Lac Ste. Anne County

Parts of the North Saskatchewan and Athabasca River Basins
Parts of Tp 053 to 059, R 01 to 09, W5M
Regional Groundwater Assessment

Prepared for

LAC STE.ANNE

The County with a "Mission"

In conjunction with

Agriculture and Agri-Food Canada	Agriculture et Agroalimentaire Canada
Prairie Farm Rehabilitation Administration	Administration du rétablisseme agricole des Prairies

Canada

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1-800-661-7972
Our File No.: **97-112**

July 1998

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(Revised November 1999)

PERMIT TO PRACTICE
HYDROGEOLOGICAL CONSULTANTS LTD.
Signature ______________________________
Date ______________________________
PERMIT NUMBER: P 385
The Association of Professional Engineers,
Geologists and Geophysicists of Alberta

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

1 PROJECT OVERVIEW

"Water is the lifeblood of the earth." - Anonymous

How a county takes care of one of its most precious resources - groundwater - reflects the future wealth and health of its people. Good environmental practices are not an accident. They must include genuine foresight with knowledgeable planning. Implementation of strong practices not only commits to a better quality of life for future generations, but creates a solid base for increased economic activity. **This report, even though it is preliminary in nature, is the first step in fulfilling a commitment by Lac Ste. Anne County toward the management of the groundwater resource, which is a key component of the well-being of the County, and is a guide for future groundwater-related projects**

1.1 About This Report

This report provides an overview of (a) the groundwater resources of Lac Ste. Anne County, (b) the processes used for the present project and (c) the groundwater characteristics in the County.

Additional technical details are available from files on the CD-ROM provided with this report. The files include the geo-referenced electronic groundwater database, grid files used to prepare the distribution of various hydrogeological parameters, the groundwater query, and ArcView files. Likewise, all of the illustrations and maps from the present report, plus additional maps, figures and cross-sections, are available on the CD-ROM. For convenience, poster-size maps and cross-sections have been prepared as a visual summary of the results presented in this report. Copies of these poster-size drawings have been forwarded with this report, and are included in Appendix D.

Appendix A features page-size copies of the figures within the report plus additional maps. An index of the page-size maps and figures is given at the beginning of Appendix A.

Appendix B provides a complete list of maps and figures included on the CD-ROM.

Appendix C includes the following:

1) a procedure for conducting aquifer tests with water wells;
2) a table of contents for the Water Well Regulation under the Environmental Protection and Enhancement Act; and
3) additional information.

The Water Well Regulation deals with the wellhead completion requirement (no more pits), the proper procedure for abandoning unused water wells and the correct procedure for installing a pump in a water well.

1.2 The Project

It must be noted that the present project is a regional study and as such the results are to be used only as a guide. Detailed local studies are required to verify hydrogeological conditions at given locations.

The present project is made up of five parts as follows:

Module 1 - Data Collection and Synthesis
Module 2 - Hydrogeological Maps
Module 3 - Covering Report
Module 4 - Groundwater Query
Module 5 - Training Session

This report represents Module 3.

1.3 Purpose

This project is a regional groundwater assessment of Lac Ste. Anne County. The regional groundwater assessment provides the information to assist in the management of the groundwater resource within the County. Groundwater resource management involves determining the suitability of various areas in the County for particular activities. These activities can vary from the development of groundwater for agricultural or industrial purposes, to the siting of waste storage. **Proper management ensures protection and utilization of the groundwater resource for the maximum benefit of the people of the County.**

The regional groundwater assessment includes:

- identification of the aquifers[1] within the surficial deposits[2] and the upper bedrock;
- spatial definition of the main aquifers;
- quantity and quality of the groundwater associated with each aquifer;
- hydraulic relationship between aquifers; and
- identification of the first sand and gravel deposits below ground level.

Under the present program, the groundwater-related data for Lac Ste. Anne County have been assembled. Where practical, the data have been digitized. These data are then being used in the regional groundwater assessment for the County.

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[1] See glossary
[2] See glossary

2 INTRODUCTION

2.1 Setting

Lac Ste. Anne County is situated in central Alberta. This area is part of the Alberta Plains region. The County is within the North Saskatchewan and Athabasca River basins, with the boundaries mainly following township or section lines. There are two small areas where the boundary follows the Pembina River and three areas where the boundary is a lake. The area includes some or all of townships 053 to 059, ranges 01 to 09, west of the 5th Meridian.

