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GROUNDWATER IN MANITOBA:

HYDROGEOLOGY, QUALITY CONCERNS, MANAGEMENT

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ERRATA:

Page 13, the first sentence beneath the heading "***Groundwater Flow Systems" should read "The point-water potentionmetric surface****…"

Page 13, the caption for Figure 8 should read "***Point-water potentionmetric surface and expected regional groundwater flow in the Winnipeg Formation***"

ABSTRACT

Groundwater forms an important source of municipal, industrial, agricultural and residential water supply in Manitoba. Groundwater is available from a number of extensive bedrock aquifers along the margins of Hudson Bay and within the Western Canada Sedimentary Basin and from sand and gravel aquifers found within glacial deposits in many parts of the province. The geological framework for these aquifers is presented and the major aquifer units discussed in terms of occurrence, groundwater availability, yield and water quality.

Groundwater quality is highly variable in most aquifer units in Manitoba. Groundwaters become increasingly saline with depth in most bedrock and some sand and gravel aquifers. Salinity also increases from east to west in most bedrock aquifers in the Western Canada Sedimentary Basin. The concentrations of several naturally occurring constituents exceed drinking water guidelines locally. Many aquifers are poorly protected from near-surface contamination sources and, as a result, anthropogenic contamination has been found in some areas. The major groundwater quality management concerns include underground storage tanks, agricultural activities, saline water intrusion and waste disposal.

Provincial legislation relating to water resources and groundwater protection is summarized. Two agencies, Manitoba Natural Resources and Manitoba Environment, have primary responsibility for the development and administration of this legislation and for the provision of groundwater monitoring, mapping and analysis. These agencies are also responsible for ensuring that groundwater development takes place in a sustainable manner.

RÉSUMÉ

Au Manitoba, les eaux souterraines constituent une partie importante de l'approvisionnement municipal, industriel, agricole et résidentiel. Ces eaux sont contenues dans un certain nombre de vastes aquifères du substrat rocheux situés sur les bords des bassins sédimentaires de la baie d'Hudson et de l'ouest du Canada, ainsi que dans des aquifères de substrat de sable ou de gravier qu'on trouve dans des dépôts glaciaires à de nombreux endroits de la province. Leur structure géologique est présentée, et les principaux aquifères font l'objet d'une discussion portant sur leur nombre, leur production, et le volume et la qualité des eaux qu'ils renferment.

La qualité des eaux souterraines varie beaucoup dans la plupart des aquifères du Manitoba. Dans la majorité des aquifères de substrats rocheux et dans beaucoup d'aquifères de substrat de sable ou de gravier, la salinité des eaux augmente avec la profondeur. Elle augmente aussi lorsque l'on se déplace d'est en ouest dans la plupart des aquifères du bassin sédimentaire de l'ouest du Canada. À certains endroits, la concentration de plusieurs éléments naturels dépasse les normes fixées pour l'eau potable. Beaucoup d'aquifères sont mal protégés des sources de pollution proches de la surface et, par conséquent, on y a trouvé dans certaines régions une pollution anthropique. Parmi les principaux problèmes concernant la qualité de l'eau figurent les réservoirs souterrains de stockage, les activités agricoles, la pénétration d'eau salée et l'enfouissement des déchets.

On donne par ailleurs un résumé de la législation provinciale portant sur les ressources en eau et la protection des eaux souterraines. Ressources naturelles Manitoba et Environnement Manitoba sont les deux ministères chargés de l'élaboration et de la mise en oeuvre de cette législation. Ils s'occupent aussi de la surveillance, de la cartographie et de l'analyse des eaux souterraines, et veillent à ce que l'exploitation de cette ressource se fasse de manière durable.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the many individuals whose hard work and dedication over the past several decades has provided the excellent level of understanding of groundwater conditions in Manitoba which has been summarized in this report. Chief among these have been a number of provincial hydrogeologists: L. Gray, M. Rutulis, F. Render, A. Pedersen. J. Little and D. Sie.

The authors would also like to express our appreciation to the numerous individuals who reviewed this report and provided valuable constructive comments. Thanks also to J. Jewell for typing and retyping the seemingly endless drafts of the report while maintaining her sense of humour and to R. Palka who drafted the figures and organized the document.

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INTRODUCTION

This report describes the groundwater resources and quality in Manitoba, environmental concerns relating to groundwater quality, and the tools available for groundwater management and protection (legislation, institutions and programs). It is one of a series of reports that cover the 10 provinces and two territories of Canada.

The primary focus of this report is on groundwater quality but groundwater resources and management of these resources are also discussed in recognition of the close relationship between quality and quantity. Also discussed are instruments for management directed primarily at protecting surface water or drinking water, but used also to protect groundwater. It should also be recognized that in some cases groundwater is protected mainly because it may be a pathway for contamination of surface water.

The report is organized into five sections:

1) a description of the regional physical hydrogeology of Manitoba and a discussion of groundwater quality,

2) groundwater quality concerns caused either by human activity or of natural origin,

3) the legal basis for groundwater management ("legislative instruments"),

4) the provincial institutions for groundwater management ("institutional instruments"), and

5) specific programs (i.e. monitoring, data collection, classification and management plans, technical and financial assistance, etc.).

The report was produced jointly by Environment Canada (the State of the Environment Reporting and the National Hydrology Research Institute) and the Manitoba Department of Natural Resources. Many provincial and federal officials provided support and assistance in the form of information and reviews. Because the responsibility for our water resources lies primarily with the provincial governments, and it is the provincial officials who deal with groundwater on a regular basis, their support and collaboration is particularly valuable.

This report, together with those of the other provinces and territories, has several purposes. First, the reports will form the basis for a forthcoming overview of groundwater in Canada. That overview will be part of the new federal effort to report on the state of the environment in Canada, an effort tied to the goal of sustainable development. Second, the report attempts to provide comprehensive information on the different concerns and activities related to groundwater in the province. Thus this report can be useful for anyone involved in groundwater, be they the public, consultants, industry or officials of different levels of government. In effect, the report can form a bridge between different groups and help them to understand more fully each others' concerns, goals and endeavours. Finally, we want to provide a description of how groundwater concerns are dealt with in the various jurisdictions of Canada. We hope this may lead to increased awareness and form the basis for future collaboration.

As will be apparent throughout the report, the tools for groundwater management are mostly legislation, institutions or programs developed for overall water management, or for the management of waste, pesticides and other potential pollutants rather than for groundwater management alone. This may reflect the nature of groundwater management, indicating that groundwater and its management should be considered as one component part of a much larger scheme of land and water management, not as an isolated concern.

1. HYDROGEOLOGY

1.1 PHYSIOGRAPHY, DRAINAGE AND CLIMATE

1.1.1 Physiographic Regions

Manitoba may be divided into four physiographic regions: the Precambrian Shield which covers about 60% of the province, the Hudson Bay Lowland, the Manitoba Lowland and the Manitoba Upland. The latter two form the Western Glaciated Plains region of Lennox et al. (1988). These regions are shown on *Figure 1*.

The Precambrian Shield physiographic region stretches from northwestern to southeastern Manitoba and consists of a hummocky terrain of eroded crystalline bedrock, partly to mostly covered by Quaternary deposits. Surface elevation generally does not exceed 350 m above sea level with relief seldom exceeding 30 m. Much of the land surface is occupied by swamp and muskeg. Drainage is generally poor.

The Hudson Bay Lowland physiographic region is an area of low relief and poor drainage lying along the southwestern shores of Hudson Bay. This area is underlain by Paleozoic carbonates on which rest variable thicknesses of calcareous tills and marine and non-marine sands, silts and clays.

The Manitoba Lowland is an area of gentle relief lying to the east of the Manitoba Escarpment. This area is underlain by gently southwestward dipping Paleozoic and Mesozoic sediments consisting mainly of carbonate rocks with some clastic and argillaceous units. Bedrock is overlain by glacial tills and proglacial lacustrine sediments. The major lakes of Manitoba occupy portions of this lowland area.

The Manitoba Upland lies to the west of the Manitoba Escarpment. Bedrock consists of Mesozoic and Cenozoic shales and sandstones with minor limestones and evaporites. This is an area of rolling hills grading into a series of uplands known as the Porcupine Hills, Duck Mountain, Riding Mountain, the Pembina Hills and Turtle Mountain. Elevations locally exceed 800 m above sea level.

1.1.2 Drainage

The major lakes of the Manitoba Lowland act as collectors for drainage within the southern part of the province. Drainage is directed through Lake Winnipeg into the Nelson River system which discharges into Hudson Bay. The surface water drainage basins of Manitoba are shown on *Figure 2*.

Major rivers entering southern Manitoba from the west include the Saskatchewan carrying drainage from much of southern Alberta and Saskatchewan, with discharge into Lake Winnipeg at Grand Rapids, and the

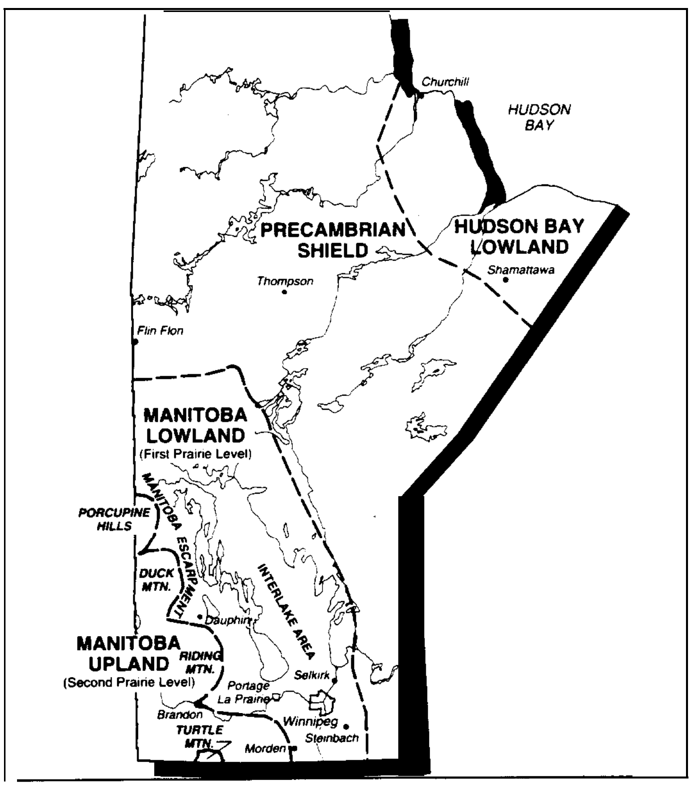


Figure 1. Physiographic regions of Manitoba.

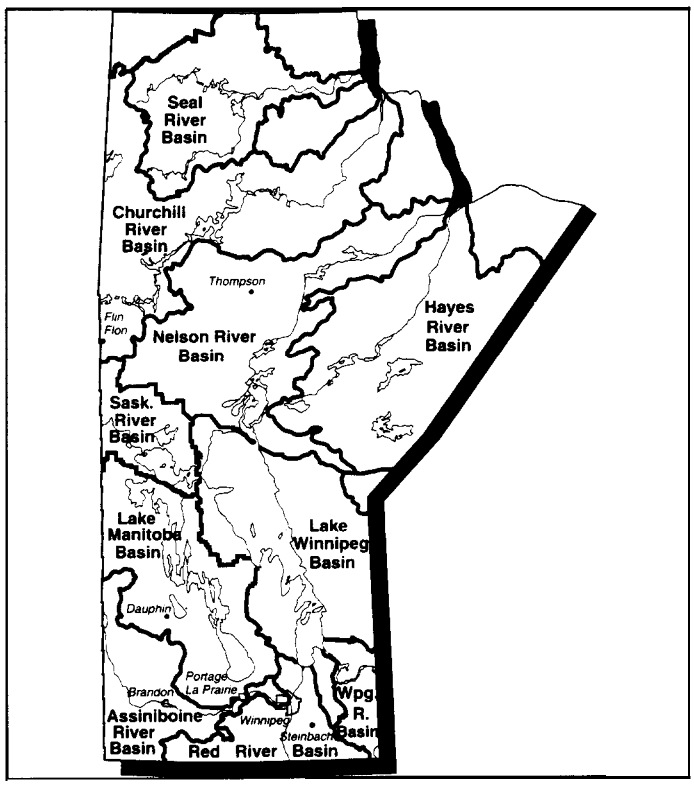


Figure 2. Surface water drainage.

Assiniboine and Souris which carry drainage into Manitoba from southeastern Saskatchewan and northwestern North Dakota. The central part of the Manitoba Upland and the western Interlake drain into Lakes Manitoba and Winnipegosis through a series of smaller streams. Discharge from the Lake Manitoba basin flows into Lake Winnipeg via the Dauphin River.

The Red River enters southern Manitoba at Emerson, carrying run-off water from parts of Minnesota, North Dakota and South Dakota. The river then collects drainage from much of southcentral Manitoba before converging with the Assiniboine River at Winnipeg and continuing northward, discharging into Lake Winnipeg. The Red River drainage basin occupies an area of about 111,000 km^2 of which about 100,000 km^2 lies in the United States. Lake Winnipeg also receives drainage from southeastern and eastern Manitoba, parts of northwestern Ontario and the eastern Interlake. The Winnipeg River forms the major source of inflow to the lake from the east. It drains an area of about 150,000 km^2, extending eastward into northwestern Ontario almost to Lake Superior and southward into Minnesota. Outflow from the lake occurs into the Nelson River, which forms one of a series of large river systems, including the Hayes, Churchill and Seal, which carry run-off from northern and central Manitoba into Hudson Bay.

Drainage and surface water flow patterns have been extensively modified within southern Manitoba over the past hundred years. Major hydroelectric dams have been constructed on the Saskatchewan and Winnipeg River systems and numerous smaller dams have been built on most other river systems to regulate water levels and create reservoirs. Drainage of marshes and swamps has occurred to improve or develop agricultural land. A network of drains has been constructed to minimize flooding and to rapidly remove excessive amounts of rainfall or snowmelt from agricultural land. In northern Manitoba, hydroelectric dam construction and water diversion have been carried out on the Churchill and Nelson River systems.

1.1.3 Climate

Manitoba's climate is continental, characterized by large seasonal variations in temperature and precipitation. The mean annual temperature varies from 3.3°C in parts of the south to -7.3°C in the far north. Winters are cold with January mean temperatures varying from -18°C in the south to -28°C in the far north. July is the warmest month with mean temperatures varying from 20°C in the south to 12°C in the far north.

Average annual precipitation ranges from a high of approximately 600 mm in the southeastern corner of the

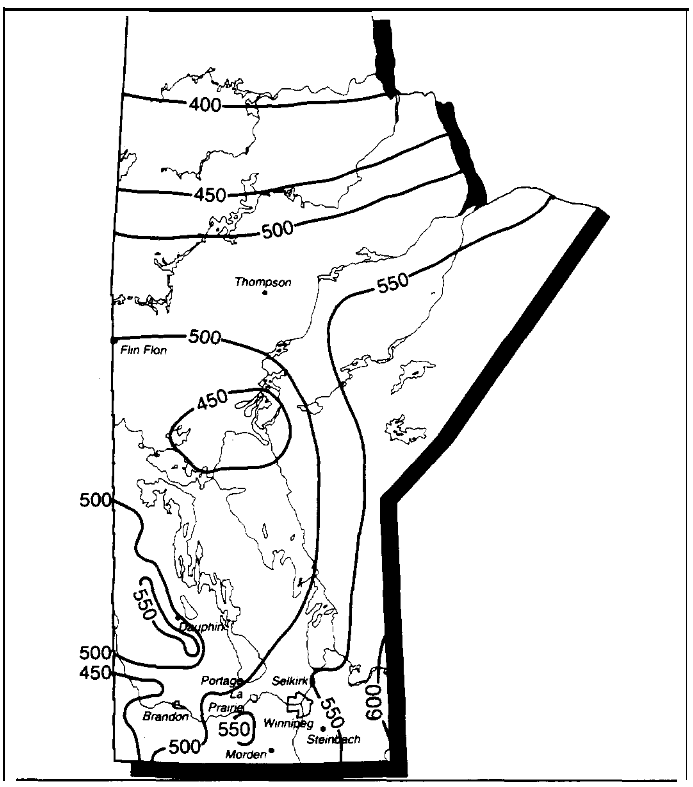


Figure 3. Mean annual precipitation in millimetres, 1951 - 1980.(Environment Canada, 1982).

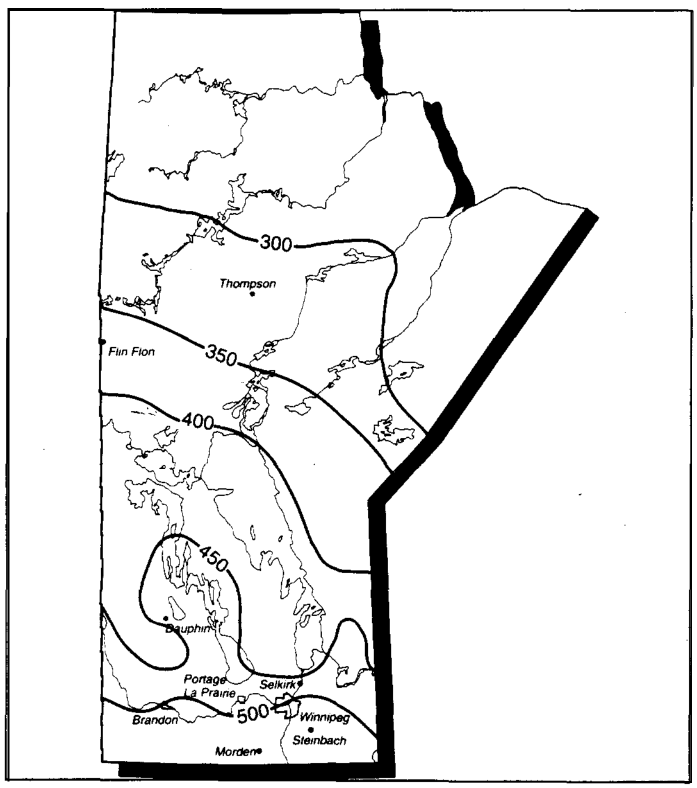


Figure 4. Mean annual potential evapotranspiration in millimetres, 1931 - 1960. (Agriculture Canada, 1976).

province to about 400 mm in northern Manitoba *(Figure 3)*. About two-thirds of annual precipitation falls from May to October, generally as showers and intense thunder-showers. Annual snowfall ranges from 120 cm in the south to 170 cm in the north. Evapotranspiration is relatively high in the south, exceeding 450 mm, but declines to less than 300 mm in the north *(Figure 4).*

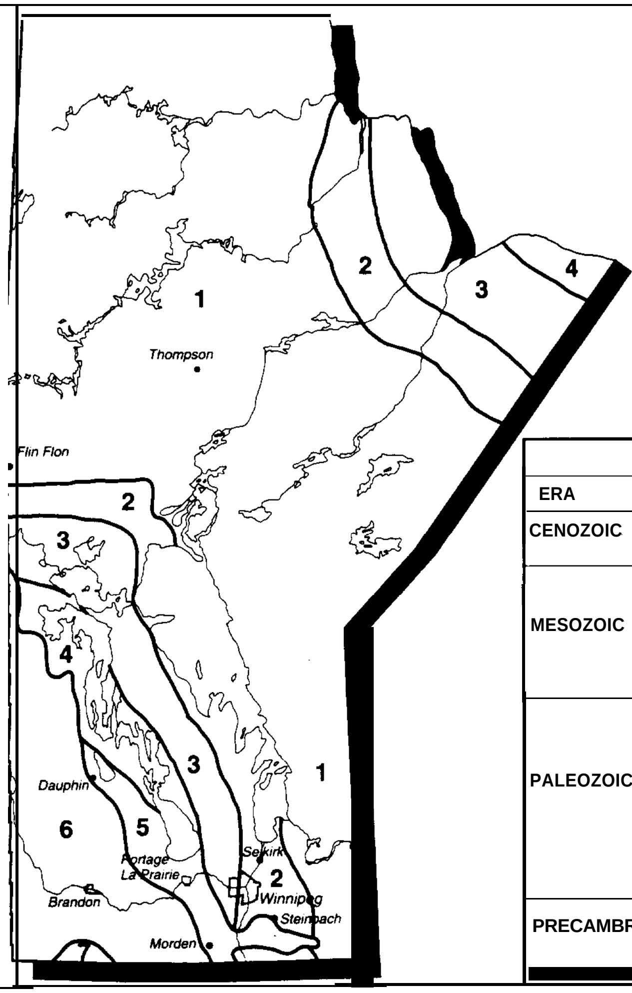
1.2 BEDROCK GEOLOGY

Bedrock units in Manitoba consist of sedimentary rocks found in two large depositional basins occupying the southwestern and northeastern parts of the province, and a large area of Precambrian igneous and metamorphic rocks which occupies most of northern Manitoba and stretches south and east to the Ontario border *(Figure 5)*.

