Little Saskatchewan River (05MF)
Integrated Watershed Management Plan:
State of the Watershed Report
Groundwater Resources

Groundwater Management Section
March 2008

Manitoba Water Stewardship

Summary

Groundwater is the responsibility of the province and therefore the province has a number of Acts and regulations to protect and regulate the development of this resource. To understand groundwater in the Little Saskatchewan watershed the province, starting in 1960, has undertaken a number of studies in the area and currently operates three monitoring wells. In addition the province licenses water well drillers and also collects and stores information about water wells. There are approximately 2500 well logs on file for this watershed.

Over 90% of the wells on record within the Little Saskatchewan watershed are used to provide water for domestic users. Production wells completed in sand and gravel outnumber those completed in bedrock by approximately three to one.

Sand and gravel aquifers throughout most of the watershed exist as discrete buried lenses of limited extent. Major buried sand and gravel aquifers are located in the Clear Lake area and shallow unconfined aquifers are located in the Rivers area. Sand and gravel aquifers are scarce along the eastern margin, near Minnedosa. The upper surface of sand and gravel aquifers range from the near surface up to 100 or more metres deep. The reported well yield is highly variable from place to place but is generally sufficient for most domestic requirements.

Water quality within sand and gravel aquifers is also highly variable. Most groundwater sources exceed one or more of the aesthetic objectives for drinking water. Total dissolved solids average 1,150 mgL^{-1}; the water is generally hard and iron and manganese are commonly present. The dissolved solids are mostly made up of calcium, magnesium, sodium, bicarbonate and sulphate; and with increasing TDS greater concentrations of sodium, sulphate increase and occasionally chloride.

The Odanah shale, which is present throughout the watershed except in the southernmost portion, forms the bedrock water source. Wells completed into bedrock average 1.5 Ls^{-1} during drillers pump tests. The TDS is slightly higher than water from sand and gravel aquifers, averaging 1,430 mgL^{-1}. In addition to TDS, water quality is also affected by iron, manganese and hardness.

Overburden thickness is highly variable. The greater the thicknesses of the till overburden will restrict the amount of recharge to underlying aquifers but it will also provide a greater amount of protection to these same aquifers.

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Introduction

Groundwater, like most natural resources, is the jurisdictional responsibility of the provinces. The transfer of responsibility for water from the federal government to the provinces began with *The Natural Resource Transfer Agreement* in 1930, and although groundwater was not specified, it was assumed to be included. In the same year Manitoba passed the *Water Rights Act* which was consequently amended in 1959 to include groundwater. The 1959 *Water Resources Administration Act* was established to create a comprehensive water management agency. Shortly after, *The Ground Water and Water Well Act* (1963) passed and was meant to address drilling practices and groundwater data collection. Groundwater is regulated under a number of provincial acts including *The Environment Act, The Water Protection Act, The Health Act, The Drinking Water Safety Act, The Water Resources Conservation Act, The Planning Act, The Water Rights Act, The Ground Water and Water Well Act* and subsequent Regulations.

Early regional studies of groundwater and aquifers in Manitoba were carried out by the federal government. These consisted of door to door well surveys, township summaries of water supply and quality, regional maps of surficial geology, well locations and producing zones and some site specific studies. Formal studies of groundwater were initiated by the province in the late 1950's and by the mid 60's the Groundwater Management Section began operating a monitoring well network.

The Groundwater Management Section (GMS) of Water Stewardship advises on groundwater management issues including allocation of groundwater and groundwater protection. The GMS operates a monitoring well network, from which data on groundwater conditions such as water levels and water quality is collected, stored and compiled. Studies meant to address specific aquifer or groundwater concerns have been carried out by the section as have regional groundwater resource mapping. Systematic hydrogeologic mapping was conducted from the 1960's through the 1980's consisting of regional stratigraphic drilling, pump testing, well data and quality compilations resulting in 11 regional groundwater availability map series on a scale of 1:250,000. The Section has also prepared reports on hydrogeology and groundwater resources at various scales including towns, drainage basins, municipalities, planning districts and watersheds over the years.

The Ground Water and Water Well Act and Well Drilling Regulation require that water well drillers be licensed by the province and that the driller supply the province with a report of wells drilled. The report should contain information on date, ownership, the well location, a description of the material drilled, and information on well construction and pump testing if completed. This information is stored within a database in the Groundwater Management Section.

A glossary of select terms used in this report is provided in Appendix A.

Groundwater Backgrounder

Groundwater is water that fills the pores and fractures in the ground. At some point as water recharges the soil and moves down through the profile all of the pore space will be saturated. The surface where this occurs is called the water table. Not only must sediment or rock be saturated to recover groundwater, it must also be permeable enough to allow the water to move at a reasonable rate. Because these properties are largely controlled by the material the water is moving through the geology of the formations are important in understanding water movement. Additionally the natural water quality which the water acquires is highly dependent upon the materials it flows through.

Aquifers and Aquitards

A geologic formation from which economically significant quantities of water flows to a spring or can be pumped for domestic, municipal, agricultural or other uses is called an aquifer. From glacial times (the Quaternary period of geologic time) and on, aquifers are primarily formed within sand or gravel deposits. Within pre-glacial or bedrock formations, aquifers are formed from sandstone, hard fractured shale/siltstone, permeable limestone, or fractured granitic or metamorphic rocks. Aquifers can be separated vertically by less permeable layers; layers that do not readily allow water flow or act as barriers to flow. These confining layers are called aquitards and are principally formed from glacial till or clay deposits in Quaternary sediments or by unfractured or soft shale, massive or unfractured limestone, or gypsum in bedrock layers.

During recharge water moves vertically through the soil and shallow geologic horizons until it reaches the water table. The water table can be determined within a shallow dug or drilled hole by allowing the water level to come to a static or resting position. In permeable material the water table forms the top of an unconfined aquifer. In an unconfined aquifer the water table and consequently the amount of water in storage, changes over the seasons or longer climatic periods as water levels fluctuate in response to recharge or discharge from the aquifer.

