

Dakota Aquifer System in the Province of Manitoba

by Maris Rutulis

Abstract

In Manitoba, the aquifer system that corresponds to the Dakota aquifer system in United States is formed by sandstone beds of the Lower Cretaceous Swan River formation. The Swan River formation underlies thick Cretaceous shale beds and extends from Manitoba escarpment southwesterly into Saskatchewan and North Dakota. Along the northern part of the Manitoba escarpment the Swan River formation underlies surficial deposits in fairly extensive areas east of the escarpment. In the areas where the Swan River formation is overlain by the Cretaceous shales, water in the sandstone aquifers is salty. In some of the areas where the sandstone beds of the Swan River formation are overlain by surficial deposits or only thin shale beds, water in the sandstone is fresh. In these areas the Swan River sandstone aquifers are used for domestic, farm and municipal water supply. For one municipal water system the water is demineralized by the reverse osmosis process. No accumulation of petroleum in the Swan River formation has been reported in Manitoba.

Introduction

The Dakota aquifer system of the United States is correlated with the sandstone beds of the Lower Cretaceous Swan River formation in Manitoba. No petroleum accumulation has been reported in the Swan River formation and unfavorable geological conditions would appear to preclude any potential oil fields. Consequently this paper deals with the ground water aspect of the formation. The Swan River sandstone aquifers are significant sources of potable water in some parts of Manitoba but in other parts they contain highly mineralized water that can have a detrimental effect on fresh water in other aquifers.

This report (Figure 1) is based on available information consisting mainly of ground water availability

studies on regional and municipal scales carried out by the Manitoba Water Resources Branch (Planning Division, 1971, 1972, 1973, 1976 a,b; Little 1973 a,



Figure 1. Index map showing study map area in relation to adjacent provinces and states

1973 b, 1980), several ground water investigations for municipal water supplies for towns and published reports and maps (Wickenden 1945; Halstead 1959; Davies et al. 1962; Klassen et al. 1970; Manitoba Mineral Resources Division 1979). A draft map with notes of a preliminary study of the areal distribution and stratigraphy of the Swan River formation by Dr. H.R. McCabe, stratigrapher of the Geological Services Branch, Manitoba Department of Energy and Mines, was used in preparing maps and discussion of the geological setting of the Swan River formation.

Geological Setting

Stratigraphic Position

The Swan River formation constitutes the basal unit of the Cretaceous formations in Manitoba. The areal distribution of the Swan River formation in Manitoba is outlined in Figure 2.

In the southern part of the study area the Swan River formation is underlain by Jurassic rocks consisting mainly of shale with thin beds of limestone, sandstone and evaporites (Figure 3). In the northern part (Figure 4) the Jurassic formations are absent and the Swan River formation is underlain by Devonian formations consisting mainly of carbonate rocks. The Jurassic formations probably terminate in the Duck Mountain area. However, because in the northern part distinction between Jurassic formations and the Swan River formation is not possible with available data, the Swan River formation may possibly include some Jurassic sandstone beds. Throughout the area west of the Manitoba escarpment the Swan River formation is overlain by a thick sequence of Cretaceous shales that in the southwestern corner of Manitoba reach a maximum thickness of about 730m (2,400 feet).

In the southern part of the study area the formation subcrops in a narrow belt just east of the Manitoba escarpment. Some isolated scattered subcrop areas related to channels in the Jurassic and older rocks exist in the central part (Figure 2). In the northern part the subcrop area is considerably wider and in places extends some 30km (20 miles) east of the escarpment.

The Swan River formation is exposed in river banks in the northern part of the study area. The most southerly outcrop is about 10km (6 miles) northwest of Dauphin (Figure 2). Several outcrops, including the type outcrop, occur along Swan River east of the town of Swan River. Numerous outcrops are found along the Red Deer River just west of the Manitoba-Saskatchewan boundary at the north limit of occurrence of the formation in Manitoba. One of the largest exposures of the sand and sandstone beds of the Swan River formation, a cliff approximately 10m high and 200m long (30 x 600 feet), is located in this area (Wickenden 1945).