Sediments in the northern basin, known as the Hudson Bay Basin (HBB), consist of Paleozoic carbonates with minor argillaceous and clastic rocks. These bedrock units dip gently northeastward at 2 to 7 m/km toward the depositional centre of the basin located within Hudson Bay, attaining a maximum thickness of about 1800 m (Sanford et al., 1968).

Bedrock in the southcentral and southwestern parts of Manitoba consists of Paleozoic, Mesozoic and Cenozoic rocks that form the eastern edge of the Western Canada Sedimentary Basin (WCSB). Paleozoic rocks are primarily carbonates with minor clastics and evaporites while Mesozoic rocks are dominantly shales with lesser amounts of sandstones, carbonates and evaporites. Paleozoic rocks in this basin dip gently toward the southwest at 2 to 10 m/km with the dip increasing toward the southwest. Mesozoic rocks are flatter lying, dipping at 1 to 3 m/km toward the southwest. Cenozoic rocks are found only in the Turtle Mountain area and dip gently toward the south. The bedrock geology within the WCSB is summarized in *Table 1*.

Precambrian rocks form the bedrock throughout most of northern and eastern Manitoba. Rocks belong to the Churchill and Superior Provinces and consist primarily of granitic and gneissic rock types.



LEGEND

ERA	PERIOD	MAJOR ROCK TYPES
CENOZOIC	7 TERTIARY	SHALE, SANDSTONE, SILTSTONE
MESOZOIC	6 CRETACEOUS	SHALE, MINOR SANDSTONE, AND LIMESTONE
	5 JURASSIC	SHALE, LIMESTONE, SANDSTONE, GYPSUM/ANHYDRITE
PALEOZOIC	4 DEVONIAN	DOLOSTONE, LIMESTONE, SHALE, EVAPORITES
	3 SILURIAN	DOLOSTONE, SHALE
	2 ORDOVICIAN	DOLOSTONE, LIMESTONE. SHALE, BASAL SANDSTONE
PRECAMBRIAN 1		IGNEOUS AND METAMORPHIC CRYSTALLINE ROCKS

Figure 5. Generalized bedrock geology of Manitoba.

ERA	PERIOD	FORMATION (GROUP)	MEMBER	BASIC LITHOLOGY	THICKNESS METRES	HYDROSTRATIGRAPHIC UNITS AQUIFERS AND AQUITARDS	
CENOZOIC	Quat. Recent			Soil, alluvial deposits, sand dunes, bogs			OVERBURDEN UNIT
	Quat. Pleistocene			Glacial deposits	0—260		
	Tertiary Eocene to Pliocene	Not reported in Manitoba					UPPER CLASTIC UNIT
	Tertiary Paleocene	Turtle Mountain		Shale, sandstone, lignite	—145+	sandstone aquifer	
MESOZOIC	Cretaceous	Boissevain		Sand and sandstone, greenish grey, kaolinitic shale	30—45		
		Pierre Shale	Coulter	Bentonitic clayey silt	20—55		
			Odanah	Hard grey siliceous shale	—245+	shale aquifer	
			Millwood	Greenish bentonitic shale	15—150		
			Pembina	Non-calc. shale, bentonite beds	2—12		
		Niobrara		Calcareous speckled shale	2—32	shale aquitard	
		Morden Shale		Carbonaceous shale, septarian concretions	15—60		
		Favel		Calc. speckled shale, limestone bands	18—40		
		Ashville (Ashville sand)		Non-calc. silty shale; 0-27m sand	37—113		
		Swan River		Sand, sandstone, shale, clay, lignite	0—120		
	Jurassic	Waskada		Varicoloured shale	0—50		
		Melita		Varicoloured shale, calc. shale, limestone	100—145	sandstone aquifers	
		Reston		Argillaceous limestone and shale	0—50		
		Amaranth	Upper evaporite	Anhydrite, gypsum, shale, dolostone	0—50		
			Lower red beds	Dolomitic shale to siltstone, anhydritic	0—42		
	Triassic	Not reported in Manitoba except Permian? Lake St. Martin cryptoexplosion structure					
PALEOZOIC	Permian						CARBONATE - EVAPORITE UNIT
	Pennsylvanian					evaporite aquitard	
	Mississippian	Charles		Dolostone and anhydrite	—37		
		Mission Canyon		Limestone, dolostone, anhydrite; oil production	80—100		
		Lodgepole	Whitewater Lake Virden Scallion Routledge	Limestone, argillaceous and cherty; shale, oil production	145—175	carbonate aquifer	
		Bakken		Black shale and siltstone	3—15		
	Devonian	Qu'Appelle Group	Three Forks	Red dolomitic shale	11—55	shale aquitard	
		Saskatchewan Group	Birdbear	Fossiliferous limestone and dolostone	12—43		
			Duperow	Shaly limestone, dolostone, anhydrite; cyclical	120—195		
		Manitoba Group	Souris River First Red	Limestone, evaporite, shale; cyclical	65—95	carbonate aquifer	
			Dawson Bay Second Red	Limestone, anhydrite, basal red shale	42—67		
		Elk Point Group	Prairie Evaporite	Halite, with potash, anyhdrite, dolostone	0—130		
			Winnipegosis	Dolostone, reef and inter-reef	9—107	evaporite aquitard	
			Elm Point	High-calcium limestone	0—14+		
			Ashern	Dolostone and shale, brick red	2—18		
	Silurian	Interlake Group		Dolostone	53—115		
	Ordovician	Stonewall		Dolostone	9—21		
		Stony Mountain	Gunton Penitentiary Gunn	Dolostone, upper part shaly Argillaceous dolostone Fossiliferous calc. shale; red, grey, green	30—50	carbonate aquifer	
		Red River	Fort Garry Selkirk Cat Head Dog Head	Dolostone, minor limestone Dolomitic limestone, mottled Dolostone, cherty Dolomitic limestone, mottled	53—150	sandstone aquifer	
		Winnipeg		Quartzose sand, sandstone; shale	0—67		BASAL CLASTIC UNIT
	Cambrian	Deadwood		Glauconitic sandstone	?		
PRECAMBRIAN							PRECAMBRIAN

Table 1. Geological formations and hydrostratigraphic units in the WCSB of Manitoba, (Adapted from Simpson et al., 1987.)

1.3 SURFICIAL GEOLOGY

The bedrock surface throughout most of Manitoba is covered by overburden of varying thickness consisting mainly of glacial tills, proglacial lacustrine sediments and shallow marine deposits. The thickest overburden is found in the Manitoba Upland where bedrock is typically covered by 20 to 40 m of glacial till, outwash, and lacustrine deposits; however thicknesses in this area range from less than 10 m northeast of Turtle Mountain to more than 120 m in some bedrock channels and 250 m in the Duck Mountain area.

Drift thickness in the Manitoba Lowland is quite variable. Overburden (primarily glacial till) thickness is less than 10 m throughout large parts of the western and northern areas of the Lowland but is generally somewhat greater near the Manitoba Escarpment. Drift thickness increases to more than 100 m southwest of Lake Manitoba and near the Manitoba-U.S.A. border where thick deltaic and glaciolacustrine deposits are found overlying the tills.

Bedrock in the Hudson Bay Lowland is covered by up to 30 m of till and shallow marine and non-marine deposits. The thickness of glacial and lacustrine sediments overlying the Precambrian Shield is variable but generally thin with bedrock outcrop being common in many areas. Where thick glacial moraine deposits were laid down, overburden thickness locally exceeds 100 m.

1.4 HYDROSTRATIGRAPHIC UNITS

The bedrock and surficial deposits of Manitoba can be divided into a series of hydrostratigraphic units. Maxey (1964) defined hydrostratigraphic units as “bodies of rock with considerable lateral extent that compose a geologic framework for a reasonably distinct hydrologic system”. The divisions that will be used in this paper are shown on *Table 1*. This table presents a modified version of the terminology proposed by Simpson et al. (1987) for southern and central Manitoba. Sedimentary rocks of the HBB, although not specifically shown in the table, form a northern extension of the basal clastic and carbonate-evaporite units.

Precambrian igneous and metamorphic rocks form the basal hydrostratigraphic unit. Groundwater flow in these rock types is predominantly through fractures. Bulk rock permeabilities are low although local permeabilities may be quite high in fracture zones. The rocks are generally relatively insoluble.

In the WCSB, the Precambrian basement is overlain by Cambrian and Ordovician sandstones and shales. These rocks are referred to as the basal clastic hydrostratigraphic unit. The sandstone aquifers in these formations are separated from the overlying, predominantly carbonate rocks by an upper shale that appears to act as a very effective aquitard throughout the southern part of the basin. In the northern part of the basin, the basal clastic unit consists primarily of sandstones and the upper shale may be missing. In this area the basal clastic unit is considered to form part of the overlying carbonate-evaporite hydrostratigraphic unit.

In the HBB a thin silica sandstone (and shale?) unit is found at the base of the Paleozoic succession. These strata are included as part of the overlying carbonate-evaporite unit.

The basal clastic unit is overlain by a thick sequence of Paleozoic carbonates with minor shales, sandstones and evaporites in both the WCSB and the HBB. Simpson et al. (1987) referred to these rocks as the carbonate-evaporite hydrostratigraphic unit. In the WCSB they subdivided this unit into two zones: the basal zone composed of formations that outcrop to the east and north of the overlying Mesozoic rocks and the upper zone composed of formations that subcrop beneath Mesozoic rocks.

Simpson et al. (1987) proposed that the Mesozoic and Cenozoic sediments overlying the carbonate-evaporite unit be considered a single hydrostratigraphic unit, which they termed the upper clastic unit. This is also the classification system used in Saskatchewan (Pupp et al., 1991). This terminology has been retained in this report; however, it should be recognized that while this unit, in the large sense, forms a regional aquitard, in Manitoba these sediments also contain a number of distinct strata that form widespread aquifers. These include the limestones of the Jurassic Reston and Melita Formations, the sandstones of the Swan River Formation, the fractured shales of the Odanah Member of the Pierre Shale and the sandstones of the Cretaceous Boissevain and Paleocene Turtle Mountain Formations. The argillaceous sediments separating each of these aquifers are regarded as aquitards.

Unconsolidated preglacial and Quaternary sediments in many areas of Manitoba also contain significant aquifers. The separation of these aquifers from one another prevents the sediments from being considered a single hydrostratigraphic unit under the definition given by Maxey (1964); however, for convenience the unconsolidated preglacial and Quaternary sediments found overlying bedrock will be termed the overburden unit. These sediments include many sand or sand and gravel aquifers lying within, underlying, or overlying less permeable tills or clays. Most of these aquifers have limited areal distribution although some surficial sands may extend for tens of kilometres as distinct geological units.

In the following sections the physical hydrogeology and hydrogeochemistry of the hydrostratigraphic units will be discussed within each of the three major physiographic units of the province. As well, each of the aquifers identified in the upper clastic unit of the Western Glaciated Plains physiographic region will be discussed in some detail.

1.5 PRECAMBRIAN SHIELD PHYSIOGRAPHIC REGION

The Precambrian Shield physiographic region occupies much of northern, central and southeastern Manitoba *(Figure 1)*. This area is generally sparsely populated and possesses an abundance of surface water resources. Consequently the demand for groundwater is low and, except for the southeastern part of the region, little is known about the distribution of aquifers, their yield or water quality. Within this region, groundwater supplies are available from Precambrian crystalline igneous and metamorphic rocks and from sand and gravel units in the overlying Quaternary sediments. Discussion in this report will deal primarily with southeastern Manitoba but reference will be made to other parts of the Shield where information warrants.

Hydrogeological studies of portions of the southeastern part of the region have been undertaken by several provincial and federal agencies. The Manitoba Water Resources Branch published a series of maps showing groundwater conditions and quality within parts of the area (Little, 1980; Betcher, 1985, 1986a). Rutulis (1979, 1982) discussed the hydrogeology of the Beausejour and Lac du Bonnet areas and Charron (1974) mapped the physical and geochemical hydrogeology of surficial aquifers lying west of the Winnipeg and Whitemouth Rivers. Lebedin (1978) carried out a test drilling program in the Beausejour area and identified several widespread sand and gravel aquifers. A study of the distribution and sources of uranium in groundwater in a part of this area was presented by Betcher et al. (1988). Atomic Energy of Canada Limited (AECL) is currently carrying out an intensive research effort to examine groundwater conditions within a portion of a granitic batholith east of the Town of Lac du Bonnet (Davison, 1984). This research is being undertaken as a component of their overall program of assessing the potential for deep disposal of high level radioactive wastes in igneous rocks. The Manitoba Water Services Board has also carried out a considerable amount of test drilling, local aquifer evaluation and water supply well installation for provincial parks in this area.

1.5.1 Precambrian Igneous and Metamorphic Rocks

The hydraulic conductivity of unfractured crystalline igneous and metamorphic rocks is typically very low, in the range of 10^{-9} m/s to 10^{-14} m/s or less (Brace, 1980). The porosity of these rocks is also very small, generally less than 2% (Freeze and Cherry, 1979). Most groundwater movement occurs through secondary permeability features consisting of joints, shears, or faults. The distribution of these features in the subsurface is very difficult to predict. Studies have indicated that large variations in the frequency of secondary features should be expected on both a local and a regional scale. The permeability of individual features may also show marked variations over short distances (Davison and Kozak, 1988). Snow (1970) and others (see review by Trainer, 1988) have indicated that the frequency and permeability of fractures decline with depth. The zone of active groundwater circulation is generally thought to be confined to the upper 60 to 150 m of bedrock where joints are more common and tend to be more open. More recent work has indicated that significant zones of secondary permeability may persist to depths well in excess of a kilometre (Trainer, 1988; Farvolden et al., 1988).

Detailed studies by AECL in southeastern Manitoba and northwestern Ontario have shown that many of the classical concepts of groundwater flow system development are applicable to Precambrian terraines, with modifications to incorporate the influence of structural features forming high permeability boundaries. The water table in these terrains has been found to form a subdued replica of the‘surface topography (Farvolden et al., 1988; Thorne and Gascoyne, 1993). Water table mounds and downward directed hydraulic head gradients have been mapped beneath bedrock knolls indicating groundwater recharge in upland areas, likely dominated by direct infiltration of rainfall and snowmelt into exposed fractures (Thorne and Gascoyne, 1993). Discharge occurs into adjacent, usually sediment or water filled, depressions where upward head gradients have been measured and flowing artesian conditions locally encountered. Recharge rates are very low; Thorne and Gascoyne (1993) estimate recharge to the granitic bedrock to be less than 5 mm/yr at a research site near Lac du Bonnet in southeastern Manitoba.

Major sub-vertical and sub-horizontal structural features, which may have permeabilities many orders of magnitude higher than the surrounding rock mass, exert strong controls on groundwater movement and the extent of flow system development (Farvolden et al., 1988; Davison, 1984). Generally however, Canadian studies have found fresh groundwater indicative of active groundwater flow, to depths of about 150 m. Salinity typically increases rapidly below this depth, indicating that groundwater movement and fluid exchange with the near-surface environment has become extremely sluggish.

Groundwater development from Precambrian rocks is quite limited in Manitoba, a consequence of the small demand for groundwater in this region and the uncertainty, low yield and considerable expense of drilling in igneous and metamorphic rocks. Sand/gravel aquifers provide a less expensive source for development of water supplies, where they are present. Most groundwater development from the Precambrian rock unit has taken place in cottage areas of southeastern Manitoba where Quaternary sand and gravel aquifers are sparsely distributed. Several hundred wells have been completed into the unit in this area. Reported well yields have ranged from "dry" holes to more than 14 L/s. A review of water well records for 196 wells in this area showed 53% reported yields less than 0.2 L/s and 85% reported yields below 1.0 L/s. Eleven per cent of the wells had reported yields in excess of 1.5 L/s. Specific capacities as high as 5.4 L/s/m have been reported but most specific capacities ranged from 0.01 to 0.001 L/s/m. Water producing zones were commonly found at depths in excess of 60 m and not infrequently at depths 100 m or more below the bedrock surface.

Groundwaters in igneous and metamorphic rock terrains generally consist of solutions of low total dissolved solids, developed by incongruent dissolution of aluminosilicate minerals. Sodium, calcium, magnesium and bicarbonate typically form the dominant dissolved constituents while chloride and sulfate tend to be found at low concentrations (Freeze and Cherry, 1979). Most analyses on file with Manitoba Water Resources were carried out on samples collected in the southeastern part of the province as part of a study of the occurrence of uranium in groundwaters in this area (Betcher et al., 1988). Somewhat surprisingly, the total dissolved solids (TDS) content of most of these groundwaters was quite high, averaging 1045 mg/L with some analyses showing several thousand mg/L. The dominant groundwater type was calcium-magnesium-sodium-bicarbonate-sulfate.(1) Betcher et al. (1988) proposed that this unusual groundwater quality reflected the influence of recharge waters having first undergone substantial geochemical development in clayey surficial deposits overlying the bedrock. Very few analyses are available for water samples from Precambrian rock wells completed in other parts of the province.

Detailed studies undertaken by AECL near Lac du Bonnet have found a complex pattern of fresh groundwaters overlying saline groundwater at depths greater than several hundred metres. Fresh groundwaters are Na - HCO_3 or Ca - HCO_3 types where recharge has occurred in exposed bedrock areas but Ca - Mg - HCO_3 - SO_4 type where bedrock is overlain by lacustrine clays (Davison, 1984). The origin of the high salinity found at depths is not well understood but, in this area at least, may reflect the intrusion of saline groundwater from Paleozoic sediments lying to the west or, perhaps, remnant marine waters from ancient inland seas that covered parts of Manitoba in the past (Gascoyne et al., 1989). A few shallower wells near the Winnipeg River have been found to contain similar groundwater quality to that found at depth by AECL, perhaps indicating upwelling of these waters near major groundwater discharge areas.

1.5.2 Sand and Gravel Aquifers

Precambrian bedrock is overlain in most areas by Quaternary deposits consisting of glacial tills, glaciolacustrine clays, silts and sands, emerged marine deposits and organics (Manitoba Mineral Resources Division, 1981). The thickness of these deposits is highly variable, ranging from extensive areas where bedrock outcrops are common to areas where glacial moraines and outwash deposits in excess of 100 m thick are found. An interesting feature of these Quaternary deposits is the widespread occurrence of glaciolacustrine and glaciomarine clays that were deposited in Lake Agassiz and the Tyrrell Sea. These clays overlie bedrock or glacial tills through much of the Precambrian Shield in the province and undoubtedly exert a considerable influence on recharge to, and water quality in, the underlying aquifers.

While the groundwater potential within surficial deposits over much of the Shield remains largely unexplored, a good understanding of the distribution of aquifers in Quaternary deposits in southeastern Manitoba has been developed and can serve as a model for groundwater exploration in other parts of this physiographic region. Widely distributed sand and gravel aquifers associated with a series of upland moraines and glaciofluvial deposits (Teller and Fenton, 1980) have been mapped in this area (Betcher, 1985; Lebedin, 1978; Charron, 1974). Sand and gravel thicknesses in excess of 30 m have been reported locally. These aquifers form the primary source of rural and community water supply in this area. Well yields locally exceed 5 L/s and the regional aquifer capacity may be substantial. A ground-

(1) *Groundwater geochemical types, as given in this report, include all anions or cations which comprise 20% or more of total equivalent anion or cation composition. Anions and cations are listed in decreasing percent equivalent order.*

water supply investigation near the Village of Piney for instance indicated a safe yield in excess of 190 x 10^6 L/yr from a sand and gravel aquifer found at depths from 23-53 m (KGS Group, 1993). Groundwater quality in these aquifers is generally excellent with TDS concentrations typically from 300 mg/L to 500 mg/L.

Outside areas of extensive sand and gravel aquifers associated with moraine and outwash complexes, surficial aquifers in other parts of southeastern Manitoba tend to be scattered and local in nature with little potential for substantial yields. Thin sand and gravel deposits are found in some areas at the till/bedrock contact, particularly in valley infill deposits. Inter-till sand and gravel aquifers are also found locally where thicker till deposits have been laid down. Some outwash sands and gravels, have also been developed for water supplies. In some areas large diameter bored wells have been completed in lacustrine silts and fractured clays where other aquifers are not present. Yields from most of these wells are very small, suitable only for individual dwellings. Water quality tends to be excellent in sand and gravel aquifers that receive direct recharge from rain or snow melt but TDS concentrations may exceed 1000 mg/L in deeper aquifers overlain by lacustrine clays.