If an aquifer is situated between aquitards and the water level in a well rises above the base of the upper confining unit the aquifer is called a confined aquifer. In a confined aquifer all of the pore space is filled with water and any addition or reduction of water in storage results in a change of water pressure in the aquifer. When the pressure in the aquifer is above the local ground surface, drilling into this formation will result in a flowing artesian well. Confined aquifers are recharged either at a location of higher elevation where the aquifer is no longer confined or it is recharged slowly, through the layers that confine it.

Groundwater discharge can be dispersed over large areas or focused, such as in springs and generally discharge areas are topographically controlled. Springs form where the water table intersects the ground surface, commonly in depressions or hillsides, including river banks. If a higher permeability layer overlies a lower permeability layer on a hillside or river bank the vertical flow of groundwater may be impeded by a low permeability layer causing the water to move laterally to discharge as a spring. Some springs are formed from flowing artesian aquifers where water moves up along fractures or are man-made resulting from unsealed boreholes or blow-outs at the bottom of excavations. Groundwater may also discharge over larger areas resulting in perennially wet areas, fens, bogs or swamps.

Groundwater Flow

Groundwater moves from higher elevation to lower elevation or from higher pressure to lower pressure. The height of the water table or the pressure in an aquifer is called the hydraulic head. The difference in hydraulic head in an aquifer between two locations is used to determine the hydraulic gradient. The groundwater flow direction is from the higher to lower hydraulic pressure along the maximum slope of the hydraulic gradient. Under ambient conditions, groundwater typically moves quite slowly. The ability for a geologic material to move water is called hydraulic conductivity. The amount of groundwater that moves through a geologic material will depend upon the hydraulic gradient, the hydraulic conductivity and the thickness of the aquifer or aquitard. In unconfined aquifers the water table loosely mimics the surface elevation and in areas of low topographic relief the typical hydraulic gradient is in the range of one metre of water head decline per kilometer distance.

In a prairie pothole landscape, sloughs will focus recharge into very localized flow systems. In these settings the water table may be high under the sloughs; the amount of recharge coming from sloughs will greatly depend upon the location of the slough in the landscape and the material underlying the slough.

Aquifer Studies and Groundwater Data

The Little Saskatchewan River watershed lies within the Riding Mountain (62K; Sie, 1978), Neepawa (62J; Betcher, 1983), Virden (62F; Betcher, 1983), and Brandon (62G; Sie & Little, 1976) Groundwater Availability Study map sheets. The groundwater resources in these map series were compiled by the province on a 1:250,000 map scale. The province also completed a number of planning district and municipal groundwater reports including the Groundwater Availability Study, Minnedosa Area (Rural Municipalities of Elton, Odanah, Saskatchewan and Minto), Groundwater Resources in the Neepawa and Area Planning District (Rutulis, 1979), Groundwater Resources in the Brandon and Area Planning District (A Synopsis) (Rutulis, 1981) and South Riding Mountain Planning District Development Plan (A Synopsis) (Rutulis, 1980).

The provincial Groundwater Availability Studies include a set of diagrams showing the map sheet location, drift thickness, bedrock topography, surface deposits, a number of cross-sections and a table of selected well water chemistry. The Groundwater Availability series have formed the main regional scale compilation of groundwater data to date. The groundwater synopsis consists of a brief description of groundwater resources and includes maps.

Groundwater Data and Monitoring

The Groundwater Management Section of Water Stewardship maintains a database of well logs for the province. There are approximately 2500 wells and test hole records in the Little Saskatchewan River watershed (Figure 1).

Within the watershed approximately 1,650 logs were completed as production wells and 800 logs were from test holes. The remainder was classified as monitoring wells or other uses. Approximately 450 drill holes ended in bedrock and of these almost 400 of these were completed as production wells. The remainder of the logs ended in overburden; of these greater than three-quarters (1200) were developed as production wells.

The government of Manitoba was involved in drilling wells in this area in the early decades of the last century (1903 to 1920). These records appear to be for private water supplies. Groundwater studies were not undertaken until the early 1960's with test drilling in the Erickson area (1960-61), Rivers (1962, 1974), Rapid City (1964), Minnedosa (1966-68), Sandy Lake (1967), Oak River (1974), south Riding Mountain (1976-77), Virden (1977), Audy Lake (1998), Odanah Shale and rural groundwater quality studies (2000). In total 84 test holes have been drilled by the province, of which seven were completed as observation wells (Figure 2). Three observation wells are currently still active.

The longest water level record from a monitoring well in the watershed comes from station G05MF004 for the period 1970 to 2006. This well is located near the Little Saskatchewan River in Minnedosa. This hydrograph shows the annual spring recharge followed by fall and winter recession (Figure 3).

The province also warehouses groundwater chemistry information from provincial monitoring wells, private wells sampled during various groundwater projects and results that are supplied to the province from drillers or other sources. Only three provincial test / observation wells have chemical analysis. The chemistry from the provincial monitoring wells is available to the public.

Bedrock Aquifers

The Odanah member of the Pierre Shale Formation consists of brittle layers of rock separated by of softer bentonite clay layers. Fractures can form within the brittle layers which store and transmit water. The Odanah forms the uppermost bedrock unit beneath most of the watershed. The soft Millwood shale aquitard underlies the Odanah and forms the uppermost bedrock unit in areas where the Odanah has been eroded. For all practical purposes the Millwood formation does not transmit water. The Odanah is absent from the southern most portion of the watershed, throughout most of the area south of Minnedosa (Figure 4). Below the Millwood the groundwater is saline and non-potable. The top of the Millwood forms the base of groundwater exploration in the watershed.