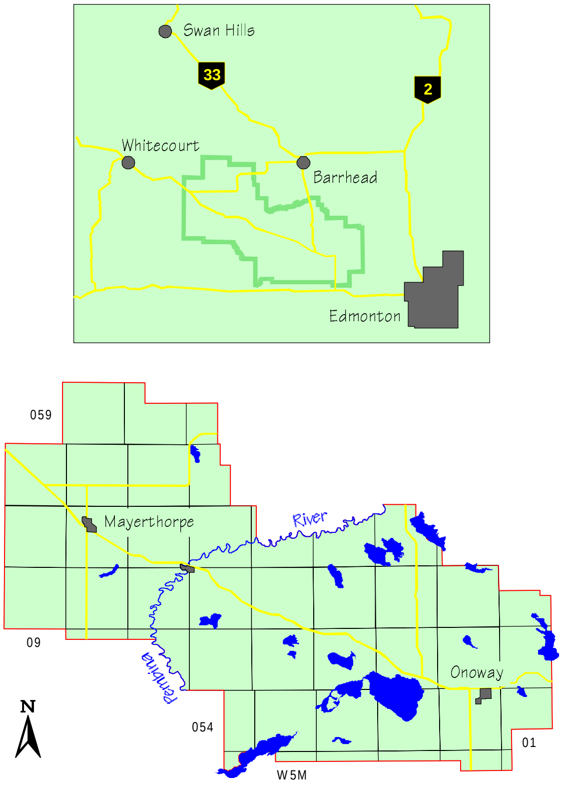


Figure 1. Index Map

The ground elevation varies between 640 and 880 metres above mean sea level (AMSL). The topographic surface generally decreases toward the Pembina River and toward the northeastern part of the County.

2.2 Climate

Lac Ste. Anne County lies within the Dfb climate boundary. This classification is based on potential evapotranspiration values determined using the Thornthwaite method (1957), combined with the distribution of natural ecoregions in the area. The ecoregions map shows that the County is located in both the Low Boreal Mixedwood region and Mid Boreal Mixedwood region. Increased precipitation and cooler temperatures, resulting in additional moisture availability, influence this vegetation change.

A Dfb climate consists of long, cool summers and severe winters. The mean monthly temperature drops below –3 °C in the coolest month, and exceeds 10 °C in the warmest month.

The mean annual precipitation averaged from two meteorological stations within the County measured 522 millimetres (mm), based on data from 1963 to 1993. The mean annual temperature averaged 2.7 °C, with the mean monthly temperature reaching a high of 16.0 °C in July, and dropping to a low of -12.6 °C in January. The calculated annual potential evapotranspiration is 515 millimetres.

2.3 Background Information

There are currently records for 5,399 water wells in the groundwater database for Lac Ste. Anne County. Of the 5,399 water wells, 5,013 are for domestic/stock purposes. The remaining 386 water wells were completed for a variety of uses, including municipal, observation and industrial purposes. Based on a rural population of 8,059, there are 2.7 domestic/stock water wells per family of four. The domestic or stock water wells vary in depth from less than 3 metres to 305 metres below ground level. Lithologic details are available for 3,875 water wells.

Data for casing diameters are available for 3,612 water wells, with 87 indicated as having a diameter of more than 250 mm and 3,525 having a diameter of less than 250 mm. The casing diameters of greater than 250 mm are mainly bored water wells and those with a surface casing diameter of less than 250 mm are for drilled water wells.

