
- JURASSIC SHALE AND LIMESTONE - Jurassic formations. Shale aquitard. The limestone beds form aquifers. Mainly salty water. Minor fresh water areas.
- PALEOZOIC CARBONATE ROCKS - Devonian formations. Extensive aquifer system. Main transmission zone of salty water. A few very local fresh water areas.

IIIIIIIIIII BOUNDARY of Manitoba Escarpment Storage Study Area

Modified after MANITOBA MINERAL RESOURCES DIVISION, 1979

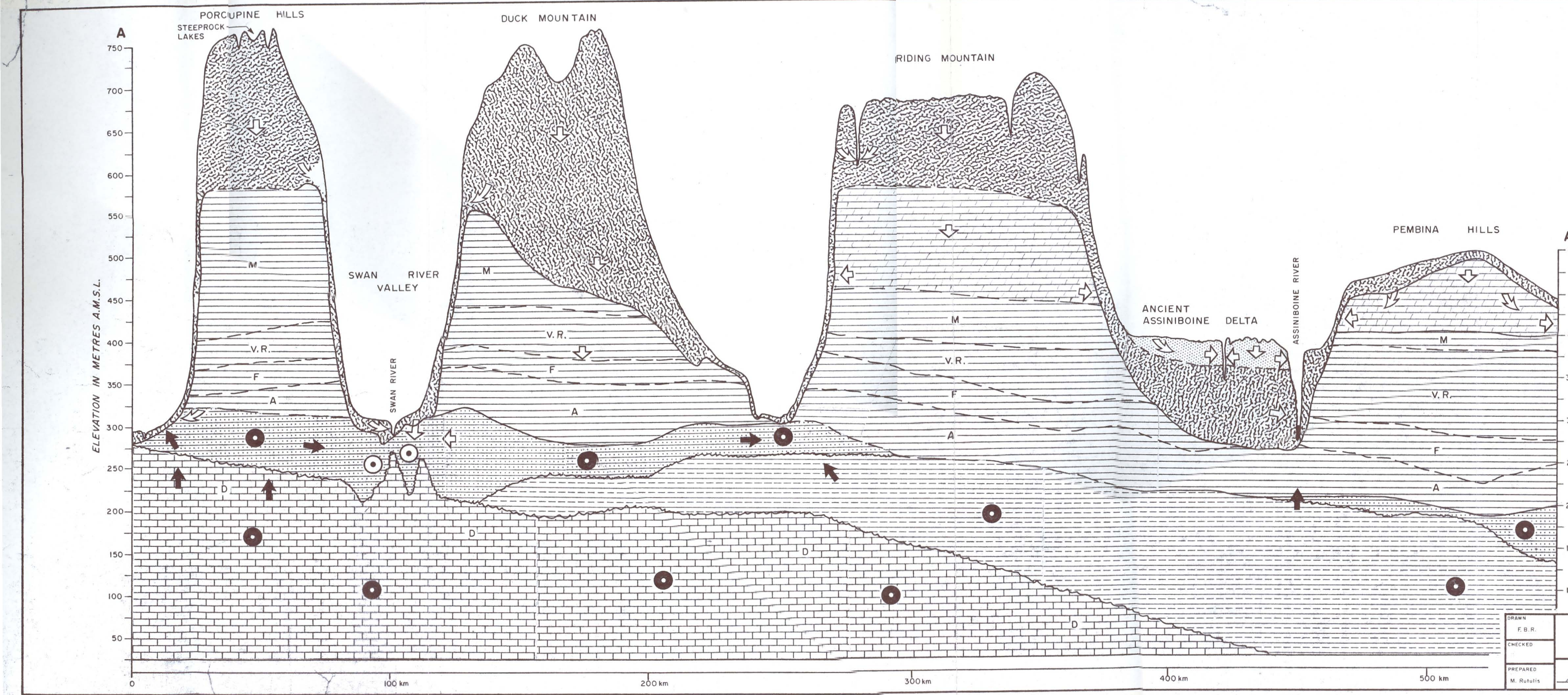


0 10 20 30 40 50 60

Scale In Kilometres

DRAWN B.R. / CHECKED	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	MANITOBA ESCARPMENT STORAGE STUDY
PREPARED M. Rutulis	SUBMITTED / APPROVED	BEDROCK HYDROGEOLOGY
		SCALE AS SHOWN · DATE 85 06 14 · SHEET 4 OF 12 · FILE NO. 80-1-7-1038