Wells completed into the Odanah shale range from a few metres below ground to depths greater than 100m. Water supply from these wells ranges from less than adequate to more than adequate for most domestic needs. Driller's well test yields from the Odanah shale vary from less than 0.02 Ls^{-1} to 10 Ls^{-1} and average 1.5 Ls^{-1}. The total dissolved solids (TDS) of the Odanah ranges from 360 to greater than 3,000 mgL^{-1} and averages 1,430 mgL^{-1}. The northern portion of the watershed has a greater proportion of low TDS waters (Figure 4). The dissolved constituents primarily consist of sodium, (Na) calcium (Ca), magnesium (Mg), sulphate (SO_4), bicarbonate (HCO_3) and occasionally chloride (Cl). Lower TDS waters are predominantly Ca-Mg-HCO_3 with increasing sodium and sulphate occurring with increasing TDS. Hardness ranges from 150 to greater than 1000 mgL^{-1} $CaCO_3$ (approximately 9 to 60 grains per gallon) and averages 440 mgL^{-1} $CaCO_3$. Iron and manganese range from less than detection to greater than 10 mgL^{-1} and 1.9 mgL^{-1}, respectively, with average concentrations of 1.5 mg/L for iron and 0.5 mgL^{-1} manganese. This corresponds to almost 70% of the Fe and 95% of the Mn sample results above the aesthetic value for drinking water quality. Although there are few comprehensive analysis of groundwater from the shale within the provincial database the following analytes are above the aesthetic guidelines for drinking: 50% of the samples for sodium (500 mgL^{-1}), 41% for sulphate (500 mgL^{-1}), and 12% for chloride (250 mgL^{-1}). The Health-based limit was exceeded in one of 16 samples for nitrate (10 mgL^{-1} as N) and in two of five samples for arsenic (0.010 mgL^{-1}).

Extensive erosion and deposition prior to glaciation forms buried valleys cut into the bedrock that may contain permeable sediment and form aquifer systems. These valleys may be infilled with Tertiary age sediments and / or Quaternary (glacial) sediments. Pederson (1973) identified one such valley west of Minnedosa. Further work is required to explore and define buried valleys that contain sediments suitable for forming aquifers.

For potable groundwater exploration the top of the Millwood shale should adequately define the base of exploration throughout the watershed. Groundwater from bedrock below this will be increasingly brackish or saline.

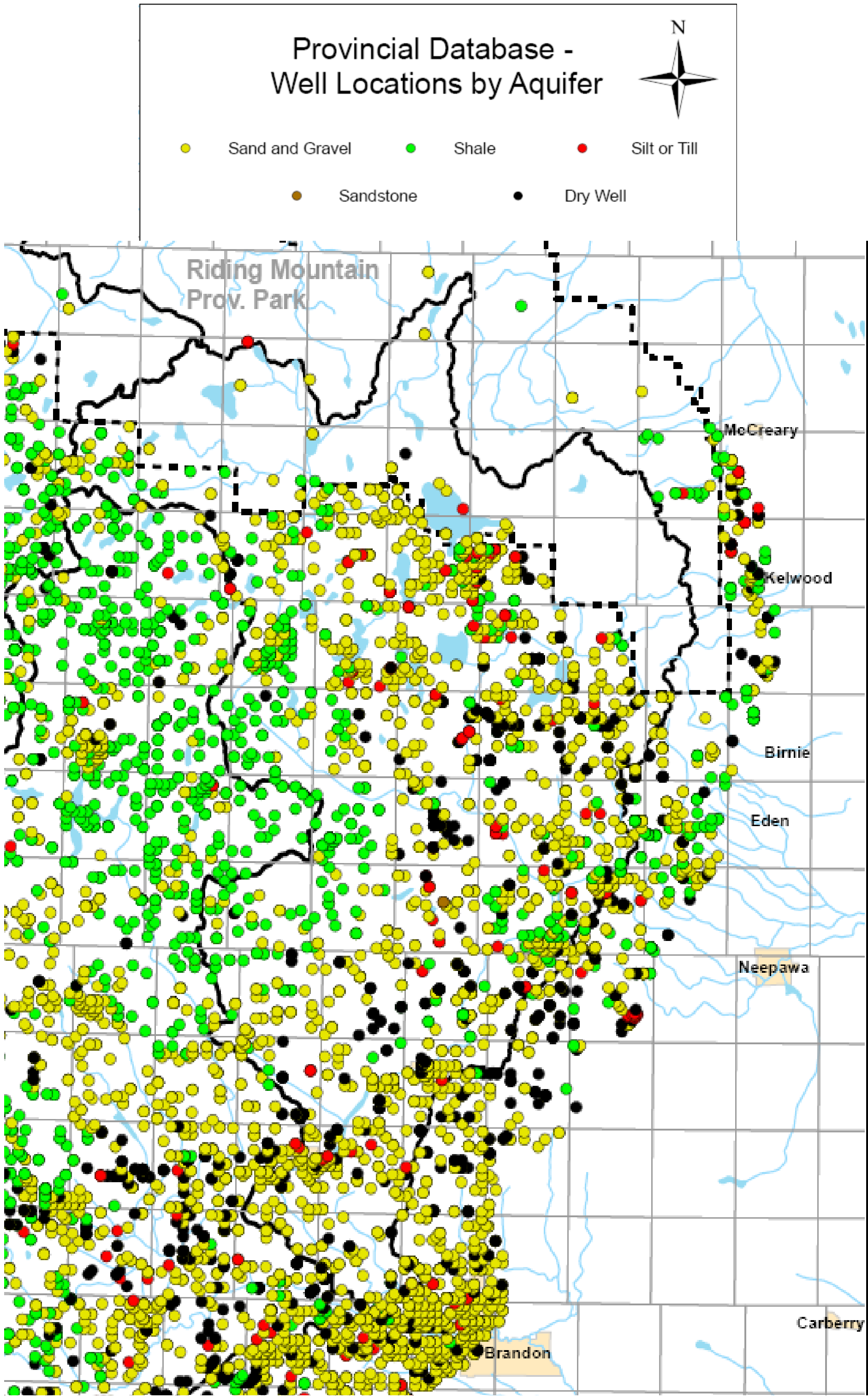

Figure 1. Well log locations from the provincial well database coded by aquifer material in which the borehole ended or was completed into. Wells are displayed in the centre of the quarter-section in which they are drilled unless more accurate information is available. Multiple wells may be stacked at any one location. There are approximately 2500 well logs recorded within the watershed.