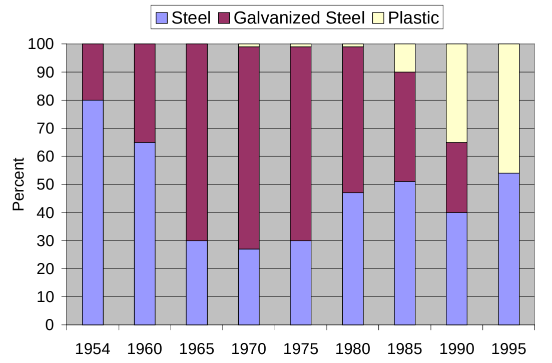


Figure 2. Surface Casing Types used in Drilled Water Wells

There are five different materials that have been used for surface casing over the last 40 years in water wells completed in the County. The three most common materials are galvanized steel, steel and plastic. Steel casing was in use in the 1950s and is still used in 54% of the water wells being drilled in the County. Galvanized steel surface casing was used in 20% of the new water wells in the mid-1950s. By the mid-1970s, galvanized steel casing was being used in more than 70% of the water wells. From 1975 onward, there was a general decrease in the percentage of water wells using galvanized steel, with the last reported use in October 1994. Plastic casing was used for the first time in August 1972. The percentage of water wells with plastic casing has increased and in the mid-1990s, plastic casing was used in 46% of the water wells drilled in the County.

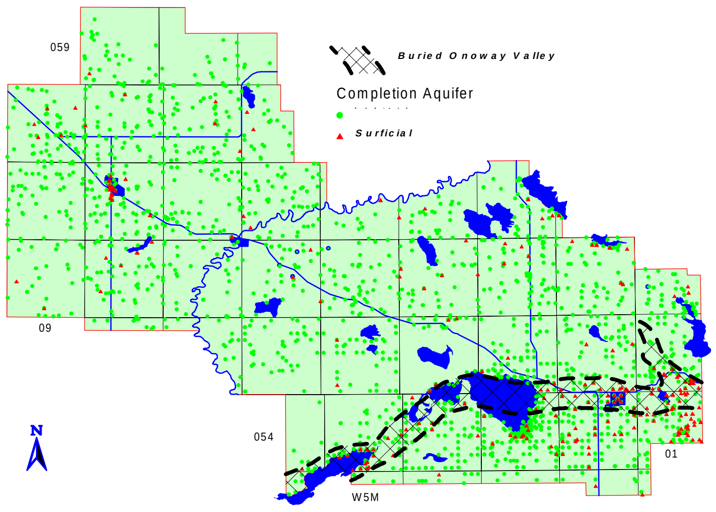


Figure 3. Location of Water Wells

There are 3,404 water well records with sufficient information to identify the aquifer in which the water wells are completed. The water wells that were not drilled deep enough to encounter the bedrock plus water wells that have the bottom of their completion interval above the bedrock surface are water wells completed in surficial aquifers. The number of water wells completed in aquifers in the surficial deposits is less than 9%, a total of 302 water wells. Seventy percent of the surficial water wells are completed in the Buried Onoway Valley or within 3.5 kilometres to the south.

The remaining 3,102 water wells have the top of their completion interval deeper than the depth to the bedrock surface. From the above map, it can be seen that water wells completed in the surficial aquifers occur mainly in the southeastern part of the County and water wells completed in the bedrock aquifers occur over most of the County.

Water wells not used for domestic needs must be licensed. At the end of 1996, 156 groundwater diversions were licensed in the County. The total maximum authorized diversion from these 156 water wells is 4,688 cubic metres per day (m³/day); 80 percent of the authorized groundwater diversion is allotted for agricultural use. The largest licensed groundwater diversion within the County is for the Town of Lac Ste. Anne, having a diversion of 676.2 m³/day.