1.6 HUDSON BAY LOWLAND PHYSIOGRAPHIC REGION

This region, bordering the southwestern shores of Hudson Bay, is underlain by bedrock consisting of a sequence of carbonate-dominated Paleozoic sediments overlying a thin basal sandstone that rests directly on Precambrian crystalline basement. Bedrock is overlain by a sequence of pre-Pleistocene, Pleistocene and recent unconsolidated sediments which locally may exceed 100 m in total thickness. In most areas, Pleistocene tills and outwash deposits are covered with a thin mantle of clays, silts, and sands laid down in Lake Agassiz and, near Hudson Bay, the Tyrrell Sea which covered much of the region following withdrawal of the Wisconsinan ice sheets. The area lies within the zone of discontinuous permafrost; much of the land surface consists of muskeg, bogs and swamps.

In this region, bedrock can be divided into two hydrostratigraphic units: the basal Precambrian igneous and metamorphic rock unit and the overlying carbonate-evaporite unit. The limited information available on the lithology of the basal sandstone in this region indicates that, regionally, it is likely hydraulically connected to the overlying carbonate rocks and therefore has been included as part of this unit.

There has been no water well development in the Precambrian rock unit in the Hudson Bay Lowland region. The hydrogeology of this unit is undoubtedly similar to the description given in Section 1.5.1, although the geochemical type and distribution of groundwater quality may differ. The following discussion of bedrock aquifers will be limited to the carbonate-evaporite unit.

1.6.1 Carbonate-Evaporite Unit

The carbonate-evaporite unit consists of limestones and dolostones with minor shale and sandstone of Ordovician through Devonian age. Sediments dip gently to the northeast at 2 to 7 m/km with a maximum onshore thickness of 884 m (Manitoba Mineral Resources Division, 1979). Due to the sparse population and low level of development within this region, there has been very little exploration for, or development of, groundwater. Consequently, little information is available on the hydrogeology of this aquifer unit although it is expected to have similar physical properties to the carbonate-evaporite unit found in southern Manitoba (see Section 1.7.1.2).

Groundwater movement occurs principally through an extensive network of discontinuities consisting of joints, bedding planes, and solution features. The density and interconnection of discontinuities exhibits considerable spatial variability, both laterally and vertically. In those areas or strata where the development of solution features and solution-enlarged joints or bedding planes has been most pronounced, very high bulk-rock hydraulic conductivities may be present and the carbonates will form a productive aquifer. Conversely, where massive sparsely jointed sediments are found, the bulk-rock hydraulic conductivity may be very low and the unit will function locally as an aquitard.

The only parts of the region where exploration has provided a good local understanding of the carbonate-evaporite unit have been sites where exploration for or development of hydroelectric dams has been undertaken. Over the past several years Manitoba Hydro has gathered a considerable amount of information on the hydrogeology of the Silurian and Ordovician portions of this unit near the site of the proposed Conawapa generating station on the Nelson River, about 100 km upstream of Hudson Bay. Extensive test drilling has been undertaken to define the local geology and the type and distribution of secondary features in these carbonates. Water pressure tests using single and double packer arrangements have been conducted in numerous test holes and pumping tests have been carried out at several locations as part of water supply development for construction camp and potential town sites. The following description of the hydrogeology of this site has been taken from several internal Manitoba Hydro memoranda kindly supplied by J. Ellis, Exploration Department, Manitoba Hydro.

The carbonate-evaporite unit at the Conawapa site is overlain by 30 to 80 m of overburden consisting of preglacial gravels and sands, glacial tills with some sand and gravel and postglacial silts and clays. Bedrock consists of 35 to 60 m of limestones and dolostones overlying a thin argillaceous sandstone that rests directly on weathered Precambrian basement. Static water levels in the bedrock unit at the site lie a few metres above the bedrock surface and slope very gently toward the Nelson River. Water levels in the aquifer respond to water level changes in the river.

Water pressure testing indicates variable but generally good to excellent hydraulic conductivities in the carbonate rock section. Intervals several metres in length isolated with double packers typically show hydraulic conductivities from 10^{-3} to $5x10^{-3}$ cm/s with values exceeding 10^{-2} cm/s in some zones. The lower 10 m or so of the carbonate section at the site appears to have a consistently lower hydraulic conductivity. Pumping tests carried out on the aquifer at rates from 5.6 to 31.5 L/s provide bulk-rock hydraulic conductivity values ranging from $1x10^{-3}$ cm/s to $2.4x10^{-3}$ cm/s. Storativity values ranged from $5x10^{-4}$ to $2x10^{-3}$.

Groundwater quality at the site reflects primary geochemical development in a carbonate-rich environment at low temperature (for a comprehensive discussion of this topic, refer to Freeze and Cherry, 1979, pages 261 to 268). Groundwaters are slightly alkaline calcium-magnesium-bicarbonate type with TDS concentrations from 400 to 450 mg/L. Sulfate concentrations are generally less than 60 mg/L. Sodium and chloride generally occur at low concentrations; however, groundwaters with elevated sodium and chloride concentrations have been found in some holes. The TDS concentrations of some of these samples exceed 1,300 mg/L. Elevated sodium and chloride concentrations likely reflect an influence from the marine waters of the Tyrrell Sea which invaded this isostatically depressed region about 8,000 years BP. A similar groundwater quality has been found at Shamattawa (see *Figure 1* for location) where individual wells completed into the carbonate-evaporite unit provide the water supply for the community. Chloride concentrations range from 44-59 mg/L and sodium concentrations exceed 100 mg/L in this area. Some wells in the community also produce flammable gas (S. Cook, Health Canada, personal communication).

1.6.2 Sand and Gravel Aquifers

The authors are not aware of any studies of the groundwater supply potential of overburden sand and gravel aquifers undertaken in the Hudson Bay physiographic region. Undoubtedly, inter-till and intra-till outwash and other sand and gravel aquifers are widely distributed in the region as in other glaciated parts of the province. The potential for water supply from these units is unknown. Water quality in some aquifers may be affected by remnant salinization as discussed above.

1.7 WESTERN GLACIATED PLAINS PHYSIOGRAPHIC REGION

This region encompasses most of southern and central Manitoba, excluding only the southeastern part of the province and the area east of Lake Winnipeg *(Figure 1)*. Bedrock consists of Paleozoic carbonates and minor shales and sandstones overlying Precambrian basement throughout the eastern part of the region and Mesozoic and Cenozoic shales with minor sandstones, carbonates and evaporites overlying Paleozoic rocks throughout the western part of the region *(Figure 5)*. A cross-section along the Manitoba-U.S.A. border showing hydrostratigraphic units within the WCSB is given in *Figure 6*. Bedrock is overlain by a variable thickness of Quaternary deposits ranging from broad areas of thin overburden in the Interlake region and parts of southcentral Manitoba to areas where overburden thicknesses exceed 100 m in the southwestern and southcentral uplands. Glacial tills form the dominant overburden material but significant areas of glaciolacustrine clays, silts, and sands are also found in the region. Considerable development of groundwater resources has taken place, providing a good base of information on groundwater occurrence and quality in both bedrock and overburden aquifers.

1.7.1 Bedrock Aquifers

1.7.1.1 Basal Clastic Unit

The basal clastic unit consists of sandstones and shales of the Winnipeg and Deadwood Formations. The Winnipeg Formation is a marine silica sandstone and shale sequence that directly overlies the weathered and peneplaned Precambrian bedrock surface throughout the Manitoba portion of the WCSB, excluding the extreme southwestern corner of the province where it is underlain by glauconitic sandstones and shales of the Cambrian Deadwood Formation. The remainder of the discussion of this unit will consider only the Winnipeg Formation aquifer; the Deadwood Formation has very limited distribution in the province and has no potential for potable groundwater development.

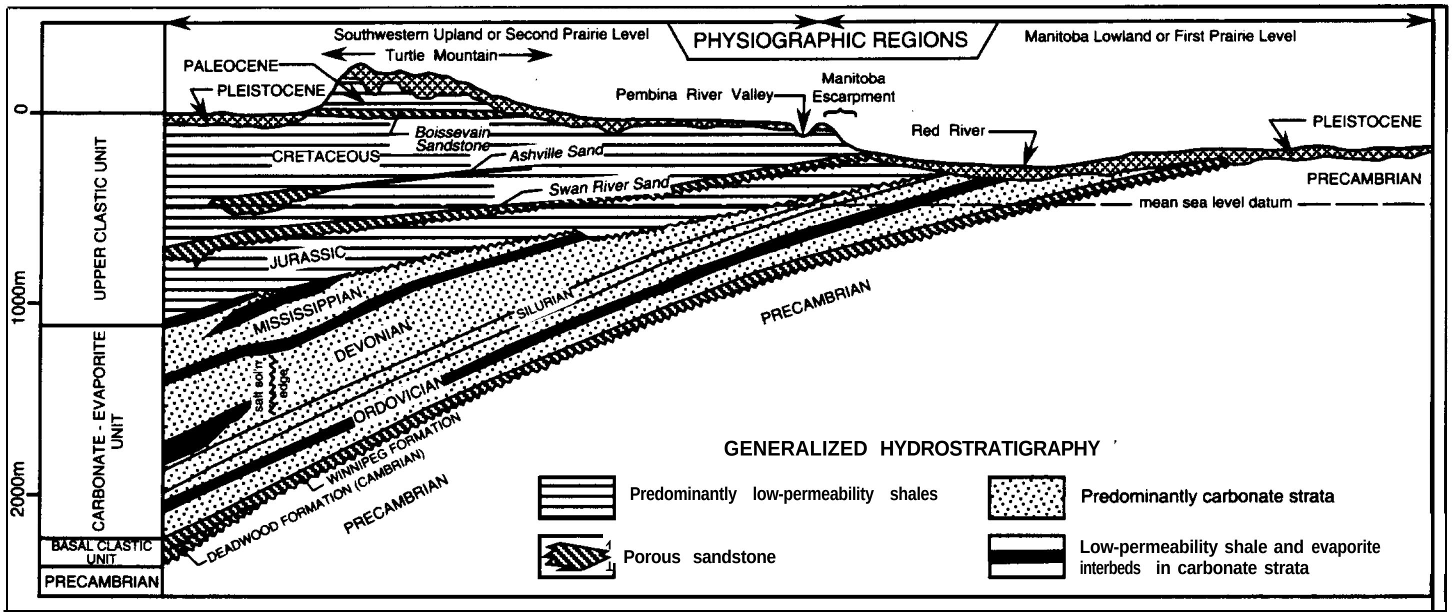


Figure 6. Geologic cross-section along Manitoba-U.S.A. border. Vertical exaggeration approximately 50:1 (modified from Simpson et al., 1987).

The Winnipeg Formation consists of a sequence of interlayered shales and variably cemented, very fine to coarse grained, silica sandstones. The thickness of the formation ranges from about 30 to 60 m in the southern part of the province but thins to less than 5 m along the northern edge of the WCSB *(Figure 7)*. Sandstone forms the dominant lithology in the northern and central parts of the Basin where the total sandstone thickness exceeds 30 m in places. (McCabe, 1978, Figures 12 and 14). Farther south the number and thickness of sandstone beds generally decline and shales predominate, particularly in the upper half of the formation. Total sandstone thickness is less than 6 m in parts of southcentral Manitoba.

The "Carman sand" forms an anomalous thickening of the sandstone section in the upper Winnipeg Formation in a portion of southern Manitoba. This east-west trending body of uniform, well sorted, clean sandstone stretches from the outcrop area westward for approximately 150 km *(Figure 7)*. The thickness of the Carman sand exceeds 20 m throughout much of this area and forms a valuable fresh water aquifer east of the Red River.

The Winnipeg Formation transitions conformably into the overlying carbonate-evaporite unit. The transition is marked by shales of varying thickness which become thin and arenaceous in the northern parts of the Basin. In southeastern Manitoba and the southern Interlake groundwater investigations have shown that this upper shale acts as an effective aquitard. Groundwater quality

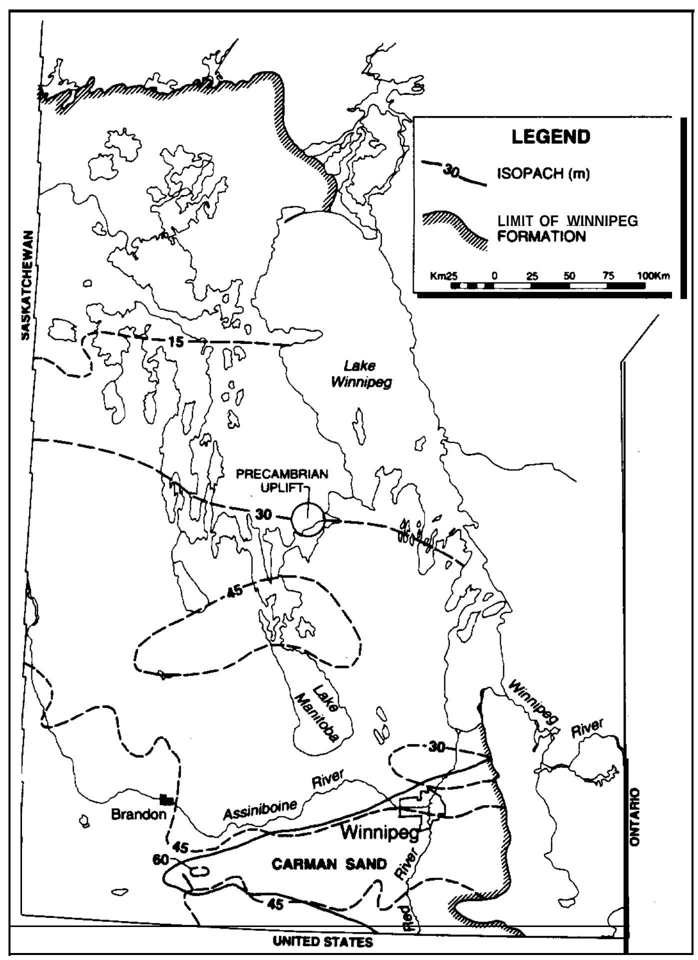


Figure 7. Isopach of the Winnipeg Formation Aquifer. The shaded area shows the extent of the Caman Sand body (after McCabe, 1978).

and hydraulic heads in sandstones underlying this shale are distinctly different from heads and water quality in the overlying carbonates (Betcher, 1986b).

Groundwater Flow Systems

The equivalent fresh water potentiometric surface and expected regional groundwater flow directions in the Winnipeg Formation in the southern and central parts of the WCSB were presented by Betcher (1986b) and are shown in *Figure 8*. Groundwater movement is predominantly from west to east with discharge apparently occurring in the outcrop area beneath Lake Winnipeg. A large area of anomalously high head is found in extreme southwestern Manitoba, creating a local northerly component to groundwater movement in this area. The cause of this anomalous head is not well understood. Fresh water recharge to the aquifer occurs in southeastern Manitoba where the outcrop area underlies a series of upland moraines. Groundwater movement is to the west and northwest from this recharge area. Westward moving recharge is eventually deflected northward along a fresh water-saline water boundary *(Figure 9)* and migrates toward Lake Winnipeg. Discharge from this southeastern flow system occurs into overlying sediments along part of the subcrop area immediately south of Lake Winnipeg and has also been observed where deep paleo-channel features in the overlying carbonate-evaporite unit have been eroded through the upper shales of the Winnipeg Formation. Groundwater flow and recharge/discharge patterns are not well understood in the northern part of the WCSB.

Regional Hydrogeochemistry

Figure 9 shows the distribution of total dissolved solids in groundwaters in the Winnipeg Formation aquifer. Sodium-chloride type brines (TDS >100 g/L) are found in the aquifer in southwestern and southcentral Manitoba while saline and brackish groundwaters extend into the western Interlake region and as far east as the outcrop area south of Lake Winnipeg. Fresh groundwaters are confined to the northern part of the basin, the eastern Interlake region and parts of southeastern Manitoba.

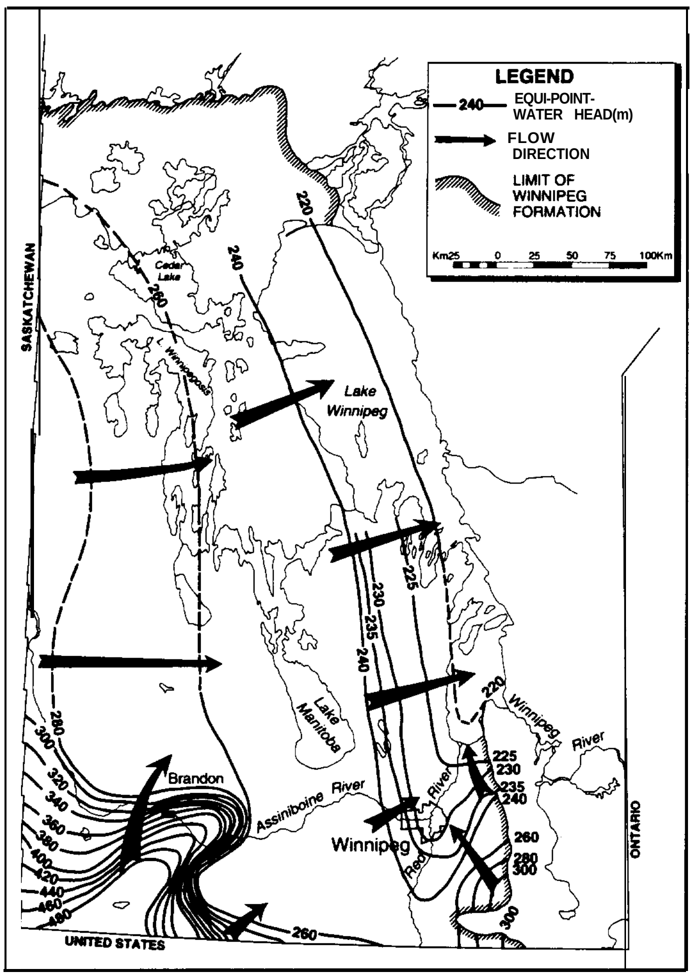


Figure 8. Equivalent fresh water head and regional groundwater flow in Winnipeg

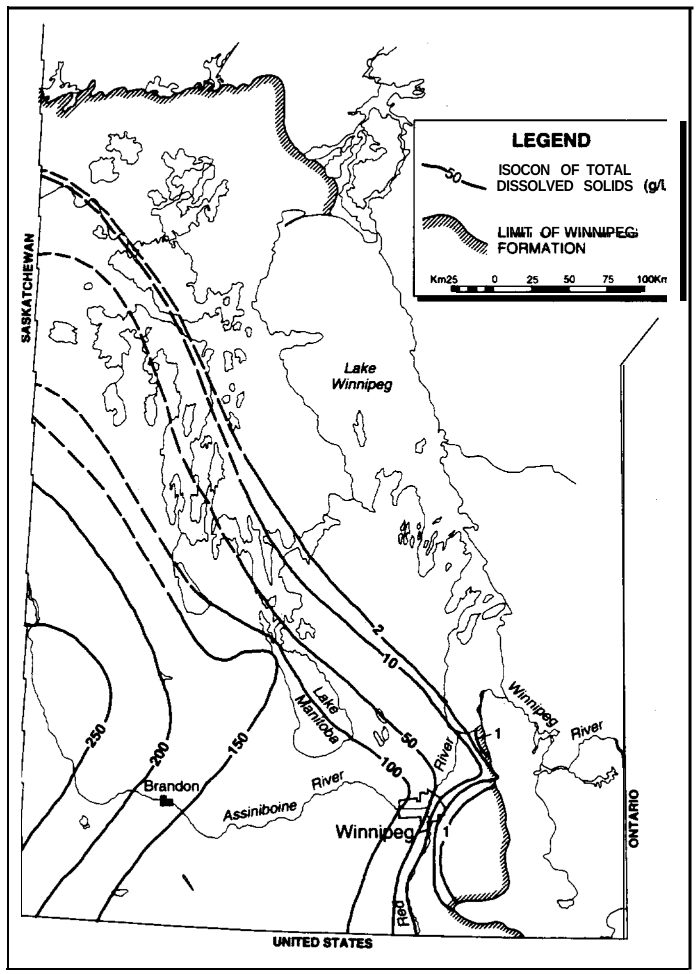


Figure 9. Total dissolved solids of Winnipeg Formation groundwaters (g/L).