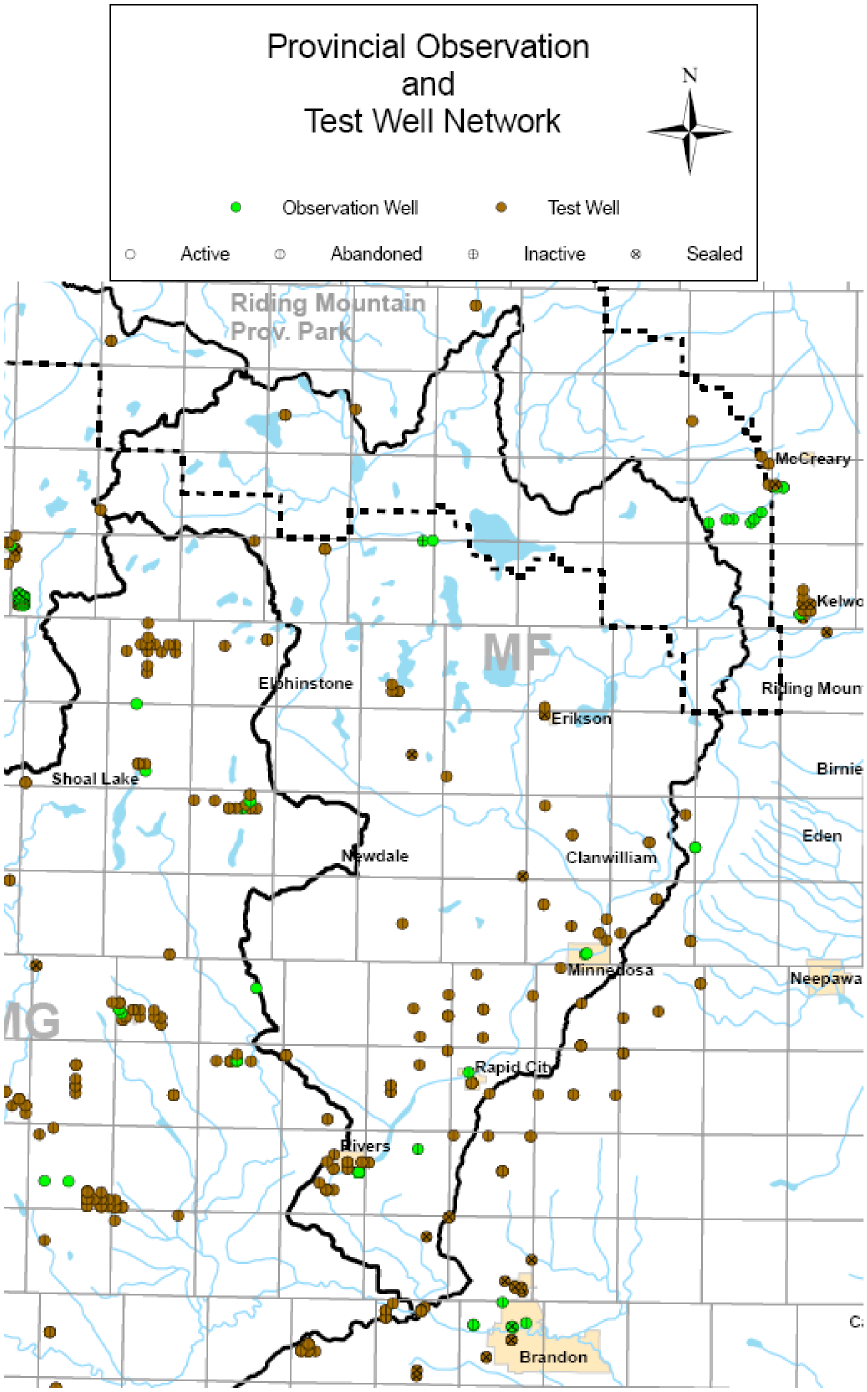

Figure 2. Location of Groundwater Management's drilling activity including status for the watershed and surrounding area.

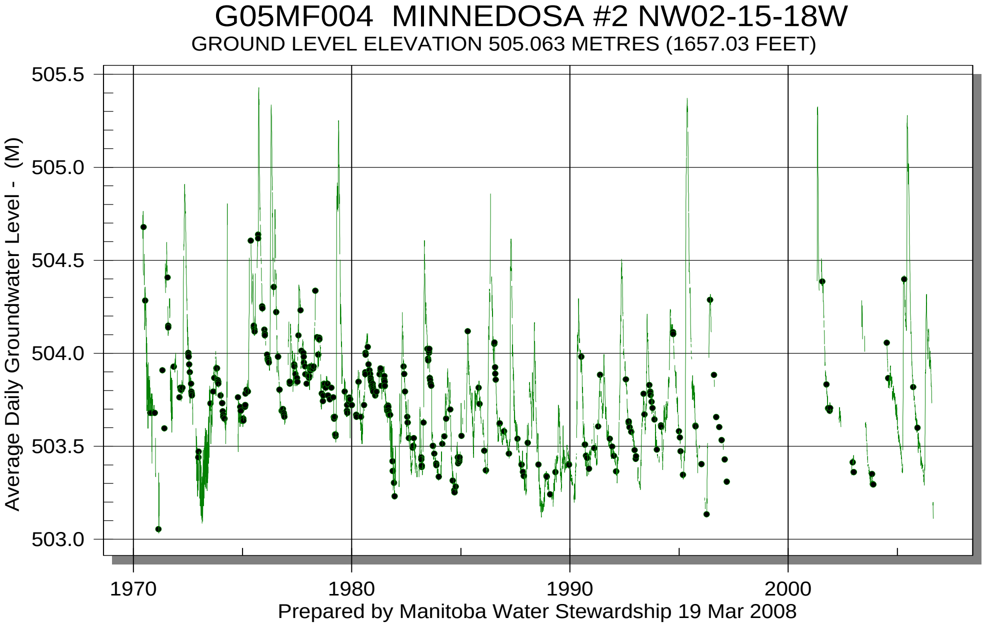

Figure 3 Groundwater elevations were recorded at monitoring station G05MF004 between 1970 and 2006. This well is completed into a gravel aquifer at a depth of 9.5 metres below ground.