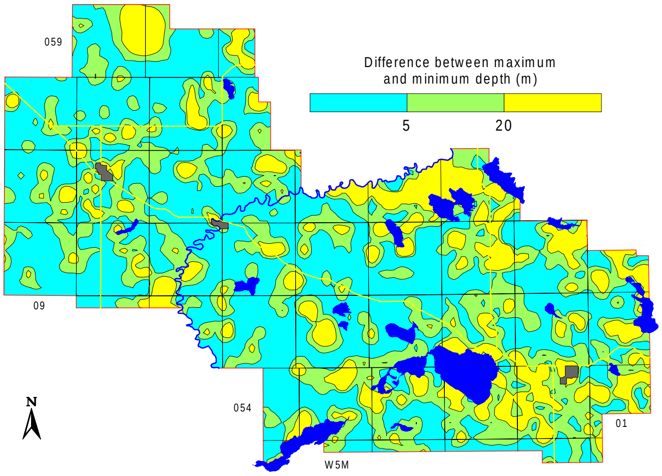


Figure 4. Depth of Existing Water Wells

At many locations within the County, more than one water well is completed at one legal location. Digitally processing this information is difficult. To obtain a better understanding of the completed depths of water wells, a surface was prepared representing the minimum depth for water wells and a second surface was prepared for the maximum depth. Both of these surfaces are used in the groundwater query on the CD-ROM. When the maximum and minimum water well depths are similar, the impression is that there is only one aquifer that is being used. Over approximately 65% of the County, the difference between the maximum and minimum depth is less than five metres. The areas where the greatest differences occur are in areas where there are aquifers in the surficial deposits and in the bedrock. The area where the difference between the minimum and maximum depth is largest is in the southern part of the County. There are other areas scattered throughout the County with a large area in the northeastern part of the County.

The TDS concentrations in the groundwaters from the upper bedrock in the County are generally less than 2,000 milligrams per litre (mg/L). Groundwaters from the surficial deposits can be expected to be chemically hard with a high dissolved iron content. Groundwaters from the bedrock aquifers frequently are chemically soft with concentrations of dissolved iron generally less than 0.5 mg/L. The chemically soft groundwater can be high in sodium concentration. Approximately 30% of the chemical analyses indicate a fluoride concentration above 1.0 mg/L.

Proper management of the groundwater resource requires water-level data. These data are often collected from observation water wells. At the present time, data are available from two **Alberta Environmental Protection** (AEP)-operated observation water wells within Lac Ste. Anne County. Additional data can be obtained from some of the licensed groundwater diversions. In the past, these data have been difficult to obtain from AEP, in part because of the failure of the licensee to provide the data.

However, even with the available sources of data, the number of water-level data points relative to the size of the County is too few to provide a reliable groundwater budget. The most cost-efficient method to collect additional groundwater monitoring data would be to have the water well owners measuring the water level in their own water well on a regular basis.