The hydrogeochemistry of fresh groundwaters in the aquifer shows considerable variation. In the Interiake area, groundwaters are typically very soft sodium-mixed anion type with TDS values from 1000-1300 mg/L. Chloride concentrations range from 300-500 mg/L and sulfate from 200-300 mg/L. The pH of these groundwaters normally exceeds 8.2 and pH values exceeding 9.0 are not uncommon. Many wells vigorously effervesce nitrogen gas. Stable isotope analyses of water samples consistently provide oxygen-18 values from -20 to -24‰, indicating that these groundwaters were recharged during a much colder climatic period than currently exists in southern Manitoba.(the oxygen-l 8 value of modern recharge in this area is approximately -12 to -15‰). The most depleted oxygen-18 values are comparable to results obtained from pore waters extracted from the middle portions of thick Lake Agassiz clay deposits in southern Manitoba and northern North Dakota (Remenda, 1993). These values are thought to represent the isotopic signature of Lake Agassiz waters and, consequently, the mean oxygen-18 composition of precipitation during the late Pleistocene (Remenda, 1993). Fresh groundwaters currently found in the Winnipeg Formation in the eastern Interlake are therefore believed to have been recharged into the aquifer along the outcrop area during the late Pleistocene or early Holocene. This recharge likely displaced pre-existing saline fluids in the aquifer. Residual saline fluids provide the source for elevated sodium and chloride concentrations found in the groundwaters today. The present west to east regional movement of water in the Winnipeg Formation aquifer in the Interlake is flushing these fresh waters from the aquifer at a rate of approximately 1 m/yr (Betcher, 1986b).

In southeastern Manitoba, isotopically light fresh groundwaters with similar geochemistry to the Interlake groundwaters discussed above are found bordering the fresh water-brackish water boundary *(Figure 9)*. To the east, these groundwaters rapidly give way to isotopically modern mixed anion-bicarbonate type groundwaters with TDS values from 400 to 600 mg/L, typical of groundwaters found in the carbonate-rich Quaternary deposits overlying the aquifer recharge area. Recharge taking place in Recent times along the outcrop area has advanced northward and westward, displacing pre-existing saline groundwaters and a narrow zone of late Pleistocene recharge. Betcher (1986b) has estimated the rate of northward advance of the fresh water-brackish water boundary to be about 10 m/yr. It is not known if the water quality boundary continues to advance to the west.

Hydraulic Properties and Well Yields

Reported yields from wells completed into the Winnipeg Formation aquifer range from 0.2 L/s to 10 L/s. In most cases only a portion of the total available sandstone thickness had been utilized; potential yields in most developed areas of the aquifer probably exceed 1 L/s. Well yields will depend on the thickness of sandstone units present, grain size distribution of the sandstones, the degree of cementing and, possibly, the extent of fracturing. Most sandstone units have been cemented to some degree by kaolinitic clays, carbonates or iron-oxides. Fracturing has been observed in sandstone outcrops on Black Island in Lake Winnipeg where the formation has been mined for silica sand. The senior author has also encountered high yield situations when drilling test holes into the aquifer which are most reasonably explained by assuming that fractures were intersected in the sandstone beds.

Betcher (1986b) reported the results of pumping tests carried out in 20 wells in the eastern Interlake and southeastern parts of the province which penetrated the full thickness of the aquifer. Transmissivity values ranged from 5.2×10^{-5} m^2/s to 3.6×10^{-2} m^2/s with most results in the 10^{-4} to 10^{-5} m^2/s range. The hydraulic conductivity of sandstone units ranged from 1.1×10^{-3} m/s to 3.2×10^{-6} m/s with 16 of 20 values between 10^{-4} and 10^{-6} m/s.

Groundwater Use

The Winnipeg Formation aquifer is currently used as a source of domestic water supply in southeastern Manitoba and along the western shore of Lake Winnipeg. In southeastern Manitoba an estimated eight hundred wells have been drilled into the aquifer, most in the area of naturally "soft" groundwaters bordering the fresh water-saline water front. These soft groundwaters are a desirable commodity since other aquifers in the area contain very hard waters which require softening. Well completion generally consists of drilling 3 m to 6 m into the first sandstone horizon and installing well screens or leaving the well as an open hole. Completion through the full sandstone thickness would increase the yield of most wells. Unscreened wells are subject to caving and may produce silt or fine sand.

Most wells drilled into the Winnipeg Formation aquifer have been completed as open holes through the bedrock section, interconnecting the Winnipeg Formation aquifer with the overlying carbonate-evaporite unit. This has allowed a continuous exchange of fluids of differing quality between the two aquifers, resulting in substantial loss of groundwater from the Winnipeg Formation. This may eventually result in significant water quality changes in the aquifer. This will be discussed later in this paper.

The Winnipeg Formation is also used for disposal of water softener backwash water at a Manitoba Hydro AC-DC converter station about 25 km northwest of Winnipeg.

Approximately 9,000 m^3 of fluid with a TDS of approximately 21,000 mg/L is injected annually into a single disposal well completed into the Winnipeg Formation. Natural formation waters in the aquifer at this location are sodium-chloride type brines with a TDS of approximately 113,000 mg/L (Betcher, 1984).

1.7.1.2 Carbonate-Evaporite Unit

The most extensive aquifer system in the province is the carbonate-evaporite unit of the Western Glaciated Plains region, stretching throughout the Manitoba portion of the Western Canada Sedimentary Basin (see *Figures 5* and *6*). The unit consists of a gently dipping layered sequence of dolostones and limestones with minor shales and evaporites of Ordovician through Mississippian age. The entire sequence is generally regarded as a single hydrostratigraphic unit; however, the hydraulic interconnection between strata is often poorly understood and in many areas it may be more appropriate to consider the unit as a series of aquifers separated by aquitards.

The carbonate-evaporite unit directly overlies the Winnipeg Formation aquifer and is in turn overlain in southwestern Manitoba by thick shales, sandstones and evaporites of Mesozoic and Cenozoic age which form the upper clastic unit of Simpson et al. (1987). In this paper we will concentrate our discussion on the hydrogeology of that portion of the carbonate-evaporite unit lying east and north of the erosional edge of the overlying upper clastic unit. This is locally referred to as the carbonate rock aquifer, a terminology that will be maintained in this discussion. Where the carbonate-evaporite unit is overlain by Mesozoic and Cenozoic sediments, groundwaters in the unit are saline or brines and offer no potable water development potential.

Groundwater movement through the carbonate sediments occurs primarily through secondary features such as joints, bedding planes, and solution conduits. The carbonates are typically well lithified by compaction and cementation. Intergranular porosities generally fall in the range of 5-7% (Bannatyne, 1988) but visual examination indicates these pore spaces are not well interconnected in most rock units. The primary hydraulic conductivity of these carbonates is likely very low and intergranular water flow not a significant factor contributing to most water well yields. This is indicated by the occasional “dry” hole drilled into the carbonate rock aquifer. McCabe (1963) states that fracture permeability also controls fluid movement in the deep oil producing regions of the aquifer system in southwestern Manitoba.

Ford and Williams (1989) have shown that carbonate systems with low primary porosity and permeability such as found in Manitoba will tend to undergo dissolution processes that will lead to the development of networks of discrete, very permeable solution conduits. These networks form the primary pathways for groundwater movement in most carbonate aquifers. The presence of such solution-enhanced permeability and its significant influence on groundwater flow in the carbonate rock aquifer has been recognized by hydrogeologists and water well drillers working in Manitoba for many years. During drilling in the aquifer, groundwater production occurs from discrete intervals separated by zones where no noticeable additional groundwater influx occurs. Production zones are often associated with bit drops, loss of drilling mud or air and the absence of cuttings return, indicating the presence of open cavities in the rock. These features are well documented by mechanical caliper logs (*Figure 10*). In some areas, very high groundwater production rates have been found associated with sand and gravel

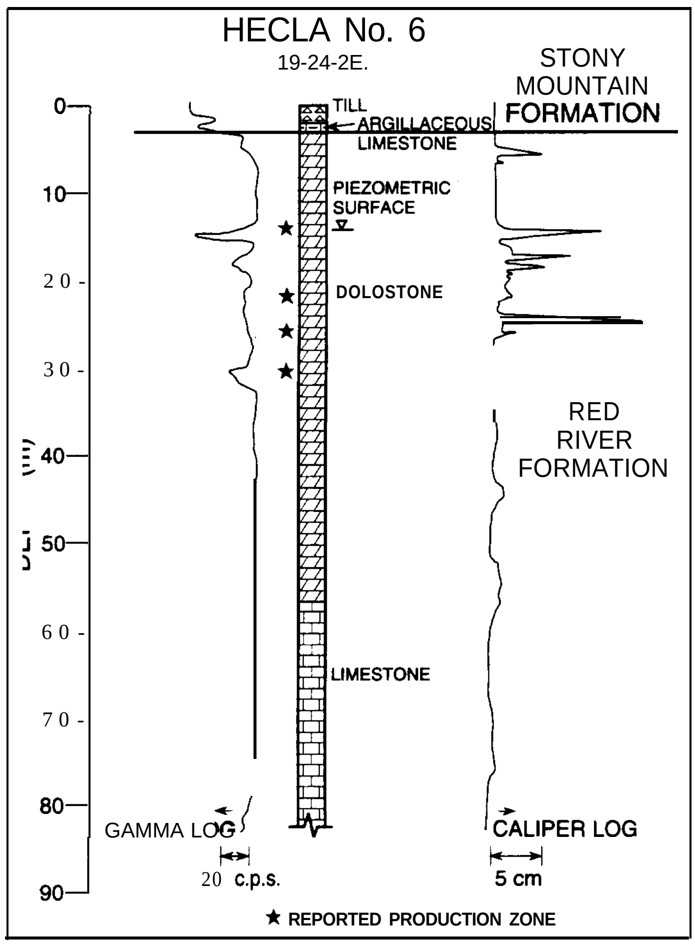


Figure 10. Caliper log of test hole into carbonate-evaporite unit showing fracture development in upper Red River Formation. This unit has been found to be a zone of enhanced permeability throughout the outcrop area in southern Manitoba.

infilled caverns or zones where the bedrock has been highly weathered to a "pumice-like" appearance. These subsurface observations, the presence in many areas of large springs, and the documentation of caves and other karst features in exposed bedrock areas (Anonymous, 1992) indicate that groundwater movement in the carbonate rock aquifer in Manitoba occurs primarily through a well-interconnected network of secondary and dissolution-enhanced features. An excellent discussion of the influence of fractures and karst features on the movement of groundwaters in the carbonate rocks near Grand Rapids was given by Grice (1964). Many of these features were likely formed during periods of intense dissolution in the geologic past when marine episodes were replaced by terrigenous conditions. Simpson et al. (1987) discuss major erosional episodes in Manitoba at the end of the Paleozoic Era and during the early Cretaceous. Jurassic and Cretaceous Swan River sediments form infill materials in paleo-sinkholes and channel karst features in many parts of southern and central Manitoba, attesting to the ancient origin of many of these solution features.

Studies are on-going in Manitoba to evaluate whether the distribution of secondary permeability features can be placed into a stratigraphic or spatial framework. This is important, for instance, in attempting to define target stratigraphic horizons for development of high capacity wells. Experience to date indicates that in most areas where the carbonate rock aquifer forms the uppermost bedrock unit, the upper few metres to perhaps the upper 10 m of bedrock is frequently heavily fractured and very permeable (Render, 1970). This fracturing is presumably the result of glacial stresses or near-surface solution enhancement of existing joint networks. Below this zone of enhanced permeability, most wells will intersect further fractures. In some areas where intensive drilling has occurred (for instance in subdivisions or small communities) water well records indicate these deeper fractures are intersected at roughly similar depths in most wells, indicating either a stratigraphic-fracture relationship or individual permeable features that have rather large areal extents. In other areas of similar size, however, no consistency has been found in the depth to significant water-producing fractures.

The Fort Garry Member of the Red River Formation has been shown to be a stratigraphic interval of enhanced permeability throughout the outcrop area of southern Manitoba with possible extension to the northern part of the WCSB in Manitoba and even to beds of similar age in the HBB (Betcher et al., 1992; R. Bezys, Manitoba Energy and Mines, personal communication). It has been proposed that the enhanced permeability in this interval resulted from dissolution features developing during and subsequent to removal of anhydrite beds originally deposited in the Member (Betcher et al., 1992); alternately, it may be a result of karst development during a period of emergence shortly after deposition (Noiseux, 1992).

Groundwater Flow Systems

The potentiometric surface of the carbonate rock aquifer has been mapped as part of specific local studies (Grice, 1964, Baracos et al., 1983, UMA Engineering Ltd. and Conestoga-Rovers & Associates, 1993) and, in some areas, on a 1:250,000 scale (Render, 1965; Betcher, 1986a). However, no map of regional flow within the entire aquifer has, as yet, been compiled. Some regional results for Manitoba were presented by Downey (1984) as part of his work modeling groundwater movement in the Cambrian-Ordovician aquifer in the northern Great Plains and southern prairies of Manitoba and Saskatchewan. However, some of Downey's assumptions about boundary conditions in Manitoba were incorrect. A qualitative interpretation of regional groundwater flow in the aquifer is presented in *Figure 11.* This inter-

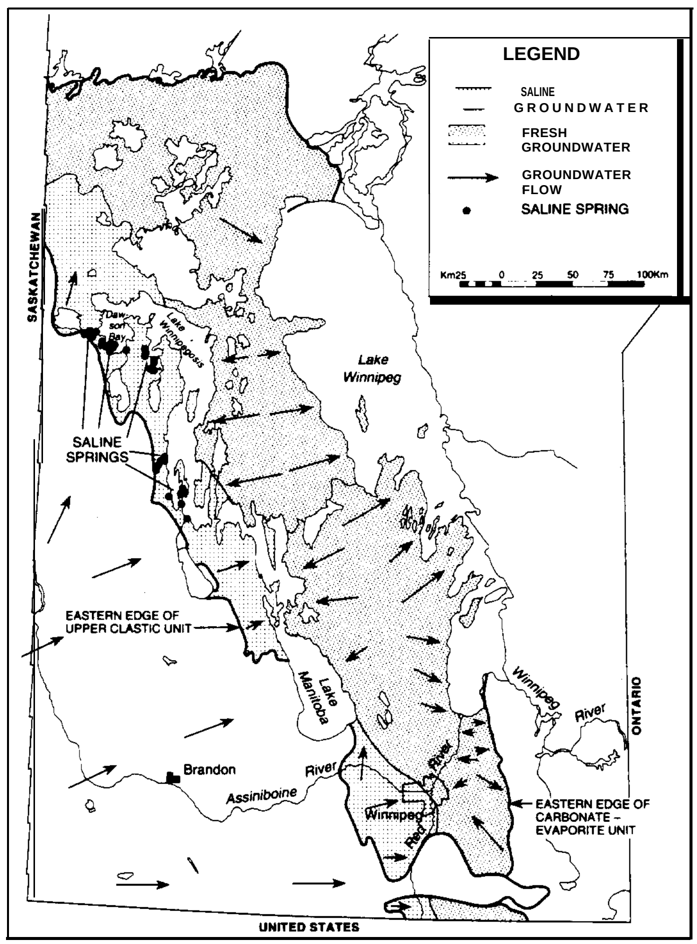


Figure 11. Regional groundwater movement in carbonate - evaporite unit.

pretation is based on general theory of groundwater flow system development, available potentiometric surface maps for parts of the aquifer, the locations of springs, regional groundwater geochemistry, topography, and studies by Downey (1984).

The general features of this map include an east to northeast flow of saline groundwaters and brines in the aquifer system in southwestern Manitoba, a fresh groundwater mound in the Interlake area with flow occurring outward from the mound, and a northwesterly flow of fresh groundwater in southeastern Manitoba where recharge occurs along the eastern edge of the WCSB.

Southwestern Manitoba lies along the eastern and northern edge of a continental scale groundwater flow system developed in the Paleozoic sediments of the Williston Basin. This system has been discussed by Downey (1984). Recharge to the continental system occurs where Paleozoic sediments have been uplifted and brought near the ground surface in parts of Montana, Wyoming and South Dakota. Recharge waters move down dip in an east to northeasterly direction toward the center of the basin before eventually rising out of the basin toward discharge areas in eastern North Dakota and southern Manitoba. Groundwater salinity increases along the flow path of this continental system, particularly where groundwaters are forced to move past a large area of quasi-stationary brine occupying the deepest portion of the Williston Basin (Downey, 1984).

Discharge areas for the continental system in Manitoba occur along a northwest to southeast trending belt lying to the east of the Mesozoic shale cover *(Figure 11).* Groundwaters in the carbonate rock aquifer are brackish to saline in this area although, locally, pockets of fresh water may be found overlying saline waters at shallow depth. A series of salt water springs with TDS values from 30,000 to 60,000 mg/L are found along the western shore of Lake Winnipegosis and the Red Deer River just west of Dawson Bay (Stephenson, 1973; McKillop et al., 1992). Subsurface springs have also been noted along the western edge of Dawson Bay (B McKillop, Manitoba Museum of Man and Nature, personal communication). Van Everdingen (1971) provided evidence for diffuse seepage of saline groundwaters into Lakes Manitoba and Winnipegosis. Areas of saline soils found south of Lake Manitoba are also thought to reflect upward discharges of saline groundwaters in these areas (R. Eilers, Manitoba Land Resource Unit, personal communication).

The central portion of the Interlake forms a major area of fresh water recharge to the carbonate aquifer. In much of this area only a thin covering of clay or till rests on the bedrock aquifer and outcrop is common. A recharge mound has developed between the lakes with regional groundwater flow occurring both easterly toward Lake Winnipeg and westerly towards Lakes Manitoba and Winnipegosis. Discharge occurs as seepage and spring flow into numerous streams, marshes and lakes found throughout the Interlake. Where large solution conduits outcrop in these areas, spring discharge rates can be very high, from 10 L/s to perhaps 100 L/s. The extent of direct regional discharge to the major lakes in the Manitoba Lowland is unknown. Recent geophysical surveys of Lake Winnipeg for instance indicate that bedrock aquifers beneath the lake are overlain by thick clayey deposits which will inhibit the upward discharge of groundwaters.

In southeastern Manitoba piezometric surface maps (Render, 1965; Betcher, 1986a) indicate recharge to the aquifer taking place along its outcrop edge and where it is overlain by a series of thick glacial uplands. Groundwater movement is primarily to the west and northwest. The drawdown cones developed by groundwater withdrawal within the City of Winnipeg and the Town of Selkirk and by groundwater discharge to the Red River Floodway exert a considerable local influence on groundwater movement (Render, 1970, 1986). Natural discharge occurs as spring flow into local streams and apparently as seepage into the Red River, particularly north of Winnipeg.

Hydraulic Properties and Well Yields

On a local scale, the hydraulic properties of the carbonate rock aquifer vary markedly both laterally and vertically, a consequence of the movement of groundwater through a complex and highly heterogenous fracture network. This is reflected in considerable variability in well yield. Commonly, the greatest yields are associated with permeable features intersected in the upper few metres of bedrock where glacial action or the presence of paleokarst features have created large open fractures. Where these features were not intercepted or have been cased off, in some areas wells may provide only small yields even if drilled to considerable depth. In most areas, however, water-producing features are found in discrete intervals throughout the depth of the aquifer.

Reported transmissivity values range from near zero in a few isolated wells to values exceeding 12,000 m^2/d. In the Winnipeg area, for instance, transmissivities range from less than 100 m^2/d (a few “dry” wells have been drilled) to more than 2500 m^2/d (Baracos et al., 1983). Well yields show a similar variability with yields from less than 0.2 L/s to more than 120 L/s being reported. Most

10 cm diameter domestic wells in the aquifer will yield 0.5 L/s to 5 L/s while wells developed for high capacity municipal or industrial purposes will generally yield 5 L/s to 10+ L/s.

Regional Hydrogeochemistry

Saline groundwaters and brines associated with the continental flow system are found throughout southwestern and southcentral Manitoba. The transition to fresh groundwaters occurs rather abruptly to the east and north of this salt water area with the major physiographic depressions of southern and westcentral Manitoba forming the boundary between saline and fresh waters. Figure 12 shows the generalized distribution of groundwater quality in the upper few tens of metres of the unit.

Brines and saline groundwaters found in the aquifer exhibit a rather uniform composition. The brines are sodium-chloride type waters with TDS concentrations up to 320,000 mg/L. Sodium comprises greater than 80% of total cation equivalents with calcium then magnesium being the other significant cations. Chloride comprises more than 95% of all anion equivalents with relatively minor concentrations of sulfate. Saline groundwaters with a TDS exceeding 50,000 mg/L show a similar geochemistry although sulfate may form up to 15% of total anion equivalents. At lesser TDS values, saline groundwaters may contain up to 40% calcium + magnesium cation equivalents per million and up to 40% sulfate equivalents per million.