Areal Distribution and Thickness

The general trend of the eastern boundary of the Swan River formation is north-northwesterly from the vicinity of Winkler (Figure 2) near the International Boundary towards the Saskatchewan-Manitoba

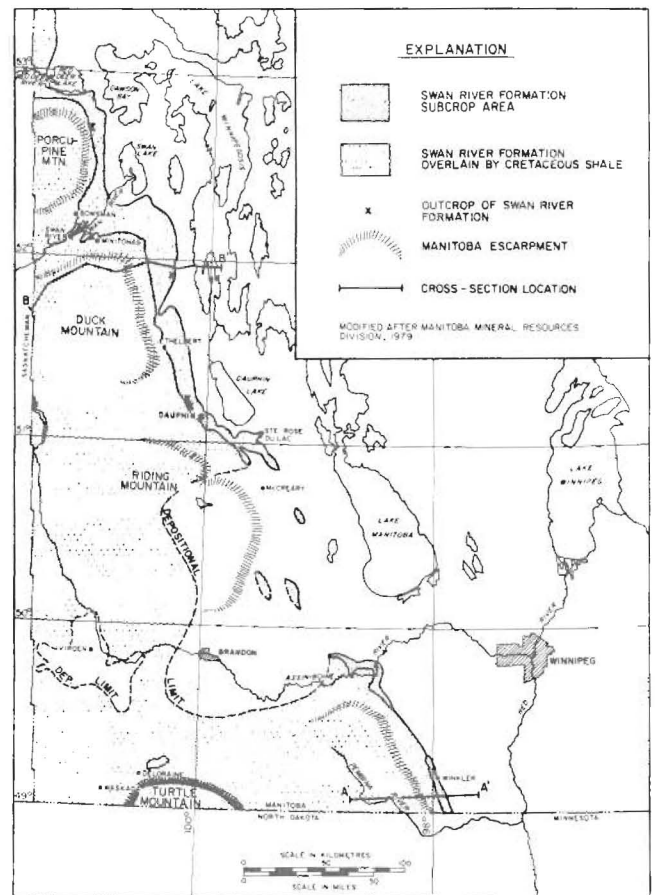


Figure 2. Areal distribution of the Swan River formation (Dakota sandstone) in Manitoba and locations of cross sections

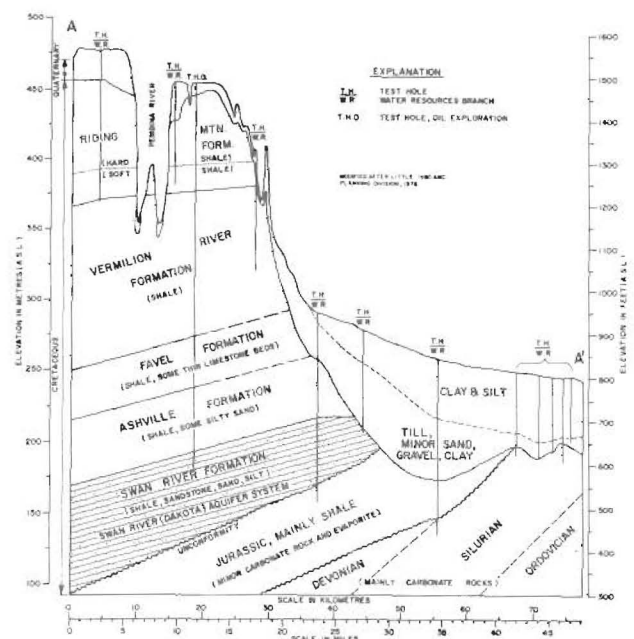


Figure 3. Stratigraphic position of the Swan River formation near the International Boundary

boundary just north of the 53rd parallel. This general trend is interrupted by a major non-depositional area (Figure 2) where only scattered outliers exist along the general trend line and the boundary of the main body of the formation deviates some 80km (50 miles) to the west. A fairly extensive isolated non-depositional area covering some 1,600km² (600 square miles) occurs near the Manitoba-Saskatchewan boundary about 100km (60 miles) north of the International Boundary. The total area underlain by the Swan River formation is 40 x 10³ km² (16 x 10³ square miles).

The thickness of the Swan River formation varies considerably from place to place within short distances because the formation has been deposited on an uneven erosional surface. In most of the southern half (south of Riding Mountain) the thickness ranges from zero to 30m (0-100 feet). Over valleys and channels in the underlying strata in the southwest corner of the province the thickness ranges from 60m (200 feet) to more than 90m (294 feet). In the northern area (Planning Division 1973) the Swan River formation thickness ranges from 30m (100 feet) to more than 100m (330 feet). The thickness of the formation in the northern area varies considerably because of channels and valleys in the underlying strata (Figure 4).