3 TERMS

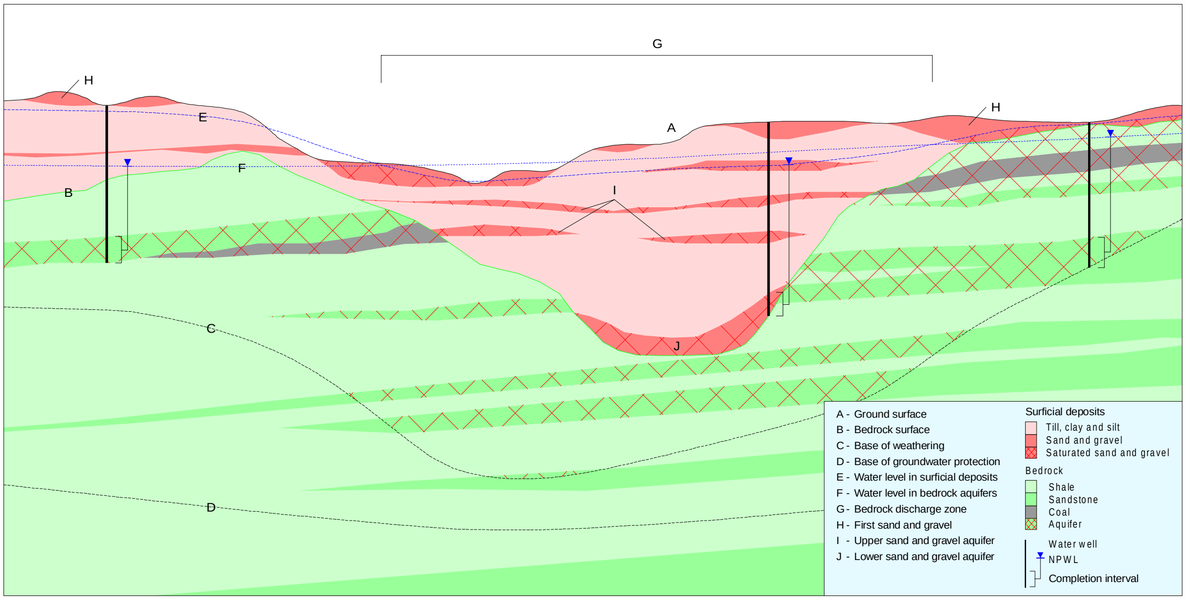
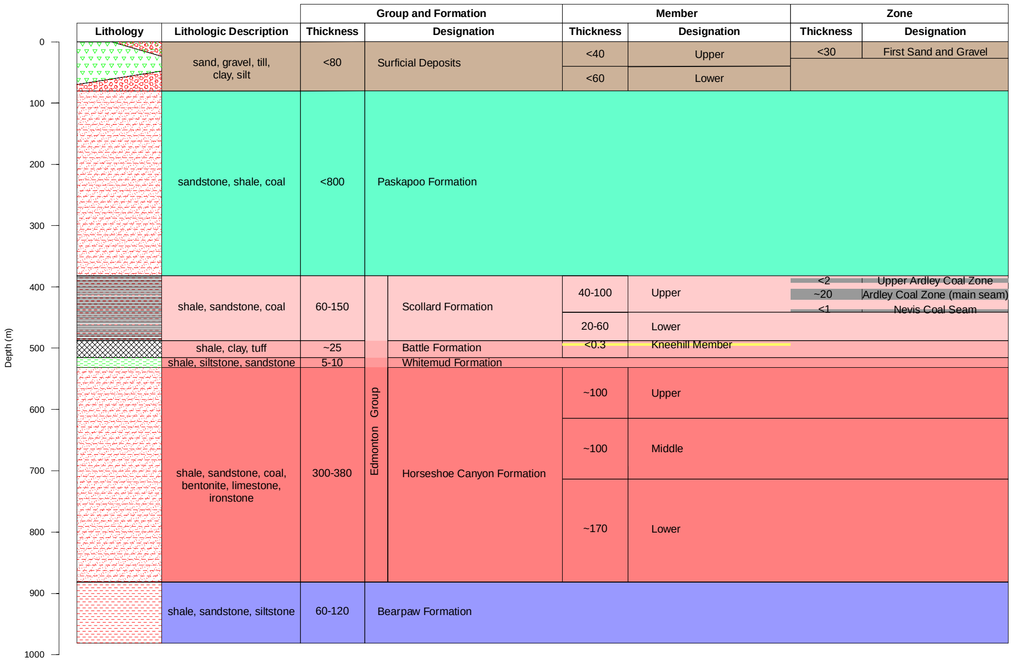


Figure 5. Generalized Cross-Section (for terminology only)



		Group and Formation			Member		Zone	
Lithology	Lithologic Description	Thickness	Designation		Thickness	Designation	Thickness	Designation
	sand, gravel, till, clay, silt	<80	Surficial Deposits		<40	Upper	<30	First Sand and Gravel
					<60	Lower		
	sandstone, shale, coal	<800	Paskapoo Formation					
	shale, sandstone, coal	60-150	Edmonton Group	Scollard Formation	40-100	Upper	<2	Upper Ardley Coal Zone
							~20	Ardley Coal Zone (main seam)
							<1	Nevis Coal Seam
					20-60	Lower		
	shale, clay, tuff	~25		Battle Formation	<0.3	Kneehill Member		
	shale, siltstone, sandstone	5-10		Whitemud Formation				
	shale, sandstone, coal, bentonite, limestone, ironstone	300-380		Horseshoe Canyon Formation	~100	Upper		
					~100	Middle		
					~170	Lower		
	shale, sandstone, siltstone	60-120	Bearpaw Formation					

Figure 6. Geologic Column

4 METHODOLOGY

4.1 Data Collection and Synthesis

The AEP groundwater database is the main source of available groundwater data. The database includes the following:

1) water well drilling reports;
2) aquifer test results from some water wells;
3) location of some springs;
4) water well locations determined during water well surveys;
5) chemical analyses for some groundwaters;
6) location of flowing shot holes;
7) location of structure test holes; and
8) a variety of data related to the groundwater resource.

The main disadvantage to the database is the absence of quality control. Very little can be done to overcome this lack of quality control in the data collection, other than to assess the usefulness of control points relative to other data during the interpretation. Another disadvantage to the database is the lack of adequate spatial information.