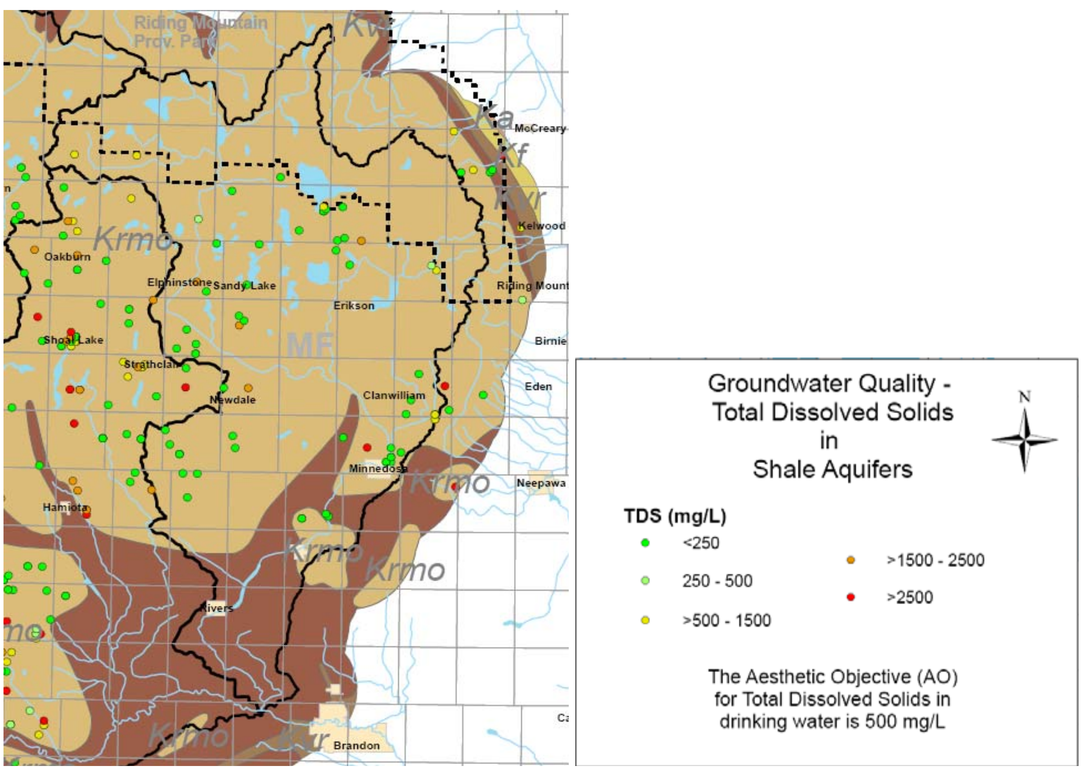

Figure 4. Display of total dissolved solids (TDS) in groundwater from shale wells within the watershed and surrounding area. The light brown background shows the approximate area underlain by the Odanah shale, where the darker brown is underlain by the Millwood shale aquitard.

Sand and Gravel Aquifers

Within glacial and recent sediments aquifers are formed as sand and gravel within or at the base of glacial till, at the ground surface or near surface from glacial outwash or alluvial sand deposited from modern or ancient rivers. Most sand and gravel aquifers within the watershed consist of buried lenses of sand and or gravel (Figure 5). Unconfined sand aquifers are found in the Rivers area and major buried sand and gravel aquifers are present in the area between Clear Lake and Proven Lake in the northern part of the watershed. On the eastern margin of the watershed, near Minnedosa, sand aquifers are scarce.

The uppermost boundary of sand and gravel aquifers range from a few metres below ground up to 100 metres depth and wells range from a few metres deep to more than 150 metres. Thicker till units will restrict the recharge rate to confined sand and gravel aquifers but will provide a greater amount of protection to the underlying aquifers. The recharge rate to most confined sand and gravel aquifers will be highly dependant upon the thickness and also the properties of the overlying glacial till material.

Most sand and gravel aquifers (Figure 5) are accessed by drilled wells and less than 15 percent of the wells recorded are wide diameter (>30 cm). Wide diameter (bored) wells are most commonly used where the well yield in shallow aquifers is low and additional storage within the well is required. Well yield from sand and gravel aquifer is variable, but generally adequate for individual domestic uses. The average reported well yield is 1.6 Ls^{-1} and there is potential in some aquifers for high capacity wells. Half of the wells are reported to yield greater than 1 Ls^{-1}. The average total depth of wells completed into sand and gravel aquifers is 53 metres and the average depth to the top of the uppermost sand and gravel is greater than 15 metres; although these values are highly variable.

Because of the wide range in aquifer depths and conditions the chemistry of water from sand and gravel aquifers is also highly variable. The total dissolved solids (TDS) ranges from just less than 300 mgL^{-1} to 2,700 mgL^{-1}, with an average concentration around 1,150 mgL^{-1} (Figure 7). The hardness averages approximately 700 ppm $CaCO_3$ with a range from less than 100 to greater than 2,500 (approximately 6 to 150 grains per gallon). Values greater than 200 are considered poor for drinking water and values over 500 are generally considered undesirable for most domestic purposes. In groundwater with low TDS values, the dissolved solids predominantly consist of calcium (Ca), magnesium (Mg), bicarbonate (HCO_3) and sulphate (SO_4). With increasing TDS a greater proportion of the solids are dominated by sodium (Na) and sulphate (SO_4) and occasionally a greater proportion of chloride (Cl).