Lithology

The Swan River formation consists of shale, clay, silt, sandstone, sand and lignite. The proportion of these materials varies over a wide range and often within short distances; at some locations shales and clays may be dominant and at others sandstone and loose sand constitute most of the formation. In some areas thin layers of limestone or carbonate cemented sand are present.

The lignite beds are very common but usually are only a few centimeters (an inch or so) thick. However, at one location about 10km (6 miles) east of the town of Dauphin a 5m (16 feet) thick lignite bed was penetrated by a ground water test hole. Other test holes in the vicinity found only the usual thin beds of lignite. A thick layer of lignitic material was intersected about 30km (18 miles) north of Ethelbert.

In the southern part of the study area the unconsolidated sand and sandstone beds are found in the upper part of the formation. In the northern part the stratigraphic position of the sand and sandstone is considerably more variable and they may occur anywhere within the formation. Often the sand and sandstone are present as numerous thin beds interbedded in the shale, silt and clay. The total thickness of the sand and sandstone beds may range from less than 1m to more than 40m (3-135 feet).

The grain size of the sand and sandstone also varies over a wide range; it ranges from very fine- to coarse-grained sand. Some basal gravel beds in pre-Cretaceous erosional channels have been reported in southwestern Manitoba.

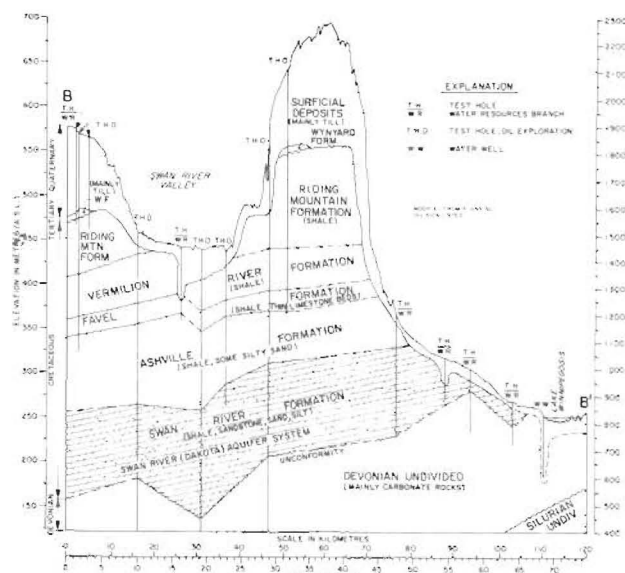


Figure 4. Stratigraphic setting of the Swan River formation in the northern part of the study area

Ground Water Aquifers

In Manitoba, the sandstone or unconsolidated sand aquifers that occur within the Swan River (Dakota) aquifer system are called the Swan River sandstone aquifers.

In the areas where the Swan River sandstone aquifers are developed for water supply they seem to occur at random in any stratigraphic position within the Swan River formation, i.e. they may be at the top or the bottom of the formation or at any other position in between. The aquifers consist of deposits of sandstone and unconsolidated sand separated both horizontally and vertically by shale and clay. The areal extent of the aquifers may range from a few hectares (acres) to many square kilometers (miles). The thickness of the aquifers varies from less than 1m (3 feet) to more than 30m (100 feet). The material forming the aquifers ranges from coarse, clean quartz sand to silty, very fine sand interbedded with numerous thin beds of shale and clay. Aquifer conditions often change from the one extreme to the other within short distances. Consequently, extrapolation between widely spaced wells or test holes, i.e. 1km or more, is risky and may seriously misrepresent actual conditions.

The depth to the aquifers ranges from less than 100m (330 feet) in the Swan River formation subcrop area to more than 650m (2,000 feet) in the southwest corner of Manitoba.

Potentiometric Surfaces

The potentiometric surface of the Swan River sandstone aquifers has been measured at a number of points along and east of the Manitoba escarpment. The potentiometric surface of the aquifer system in the southwest corner of Manitoba is indicated by two

flowing wells near Deloraine and Waskada in the vicinity of Turtle Mountain (Figure 2). East of the Manitoba escarpment the potentiometric surface ranges from a few meters (yards) below ground level to slightly above ground level corresponding more or less to the ground surface at the base of the escarpment, which ranges from 330m to 365m (1,000 to 1,200 feet), above sea level. The ground elevation at the flowing well at Waskada is 472m (1,550 feet) and at Deloraine it is 500m (1,640 feet). This indicates that the elevation of the potentiometric surface in the western part of the Swan River aquifer system is some 100m to 150m (300 to 550 feet) higher than near its eastern boundary.