Fresh groundwaters are typically calcium-magnesium-bicarbonate types with TDS values from 400 mg/L to 800 mg/L. Sulfate and sodium locally form a significant percentage of the dissolved components, particularly in two areas of elevated TDS lying to the east and northeast of Winnipeg *(Figure 12)*. This may reflect local recharge of groundwater from the overlying clays and tills. The transition to saline groundwater near the fresh water-saline water boundary is marked by an increase in TDS due primarily to increases in sodium, chloride and sulfate. The average composition of fresh groundwaters in the aquifer system is indicated in *Table 2* based on more than 500 analyses.

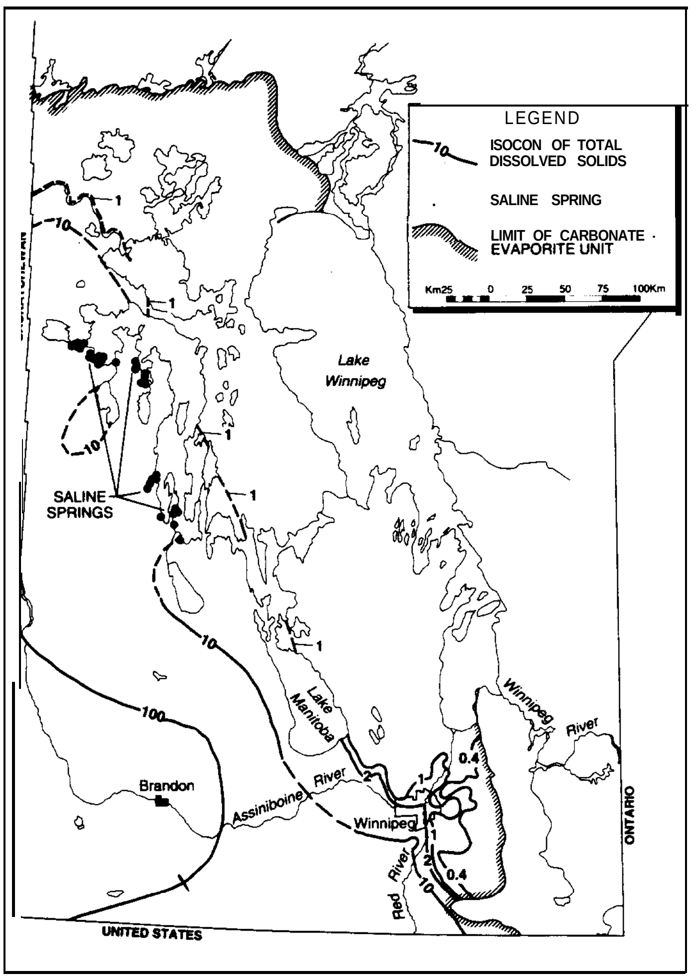


Figure 12. Groundwater quality in carbonate - evaporite unit.

PARAMETER	CONCENTRATION (mg/L)
Calcium	61.6
Magnesium	55.6
Sodium	53.2
Potassium	6.5
Chloride	46.4
Sulfate	87.9
Bicarbonate	415.2
Carbonate	2.0
PH	7.71
Temperature (°C)	6.8
Silica	11.3
Nitrate + Nitrite (N)	0.93
Boron	0.29
TDS	553
F	0.45
Log (P_{CO_2})	-2.23
SI_{cal}	+0.18
SI_{dol}	+0.50
SI_{gyp}	-1.73

Table 2. Geochemisty of fresh groundwaters in the carbonate - evaporite unit.

Groundwater Use

The carbonate aquifer is a major source of groundwater supply for municipal, industrial, rural residential, and agricultural uses throughout a large portion of southeastern and central Manitoba. Virtually all communities overlying the fresh water portion of this aquifer rely partially or exclusively on it for their water supplies. The aquifer also provides groundwater for many industrial and commercial heating/cooling systems, concentrated in the Winnipeg area. It is estimated that more than 20,000 wells are currently withdrawing water from this aquifer.

1.7.1.3 Jurassic Aquifers

Limestones, dolostones, and sandstones in Jurassic rocks form a series of aquifers at potentially exploitable depth in an outcrop area stretching northwest to southeast through southcentral Manitoba from just north of Dauphin Lake to the Manitoba-U.S.A. border near Gretna *(Figure 5)*. Very little exploration of these aquifers has been undertaken. The available information indicates that water quality is generally brackish to saline. A few wells completed in Jurassic rocks have produced fresh water southeast of Dauphin Lake. Some wells have also been completed into Jurassic aquifers in a large channel infill feature south of Winnipeg *(Figure 5)*. Water quality in these wells is not known but is likely brackish; a number of these wells have produced significant amounts of methane gas. West of the outcrop area groundwater quality in Jurassic rocks is thought to be saline.

1.7.1.4 Swan River Formation Aquifer

The Swan River Formation is a marine to non-marine sequence of variably cemented silica sandstones, siltstones, shales, and occasional lignite. The thickness of the formation ranges up to 120 m. The deposits are extremely heterogeneous; the thickness, stratigraphic distribution, cementing, and grain size distribution of sandstone units show rapid spatial variation in many areas. The extent of Swan River sediments is shown in *Figure 13*.

West of the Manitoba Escarpment, the Swan River Formation is overlain by up to several hundred metres of Cretaceous shale with an expected very low hydraulic conductivity (Davis, 1988; Neuzil, 1994). The shale acts as an effective aquitard separating the Swan River Formation aquifer from the overlying Odanah shale and Quaternary aquifers. The formation is underlain by up to several hundred metres of Jurassic shales, evaporites, carbonates and sandstones in southern and central areas and by Devonian carbonates in northern areas. Jurassic

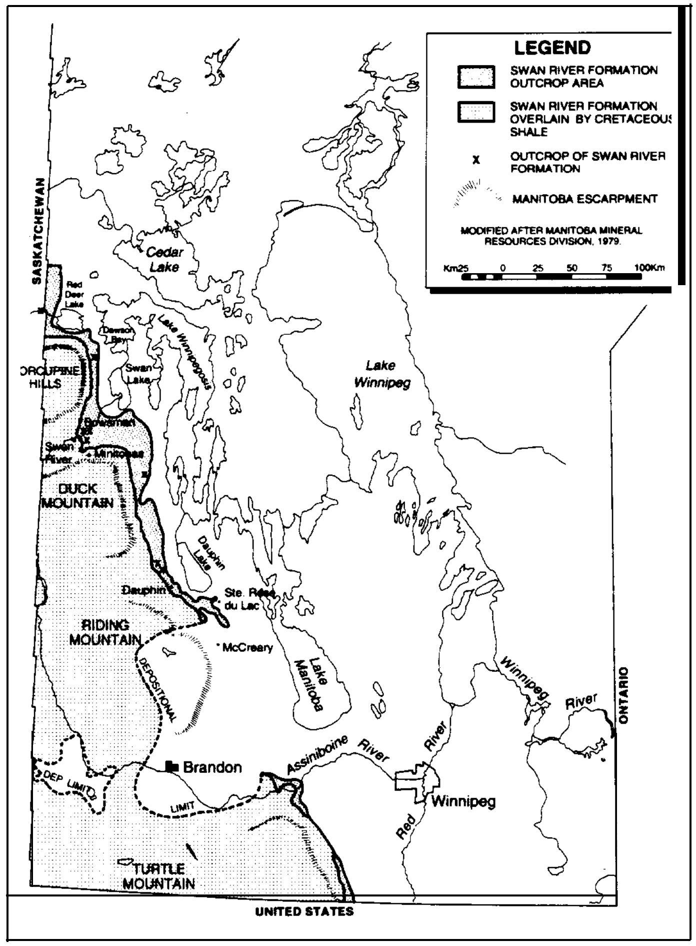


Figure 13. Distribution of the Swan River Formation.

sediments are thought to form an effective underlying aquitard in the southern and central areas, but the degree of interconnection of the Swan River Formation aquifer with Devonian rocks forming part of the carbonate-evaporite unit in the northern areas is uncertain. Likely, the sandstone units are separated from the underlying carbonates by some thickness of shale.

Under these conditions the Swan River Formation is thought to act as a "drain" for the overlying and underlying low-permeability sediments, channeling leakage from these deposits to eventual discharge areas along and east of the Manitoba Escarpment (Rutulis, 1984). The rate of recharge to the aquifer is likely very low. No significant groundwater discharge features, such as springs, have been noted in outcrop areas.

Hydraulic Properties and Well Yields

Rutulis (1984) and Betcher (1992) have summarized the hydraulic properties and yields of wells drilled into the Swan River Formation along the northern part of the Manitoba Escarpment. Well yields and transmissivity values are dependent on the thickness, grain size distribution, and cementing of the sandstone units, all of which are highly variable in this formation. Based on information supplied in water well logs reported to the province, well yields in this area range from 0.08 L/s to 7.55 L/s with a mean of 1.5 L/s. Many wells were completed through only a portion of the total sandstone thickness so reported well yields are conservative. Where pumping test information is available, transmissivity values have ranged from 0.5 m^2/d to 108 m^2/d.

Regional Hydrogeochemistry

West of the Manitoba Escarpment and where the outcrop area is overlain by thick unconsolidated sediments, groundwaters are saline with TDS concentrations ranging from 5,000 mg/L to about 50,000 mg/L. These groundwaters are sodium-chloride-bicarbonate type waters. Cation exchange has reduced calcium and magnesium concentrations to less than 10 mg/L in parts of this area.

Recharge-discharge conditions and, subsequently, groundwater quality are more complex in the outcrop area east of the Manitoba Escarpment. Wide variations in groundwater salinity are found over relatively short distances with TDS changes of thousands to tens of thousands of milligrams per litre observed over distances of only a few kilometres laterally or a few tens of metres vertically. This reflects the extreme heterogeneity of the formation. Fresh groundwaters vary from calcium-magnesium-bicarbonate types, thought to occur in areas where recharge is relatively rapid and direct, to sodium-mixed anion types with very low hardness, thought to be older waters that have undergone extensive geochemical alteration. Stable isotope work in the Swan River area lends some support to this interpretation.

Groundwater Use

There are probably several hundred wells used for domestic and farm water supplies completed into the Swan River Formation within the outcrop area. The TDS in some of these wells exceeds 3,000 mg/L. Three communities with populations less than 1,200 also use the aquifer for municipal water supply. One of these communities treats the groundwater using the reverse osmosis process. In 1987 five wells were completed into the Swan River Formation in southwestern Manitoba to provided groundwater for pressure maintenance in oil fields. The combined capacity of these wells was approximately 20 L/s (R. Dubreuil, Manitoba Energy and Mines, personal communication).

1.7.1.5 Odanah Shale Aquifer

The Odanah shale is a hard, brittle, siliceous, grey shale forming the middle member of the Pierre Shale. In outcrop the shales are fissile and heavily fractured, and contain joints and bedding planes that are open and transmissive to water. Near Turtle Mountain, the Odanah Member is overlain by the Coulter Member which consists of soft bentonitic siltstone and shale. Elsewhere, the Odanah Member is overlain by a variable thickness of glacial and postglacial deposits. The Odanah Member is underlain by up to several hundred metres of soft cretaceous shales with minor limestone and bentonite. These underlying materials are expected to have very low permeabilities. The maximum thickness of the Odanah Member is about 240 m (Bannatyne, 1970, Figure 31) but the bedrock surface has been heavily eroded and the thickness can show significant local variation. The distribution of Odanah shale is shown in *Figure 14*.

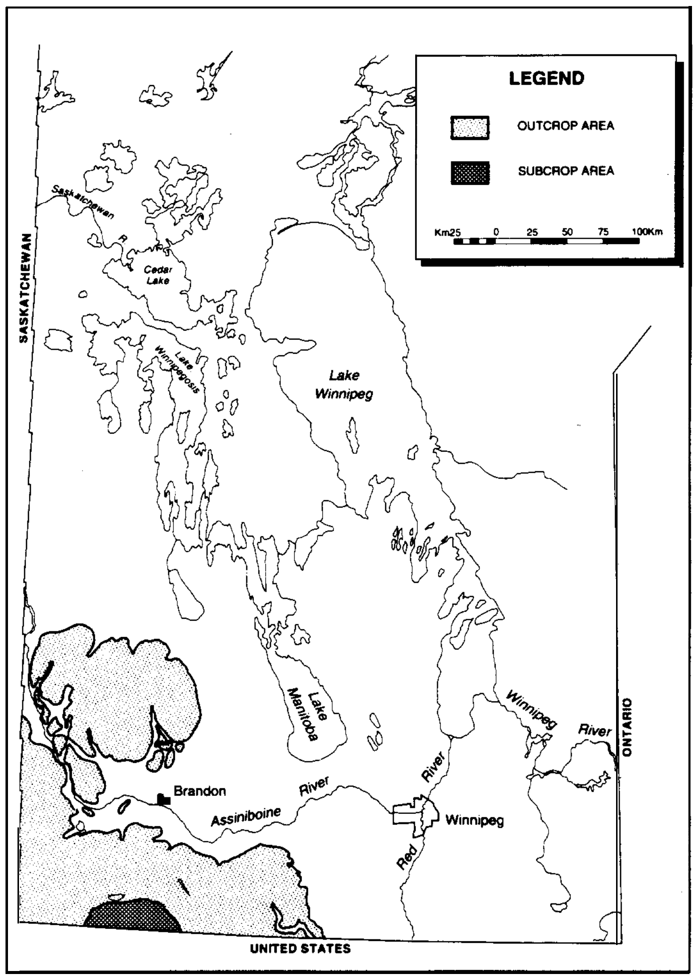


Figure 14. Distribution of the Odanah Shale Aquifer (after Bannatyne, 1970).

No studies have been carried out of large scale groundwater movement in the Odanah aquifer in Manitoba. Likely, there are significant local to intermediate flow systems developed in areas where overburden thickness is not great. Intermediate to regional systems may exist in areas with thick overburden cover. Recharge is likely by upward and downward leakage of water from the surrounding low permeability materials with local focused discharge in outcrop areas. However, the authors are not aware of any significant areas of concentrated discharge from the aquifer.

Hydraulic Properties and Well Yields

Groundwater movement in the Odanah shales is primarily through fractures, joints and bedding plane openings. The "shale" itself is composed mainly of amorphous silica with a fairly low content of clay minerals (Bannatyne, 1970). The permeability of the intergranular medium is likely very low. Fracturing in the shales appears to be irregular and unpredictable. Well drillers typically describe the aquifer as interlayered hard and soft shales with water production occurring from the hard layers. Yields from wells are typically less than 0.5 L/s but yields in excess of 1 L/s are not uncommon. A few wells with yields exceeding 10 L/s have been reported. Most domestic wells in the shale are simply deepened until a usable yield is obtained or until the underlying soft, unfractured Millwood shale is encountered.

Regional Hydrogeochemistry

No summary studies of groundwater quality in the Odanah shale aquifer have been carried out in Manitoba but numerous analyses have been presented in regional studies carried out by Manitoba Water Resources (Betcher, 1992, 1989, 1983; Sie and Little, 1976). Groundwater quality is quite variable with reported TDS concentrations from about 500 mg/L to about 9,000 mg/L. Water quality appears to decline with depth in many areas. Groundwater geochemical types are also quite variable, reflecting the complexity of the recharge/discharge conditions. The most common groundwater types are sodium-calcium-sulfate-chloride-bicarbonate and calcium-magnesium-sodium-bicarbonate-sulfate.

Groundwater Use

The Odanah shale is an important local aquifer through much of southwestern and southcentral Manitoba, particularly in those areas where sand and gravel aquifers are not present or are poor producers. Several thousand wells currently draw water from the shale with 100 to 200 additional wells being completed into the aquifer each year. Five communities are currently served by wells completed into the shale.

1.7.1.6 Boissevain and Turtle Mountain Formation Aquifers

The Boissevain and Turtle Mountain Formations are found in an 1,100 km^2 upland area known as Turtle Mountain *(Figure 1)* bordering the United States in southwestern Manitoba. This upland rises as much as 240 m above the surrounding prairie level. The Boissevain Formation consists of sand with minor clay, silt, and sandstone and has an average thickness of about 30 m (Bamburak, 1978). It overlies the bentonitic siltstones and shales of the Coulter Member of the Pierre Shale. The Boissevain Formation is overlain by the Paleocene Turtle Mountain Formation which consists of bentonitic, carbonaceous sands, silts and clays with minor lignite (Bamburak, 1978). The maximum known thickness of the Turtle Mountain Formation is 158 m. The formation has been deeply incised with numerous channels. Both formations are overlain by glacial and postglacial sediments up to 120 m thick.

No formal studies of groundwater flow in the Turtle Mountain and Boissevain Formations have been undertaken. Rutulis (1978) indicates that recharge occurs in the upland areas to the south with discharge to the outcrop area along the northern part of Turtle Mountain. Rutulis appears to have based his analysis on general topographic trends rather than actual measurements of groundwater heads in wells. Western Ground-Water Consultants Ltd. (1982) suggest a southward regional flow of groundwater may in fact be occurring.

Hydraulic Properties and Well Yields

The sand and sandstone units in the formations provide permeable zones for well development but yields are generally low. Western Ground-Water Consultants Ltd. (1982) reported that yields up to 5.5 L/s are possible in the coarser sands found along the northern extent of the formations, but elsewhere yields of only 0.2 L/s or less are expected.

Regional Hydrogeochemistry

Groundwater quality is generally poor in these formations with TDS concentrations typically ranging from 1,000 mg/L to 2,400 mg/L. Groundwaters are sodium-calcium-magnesium-sulfate-bicarbonate types with sulfate frequently exceeding the drinking water aesthetic objective of 500 mg/L (Health and Welfare Canada, 1993). Sodium concentrations range from 100 mg/L to

450 mg/L but chloride concentrations are generally less than 40 mg/L indicating a significant amount of geochemical modification of the groundwaters by cation exchange.

Groundwater Use

Well records indicate that perhaps 100-200 wells have been completed into the Boissevain and Turtle Mountain Formations in Manitoba. These formations are overlain by significant thicknesses of overburden containing widely distributed sand and gravel lenses that form the main aquifers in the Turtle Mountain area.

1.7.2 Sand and Gravel Aquifers

Sand and gravel aquifers are widely distributed in the Western Glaciated Plains region of Manitoba, occurring in Pleistocene inter- and intra-till deposits, moraines, outwash areas, as Pleistocene or pre-Pleistocene infills of some buried valleys, in glaciolacustrine beach and deltaic deposits associated with Lake Agassiz, and in Recent alluvial sediments. A generalized map showing the distribution of sand and gravel aquifers in the Western Glaciated Plains region is shown in *Figure 15*.

Inter- and intra-till sand and gravel deposits are found extensively in many parts of the till plains of southern Manitoba. These deposits are less common in the relatively thin till found in the Interlake region. Here sand and gravel are most commonly found at the bedrock-till interface. Few detailed studies have been done on any of these deposits to determine their extent and stratigraphic relationship to surrounding materials. However, some individual aquifers are known to extend over areas as large as 130 km^2 (Little, 1973). In most cases though, these aquifers are expected to have limited areal extent. Some basic studies of the relationship between till stratigraphy and the occurrence of sand and gravel aquifers are needed in Manitoba to aid in predicting the occurrence of these bodies.

Sand and gravel deposits in glacial moraines, eskers, kames, and outwash materials form extensive aquifers in southeastern Manitoba and locally in southwestern and southcentral Manitoba. These aquifers are generally overlain by thick glaciolacustrine clays in the southcentral part of the province. A series of moraines and outwash deposits, termed the Agassiz-Sandiland Upland (Teller and Fenton, 1980), form an extensive series of sand and gravel aquifers in southeastern Manitoba, running north-south from Lake Winnipeg to the United States. Although the exact dimensions of these aquifers have not been fully defined, regional test drilling indicates large areas of sand and gravel with considerable development potential (Betcher, 1985; Lebedin, 1978). In southcentral Manitoba a number of generally north-south oriented glaciolacustrine sand and gravel aquifers have been mapped which form important (and in places sole) local sources of water for a number of communities. These include the Elie, Winkler and Miami aquifers (Render, 1987).

Several buried valley aquifers have been mapped *(Figure 15)* in southwestern Manitoba although the full extent of these aquifers has not generally been determined. These aquifers are usually very heterogeneous, narrow and covered by thick deposits of till making them difficult targets for exploration. However,where they occur they form important local aquifers.

A number of very large sand aquifers that formed as lacustrine, deltaic, or alluvial deposits in proglacial and postglacial lakes and rivers are found in southcentral and southwestern Manitoba These include the Assiniboine Delta, Oak Lake, Glenora, and Almasippi sand aquifers. The largest of these aquifers is the Assiniboine Delta aquifer, described by Render (1988). This unconfined sand aquifer extends over an area of approximately 4000 km^2 and has an average saturated thickness of about 18 m. It forms an important source of water for municipal, industrial, and agricultural uses. Current irrigation withdrawals exceed 6 $x10^9$ litres annually.