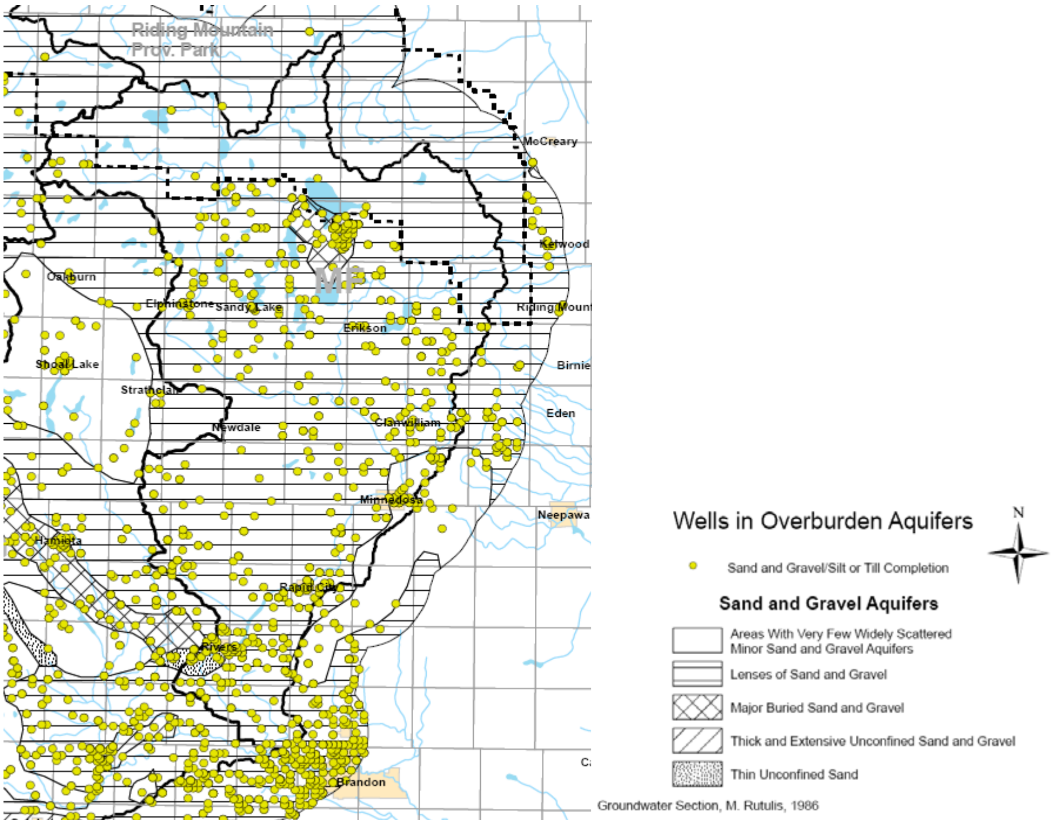

Figure 5. Diagram showing locations of wells completed into overburden material. Throughout most of the area overburden aquifers consist of buried lenses of sand and gravel, except in the Rivers area where unconfined sand and gravel is found and a major buried aquifer south of Clear Lake (after Rutulis 1986).

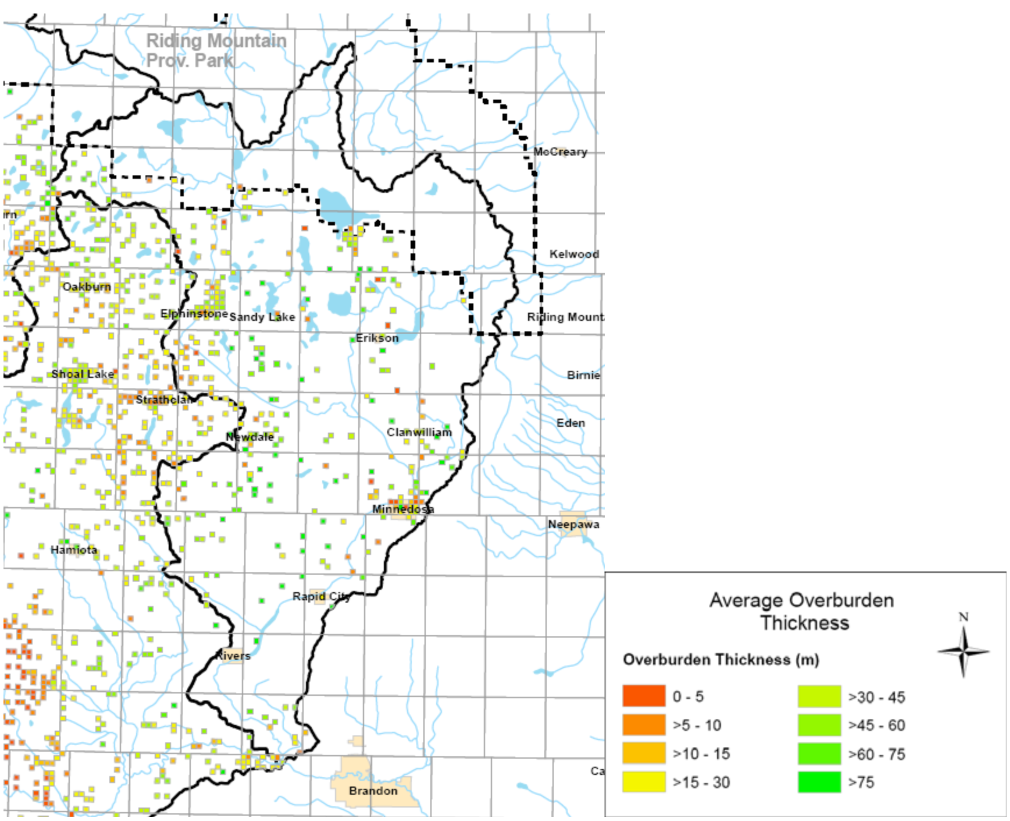

Figure 6. Diagram showing the average overburden (drift) thickness where bedrock was encountered in a drill hole. Most of the watershed has relatively thick (>30 m) cover over the bedrock.