The hydraulic gradient of the aquifer system in southern Manitoba ranges from 0.5 to 0.75 m/km (2.6 to 3.9 ft/mi), if it is assumed that the hydraulic gradient is nearly uniform over the whole distance from the Turtle Mountain area to the Manitoba escarpment, which is approximately 200km (120 miles). The actual gradient probably is much flatter than that in the western part and considerably steeper in the vicinity of the Manitoba escarpment.

Flow Systems

Both regional and local flow systems exist within the Swan River aquifer system. The regional-flow system likely originates in the area west of Manitoba. As indicated by the much higher potentiometric surface in the western part of the area than along the Manitoba escarpment, the regional flow is in an easterly direction. The regional flow transmits deep, salty water from west to east. The fact that in the vicinity of Turtle Mountain (Figure 5) water in the Swan River sandstone aquifers generally is less mineralized (but still salty) than at other locations in the western area seems to indicate that flow systems originating in the Turtle Mountain area merge with the regional flow system. If the regional flow system were dominant in all areas of the Swan River aquifer system, no fresh water aquifers would exist within it. Since water in many Swan River sandstone aquifers along and east of the Manitoba escarpment in fresh, local water flow systems must exist and must be dominant in these areas. The local flow systems may exist in areas where the Swan River is overlain by relatively thin surficial deposits and bedrock. These conditions exist at the base of the Manitoba escarpment and east of it. Hence, all the fresh water Swan River sandstone aquifers or parts of the aquifers that contain fresh water are located in this area. The regional flow system, however, often intrudes upon even those Swan River sandstone aquifers that are buried only under a thin layer of surficial deposits resulting in salty water in the vicinity of McCreary, Dauphin and Ste. Rose.

The Swan River formation is in contact with Devonian carbonate rocks in the northern area (Figure 4). The carbonate rocks generally are permeable and have a fairly high transmissivity. Consequently water from the Swan River formation can easily enter the carbonate rocks and merge with flow systems that

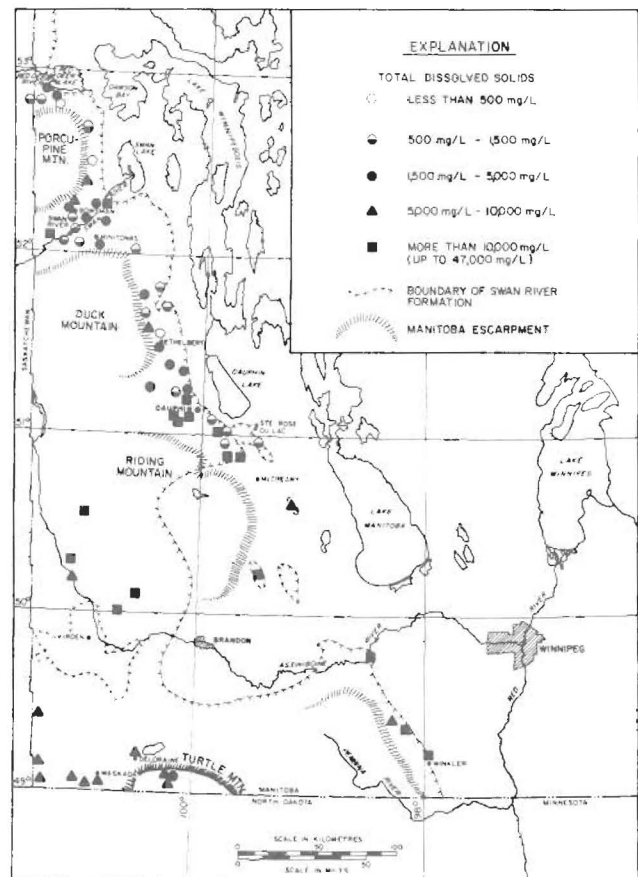


Figure 5. Total dissolved solids concentration in Swan River sandstone aquifers. Sodium and chloride are the dominant ions in the highly mineralized waters.

exist there and vice versa. Thus, in the northern area the base of the regional flow system of the Swan River aquifer system and, in fact, the base of the aquifer system itself becomes very vague.