Groundwater Quality

Groundwater quality is generally excellent in sand and gravel aquifers having significant surface outcrop. Total dissolved solids concentrations, for instance, typically range from 200 to 450 mg/L in the Oak Lake and Assiniboine Delta aquifers and in the extensive shallow sand and gravel aquifers in southeastern Manitoba. Groundwaters are calcium-magnesium-bicarbonate type. Similar groundwater qualities are found in smaller, shallow sand and gravel aquifers elsewhere in the province although local conditions, such as saline groundwaters in underlying sediments, may influence quality.

Groundwater quality in sand and gravel aquifers without significant outcrop tends to be higher in dissolved solids than similar aquifers with extensive outcrop. This results from an influx of poorer quality water from the surrounding clays or tills or, in some cases, bedrock units. The mean TDS found in 165 analyses of groundwaters from inter- or intra-till aquifers in southwestern Manitoba, for instance, is 1,340 mg/L with the mean groundwater composition being a sodium-calcium-magnesium-sulfate-bicarbonate type. This reflects an influx of groundwater from the surrounding Cretaceous shale-rich tills. In the

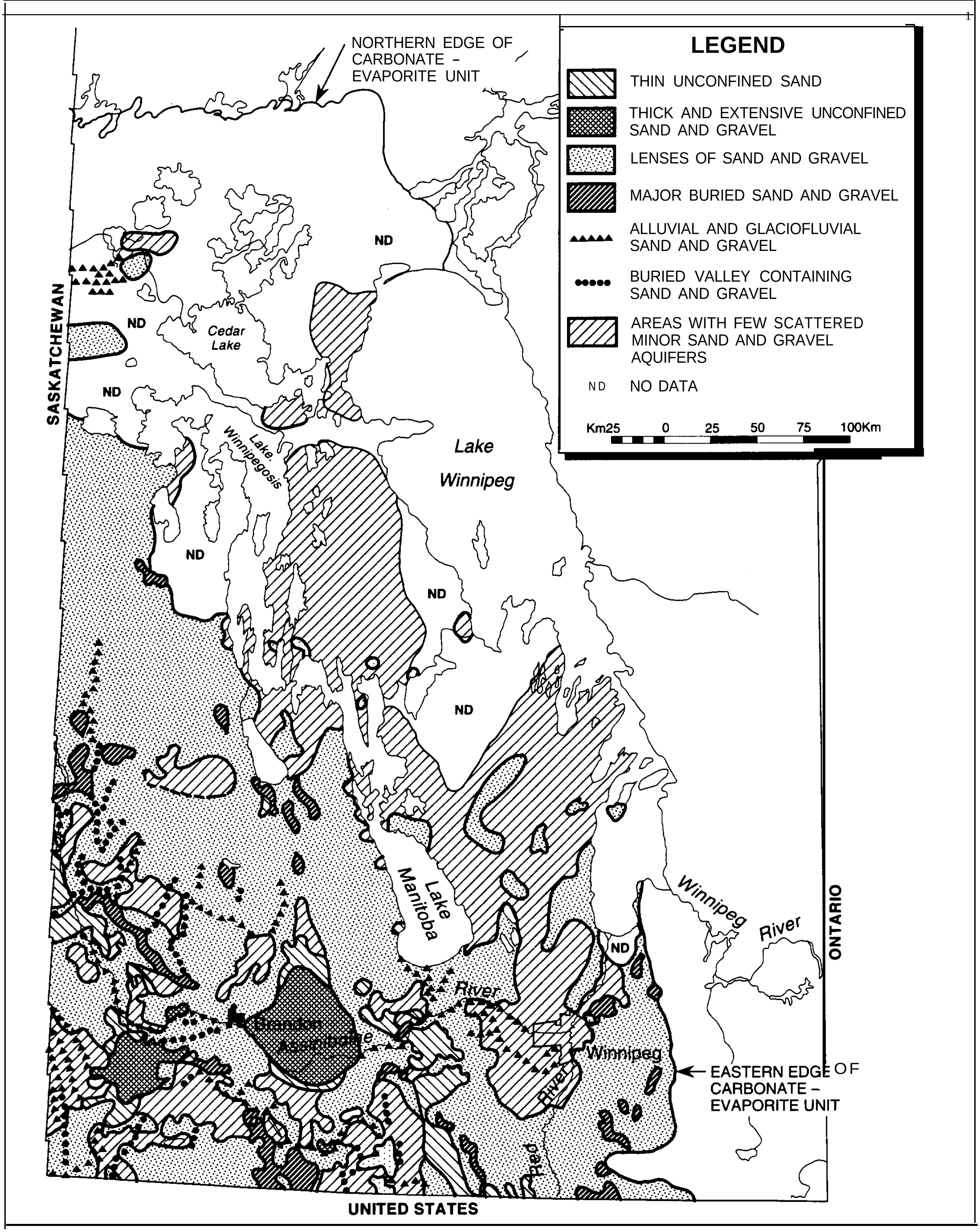


Figure 15. Sand and gravel aquifers in the Western Glaciated Plains Region (modified after Rutulis, 1986).

Interlake area, groundwaters in inter- or intra-till sand and gravel aquifers tend to be calcium-magnesium-bicarbonate types with a TDS less than 600 mg/L, reflecting the influx of groundwater from the underlying bedrock aquifer or from the surrounding carbonate-rich tills.

In areas where the bedrock units contain saline groundwater, sand and gravel aquifers in overlying sediments may also contain groundwaters with high salinity. This is particularly the case where the carbonate aquifer contains saline groundwater west of Lakes Manitoba and Winnipegosis and west of the Red River in southern Manitoba. Very shallow sand and gravel units in these areas may contain fresh water but, with depth, groundwaters rapidly become saline and similar in quality to that found in the underlying bedrock units. In other regions the upper parts or recharge areas of sand and gravel aquifers may contain fresh water but groundwaters in the lower parts of these aquifers may become very saline. Render (1987) has described a classic example of this situation in the Winkler aquifer in southcentral Manitoba.

Groundwater Use

Sand and gravel aquifers form the major sources of groundwater supply throughout most areas where the carbonate aquifer is not present. Approximately 35% of all wells drilled in the province are completed in sand and gravel. Statistics on total groundwater usage from these aquifers have not been compiled but many rural communities and industries and most farms in southwestern, southcentral and southeastern Manitoba rely on groundwater from sand and gravel aquifers. Some larger aquifers, particularly the Assiniboine Delta aquifer, are also used for irrigation.

Since many of these aquifers form the sole source of community, industrial, or agricultural water supplies, determination of their safe yield is of considerable importance. Manitoba Water Resources has undertaken aquifer capacity studies of several of these aquifers, including the Elie and Winkler aquifers which have shown water quality deterioration due to overpumping.

2. GROUNDWATER QUALITY CONCERNS

Groundwater forms an important source of water supply in Manitoba, particularly outside the urban Winnipeg area.(2) Outside Winnipeg, groundwater provides the primary source of water for municipal, residential, industrial and agricultural use. Of 290 community water supplies in the province, 155 rely solely on groundwater and one community (Selkirk) relies primarily on groundwater with surface water providing a back-up water source. It is estimated that groundwater provided 90% of non-urban water supplies in the province in 1981 (Hess, 1986). Water quality concerns relate to both the natural quality of groundwaters in the province and to anthropogenic contamination.

2.1 NATURAL CONSTITUENTS

Most groundwaters in Manitoba exceed the 500 mg/L aesthetic objective for TDS given by Health and Welfare Canada (1993). The mean TDS of fresh groundwaters (TDS < 2,000 mg/L) in the carbonate rock aquifer, for instance, is 780 mg/L and the mean TDS of groundwaters in buried sand and gravel aquifers in the till terraines of southwestern Manitoba is 1,340 mg/L. These high TDS values are generally accompanied by hardness values exceeding 200 mg/L and frequently exceeding 500 mg/L, sulfate concentrations near or above the Health and Welfare Canada (1993) aesthetic objective (AO)(2) of 500 mg/L particularly in sand and gravel aquifers in the southwestern tills, or chloride concentrations near or above the recommended AO of 250 mg/L. The high chloride concentrations are generally found near the transition from fresh to saline groundwaters.

Groundwaters having TDS concentrations less than 500 mg/L are found in sand and gravel aquifers in the southeastern corner of Manitoba (Betcher, 1985), in the Oak Lake and Assiniboine Delta surficial sand aquifers in southwestern and southcentral Manitoba (F. Render, personal communication) and locally in the carbonate rock aquifer. Elsewhere, low TDS groundwaters are found locally in shallow sand and gravel aquifers and in isolated locations in some bedrock aquifers.

Water quality problems associated with specific naturally occurring dissolved constituents have also been found locally in some aquifers in Manitoba. These will be discussed below.

2.1.1 Uranium

Elevated concentrations of uranium have been found in groundwaters from surficial and Precambrian rock aquifers in parts of southeastern Manitoba. A study by Betcher et al. (1988) found uranium concentrations exceeding the 100 µg/L maximum acceptable concentration (MAC)(3) established by Health and Welfare Canada (1993) in about one third of more than 100 samples collected from wells completed into the Precambrian rock aquifer in this area. Most of these wells had been drilled into the granitic rocks of the Lac du Bonnet batholith. The uranium MAC was also frequently exceeded in samples collected from seepage wells completed into fractured clays and tills.

Betcher et al. (1988) indicate two major sources for uranium found in groundwaters in this area: (1) uraniferous deposits found as fracture coatings in some parts of the Precambrian rock aquifer and (2) clays laid down as deep water deposits in proglacial Lake Agassiz. The exact nature of the source of uranium in the clays was not identified; however, it was speculated that desorption of uranium was occurring from clay minerals and organics found in the lacustrine deposits under conditions favourable for uranium solubility in groundwater (elevated P_{CO_2}, somewhat mineralized groundwater quality, high CO_3). Since this study, uranium analyses have been carried out on numerous groundwater samples from the Winnipeg Formation, carbonate rock and Odanah Shale aquifers (R. Betcher, unpublished data). Uranium concentrations in groundwaters from these bedrock aquifers have generally been less than 10 µg/L.

2.1.2 Fluoride

Fluoride concentrations exceeding the 1.5 mg/L MAC guideline are found in a number of areas *(Figure 16)*. Fluoride concentrations of several milligrams per litre and occasionally as high as 10 mg/L are found in fresh groundwaters in parts of the Swan River Formation along the eastern edge of the Manitoba Escarpment and the Winnipeg Formation along the western shore of Lake Winnipeg and south of the lake. In both areas, elevated fluoride concentrations are found in naturally softened groundwaters with elevated pH values in silica sandstone and shale formations. Fluoride concentrations of 2 to 7

(2) *The City of Winnipeg in which more than half the population of Manitoba lives currently obtains its water supply via an aqueduct that brings water by gravity flow from Shoal Lake near the Manitoba-Ontario border. However, until 1918 the city was supplied by a series of wells completed in the carbonate rock aquifer north of the city.*

(3) *For brevity, Health and Welfare Canada (1993) will not be repetitively referenced when MAC & AO guidelines are given. However, all guidelines refer to the limits established in this publication. Manitoba has adopted the Health and Welfare Canada drinking water guidelines as province water quality guidelines.*

mg/L are common in groundwaters in shattered and metamorphosed Precambrian basement rocks in the Gypsumville area (J. Rawluk, personal communication). High fluoride concentrations are also found occasionally in groundwaters from Precambrian rocks in southeastern Manitoba (one well had a fluoride concentration of 16 mg/L) and in the carbonate rock aquifer between Dauphin Lake and Lake Manitoba and south of Winnipeg *(Figure 16).* It is suspected that the high fluoride concentrations in the carbonate rock aquifer are a result of influx of groundwater from the overlying Jurassic sediments in these areas.

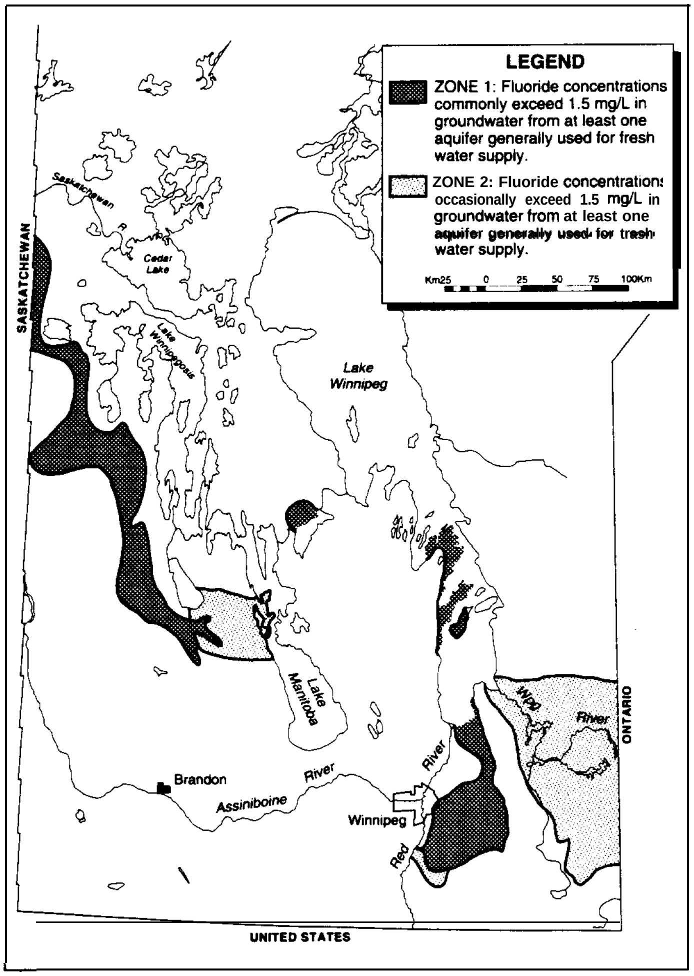


Figure 16. Fluoride concentrations in groundwater in southern Manitoba.

2.1.3 Boron

Boron concentrations exceeding the recommended 5 mg/L MAC are found in groundwaters in the Winnipeg and Swan River Formations, associated with high fluoride concentrations. High boron concentrations have also been found in some groundwaters in the Gypsumville area.

2.1.4 Arsenic

Arsenic concentrations exceeding the interim MAC of 0.025 mg/L have been found locally in groundwaters from sand and gravel aquifers near Portage la Prairie, Notre Dame de Lourdes, Virden, Birtle, Russell and Winkler in southcentral and southwestern Manitoba. Arsenic concentrations between 0.001 and 0.025 mg/L have been found in samples from a number of other sand and gravel aquifers in southcentral and southwestern Manitoba. These sand and gravel aquifers have developed over Cretaceous shale bedrock and contain a significant amount of shale in the aquifer material. A detailed study of arsenic occurrence in a part of southeastern North Dakota (Roberts et al., 1985) indicated that Cretaceous shales may form a source for arsenic in similar hydrogeological environments. However, sampling of wells completed in Cretaceous shales and shale-rich tills in southwestern Manitoba failed to find anomalous concentrations of arsenic. The source and geochemical conditions producing high arsenic concentrations in these aquifers in Manitoba remains an interesting topic for further research.

2.1.5 Radium

As part of a study of uranium concentrations in groundwater in southeastern Manitoba (Betcher et al., 1988), water samples from 105 wells were analyzed for radium-226. Three wells were found to have radium concentrations exceeding the 1.0 Bq/L MAC (Beck and Brown, 1985). All three wells were completed into granitic bedrock. Five other wells produced water with radium-226 concentrations of 0.5 to 0.9 Bq/L.

2.1.6 Iron/Manganese

Iron concentrations exceeding the 0.3 mg/L AO are very common in Manitoba groundwaters. In the fresh water portion of the carbonate rock aquifer, for instance, the mean iron concentration in more than 600 analyses was found to be 1.78 mg/L. Problems with high iron concentrations are common in most aquifers in the province.

Excessive manganese concentrations are less common. In the fresh water portion of the carbonate rock aquifer less than 12% of more than 600 analyses show manganese concentrations greater than the 0.05 mg/L AO.

2.1.7 Other Problems

Taste and odour problems are fairly common. Where these problems are not associated with contamination, the main sources of taste and odor appear to be high iron concentrations or bacterial growth in the well. Complaints of hydrogen sulphide gas are common and are likely associated with the growth of sulphur reducing bacteria (Lehr et al., 1988). Many water well drillers do not use chlorinated drill water and do not routinely chlorinate new wells. This may be contributing to the spread of iron bacteria. Highly coloured groundwaters associated with an excessive organic load are found in groundwaters supplying the Town of Virden.

2.2 ANTHROPOGENIC CONCERNS

Water quality problems associated with anthropogen contaminant sources or resulting from groundwater development are also found in some parts of Manitoba. Major groundwater contamination concerns from human activities relate to leaks and spills from petroleum storage facilities, agricultural practices, particularly in light soils with shallow underlying aquifers, waste disposal practices, leakage from agricultural and municipal lagoons, saline water intrusion from over-development of fresh groundwater supplies, seepage from septic systems in sensitive groundwater areas and bacterial contamination related to well construction and maintenance practices.

2.2.1 Saline Water Intrusion

Groundwater quality problems have been experienced in several aquifers in southern Manitoba where overdevelopment has led to saline water invasion of fresh water portions of the aquifers. There is considerable potential for an increasing number of saline water intrusion problems given the existence of significant areas with fresh water-saline water boundaries, either as vertical or lateral water quality transitions, and increasing groundwater development pressures.

The two most notable areas where saline water intrusion has occurred are in the Winkler and Elie aquifers. In both cases the aquifer consists of glacial sand and gravel deposits overlying bedrock units containing very saline groundwater. Groundwater development in excess of the rate of fresh water recharge to these aquifers has resulted in upward movement of the saline water quality boundary and deterioration of pumped water supplies (Render, 1987; J. Petsnik, personal communication). Efforts to develop artificial recharge schemes to supplement recharge to these aquifers have been halted due to trace levels of agricultural chemicals in the surface waters being considered as the sources of supply.

Lateral intrusion of saline groundwaters has occurred along the fresh water - saline water boundary in the carbonate rock aquifer south of Winnipeg. Dewatering for construction of the inlet structure for the Red River Floodway in the early 1960s resulted in local intrusion of saline water just south of the city. Although intrusion occurred rapidly once dewatering commenced, the return to the original fresh water quality following cessation of dewatering is still taking place, almost three decades later. Local saline water intrusion may also have occurred in the Town of St. Adolphe about 20 km south of Winnipeg as a result of short-term summer overpumping in an area very near the water quality boundary. There are concerns that saline water intrusion into the fresh water portion of the aquifer along the water quality front south of Winnipeg may become a more frequent local or perhaps a more general groundwater quality problem as fresh groundwater withdrawal from east of the boundary increases. Studies to define the recharge rate to the fresh water system and the effects of local and regional groundwater withdrawal on the position of the water quality front are needed.

Concerns also exist that saline water intrusion into fresh water portions of the Winnipeg Formation aquifer may occur. Betcher (1986b) has indicated that groundwater outflow from the Winnipeg Formation aquifer into the overlying carbonate rock aquifer through wells interconnecting both aquifers in southeastern Manitoba likely far exceeds recharge rates to the formation. Lowered heads in the fresh water part of the Winnipeg Formation may allow advance of saline water into portions of the aquifer currently containing fresh water.

Local saline water intrusion has occurred in parts of southeastern Manitoba where fresh groundwater in the carbonate aquifer is underlain by saline groundwater in the Winnipeg Formation. Heads in the Winnipeg Formation aquifer are locally up to several metres higher than heads in the carbonate aquifer. Numerous wells have been drilled as open holes through both aquifers in these areas by well drillers searching for increased wel! yields, naturally soft groundwater and even oil. The resulting outflow of saline water into the carbonate aquifer has, in many cases, resulted in contamination of nearby fresh groundwater supplies. In one case an area of approximately 10 km^2 of the carbonate rock aquifer just south of Winnipeg has experienced water quality degradation as a result of outflow from an improperly sealed oil exploration well drilled into the Winnipeg Formation (F. Render, personal communication).

2.2.2 Waste Disposal

Disposal of all types of wastes carries the potential for impacts on the quality of underlying groundwaters. The potential for impact depends on the geology and hydrogeology of the waste disposal site, the engineering of the site, the types of wastes and surrounding groundwater use.

Most municipal waste disposal grounds in Manitoba are operated by local governments. A number of sites are also operated in parks by provincial or federal governments and by Indian reserves. A federal-provincial study carried out in 1982 identified 760 active and inactive municipal waste disposal grounds. Of these, 94 were identified as being worthy of further study to evaluate whether significant environmental effects had or could result from these operations. Thirty-eight of the 94 sites were examined in some detail, including test drilling and groundwater sampling at a few sites. Although many of these sites were found to be poorly located from a potential groundwater contamination viewpoint, recognizable groundwater contamination was found at only a small number of sites and none was found to have produced a significant environmental impact.