A relatively high percentage of groundwater samples from sand and gravel aquifers exceed one or more of the drinking water aesthetic objectives. Aesthetic objectives apply to constituents in the water that impart a taste, colour or odour that may affect the enjoyment or acceptance of that water. Sixty-five percent of 104 samples exceed the aesthetic objectives for iron (0.3 mgL^{-1}) and 78% of 90 samples exceed the objective for manganese (0.05 mgL^{-1}). Drinking water guidelines for aesthetic objective was exceeded for 85% of the TDS (500 mgL^{-1}), 10% of the sodium (200 mgL^{-1}), 37% of the sulphate (500 mgL^{-1}), 1% of the chloride (250 mgL^{-1}) in the samples measured. There are very few analyses of relatively complete chemistry; and comprehensive metal analysis in the database. Aluminum, antimony, barium, boron, cadmium, chromium, copper, lead, uranium and zinc were all below drinking water guideline concentrations in these samples; one sample is above the health guideline for selenium. The Health-based limit was exceeded in 12% of 95 samples analysed for nitrate (10 mgL^{-1} as N) and in one of eight samples for arsenic (0.010 mgL^{-1}).

Total coliform bacteria are routinely detected in private well water. The presence of coliform bacteria is an indicator that the factors may exist where there are pathways for well water to be contaminated with water from the ground surface or from near surface. Twenty-four percent of the 37 samples had detectable coliform bacteria. E. coli is an indicator of contamination from a faecal source; eight percent of the 39 samples had measurable E. coli. Well owners that have had positive bacteria results need to assess their well for security and maintenance, and proximity to potential sources of contamination. Fact sheets are available from the province to help in sampling and interpreting the results of tests.

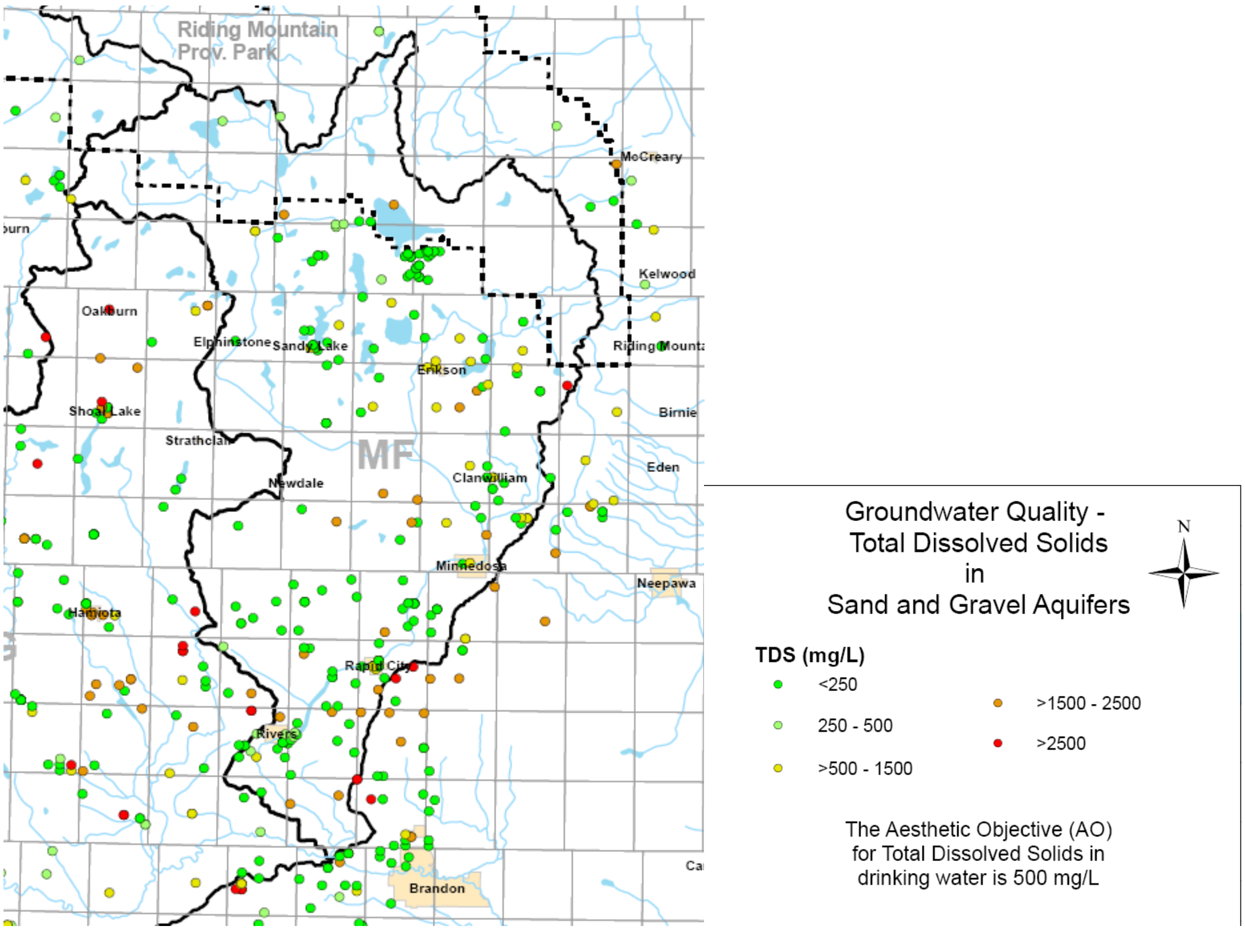

Figure 7. Distribution of total dissolved solids (TDS) in sand and gravel aquifers. TDS is a measure of the minerals and salts dissolved in the water. Most of the samples are less than the aesthetic objective.

Groundwater Use

Driller logs specify the intended water use for new production wells. The well use can be recorded as a single or multiple uses. Within the Little Saskatchewan River watershed the following water uses are recorded (Figure 8): 1039 domestic, 103 livestock, 363 combined domestic and livestock, 63 municipal, and 25 being used for irrigation and other uses. Almost 90% of the wells provide water to private domestic applications.