Transmissivity and Storage Coefficient

In general, the transmissivities of the Swan River sandstone aquifers are low and range from less than $1.0\text{m}^2/\text{d}$ to approximately about $15\text{m}^2/\text{d}$ (70 to 1,000 I.G.P.D./ft). The transmissivities of the thicker and coarser grained aquifers are in the 75 to $100\text{m}^2/\text{d}$ (5,000 to 7,000 I.G.P.D./ft) range. The transmissivities at a number of locations were determined during various ground water availability studies and are indicated in Figure 6 (Little 1973a; Planning Division 1971, 1972, 1973, 1976b). Since the transmissivity determinations are for the more permeable water bearing zones, which are discontinuous and separated by very low permeability materials such as shale and clay, the overall transmissivity of the whole Swan River aquifer system likely is very low.

Storage coefficients for the relatively high transmissivity Swan River sandstone aquifers developed for municipal supply range from 0.5×10^{-4} to 5×10^{-4} . No storage coefficient determinations have been made for the low transmissivity aquifers.

Recharge and Natural Discharge

Very little is known about the recharge in the area west of the Manitoba escarpment. The fact that water in the Swan River aquifer in the vicinity of Turtle Mountain is less mineralized than north and west of it seems to indicate that some recharge takes place in the Turtle Mountain area. Since similar topographic and geological conditions exist in the Riding, Duck and Porcupine Mountain areas, it can be assumed that some recharge takes place under these elevated areas. Because the surficial deposits in these areas consist mainly of a thick layer of clayey till and the Swan River formation is overlain by thick shale beds the recharge rate likely is very low.

The most significant recharge in respect to fresh water in the Swan River aquifer system takes place along and east of the Manitoba escarpment in the northern part of the aquifer system. As this area is in the discharge area of the regional system and, therefore, should yield only salty water, the presence of fresh water indicates good local recharge conditions in some parts of this area. The hydrograph of an observation well at Ethelbert (Figure 7) indicates good response to spring recharge. At Ethelbert the Swan River sandstone aquifer is overlain by some 40m (130 feet) of till and shale. The most likely areas where significant recharge enters the local flow systems are sandy and gravelly areas on the escarpment and at the base of it.

Natural discharge of the Swan River aquifer systems is almost unnoticeable; there are no known high discharge springs or spring areas related to it in the subcrop area and no observations have been made about its contribution to the streams that cross the

subcrop and outcrop areas. One reason for this probably is that in the northern part, where the system is near ground surface, it merges with flow systems of the Paleozoic carbonate rocks and may contribute to the discharge of the springs in the areas underlain by

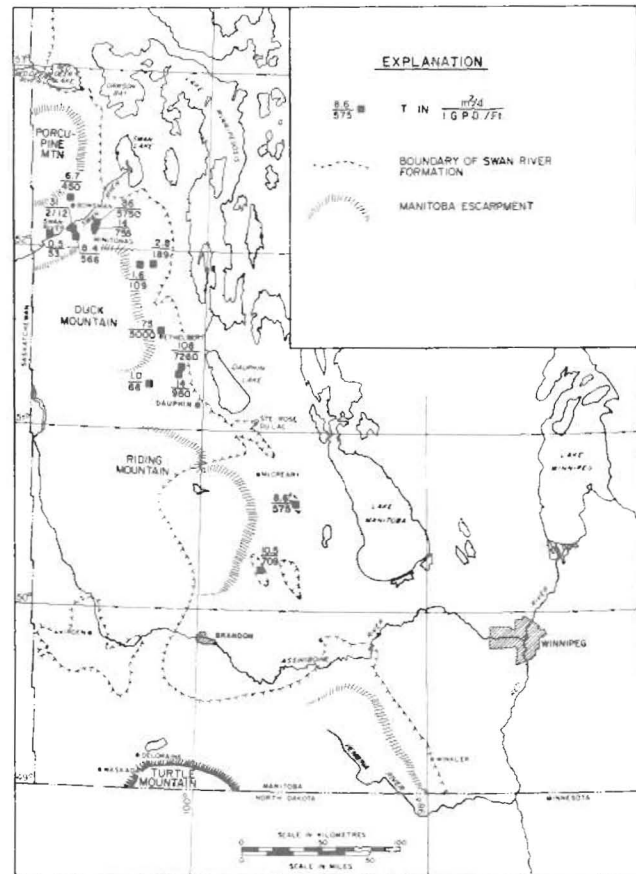


Figure 6. Transmissivity of Swan River sandstone aquifers along and east of the Manitoba escarpment