Manitoba is not a highly industrialized province but a number of significant groundwater contaminations have occurred due to spills or improper disposal of industrial wastes. Contamination of the carbonate rock aquifer with the solvents trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA) has occurred near the Town of Stony Mountain about 20 km north of Winnipeg (UMA Engineering Ltd., 1992). The area is characterized by generally thin deposits of clays and tills overlying limestones and dolostones of the Stony Mountain and Red River Formations. These carbonate rocks form the sole source of water supply in the area. Solvents have been detected in groundwater underlying an area of approximately 25 km^2 with about 9 km^2 of this area having TCE concentrations exceeding the MAC of 50 µg/L. TCA concentrations exceeding 40,000 µg/L have been detected in the most heavily contaminated areas. Contaminants entered the aquifer at a number of locations within the plant site over many years and have migrated to the south and east as two distinct contaminant plumes. Migration rates are estimated to be a few hundred metres/year. Contaminants have migrated up to 7 km from the industrial site, affecting the water quality in 37 private wells. This contamination has forced the construction of a piped water system to service the affected areas at a cost in excess of $800,000. The plant has since modified their methods of handling solvents to prevent further losses to the environment. Following an extensive investigation of the extent of contamination, a pump and treat source control remediation program is currently being carried out.

In Winnipeg, soil and groundwater contamination by organic chemicals has been found at two industrial sites. One is a former wood preservative plant that had operated in the east end of the city from 1911 to 1976. The plant used creosote containing polyaromatic hydrocarbons (PAH) throughout its operating history and pentachlorophenol (PCP) mixed with light petroleum oil from 1957 to 1976. These chemicals were found to have migrated throughout the oxidized and fractured upper 6-8 m of the lacustrine clays underlying the site. Small amounts may also have moved through a few metres of underlying sparsely fractured unoxidized clay and into the glacial tills overlying the carbonate rock aquifer (Cherry and Smith, 1990). Groundwaters from several bedrock aquifer monitoring wells on site were found to contain PAH and PCP with a PAH concentration of 76,000 ppb found in one monitoring well sample. Cherry and Smith (1990) suggest that most of the contaminants found in the aquifer were likely introduced via contaminated water entering two runoff water disposal wells completed into the aquifer in the 1950's rather than having migrated into the aquifer through the overlying sediments.

The second site is a former coal gassification plant lying near the Red River. Soil and overburden groundwaters have been found to be contaminated with a variety of organic compounds to depths as great as 14.5 m (CM2H Hill Engineering Ltd., 1994). It is unknown at the time of writing if contamination of the underlying carbonate rock aquifer has also occurred.

2.2.3 Underground Storage Tanks

Manitoba has experienced a long history of groundwater contamination from leakage of petroleum products from underground storage tanks. Significant groundwater contamination with petroleum products has been reported in Brandon, Cypress River, Ashern, Birds Hill, Stonewall, Fisher Branch, Easterville and a host of other towns and villages. The Villages of Fisher Branch and Ashern are currently considering municipal water systems to replace existing private wells due to extensive contamination problems with petroleum products.

Manitoba currently has legislation controlling installation, operation and abandonment of above ground and below ground petroleum storage tanks. More stringent legislation has recently been proposed, requiring the replacement of most older underground tanks with either fibreglass or corrosion protected steel tankages.

2.2.4 Lagoons and Septic Tanks

Due to the sensitivity of many shallow aquifers, Manitoba has experienced some local groundwater quality deterioration from direct or indirect infiltration of lagoon and septic tank effluents. Little of this has been fully documented. Impacts on groundwater quality in the Assiniboine Delta Aquifer due to seepage from unlined municipal lagoons serving the Village of Glenboro and the Town of Carberry were discussed by Rutulis (1985) and Fitzgerald et al. (1994). A number of other lagoons are known to "leak" to a significant degree (R. Rentz, Manitoba Environment, personal communication) but the effects on nearby groundwaters have not been investigated. Manitoba Environment's policy for new lagoons calls for at least one metre of liner material with a hydraulic conductivity of 10^{-7} cm/s or less.

Local groundwater contamination by infiltration of septic tank effluent has been documented in a number of areas. Concern exists that extensive water quality impacts may occur in some sensitive groundwater areas where residential developments rely on individual wells and septic tanks. Most contamination events investigated to date seem to relate to well construction problems or septic system malfunctions. However, high nitrate concentrations have recently been recognized in many private wells in the Village of lnwood in the Interlake region and the Village of Dawson Bay near Lake Winnipegosis. Leakages of septic tanks effluent into the shallow underlying fractured carbonate-evaporite aquifer appears to be the major source of nitrate problems in these communities. Seepage from local feedlot operations may be a secondary source at Inwood.

2.2.5 Agricultural Activities

There is considerable evidence that agricultural activities have resulted in some degree of impact on groundwater quality in many sensitive groundwater areas of Manitoba, although the impact in most cases is thought to be local. Most research has focussed on the accumulation of nitrate-nitrogen in the soil zone and in underlying groundwaters resulting from storage and spreading of farm manures, application of commercial fertilizers and feedlot operations [see Racz (1992) for a summary of studies carried out in the past and current research]. Studies by Manitoba Agriculture since 1992 have found significant accumulations of nitrates below the root zone beneath a number of fields in southcentral Manitoba under a variety of cropping and fertilizing conditions (J. Ewanek, Manitoba Agriculture, personal communication). Investigation was not extended into the saturated zone in these studies but the findings indicate that groundwater quality impacts can be expected under current agricultural practices in some areas. Although the authors are not aware of any studies in Manitoba, earthen agricultural lagoons are widely distributed and may represent a significant potential for seepage into underlying groundwaters in shallow aquifer areas.

Recently, nitrogen contamination of groundwaters has also been identified at some commercial fertilizer blending and distribution centres, resulting from long-term minor spills or accidents which cumulatively have released large amounts of nitrogen-rich fertilizers. In a few cases these sources have resulted in contamination of local private wells. Large scale single event spills of liquid fertilizer have also occurred at several commercial and farm storage facilities and have resulted in local groundwater contamination.

In general, most agriculture related groundwater quality problems have occurred in areas underlain by sandy overburden with shallow surficial aquifers. However, groundwaters containing high nitrate concentrations have also been identified in parts of the Interlake area and in southcentral Manitoba where fractured carbonate and shale aquifers are overlain by thin covers of glacial and postglacial materials. Water sampling in these areas has indicated that nitrate contamination of groundwaters may locally extend to depths in excess of 30 m.

A few studies have been carried out to determine if pesticide application practices are resulting in impacts on groundwater quality. A study within the Assiniboine Delta aquifer (Buth et al., 1992) included sampling 26 irrigation wells and analysis of the samples for nitrate and a suite of commonly used pesticides. Only one sample showed a trace of a pesticide, chlorothalonil, which was attributed to fungicide treatment applied through the irrigation system prior to sampling. Additional studies are planned in this aquifer and in other sensitive groundwater areas of the province over the next few years.

Several cases of individual well contamination with pesticides resulting from improper loading or washing of sprayers near wells have also been investigated by the province.

2.2.6 Bacterial Contamination

Bacterial contamination of groundwater supplies is quite common in Manitoba. The vast majority of problems appear to be very local in nature and directly related to well construction and maintenance. For example, 68 of 190 water samples taken from individual wells completed into the carbonate rock aquifer in the Village of Fisher Branch in August of 1993 showed the presence of coliform bacteria in standard laboratory analyses. Most of this contamination appears to have resulted from infiltration of bacteria along the ungrouted annulus of well casings, by direct entrance of bacteria into improperly sealed buried wells or wells located in pits or through corrosion holes in the casing. Groundwater contamination by movement of bacteria into aquifers from the near-surface without a well acting as conduit appears to be rare although this may occur in the karst areas of the Interlake where bedrock exposures are common.

Most bacteria problems could likely be eliminated by proper well construction practices (installation and grouting of adequate lengths of casing, eliminating the use of large diameter well pits), locating wells up-gradient from potential sources of contamination and proper well maintenance.

3. GROUNDWATER MANAGEMENT - LEGISLATIVE INSTRUMENTS

3.1 WATER RESOURCES LEGISLATION

3.1.1 The Water Resources Administration Act

The Water Resources Administration Act gives the authority and responsibility to the Water Resources Branch of the Department of Natural Resources for administration and management of matters related to water under a number of Acts including The Water Rights Act and The Ground Water and Water Well Act. The Water Resources Administration Act is primarily dedicated to granting administrative authority for quantitative water management in the areas of land drainage, flood protection, and water supply.

3.1.2 The Water Rights Act

The Water Rights Act vests ownership of water in the Crown and requires licences for diversion and use of water for all but domestic withdrawals. Domestic use of water is defined as water obtained from a source other than a municipal or community water distribution system at a rate of not more than 25,000 L/d for household and sanitary purposes, for the watering of lawns and gardens, and for the watering of livestock and poultry.

The Act applies equally to groundwater and surface water. Water is allocated, within sustainable limits, on essentially a first come - first served basis, unless the Act is applied within the terms of a management plan, program or policy, applied to a specific source, that requires allocation in a different manner.

The Act also identifies priorities of use: 1) domestic 2) municipal 3) agricultural 4) industrial 5) irrigation and 6) other, which come into play in certain circumstances. Licences are issued for up to a maximum term of 20 years, after which the holder of the expired licence may apply for renewal. Licences have precedence according to the date of the original application.

3.1.3 The Ground Water and Water Well Act

The Ground Water and Water Well Act:

i) specifies all persons engaged in the business of drilling water wells in Manitoba must be licensed by the province;

ii) authorizes the inspection of wells and the equipment and records of water well contractors and well owners;

iii) allows the Minister to direct that surveys of groundwater resources and studies of the conservation, development and utilization of groundwater be undertaken;

iv) authorizes the Minister to order control of flowing wells;

v) requires all reasonable precautions be taken to prevent groundwater contamination via wells; and

vi) authorizes the Minister to establish regulations related to the conservation, development and control of groundwater resources and the drilling and operation of wells and the production of groundwaters there from.

Regulations established under this Act require that a record be kept and report submitted to the province providing information on the location, construction, testing and geologic and hydrogeologic conditions encountered for each well or test hole drilled. The yield of each well must also be tested and reported. The regulations also require that dry or abandoned wells be sealed to prevent the vertical movement of water in the well. Manitoba has not established comprehensive regulations regarding well construction but relies on the voluntary cooperation of licenced water well contractors to ensure that wells are constructed in an acceptable manner.

The Act does not apply to wells developed by an owner for obtaining a domestic water supply using his own equipment. Records of shallow wells dug by hand or using readily available equipment such as backhoes are, therefore, not normally reported to the province.

3.1.4 The Planning Act

This Act provides for the establishment of provincial land land use policies and for planning by local government authorities. The Planning Act supports both provincial and municipal planning control which directly or indirectly affects land use that, in turn, may impact groundwater supply. The Act specifically includes provision for district planning and establishment of district boards, establishing municipal development plans, land use bylaws, subdivision control and enforcement powers.

3.1.5 The Municipal Act

The Municipal Act grants authority and jurisdiction to municipal governments for the establishment of municipal services such as water supply and sewage collection and treatment, utilities, and local improvements/districts. The Act also provides for by-law development that can be used in a limited way to control land uses which may affect water supply or waste disposal problems.

3.1.6 The Conservation Districts Act

The main purpose of this Act is to provide for conservation, control, and prudent use of resources including groundwater through the establishment of conservation districts and governing boards. The Act supports study and investigation of a resource for the purpose of preparing a resource management scheme and implementation of such a scheme.

3.1.7 The Manitoba Water Services Board Act

This Act gives the Board authority to assist municipalities and individuals with water supply and sewage treatment infrastructure development and operation.

3.1.8 The Department of Agriculture Act

This Act authorizes the Manitoba Water Services Board to administer the Agri-Water program to assist individual farmers with their water needs.

3.2 WATER QUALITY LEGISLATION

3.2.1 The Environment Act

The Environment Act, formerly The Clean Environment Act, and its supporting regulations provide control measures for protecting environmental health and the environment by limiting damage or degradation of Manitoba's land, air and water with a focus on ecosystem preservation.

Under this Act:

i) a proposal must be filed with the Department of Environment for all projects which are likely to have significant effects on the environment. Proposals are subject to inter-departmental review and comment and are publicly registered and advertised in order to provide the public with the opportunity for comment and objection. Based on the comments received, the department may require further information, studies or plans to be undertaken or submitted by the proponent, cause the Clean Environment Commission to hold public hearings, issue a licence to the proponent setting out terms and conditions of the licence, or refuse to issue a licence to the proponent;

ii) broad special powers are granted to the Minister or designate to deal with environmental and environmental health emergencies. Broad powers are also provided to environment officers to enter onto properties to inspect or investigate situations where pollutants may be stored, produced or discharged to the environment or where there are reasonable grounds to believe that environmental damage is occurring;

iii) orders may be issued to control site-specific situations not covered by Environment Act licences or regulations such as the discharge of contaminants to water or soil, and disposal of petroleum contaminated soil;

iv) the Minister may designate specific areas as critical or sensitive and prescribe limits or conditions on activities affecting those areas such as sewage disposal, underground gasoline storage tank installation, or water well development;

v) the "Private Sewage Disposal, System and Privies Regulation" specifies the registration, design and construction/installation of septic tanks, septic fields, pit and pail privies and sullage pits. Amendments to the regulation have been proposed to provide more control;

vi) the "Storage and Handling of Gasoline and Associated Products Regulation" requires registration of petroleum storage tanks, specifies tank and installation standards, requires daily inventory control, specifies conditions for leak testing when required, and specifies tank abandonment procedures. Presently, licensing of installers/removers, evaluation of site sensitivity and systematic tank replacement are not required by law although guidelines do exist. An amended regulation has been proposed to address current and future problems;

vii) the "Waste Disposal Grounds Regulation" sets out site classification by population served, setback distances from a variety of features, operational requirements, and requirements for closure. The regulation provides for engineering evaluation of all proposed sites. For certain types of sites (usually class1, serving more than 5,000 people) comprehensive assessment and licencing is required which may include gas and groundwater monitoring;

viii) the "Livestock Waste Regulation" requires permitting of all new, modified or expanded earthen storages holding agricultural wastes. An engineer's certificate is required for permitting, indicating that the storage has been constructed in a manner which meets the requirements set out in the Regulation. The Regulation also requires that land storage of manure and the disposal of mortalities be done in a manner which does not pollute groundwater and that application of agricultural wastes be done such that the waste is utilized as a fertilizer. The rate of application must not exceed expected crop utilization; and

ix) many developments not covered specifically by regulation must be assessed by the Department of Environment and receive an operating licence. Examples of such developments include wastewater treatment plants, major water withdrawal projects, and water injection projects.

3.2.2 The Public Health Act

Regulations under this Act provide for protection of public health by regulating certain activities that may contaminate potable groundwater supplies. These include:

i) the "Protection of Water Sources Regulation" which prohibits the discharge of a contaminant into an underground water supply via a well. Orders may be issued by the medical officer of health to desist and clean-up; and

ii) the "Water Supplies Regulation" which makes provision for the proper construction of domestic wells to prevent contamination and for proper abandonment of unused wells.

Under this regulation the Medical Officer of Health may direct remedial measures to repair or close a well which produces unsafe water or through its location, construction or maintenance poses a threat of contaminating a water supply.

3.2.3 The Pesticides and Fertilizer Control Act and The Environment Act Regulation 94/88R - Pesticides.

These Acts and Regulation control the commercial sale and application of pesticides. Licences must be obtained for sale and application of pesticides excluding fertilizers and domestic class pesticides. Regulations also govern the storage, application conditions and disposal of pesticides and the equipment used in application. Insurance for public liability and drift damage is required by applicators.

3.2.4 The Dangerous Goods Handling and Transportation Act

This Act provides for the safe handling and transportation of a broad range of dangerous goods by adoption of the federal "Transportation of Dangerous Goods Regulation" which provides for the following:

i) registration and licensing of hazardous waste haulers;

ii) proper packaging and identification of products, substances and organisms based on classification criteria;

iii) proper control and inventory of hazardous wastes via a manifest system;

iv) special power to Environment Officers to deal with emergency situations;

v) reporting of spills to the provincial emergency spill response team and local authorities and the requirement to dispose of hazardous wastes only at licenced facilities;

vi) establishment of specific regulations for hazardous materials handling and disposal at licenced hazardous waste facilities including the "PCB Storage Site Regulation" and "Anhydrous Ammonia Handling and Transport Regulation".

The Act also provides powers to the director to issue orders for investigation and remediation of contaminated sites and to contain spills or leaks of hazardous materials.

3.2.5 The Mines and Minerals Act and The Oil and Gas Act

The Mines and Minerals Act contains a number of provisions either generally or specifically directed toward protection of groundwaters. Part 6 sets out requirements for exploration drilling and abandonment of boreholes. These are further detailed by the "Drilling Regulation (MR 63/92)". Protection of groundwater is a consideration of mine closure and reclamation, dealt with under Part 14 of the Act. The "Quarry Minerals Regulation (MR 65/92)" contains operational requirements governing waste water drainage and groundwater protection in gravel pits and quarries, including prohibition of facilities for permanent storages or handling of gasoline and associated products. The Oil and Gas Act contains provisions legislating requirements for the length and methods of installation of casing in oil and gas wells, for methods of abandonment of these wells and for disposal of saline water collected during oil production.

4. GROUNDWATER MANAGEMENT – INSTITUTIONAL INSTRUMENTS

In Manitoba, groundwater regulation and management are carried out primarily by two provincial government departments having both individual and shared responsibilities. These are the Departments of Environment and Natural Resources. Generally, the Department of Natural Resources has responsibility for assessment and allocation of groundwater resources while the Department of Environment has responsibility for issues related to groundwater quality, particularly regulatory responsibilities.

Several other provincial agencies are involved in some aspects of groundwater development or protection, although this involvement is less direct in terms of management of the resource than that exercised by the Natural Resources or Environment Departments. The Water Services Board of the Department of Rural Development carries out groundwater exploration and development for community and rural water development projects. The Board and Manitoba Agriculture jointly employ four farm water technologists who provide advice on farm and rural water supply problems throughout southern and central Manitoba. Manitoba Agriculture also works with the farm community to develop guidelines for on-farm activities such as livestock manure handling and disposal which may impact on groundwater quality.

Manitoba Energy and Mines is responsible for legislation that regulates the exploration for and development of industrial minerals, base and precious metals, and oil and gas. The legislation includes regulations governing industrial mineral and base metal test hole construction and abandonment procedures, casing depths and well construction for oil exploration and production wells, and construction of groundwater withdrawal and recharge wells for pressure maintenance in oil fields.

The Manitoba Department of Health has responsibility for groundwater quality where health impacts may result from natural or anthropogenic components found in groundwater. In addition, the Clean Environment Commission has authority to hold hearings into matters of environmental significance in Manitoba and to issue recommendations based on the findings of these hearings. Hearings having some component of groundwater concern have been held frequently in the past.

Municipalities and Conservation Districts have authority to become involved with some aspects of groundwater management although, until recently, few have exercised this right.

Federally, the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada has been involved, primarily as a funding agency, in many groundwater development projects in Manitoba which service rural areas and communities. PFRA provides contributions to cover part of the costs of well installations in rural areas. In some cases PFRA has also conducted local groundwater resource evaluations and regional assessments of groundwater conditions in the province as part of regional or project specific planning studies, generally in cooperation with a provincial agency.

The federal-provincial Prairie Provinces Water Board (PPWB) has also been involved in groundwater on the prairies through their Committee on Groundwater, which provides a joint voice on groundwater issues along provincial boundaries. The PPWB has sponsored studies of regional groundwater conditions along the Manitoba-Saskatchewan and Saskatchewan-Alberta borders.

Research into groundwater in Manitoba is carried out in the Department of Civil and Geological Engineering at the University of Manitoba and, occasionally, by other Canadian universities. The federal government provides a research presence in the prairies through the National Hydrology Research Institute in Saskatoon. Some groundwater research in the province has also been carried out by the Geological Survey of Canada (GSC). A very large program of research into the safe disposal of high level nuclear wastes is currently being carried out by AECL in the Pinawa and Lac du Bonnet areas. A considerable amount of test drilling (to depths exceeding 1000 m in some cases), aquifer testing, water sampling and analysis and geological and geophysical logging has been undertaken to develop an understanding of the hydrogeology of igneous and metamorphic rocks and its interaction with overburden materials and surface water bodies. AECL has also constructed an underground laboratory to depths greater than 400 m in the Lac du Bonnet batholith to conduct intensive studies of the hydrogeology and other properties of these rocks.