The AEP groundwater database uses a land-based system with only a limited number of records having a value for ground elevation. The locations for records usually include a quarter section description; a few records also have a land description that includes a Legal Subdivision (Lsd). For digital processing, a record location requires a horizontal coordinate system. In the absence of an actual location for a record, the record is given the coordinates for the centre of the land description.

The present project uses the 10 TM coordinate system. This means that a record for the SE ¼ of section 29, township 057, range 08, W5M, would have a horizontal coordinate with an Easting of –9,686 metres and a Northing of 5,975,521 metres, the centre of the quarter section. Once the horizontal coordinates are determined, a ground elevation is obtained from the 1:20,000 Digital Elevation Model (DEM) from the Resource Data Division of AEP.

After assigning spatial control to the records in the groundwater database, the data are processed to determine values for hydrogeological parameters. As part of the processing, obvious keying errors in the database are corrected.

Where possible, determinations are made from individual records for the following:

1) depth to bedrock;
2) total thickness of sand and gravel;
3) thickness of first sand and gravel when present within one metre of ground surface;
4) total thickness of saturated sand and gravel; and
5) depth to the top and bottom of completion intervals.

Also, where sufficient information is available, values for apparent transmissivity[3] and apparent yield[4] are calculated, based on the aquifer test summary data supplied on the water well drilling reports. The apparent transmissivity results are used to estimate a value for hydraulic conductivity[5]. The conductivity values are obtained by dividing the apparent transmissivity by the completion interval. To obtain a value for regional transmissivity of the aquifer, the hydraulic conductivity is multiplied by the effective thickness of the aquifer based on nearby e-log information. Where valid detailed aquifer test results exist, the interpreted data provide values for aquifer transmissivity and effective transmissivity.

The Alberta Energy and Utilities Board (EUB) well database includes records for all of the wells drilled by the oil and gas industry. The information from this source includes:

1) spatial control for each well site;
2) depth to the top of various geological units;
3) type and intervals for various down-hole geophysical logs; and
4) drill stem test (DST) summaries.

Unfortunately, the EUB database contains very little information from above the base of groundwater protection. Because the main interest for a groundwater study comes from data above the base of groundwater protection, the data from the EUB database have limited use.

Values for apparent transmissivity and hydraulic conductivity are calculated from the DST summaries.

Published and unpublished reports and maps provide the final source of information to be included in the new groundwater database. The reference section of this report lists the available reports. The only digital data from publications are from the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1994). These data are used to verify the geological interpretation of geophysical logs but cannot be distributed because of a licensing agreement.

4.2 Spatial Distribution of Aquifers

Determination of the spatial distribution of the aquifers is based on:

1) lithologs provided by the water well drillers;
2) geophysical logs from structure test holes;
3) wells drilled by the oil and gas industry; and
4) data from existing cross-sections.

The identification of aquifers becomes a two-step process: first, mapping the tops and bottoms of individual geological units; and second, identifying the porous and permeable parts of each geological unit in which the aquifer is present.

After obtaining values for the elevation of the top and bottom of individual geological units at specific locations, the spatial distribution of the individual surfaces can be determined. Digitally, establishment of the distribution of a surface requires the preparation of a grid. The inconsistent quality of the data

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[3] For definitions of Transmissivity, see glossary
[4] See glossary
[5] See glossary

necessitates creating a representative sample set obtained from the entire data set. If the data set is large enough, it can be treated as a normal population and the removal of extreme values can be done statistically. When data sets are small, the process of data reduction involves a more direct assessment of the quality of individual points. Because of the uneven distribution of the data, all data sets are gridded using the Kriging[6] method.

The final definition of the individual surfaces becomes an iterative process involving the plotting of the surfaces on cross-sections and the adjusting of control points to fit with the surrounding data.

The porous and permeable parts of the individual geological units have been mainly determined from geophysical logs.

4.3 Hydrogeological Parameters

Water well records that indicate the depths to the top and bottom of their completion interval are compared digitally to the spatial distribution of the various geological surfaces. This procedure allows for the determination of the aquifer in which individual water wells are completed. When the completion interval of a water well cannot be established unequivocally, the data from that water well are not used in determining the distribution of hydraulic parameters.