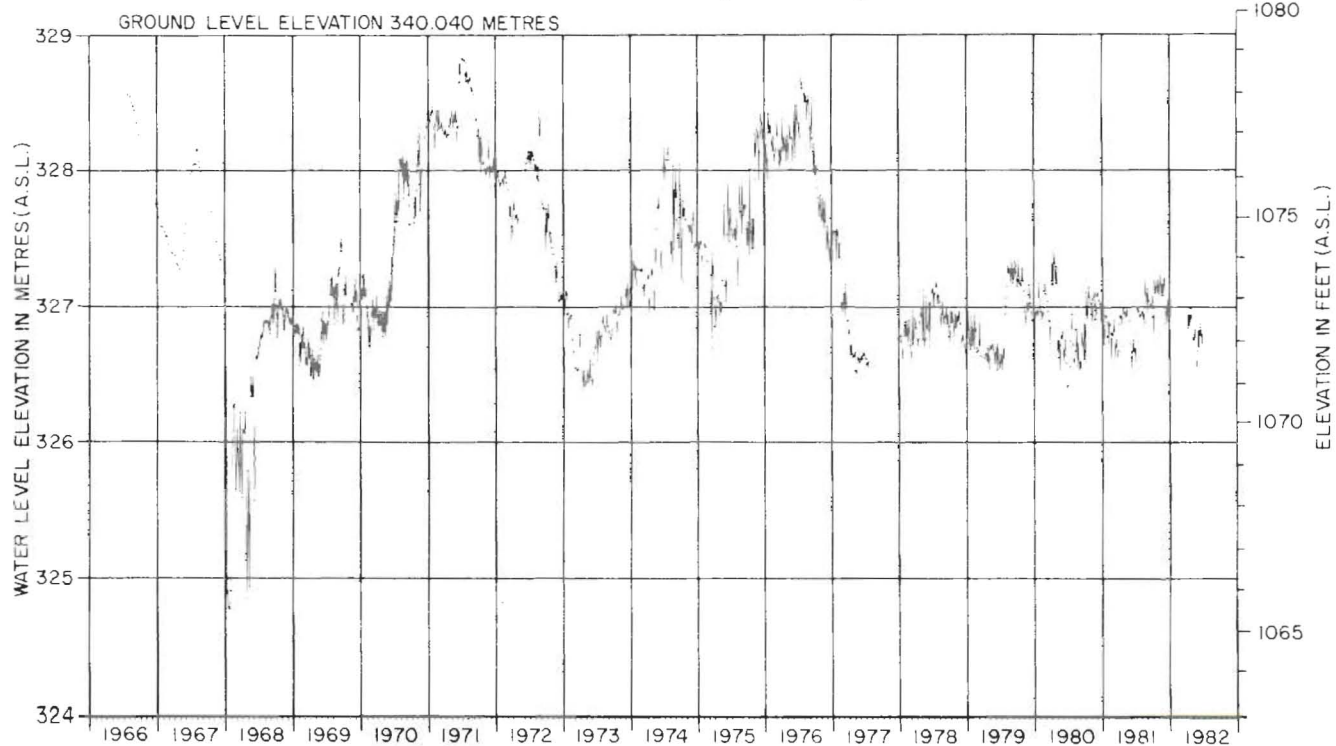


Figure 7. Ground water level fluctuations in an observation well in a Swan River sandstone aquifer at Ethelbert. The well is located 20m (65 feet) from a pumped well.

the carbonate rocks. (Numerous salt springs exist along the western shore of the lakes that lie east of the escarpment and east of the Swan River formation). In some areas the discharge from the Swan River aquifer system manifests itself as salty water in shallow aquifers and as saline soils in the subcrop area.