FIGURE 4



HYDROSTRATIGRAPHIC UNITS

- SURFICIAL DEPOSITS, UNDIVIDED
- ASSINIBOINE DELTA AQUIFER — MAJOR SUBUNIT OF SURFICIAL DEPOSITS
- ODANAH SHALE, AQUIFER
- CRETACEOUS CLAYEY SHALES, AQUITARD
  - M — MILLWOOD MEMBER, RIDING MOUNTAIN FORMATION
  - V.R. — VERMILION RIVER FORMATION
  - F — FAVEL RIVER FORMATION
  - A — ASHVILLE FORMATION
- SWAN RIVER FORMATION, AQUIFER SYSTEM
- JURASSIC SHALE AND LIMESTONE — MAINLY AQUITARD, SOME AQUIFERS
- PALEOZOIC CARBONATE ROCKS — MAJOR AQUIFER, MAIN SALT WATER TRANSMISSION ZONE
  - D — DEVONIAN FORMATIONS

PROBABLE DOMINANT DIRECTION OF GROUNDWATER FLOW

a) In section plane:

- *Fresh Water*
- *Salt Water*

b) Perpendicular to section plane — TOWARDS BACK OF DIAGRAM (EASTERLY)

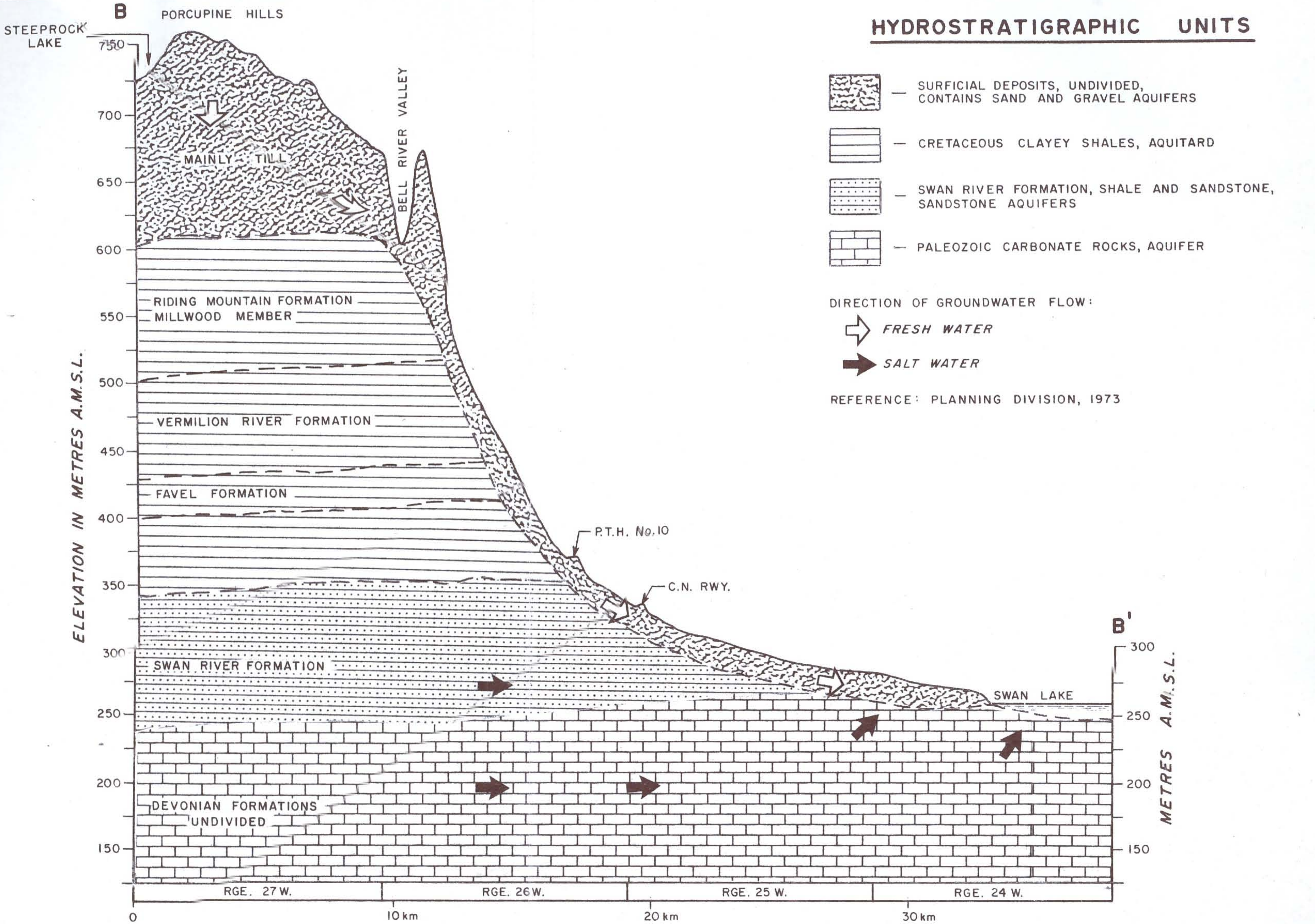
- *Fresh Water*
- *Salt Water*

NOTE: Exaggerated Scale! Drawn to true scale the section would only be 0.75 mm high: Ex. Porcupine Hills would be: ______

REFERENCES: LITTLE – 1973 a,b; 1981
PLANNING DIVISION – 1971, 1972, 1973, 1976 a,b; 1978, 1980

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH		MANITOBA ESCARPMENT STORAGE STUDY
CHECKED			SECTION A–A' LONGITUDINAL SECTION THROUGH STUDY AREA
PREPARED M. Rutulis	SUBMITTED [signature]	APPROVED [signature]	SCALE AS SHOWN · DATE 85 06 14 · SHEET 5 OF 12 · FILE No: 80-1-7-1038