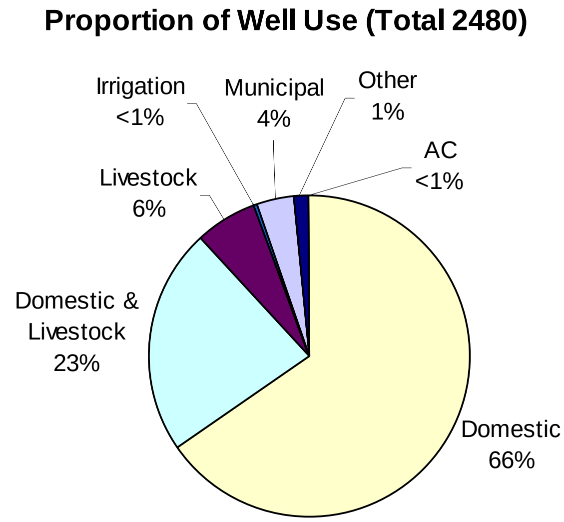

Figure 8. Proportion of production well use within the watershed: almost 90% of the wells provide private domestic water supplies.

Availability of Data and Information Gaps

Well log and groundwater information is stored by the Groundwater Management Section. Results from past well surveys indicate that only about half of the wells in service have an associated well record and the accuracy of the location of the majority of wells is only to the quarter section on which it is drilled. Wells are often located in areas of convenience, in the same general areas as potential contamination sources and neglected, abandoned or unused wells can act as a direct conduit for contaminants to enter aquifers from the surface. Abandoned and unused wells located in these areas should be sealed to lessen the potential spread of contaminants to an aquifer. The knowledge of accurate well location is an important step in identifying sites for future well sealing. The province does not have access to well surveys conducted by other organizations; additional information on wells and locations would be beneficial in managing the provinces groundwater resources.

Groundwater forms the baseflow to streams. When run off from the land surface ceases the water sustaining the flow in streams comes from groundwater. The contribution of baseflow to streams and rivers has not been well quantified nor has water quality impact from these waters been assessed.

The province has undertaken several groundwater investigations within this watershed resulting in 84 test-holes and wells being completed; currently there are three active groundwater monitoring wells. There are few comprehensive analysis of groundwater and therefore there is a lack of information on many water quality parameters from groundwater sources.

Issues, Concerns and Recommendations

- Shallow aquifers and aquifers of limited extent will be more prone to reduction in water quantity during prolonged droughts.
- High use groundwater withdrawals require assessment on an individual project basis.
- In cooperation with CD a well inventory should be completed. It should include a well inventory, GPS coordinates, information on construction and rudimentary water quality.
- Comprehensive groundwater chemistry is lacking from this area including many solutes with drinking water guidelines. This could be completed on wells selected during the well inventorying process.
- The Groundwater Management Section is currently evaluating the provincial monitoring well network to determine where there are redundancies or areas that could benefit from new or additional monitoring locations. This watershed will be included in that evaluation.
- Regional scale stratigraphic and hydrogeologic mapping and compilation would be beneficial in providing an increased knowledge of the extent, properties and relationships between stratigraphy, aquifers and surface water.
- The Groundwater Management Section is committed to completing new set of digital maps based on the watershed scale.

Vulnerable Groundwater Areas / Well-head Protection

Previous well surveys by Manitoba and other provinces show that well location, construction and maintenance are important factors in man-made water quality problems. Many of the parameters measured that lead to less than desirable potable water quality such as TDS, hardness and most occurrences of metals, are natural and not the result of man’s influence on the environment. However there are local impacts, such as nitrate and bacteria, commonly measured in well water throughout the province and the watershed authority should encourage owners of private wells to self-assess or have their well assessed for physical conditions that may affect water quality such as poor wellhead conditions, well construction, location or maintenance. Water testing should be encouraged for all drinking water sources on a regular basis.

Community or municipal wells require well specific assessment to determine the vulnerability during the development of well head protection policies. As a minimum the individual characteristics of each well, aquifer and geology should be considered to assess vulnerability in relationship to potential contaminant sources.

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Appendix A

Definition of Terms

Definitions

Alluvial Sediment deposited by moving water.

Aquifer A porous and permeable geologic formation that is saturated and capable of producing useful quantities of water to wells or springs.

Aquifer, confined An aquifer that is overlain by a layer of material with considerably lower permeability. The water within the aquifer is under pressure so that it rises above the top of the aquifer material in a well drilled into the aquifer; synonym: artesian.

Aquifer, unconfined An aquifer where the water table forms the upper boundary.

Aquitard A saturated low permeability unit that does not yield water readily.

Bedrock Material that is older than the Quaternary period; it may be very well consolidated (rock) or only poorly consolidated.

Drift or glacial drift = glacial deposit

Guideline for Canadian Drinking Water Quality

The current edition of *Guidelines for Canadian Drinking Water Quality*.

Hardness A property of water that reduces the effectiveness of soap. It is primarily caused by calcium and magnesium ions; expressed in ppm (parts per million) $CaCO_3$, or as gpg (grains per gallon U.S.) where one gpg equals 17.1 ppm.

Hydraulic conductivity The rate that water moves through water is able to move through a permeable material.

Hydraulic gradient The change in hydraulic head over a given distance in a direction which produces the maximum rate of decrease of hydraulic head.

Hydraulic head The total water pressure, generally expressed as elevation.

Lacustrine sediment Sediment deposited within lakes.

mg/L or mgL^{-1} milligrams per litre; a common unit of measure for solutes, in most groundwater it is equivalent to a part-per-million.

Outwash Stratified sand and gravel washed out from a glacier by meltwater streams and deposited in front of an active glacier.

Overburden	Unconsolidated material overlying bedrock. In Manitoba overburden is derived during glaciation or more recent time.
Permeability	The property or capacity of a porous rock, sediment or soil to transmit water, it is a measure of ease that water will flow.
Quaternary	The period of geologic time most noted for glaciation beginning between 2 and 3 million years ago and extending to the present.
Specific capacity	It is an expression of the productivity of a well obtained by dividing the rate of discharge of a well per unit of drawdown during pumping.
Total Dissolved Solid	(TDS) a measure of the concentration of dissolved minerals in water expressed in mg/L or ppm.
Water table	The surface where all the pore space is filled with water and can be observed by measuring the water level in shallow wells installed into the zone of saturation.
Well yield	The volume of water discharged from a well, frequently determined during short-term pump tests immediately after drilling the well.