Water Chemistry

Water chemistry of the Swan River aquifer system, like all other parameters and conditions pertaining to it, varies over a wide range; the total dissolved solids concentration ranges from less than 500 mg/L to more than 40,000 mg/L. In some of the aquifers, or parts of the aquifers, the water can be rated as excellent potable water. In most of the Swan River aquifer system, the water is highly mineralized. The water chemistry also varies with depth; it can be fresh in the upper part and salty at the base. Water quality at a number of locations is indicated in Figure 5.

The water chemistry depends on the ground water flow systems acting in the aquifer system; in areas where the regional-flow systems are dominant the water is highly mineralized and, conversely, where the local flow systems are dominant the water is potable. The water quality varies considerably from place to place within short distances and with depth in areas where the two types of flow systems merge. In these areas the dominance of one system or the other depends on minor variations in local conditions in the aquifers and the confining layers. In the area west of the Manitoba escarpment the deep regional-flow system dominates, and, consequently, only highly mineralized (Figure 5) water can be found in the aquifer system.

At some locations mixing of the regional and local flow systems takes place. In these areas the water has the characteristics of both types of water. Usually it has both fairly high sulfate and sodium chloride content.

A characteristic chemical property of the fresh water in the Swan River sandstone aquifers is low hardness; often it is less than 100 mg/L (Ca CO_3) and sometimes less than 50 mg/L. The soft water, however, has higher sodium and chloride ion concentrations than one would expect in a locally recharged aquifer, which indicates that a natural softening process by ion exchange may take place in the strata above the aquifer.

Well Yield

Most wells installed in the Swan River sandstone aquifers are designed for domestic and farm requirements. Hence the reported well yields, which commonly range from 0.2 L/s to 1.0 L/s (3 to 13 I.G.P.M.), more often reflects the minimum pumping requirements rather than potential well capacity.

The ground water investigations carried out for municipal water supplies indicate that the well capacity in the thicker and coarser-grained sandstone and sand aquifers can be more than 7.5 L/s (100 I.G.P.M.) and probably as high as 15 L/s (200 I.G.P.M.). Aquifer

conditions suitable for these pumping rates, however, seem to be rare. More often, even in the better aquifers, or better parts of aquifers, the maximum yield is likely to be in the 1.0 L/s to 5.0 L/s range (13 to 65 I.G.P.M.). On the other hand in the thinner and less permeable aquifers, the maximum well capacity is in the 0.1 L/s to 0.5 L/s range (1-7 I.G.P.M.).

Water Use

The earliest attempt to develop the Swan River sandstone aquifers for municipal supply was the drilling of the Deloraine well (Figure 2) during the years 1888 to 1892 (Halstead 1959). The well was 592m (1,943 feet) deep and flowing, but the water was too salty for municipal use. In the following decades other attempts to develop the Swan River aquifers for municipal water supply were made at a few other localities in southern Manitoba, but with the same results as at Deloraine.

The first municipality to develop a Swan River sandstone aquifer was the town of Swan River in the northern part of the aquifer system. After an initial attempt to use shallow sand and gravel aquifers for the municipal supply, which was abandoned because of water quality problems, a well field consisting of two wells completed in the sandstone aquifer was installed in 1961 and a third well was added in 1962. The combined production of the three wells was 8.25 L/s (110 I.G.P.M.). The pumping exceeded the capacity of the aquifer and by 1964 the potentiometric surface in the vicinity of the well field had declined some 12m (40 feet). In 1974 the well field was replaced with a new well field in a high-yield sand and gravel aquifer.

The development of the Swan River aquifers for domestic and farm requirements most likely started at the turn of the century during the first major settlement in the northern part of the study area. The Swan River sandstone and sand aquifers probably were not very popular with early drillers because of the "quicksand" that commonly plugged up wells in the days before well screens were invented or used.

At present the towns of Bowsman (population 580), Ethelbert (population 880) and Minitonas (population 1,140) are the only municipalities that draw water from the Swan River aquifers. The maximum yield of the municipal wells is 1.9 L/s (25 I.G.P.M.), 4.5 L/s (60 I.G.P.M.) and 7.5 L/s (100 I.G.P.M.) respectively and is considerably higher than the current rate of water usage. The current total sustained pumping rate of the three municipal wells is around 2.3 L/s (30 I.G.P.M.) and is minimal compared to the aquifer potential. The total yearly usage of the three towns is $7 \times 10^3 \text{ m}^3$ (15×10^6 Imp gal). The total sustained pumping rate of all the other users likely is also minimal compared to the aquifer potential.