FIGURE 5

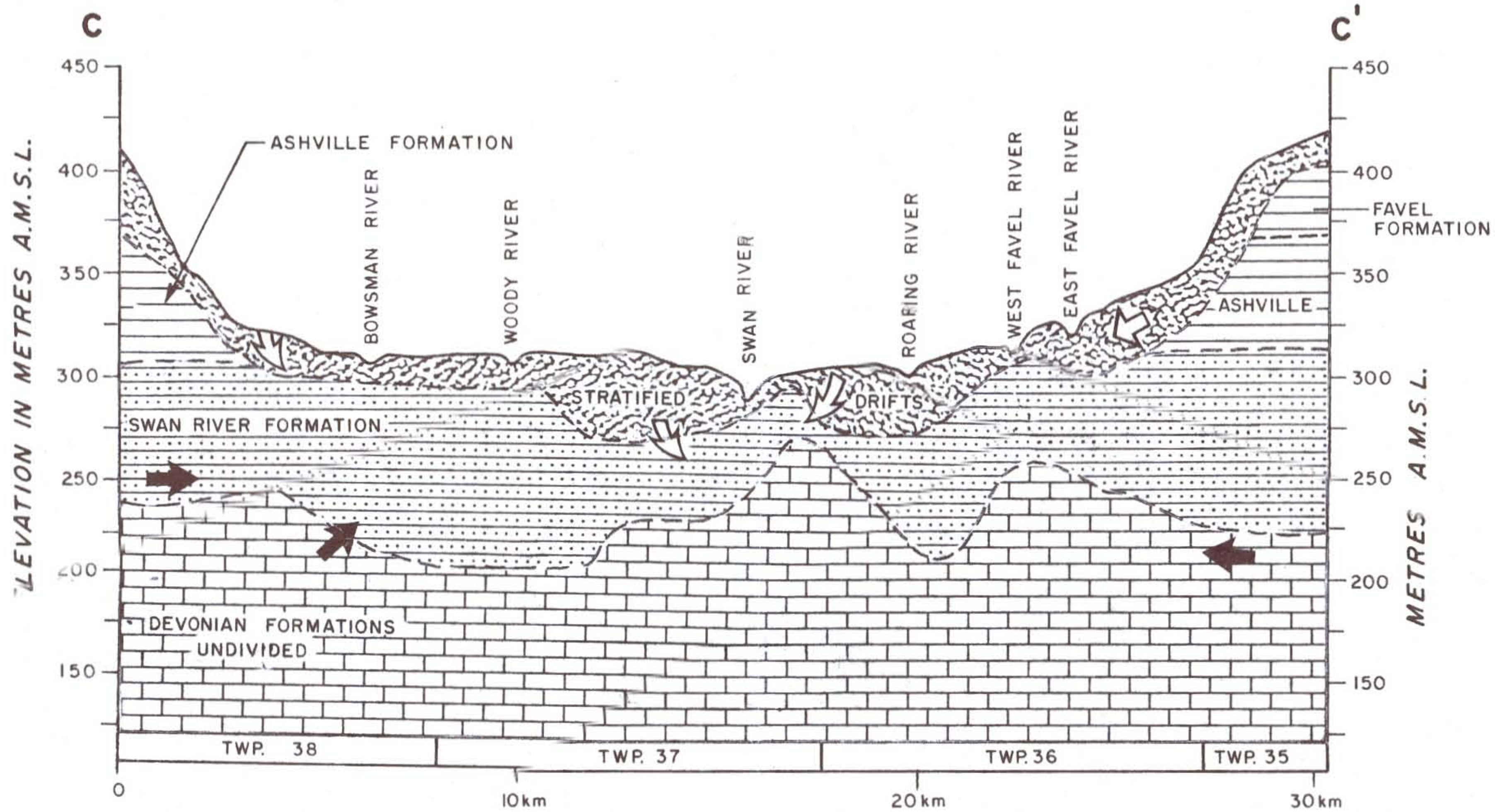


DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES **WATER RESOURCES BRANCH**	MANITOBA ESCARPMENT STORAGE STUDY
CHECKED		**SECTION B-B'** PORCUPINE HILLS SUBREGION
PREPARED M. Rutulis	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 85 06 14 · SHEET 6 OF 12 · FILE NO. 80-1-7-1038

FIGURE 6

HYDROSTRATIGRAPHIC UNITS

- SURFICIAL DEPOSITS, UNDIVIDED, CONTAINS SAND AND GRAVEL AQUIFERS
- CRETACEOUS CLAYEY SHALES, AQUITARD
- SWAN RIVER FORMATION, SHALE AND SANDSTONE, SANDSTONE AQUIFERS
- PALEOZOIC CARBONATE ROCKS, AQUIFER