A more complete description of the groundwater management activities of Manitoba Environment and Manitoba Natural Resources is given below.

4.1 DEPARTMENT OF ENVIRONMENT

This department has primary responsibility for the setting of environmental standards and for environmental protection. Manitoba Environment also administers a number of regulations on behalf of the Department of Health, including regulations governing waterworks systems, wastewater collection and wastewater treatment. Manitoba Environment is divided into Environmental Management and Environmental Operations Divisions.

4.1.1 Environmental Management Division

The Environmental Management Division has primary responsibility for carrying out the environmental licencing approvals processes set out in The Environment Act and The Dangerous Goods Handling and Transportation Act, for developing environmental quality standards for land, air and water, and for administration of regulations governing the storage and application of pesticides. The approvals system includes licensing of developments producing or disposing of hazardous wastes, some land use activities, Class 1 waste disposal grounds, municipal and industrial water and waste handling facilities and other activities requiring licencing under the Act. This includes licensing of municipal lagoons and ensuring the safety of municipal water supplies, including regular monitoring of municipal water quality. Deep well disposal operations, other than those for petroleum extraction and disposal of saline water produced in oil extraction, are licensed by the Division. As well, licensing through this Division is required for projects withdrawing more than 200 dam^3/year of groundwater from an aquifer or closed-loop systems with non-consumptive withdrawals of 25 L/s or greater.

4.1.2 Environmental Operations Division

The Environmental Operations Division is divided into five regional offices covering the province. Each region is staffed with a Director, supervisory personnel, environment officers and public health inspectors. The regions are responsible for monitoring and enforcing licences, issuing permits, undertaking investigations, assessments and clean-ups and other day to day operations within their district. From a groundwater viewpoint, this includes the investigation of groundwater contaminations and complaints of groundwater quality on all scales that happen in the district. Staff also ensure compliance with a number of certificates issued by the Department of Health.

4.2 DEPARTMENT OF NATURAL RESOURCES

The Department of Natural Resources maintains responsibility for surface water and groundwater resources management through a number of acts of which The Ground Water and Water Well Act and The Water Rights Act are most directly applicable to groundwater management. These acts and their corresponding regulations and policies are administered by various Sections in the Water Resources Branch.

4.2.1 Water Licensing Section

Groundwater usage in excess of 25,000 L/d or groundwater usage for municipal, irrigation and industrial purposes, including groundwater heating and cooling systems, must be licensed under the terms of The Water Rights Act. Priority for groundwater allocation is based on the time of receipt of an application for groundwater usage. Approval is required to carry out exploration work to establish groundwater conditions and, in most cases, a formal pumping test must be carried out and the results submitted as part of an application. The Water Licencing Section works closely with the Groundwater Management Section to ensure that licencing of groundwater withdrawal or thermal uses of groundwater take place within the sustainable limits of aquifers and to minimize the potential for impact on other users. Dual licensing of groundwater withdrawals is carried out with Manitoba Environment for cases where withdrawals exceed 200 dam^3 per year or for non-consumptive closed-loop systems where the withdrawal rate is greater than 25 L/s.

4.2.2 Groundwater Management Section

This section is responsible for administration of The Ground Water and Water Well Act which includes licensing of water well contractors, collecting well drillers' reports and maintaining a computerized storage and retrieval system for these reports. Approximately 72,000 well logs are currently on file. The section retains primary responsibility for groundwater resource evaluation. To this end, programs of groundwater mapping, including groundwater quality, are carried out, selected aquifers are studied in detail to determine their capacity for supplying groundwater without introducing detrimental effects, and studies of the potential for artificial recharge to enhance aquifer capacity have been carried out. The section also operates a network of approximately 606 groundwater monitoring stations where groundwater levels are monitored regularly. Groundwater quality is also monitored in a number of these observation wells. The section maintains a large amount of groundwater quality information, gathered from regular sampling of monitoring wells and one-time sampling of other wells as part of regional studies or local investigations. The section works cooperatively with Manitoba Environment to provide hydrogeological input into some groundwater contamination investigations and investigates cases where problems have occurred as a direct result of well construction practices.

5. GROUNDWATER MANAGEMENT – OTHER INSTRUMENTS

In this section the major programs operated by agencies involved in groundwater management in Manitoba are discussed.

5.1 MONITORING

5.1.1 Water Level Monitoring

5.1.1.1 Water Resources Branch

Groundwater level monitoring by the province was initiated in the early 1960s in the carbonate rock aquifer in the Winnipeg area in conjunction with construction of the Red River Floodway (Render, 1970) and in the Winkler aquifer near the town of Winkler. Since then the provincial network has gradually grown in size as monitoring wells have been installed as part of groundwater studies of heavily developed aquifers or to monitor water levels in specific regional aquifers. The Branch currently operates a network of 606 monitoring wells consisting of 460 wells equipped with automatic water level monitoring devices (primarily Stevens F series float operated recorders) and a further 146 wells that are read manually, usually on a weekly or monthly schedule.

Most monitoring wells are located in the carbonate aquifer in the Winnipeg area, in the Assiniboine Delta aquifer, in the Oak Lake aquifer, and in the Winkler aquifer. Regional monitoring is carried out in the carbonate aquifer in the Interlake area and in sand and gravel aquifers in southeastern Manitoba. Other observation wells are located near pumping wells in smaller aquifers where the long-term yield is uncertain.

Water level information is digitized and stored on hard disk. Retrieval software allows rapid viewing of the data in tabular or graphical form at an internal network of computer terminals. External access via modem is also available. Hard copy printout of the basic data or individual hydrographs can be achieved quickly.

5.1.1.2 Atomic Energy of Canada Limited

Extensive water level monitoring is also carried out by AECL at the Underground Research Laboratory site near Lac du Bonnet in southeastern Manitoba. This facility consists of a small mine constructed to a depth of about 460 m in the granitic rocks of the Lac du Bonnet batholith to allow research to be carried out into disposal of high level nuclear wastes. An extensive monitoring network has been established by AECL near the facility to examine the groundwater perturbations caused by construction and operation of the facility. Monitoring is carried out in approximately 250 zones in about 75 boreholes in the granitic bedrock and 100 zones in wells completed into overburden sediments within a kilometre of the facility. AECL also carries out water level monitoring in bedrock and overburden materials at several regional sites in the Lac du Bonnet area.

5.1.1.3 Other Organizations

Groundwater level monitoring is, at times, also required to be undertaken by individual operators as part of groundwater withdrawal licensing by the Water Licensing Section of the Water Resources Branch or as part of licensing by Manitoba Environment under The Environment Act. In most cases where water level monitoring has been required, the monitoring information has been supplied to the Water Resources Branch and incorporated into the provincial data base.

5.1.2 Water Quality Monitoring

5.1.2.1 Water Resources Branch

Groundwater quality monitoring for major and some trace elements is currently carried out by the Water Resources Branch in 138 monitoring wells. In addition, groundwater temperatures are monitored by the Branch in the production water from 57 wells used for heating/cooling systems in Winnipeg.

Most groundwater quality monitoring is carried out in wells within the provincial water level observation network. Most are located in the four main study areas identified previously. The sampling frequency depends on the availability of funds to carry out analyses and staff time to collect the samples. Sampling frequency has varied from quarterly to every few years. Until recently, sampling procedures have also varied from time to time. It is important to note that water quality monitoring in these wells is primarily to observe changes in major ion concentrations and not to monitor trace level organic or inorganic constituents. Results are stored on magnetic tape and hard copy and are available on request.

5.1.2.2 Department of Environment

The Environmental Approvals Branch of Manitoba Environment carries out annual sampling of municipal water systems, including approximately 100 systems utilizing groundwater. Both raw and treated water are analyzed for a comprehensive suite of inorganic and some organic constituents. Results are stored on magnetic tape and hard copy and are available on request. Site-specific water quality (organic and/or inorganic) monitoring is also carried out at several locations by Manitoba

Environment staff or local operators who report results to the department. Monitoring is carried out at selected waste disposal grounds, lagoons, and contaminated sites, including a number of communities where contamination by petroleum products has been recognized.

5.1.2.3 Other Organizations

The City of Winnipeg monitors groundwater quality and methane gas generation near major landfill sites currently operated by the city and in the vicinity of landfill sites which have been closed. This monitoring is generally carried out as a requirement of licensing of these facilities by Manitoba Environment or by order from the department. Monitoring has not generally been a requirement in the past but the trend is towards increased monitoring at sites where groundwater contamination or groundwater quality changes could occur.

5.2 MAPPING, AQUIFER RESOURCE EVALUATION

5.2.1 Regional Hydrogeologic Mapping

Regional hydrogeological mapping in Manitoba was initially undertaken by the Geological Survey of Canada. A series of GSC Water Supply Papers covering the southern parts of the province were produced by J. A. Elson and E. C. Halstead in the late 1940s through to the early 1960s. These reports discussed groundwater conditions by Range-Township units and presented water well inventory information and some geochemical analyses. In the late 1960s and during the 1970s regional studies were undertaken by the Inland Waters Branch of the federal Department of Energy Mines and Resources which became the Inland Waters Directorate of Environment Canada. Charron (1969, 1974) published a series of reports covering parts of southcentral Manitoba.

In the late 1960s a federal-provincial program was initiated to carry out regional studies to evaluate the groundwater resources of a number of municipalities or groups of municipalities. By the mid 1970s this had evolved into a program of mapping the groundwater resources of the agricultural portion of Manitoba on the basis of 1:250,000 NTS map sheet units. This program continued intermittently until 1987 when the final map sheet study was completed. In all, mapping was carried out in 11 map sheet areas *(Figure 17)*. The province is currently updating the earlier versions of these studies. Each study consists of a series of maps with notes, cross-sections and a table of groundwater analyses. The maps generally present the location plan, bedrock geology, surficial geology, overburden thickness, bedrock surface topography, generalized aquifers, groundwater quality and potentiometric surface within each map sheet area. Cross-sections show bedrock and surficial geology, pumping test results and groundwater quality. The water chemistry table may include 400 or more analyses.

In the late 1980s, the PPWB commissioned a series of six 1:250,000 scale hydrogeologic profile maps covering the sedimentary basin portion of the Saskatchewan-Manitoba border (Prairie Provinces Water Board, 1986). Each map includes a north-south cross-section showing bedrock and surficial geology along the border and the base of groundwater exploration. A plan view map covering approximately three ranges (29 km) on either side of the provincial border shows bedrock geology and overburden thickness.

The Manitoba Water Resources Branch has also produced two summary maps showing the distribution of bedrock and surficial aquifers for the entire southern and central portions of the province (Rutulis,1986,1987).

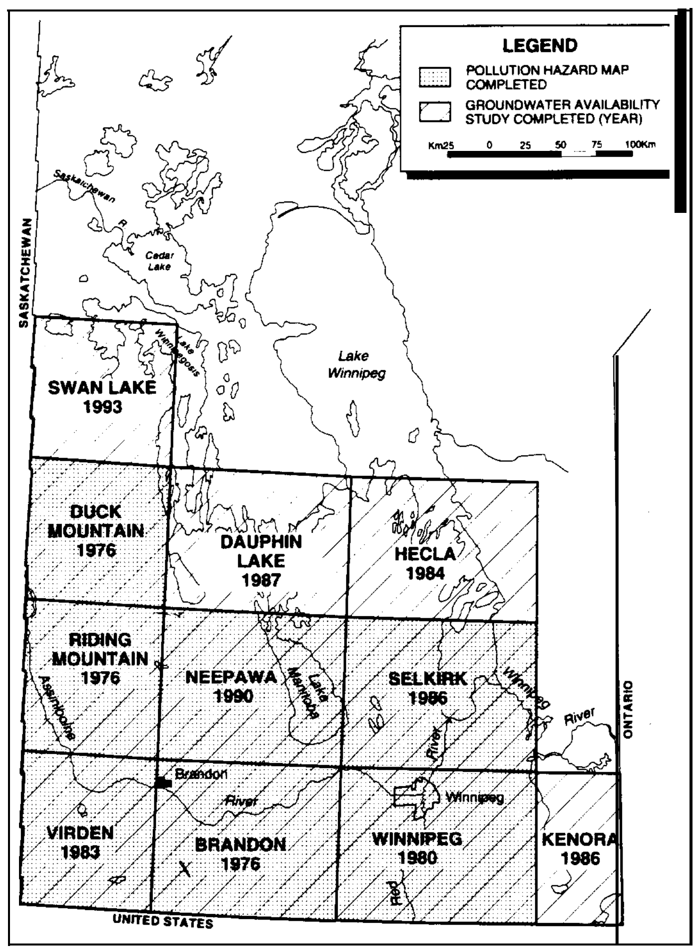


Figure 17. Regional Groundwater Availability Studies and Pollution Hazard Maps.

5.2.2 Groundwater Pollution Hazard Mapping

In the late 1970s Manitoba Water Resources completed a series of groundwater pollution hazard maps for seven 1:250,000 NTS map sheet areas in agro-Manitoba *(Figure 17)*. Pollution hazard zones were mapped using available information from bedrock and surficial geological maps, soils maps and water well logs. A pollution hazard zone was defined as an area where fresh water aquifers are overlain by less than 6 m (5 m on some maps) of clays, tills or other low-permeability materials. A program of updating the existing groundwater pollution hazard maps and producing similar maps for other map sheet areas in Agro-Manitoba is currently underway. A more complex classification scheme will be used in producing the updated and new maps.

The PPWB has prepared 1:250,000 aquifer vulnerability maps for the four southernmost map sheets on the Saskatchewan-Manitoba border using the AVI aquifer vulnerability mapping procedure (van Stempvoort et al., 1992). These cover the same areas that were mapped in the PPWB hydrogeologic profiles discussed above.

5.2.3 Aquifer Capacity Studies

Since the early 1960s the Manitoba Water Resources Branch has carried out aquifer capacity investigations that initially concentrated on major high-use aquifers. The purpose of these studies is to develop a comprehensive understanding of the hydrogeology of selected aquifers or portions of aquifers, allowing determination of the long term safe yield and leading to development of the capability to make quantitative predictions of the effects of groundwater development. To date, studies have been carried out in the carbonate rock aquifer in the Winnipeg and Selkirk areas (Render, 1970, 1986), the Assiniboine Delta aquifer, the Oak Lake aquifer, the Glenora aquifer and the smaller Miami, Winkler and Elie aquifers (Render, 1987, 1988). A 10-year plan for further aquifer capacity investigations has been presented that proposes studies for a number of additional aquifers.

5.3 DATA COLLECTION

5.3.1 Manitoba Water Resources Branch

Legislation requires the filing of a water well driller's report with the Water Resources Branch for each well or test hole constructed in Manitoba unless the well has been drilled by a private individual on private land for domestic use. Approximately 72,000 reports are currently on file and about 2,500 additional reports are submitted to the Branch annually. Each report contains the location of the well by section, township and range or river lot and parish, a geological log of materials penetrated by the well, a construction log indicating how the well was completed (casing length and type, screened interval, etc.), results of any pumping test that was done on the well (normally including the static water level, pumping rate, pumping period and water level at the end of the test) and any comments that the driller may add.

Well drillers' reports are stored in computerized files and can be retrieved by location or combinations of location and key word or owner's name. The data base can be accessed by submitting a request to the Branch or by telephone line using a personal computer and modem. On request the Branch will supply floppy discs containing the complete file of reports and a basic retrieval program.

The Branch also has approximately 15,000 groundwater chemistry analyses stored in paper files, with some of these analyses also stored in computer files. Many of the analyses have been published in tables in the Groundwater Availability reports. Most groundwater analyses are stored by location with many having been collated to the well driller's report for the well. Many of the analyses of samples collected from observation wells for long-term monitoring purposes are stored by observation well name in computerized files. This information can be accessed by submitting a request to the Branch for water quality information for specific locations.

The Branch maintains groundwater level information in computerized files for wells monitored within the provincial observation well network. This information is available as plotted hydrographs or daily water levels in hard or magnetic disc copy by submitting a request to the Branch or may be accessed by modem. Generalized maps showing the density of observation well information by river basin are also available.

Several hundred borehole geophysical logs for wells and test holes logged by the Branch throughout the province are available as paper copies. Most logs include at least two of point resistance, self potential, natural gamma or caliper logs. Logs are stored by range and are available as photocopies on request to the Branch. Many of the logs have been published as part of the cross-sections in the Groundwater Availability reports. Unlike the other prairie provinces, virtually no borehole geophysical logging is carried out by individual water well contractors in Manitoba.

Finally, the Branch maintains paper files (in the process of being computerized) of water rights licences for groundwater systems. Information included in these files are the licensed pumping rates, annual allowable withdrawals and information such as pumping test results filed as part of the application for the licence.

5.3.2 Manitoba Environment

The Environmental Management Division maintains computerized records of water quality information gathered as part of the annual sampling of municipal systems. Records are stored by community and date and are available on request to the Division.

Files are also maintained on known contaminated sites, lagoons and waste disposal grounds along with any groundwater quality information gathered as part of site investigation or monitoring. Databases of petroleum storage tank locations and incident reports are also available.

5.3.3 Manitoba Energy and Mines

The department has conducted drilling operations throughout southern Manitoba since 1969 when the first holes were drilled to provide supplemental information needed to construct stratigraphic maps for bedrock in the Interlake region. Since that time, over 250 holes (25,000 m) have been drilled in the Interlake and southern Manitoba to generate additional stratigraphic information, test and evaluate industrial mineral occurrences, and to determine the nature of the Precambrian basement in areas covered by the younger Paleozoic formations. Logs for stratigraphic holes drilled under this program are published annually in the department's Report of Activities and are available on request. Cores are also available for examination. More recently, in the Grand Rapids region, the department has begun monitoring static water levels in its stratigraphic drillholes, and to work cooperatively with the Geological Survey of Canada and the provincial Water Resources Branch in logging holes geophysically. Generally speaking, water sampling and hydraulic testing have not been conducted on these holes.

The Geological Services Branch maintains a fully computerized Stratigraphic Database containing records of all exploration and stratigraphic holes drilled in southern Manitoba. The Petroleum Branch maintains a parallel database referred to as the Manitoba Oil and Gas Well Information System (MOGWIS) containing geological and engineering data for all petroleum exploration and development holes drilled in the province. Logs for water supply wells for pressure maintenance water flooding are also maintained on this file.

Geochemical data on subsurface carbonate formations and on selected spring waters is also collected by the Geological Services Branch as an aid to mineral exploration.

5.4 TECHNICAL ASSISTANCE

5.4.1 Technology Transfer

No formal mechanism is in place in the province for transfer of technology to water well drillers. On an ad hoc basis, some degree of technological transfer occurs with selected drillers when the drillers are carrying out work for government departments. The Department of Rural Development employs a well construction superintendent who will provide assistance to well drillers to resolve difficult drilling or testing problems. Otherwise, the annual convention organized by the Manitoba Water Well Association provides a forum for information exchange.

5.4.2 Assistance with Well Problems

Assistance to individuals with well problems (water quality, well construction) is provided by three provincial Departments: Natural Resources, Rural Development and Environment. The Water Resources Branch will provide telephone or written advice to individuals with well problems and in some cases will provide more direct assistance such as borehole geophysical logging, site visits, specialized sampling and analysis, assistance in borehole sealing, regional water sampling programs to define the extent of problems, or will act as an intermediary for the well owner to obtain assistance from their driller or other government agency. The farm water technologists with Rural Development will also provide telephone advice and site visits, including field chemical analyses, to deal with well problems within rural areas of southern and central Manitoba. The well construction superintendent with this department provides more specialized assistance in difficult cases. Public health inspectors and environmental officers with the Environmental Operations Division of Manitoba Environment also provide assistance to individuals with groundwater quality problems and will investigate and work to resolve problems related to pollution of groundwater.

The responsibilities of these three departments overlap to some degree on the issue of resolving well problems. In difficult or large scale problems, there is often cooperative involvement of all three departments while in some smaller problems the individual roles are diffused and problems are generally handled by whomever receives the initial complaint.

5.5 FINANCIAL ASSISTANCE

Financial assistance is provided to bona fide farmers through Manitoba Rural Development and PFRA for the installation of wells for farm water supplies (including irrigation) and may also include financial and supervisory assistance for test drilling. PFRA provides financial assistance up to one-third of eligible costs to a maximum of $2,200 per project for irrigation projects and $1,650 for individual wells. Manitoba Rural Development will provide up to 30% of some approved development costs not covered by PFRA. PFRA also provides financial assistance up to 40% of the cost for approved water development projects for small rural communities or legally-associated groups of farmers or ranchers. Local PFRA offices should be consulted for specific details.

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