Minitonas is the only municipality in Manitoba using the reverse osmosis process to treat its water. The capacity of the Minitonas treatment plant is 135,000 liters a day (30,000 I.G.P.D.).

The use of the Swan River sandstone and sand aquifers for domestic and farm supply has increased

considerably in the last two decades since modern well construction methods (screened wells) have been used to cope with the "quicksand." Very few industrial and commercial wells have been installed in the Swan River aquifers and the total usage for these purposes is negligible.

Future development of the Swan River aquifer system in the fresh water area is likely to be similar to the existing pattern, i.e. mainly domestic, farm and municipal use and some industrial use. In areas of highly mineralized water the water probably could be used for municipal supply with reverse osmosis treatment. Since water temperature in the western part is around 15 C (60 F) it could be used as source of heat for heating public and commercial buildings.

Regulations of Aquifer Development and Protection

Aquifer management in Manitoba is implemented by the Water Resources Branch of the Manitoba Department of Natural Resources under the provisions of the Ground Water and Water Well Act and the Water Rights Act. The Ground Water and Water Well Act applies to water bearing zones to the depth of 200m (660 feet), which is the practical limit of depth to fresh water aquifers in Manitoba. Deeper water bearing zones come under the jurisdiction of the Mines Act.

The main concern of the Ground Water and Water Well Act is with well construction in respect to prevention of detrimental effect on aquifers such as uncontrolled discharge from flowing wells, unpotable water intrusion into potable water aquifers, and sealing of abandoned wells.

The administration of ground water allocation is under the Water Rights Act. A water rights license is required for all uses except domestic and normal farm requirements. In Manitoba all water belongs to the Crown, (i.e. the government), and it is allocated to the users under the provisions of the Water Rights Act. In general, water rights are granted when development does not exceed the estimated yield of the aquifer and detrimental effect on the water quality and serious interference with the water supply of existing users is not likely to occur. For example, to prevent pollution of a high-yield fresh water sand and gravel aquifer near the town of Winkler that could be affected by salt water intrusion from the Swan River aquifer system pumping rates of wells are limited to 4 L/s (50 I.G.P.M.) and the water is allocated only for municipal and domestic requirements.

Aquifer pollution prevention is implemented by the Environmental Management Division of the Manitoba Department of Consumer and Corporate Affairs and the Environment under the provisions of the Clean Environment Act. The design and location of facilities that could cause ground water pollution must be approved by the Environmental Management Division. Upon request the Water Resources Branch provides information about ground water conditions and pollution hazard at sites of proposed facilities.

The existing legislation, in general, is adequate to

carry out aquifer management and protection.

Because the Swan River aquifer system in Manitoba contains potable water aquifers and is hydraulically connected to other aquifer systems, it is not a readily acceptable zone for storage of industrial and hazardous wastes and it is doubtful it would be generally acceptable even after extensive investigations.

Summary

The Dakota aquifer system correlates with the Lower Cretaceous Swan River formation in Manitoba. The Swan River formation occupies a triangular area extending some 250km (150 miles) east and 500km (300 miles) north of the southwest corner of the province. Some fairly extensive non-deposition areas exist in the southern half of the triangle. The Swan River formation is overlain by Cretaceous shales and is underlain by Jurassic shales in the southern part and by Devonian carbonate rocks in the northern part. The thickness of the formation ranges from zero to more than 100m (330 feet).

The transmissivity of the Swan River sandstone aquifers generally is low. Even in the thickest and coarsest aquifers it rarely exceeds 100m²/d (7,000 I.G.P.D./ft). In most of the Swan River aquifer system water is highly mineralized. Potable water is found only in the northern part of the aquifer system where local fresh water flow systems dominate over the highly mineralized regional flow system.

The main uses of water from the Swan River aquifers are for domestic, farm and municipal requirements. It is not likely that the usage will change significantly in the future.

The aquifers are adequately protected from overdevelopment and pollution by existing legislation.

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Biographical Sketch

Maris Rutulis, P. Eng., is a ground water inventory geologist of the Water Resources Branch of the Manitoba Department of Natural Resources. In the first 10 years with the branch he conducted numerous ground water investigations for municipal water supplies. Since 1973 he has been responsible for the provincial ground water data and monitoring system and has prepared numerous ground water resource reports for municipal planning, water conservation and watershed districts.