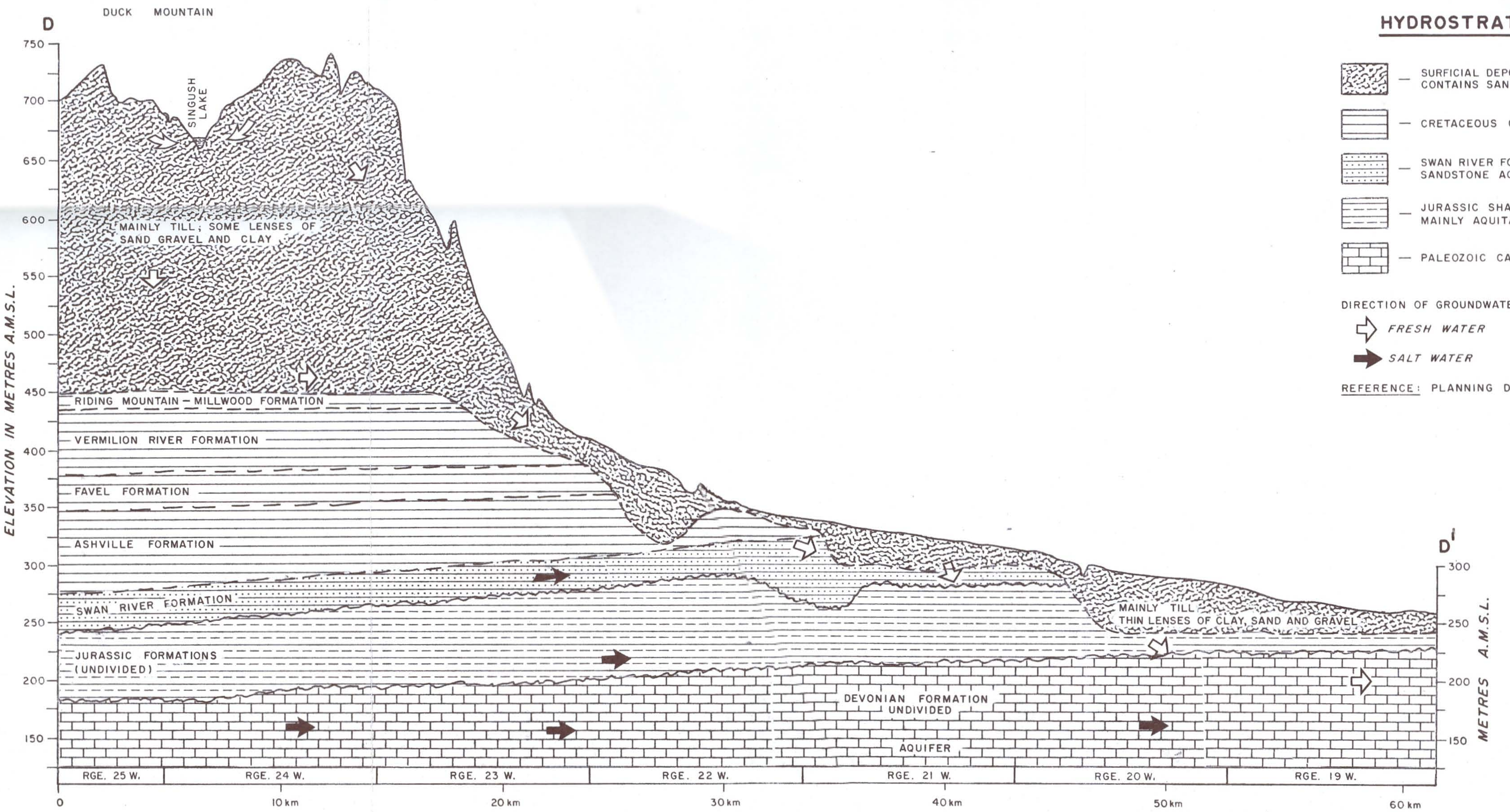
DIRECTION OF GROUNDWATER FLOW:

- FRESH WATER
- SALT WATER

REFERENCE: PLANNING DIVISION, 1973

DRAWN F.B.R.	PROVINCE OF MANITOBA	MANITOBA ESCARPMENT STORAGE STUDY
CHECKED	DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	SECTION C-C' SWAN RIVER VALLEY SUBREGION
PREPARED M. Rutulis	SUBMITTED / APPROVED	SCALE AS SHOWN; DATE 85 06 14; SHEET 7 OF 12; FILE NO. 80-1-7-1038

FIGURE 7



HYDROSTRATIGRAPHIC UNITS

- SURFICIAL DEPOSITS, UNDIVIDED, CONTAINS SAND AND GRAVEL AQUIFERS
- CRETACEOUS CLAYEY SHALES, AQUITARD
- SWAN RIVER FORMATION, SHALE AND SANDSTONE, SANDSTONE AQUIFERS
- JURASSIC SHALE AND LIMESTONE MAINLY AQUITARD, SOME AQUIFERS.
- PALEOZOIC CARBONATE ROCKS, AQUIFER

DIRECTION OF GROUNDWATER FLOW:

- *FRESH WATER*
- *SALT WATER*

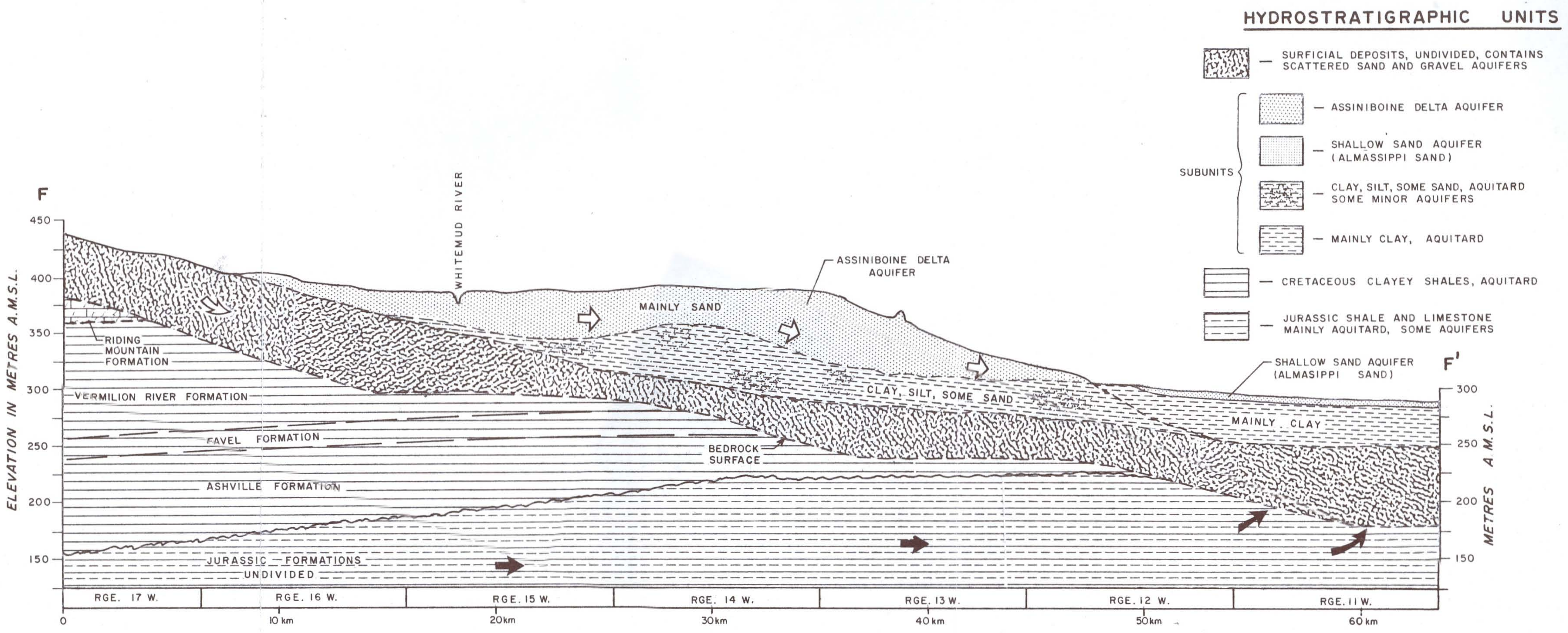
REFERENCE: PLANNING DIVISION, 1976 b

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	MANITOBA ESCARPMENT STORAGE STUDY
CHECKED		**SECTION D–D'** DUCK MOUNTAIN SUBREGION
PREPARED M. Rutulis	SUBMITTED / APPROVED	SCALE AS SHOWN · DATE 85 06 14 · SHEET 8 OF 12 · FILE NO. 80-1-7-1038

FIGURE 8

Figure 9

For a copy of this figure, contact Groundwater Management



DIRECTION OF GROUNDWATER FLOW:

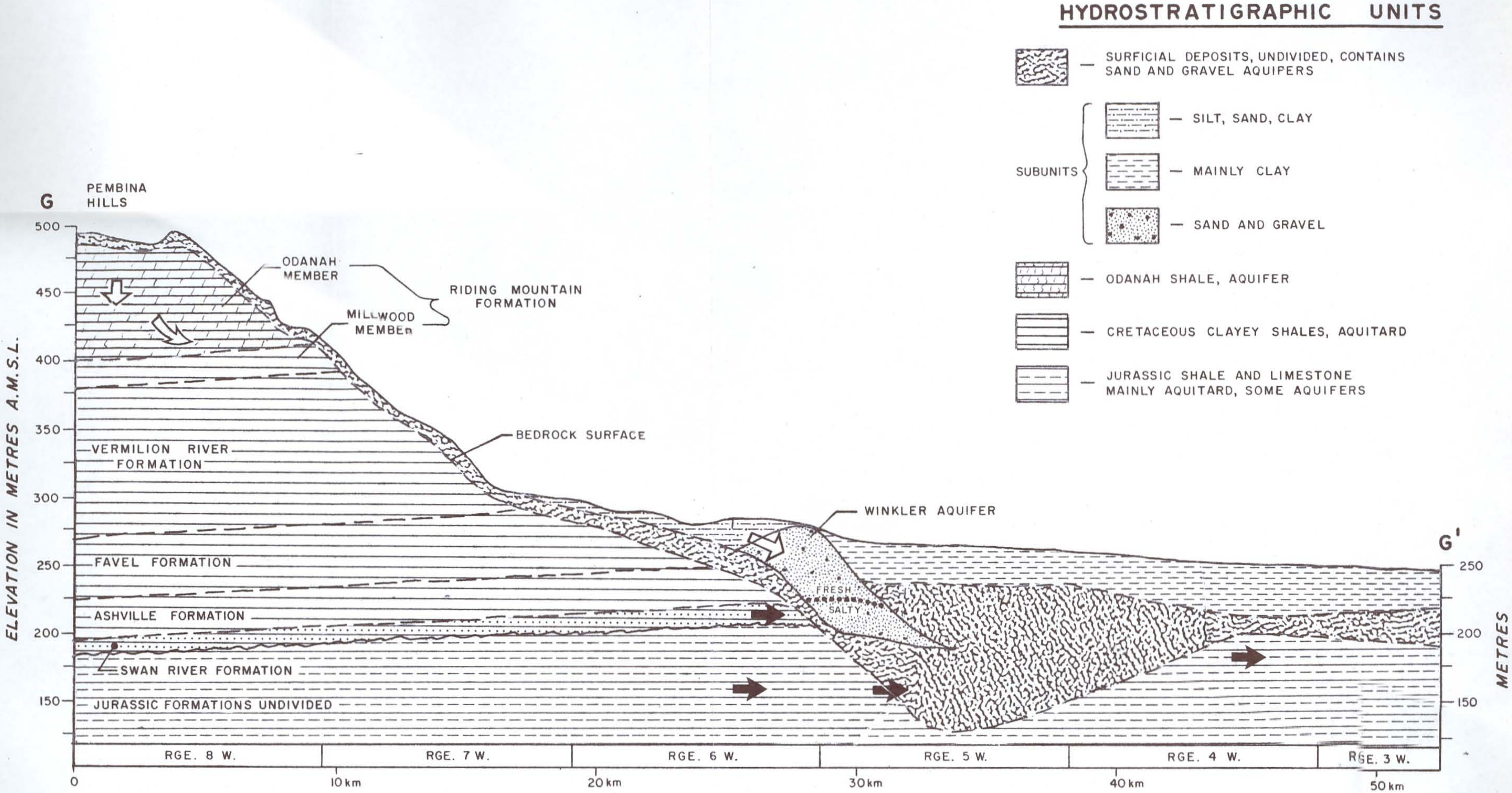
FRESH WATER

SALT WATER

REFERENCE: PLANNING DIVISION, 1979

DRAWN F.B.R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH		MANITOBA ESCARPMENT STORAGE STUDY SECTION F-F' ASSINIBOINE DELTA SUBREGION
CHECKED			
PREPARED M. Rutulis	SUBMITTED	APPROVED	SCALE AS SHOWN · DATE 85 06 14 · SHEET 10 OF 12 · FILE NO. 80-1-7-1038

FIGURE 10



DIRECTION OF GROUNDWATER FLOW:

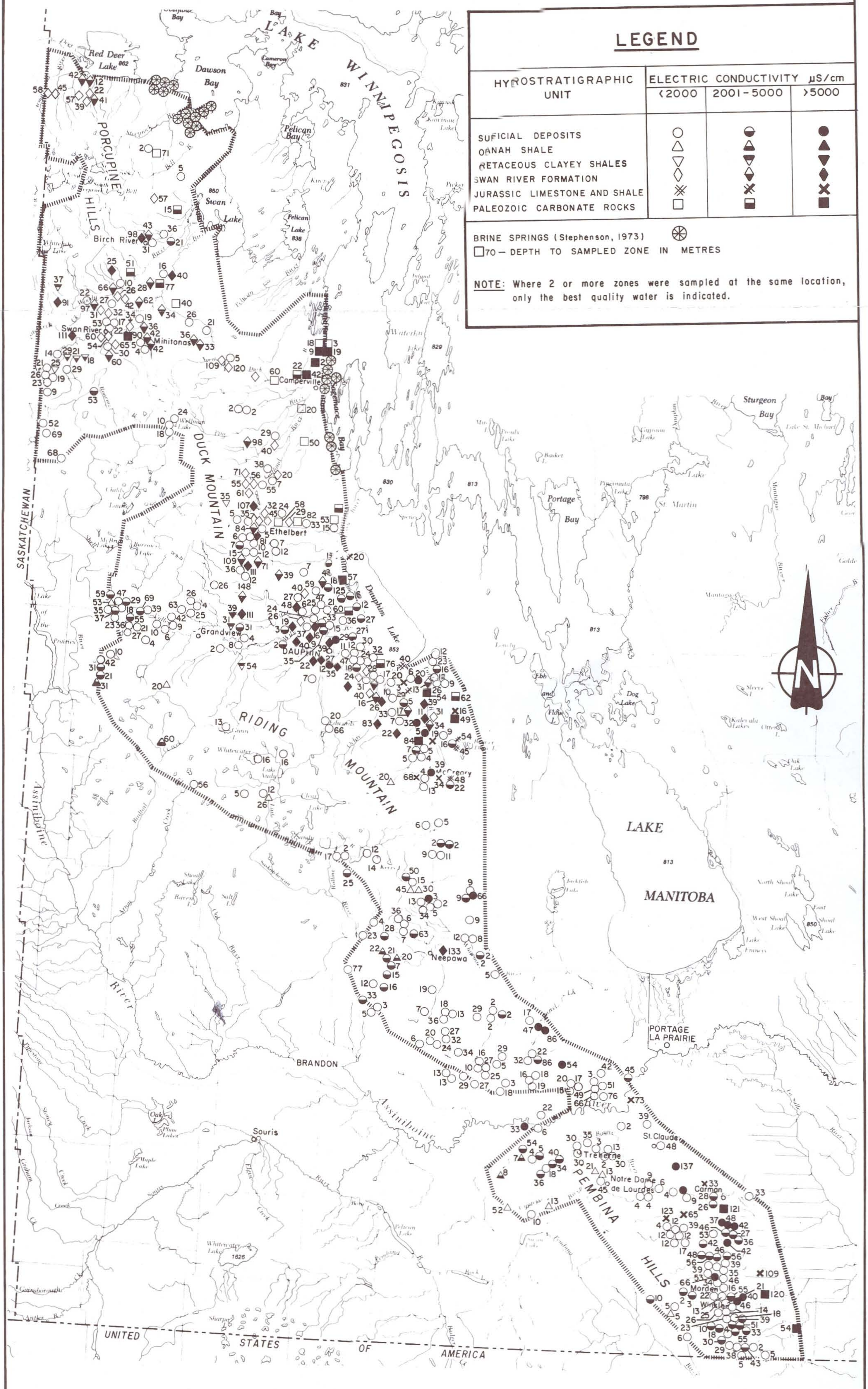
FRESH WATER

SALT WATER

REFERENCE: PLANNING DIVISION; 1976a, 1980
RUTULIS 1979

DRAWN F. B. R.	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH		MANITOBA ESCARPMENT STORAGE STUDY
CHECKED			SECTION G–G' PEMBINA HILLS SUBREGION
PREPARED M. Rutulis	SUBMITTED	APPROVED	SCALE AS SHOWN · DATE 85 06 14 · SHEET 11 OF 12 · FILE NO. 80-1-7-1038

FIGURE 11



0 10 20 30 40 50 60

Scale In Kilometres

DRAWN B.R. / CHECKED	PROVINCE OF MANITOBA DEPARTMENT OF NATURAL RESOURCES WATER RESOURCES BRANCH	MANITOBA ESCARPMENT STORAGE STUDY
PREPARED M. Rutulis	SUBMITTED / APPROVED	GROUNDWATER ELECTRIC CONDUCTIVITY
		SCALE AS SHOWN · DATE 85 06 14 · SHEET 12 OF 12 · FILE NO. 80-1-7-1038

FIGURE 12