After the water wells are assigned to a specific aquifer, the parameters from the water well records are assigned to the individual aquifers. The parameters include non-pumping (static) water level (NPWL), transmissivity and projected water well yield. The total dissolved solids, chloride and sulfate concentrations from the chemical analysis of the groundwater are also assigned to applicable aquifers.

Once the values for the various parameters of the individual aquifers are established, the spatial distribution of the various parameters must be determined. The distribution of individual parameters involves the same process as the distribution of geological surfaces. This means establishing a representative data set and then preparing a grid.

4.3.1 Risk Criteria

The main source of groundwater contamination involves activities on or near the land surface. The risk is high when the near-surface materials are porous and permeable and low when the materials are less porous and less permeable. The two sources of data for the risk analysis include (a) a determination of when sand and gravel is or is not present within one metre of the ground surface, and (b) the surficial geology map. The presence or absence of sand and gravel within one metre of the land surface is based on a geological surface prepared from the data supplied on the water well drilling reports. The information available on the surficial geology map is categorized based on relative permeability. The information from these two sources is combined to form the risk assessment map. The criteria used in the classification of risk are given in the table above.

Surface Permeability	Sand or Gravel Present Top Within One Metre Of Ground Surface	Groundwater Contamination Risk
Low	No	Low
Moderate	No	Moderate
High	No	High
Low	Yes	High
Moderate	Yes	High
High	Yes	Very High

Table 1. Risk of Groundwater Contamination Criteria

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[6] See glossary

4.4 Maps and Cross-Sections

Once grids for geological surfaces have been prepared, various grids need to be combined to establish the extent and thickness of individual geological units. For example, the relationship between an upper bedrock unit and the bedrock surface must be determined. This process provides both the aquifer outline and the aquifer thickness. The aquifer thickness is used to determine the aquifer transmissivity by multiplying the hydraulic conductivity by the thickness.

Grids must also be combined to allow the calculation of projected long-term yields for individual water wells. The grids related to the elevation of the non-pumping water level and the elevation of the top of the aquifer are combined to determine the available drawdown[7]. The available drawdown data and the transmissivity values are used to calculate values for projected long-term yields for individual water wells, completed in a specific aquifer, wherever the aquifer is present.

Once the appropriate grids are available, the maps are prepared by contouring the grids. The areal extent of individual parameters is outlined by masks to delineate individual aquifers. Appendix A includes page-size maps from the text, plus additional page-size maps and figures that support the discussion in the text. A list of maps and figures that are included on the CD-ROM is given in Appendix B.

Cross-sections are prepared by first choosing control points from the database along preferred lines of section. Data from these control points are then obtained from the database and placed in an AutoCAD drawing with an appropriate vertical exaggeration. The data placed in the AutoCAD drawing include the geo-referenced lithology, completion intervals and non-pumping water levels. Data from individual geological units are then transferred from the digitally prepared surfaces to the cross-section.

Once the technical details of a cross-section are correct, the drawing file is moved to the software package CorelDRAW! for simplification and presentation in a hard-copy form. These cross-sections are presented in this report and in Appendix A, are included on the CD-ROM, and are in Appendix D in a page-size format.

4.5 Software

The files on the CD-ROM have been generated from the following software:

- Microsoft Professional Office 97
- Surfer 6.04
- ArcView 3.0a
- AutoCAD 14.01
- CorelDRAW! 8.0
- Acrobat 3.0

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[7] See glossary

5 AQUIFERS

5.1 Background

An aquifer is a porous and permeable rock that is saturated. If the NPWL is above the top of the rock unit, this type of aquifer is an artesian aquifer. If the rock unit is not entirely saturated and the water level is below the top of the unit, this type of aquifer is a water-table aquifer. These types of aquifers occur in one of two general geological settings in the County. The first geological setting includes the sediments that overlie the bedrock surface. In this report, these are referred to as the surficial deposits. The second geological setting includes aquifers in the upper bedrock. The geological settings, the nature of the deposits making up the aquifers within each setting, the expected yield of water wells completed in different aquifers, and the general chemical quality of the groundwater associated with each setting are reviewed separately.

5.1.1 Surficial Aquifers

Surficial deposits in the County are mainly less than 40 metres thick, except in areas of linear bedrock lows where the thickness of surficial deposits can exceed 60 metres. The Buried Onoway Valley is one of the main linear bedrock lows. This linear low is present in the southern part of the County. Cross-section A-A’ closely follows the Buried Onoway Valley and shows the surficial deposits being approximately 80 metres thick along the Valley.

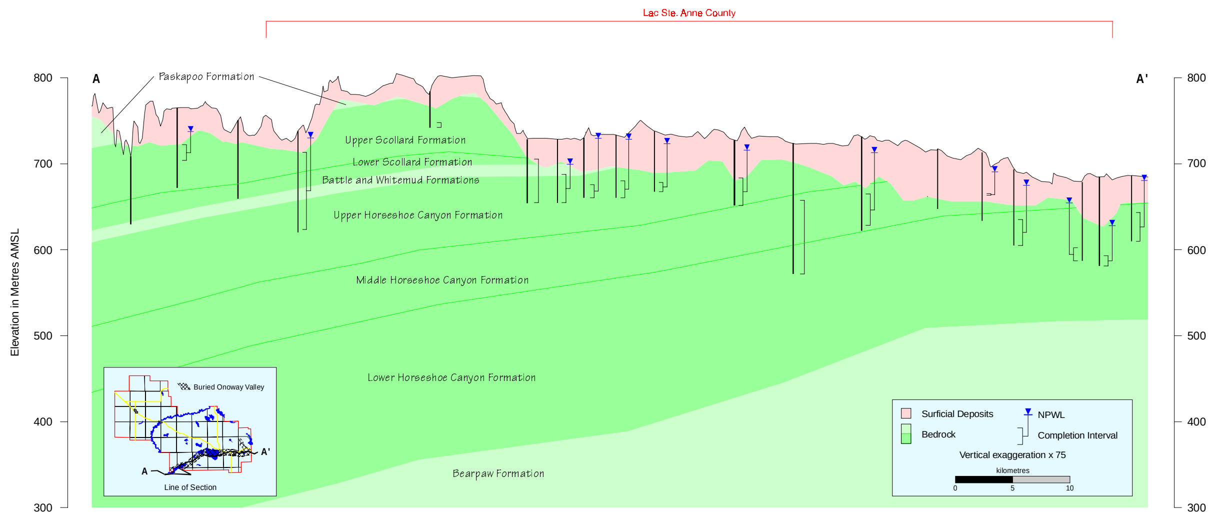

Figure 7. Cross-Section A - A'

The main aquifers in the surficial materials are sand and gravel deposits. In order for a sand and gravel deposit to be an aquifer, it must be saturated; if not saturated, a sand and gravel deposit is not an aquifer. The top of the surficial aquifers has been determined from the NPWL in water wells less than 15 metres deep. The base of the surficial aquifers is the bedrock surface.

For a water well with a small-diameter casing to be effective in surficial deposits and to provide sand-free groundwater, the water well must be completed with a water well screen. Some water wells completed in the surficial deposits are completed in low-permeability aquifers and have a large-diameter casing. The large-diameter water wells may have been hand dug or bored and because they are completed in very low permeability aquifers, most of these water wells would not benefit from water well screens. The groundwater from an aquifer in the surficial deposits usually has a chemical hardness of at least a few hundred mg/L and a dissolved iron concentration such that the groundwater must be treated before being used for domestic needs. Within the County, 10% of the water wells completed in the surficial deposits have a casing diameter of greater than 250 millimetres or no reported diameter for the surface casing, and are assumed to be dug or bored water wells.

5.1.2 Bedrock Aquifers

The upper bedrock includes rocks that are less than 200 metres below the bedrock surface. Some of this bedrock contains porous and saturated rocks that have a structure that is permeable enough to be an aquifer. Water wells completed in bedrock aquifers usually do not require water well screens and the groundwater is usually chemically soft. The data for 3,102 water wells indicate that the top of the water well completion interval is below the bedrock surface, indicating that the water wells are completed in at least one bedrock aquifer. Of these 3,102 water wells in the database, 2,985 have values for surface casing diameter. Of the 2,985 water wells, 99% have casing diameters of less than 250 millimetres.

The upper bedrock includes parts of the Paskapoo, Scollard, and Horseshoe Canyon formations. The Bearpaw Formation underlies the Lower Horseshoe Canyon Formation and is a regional aquitard[8].

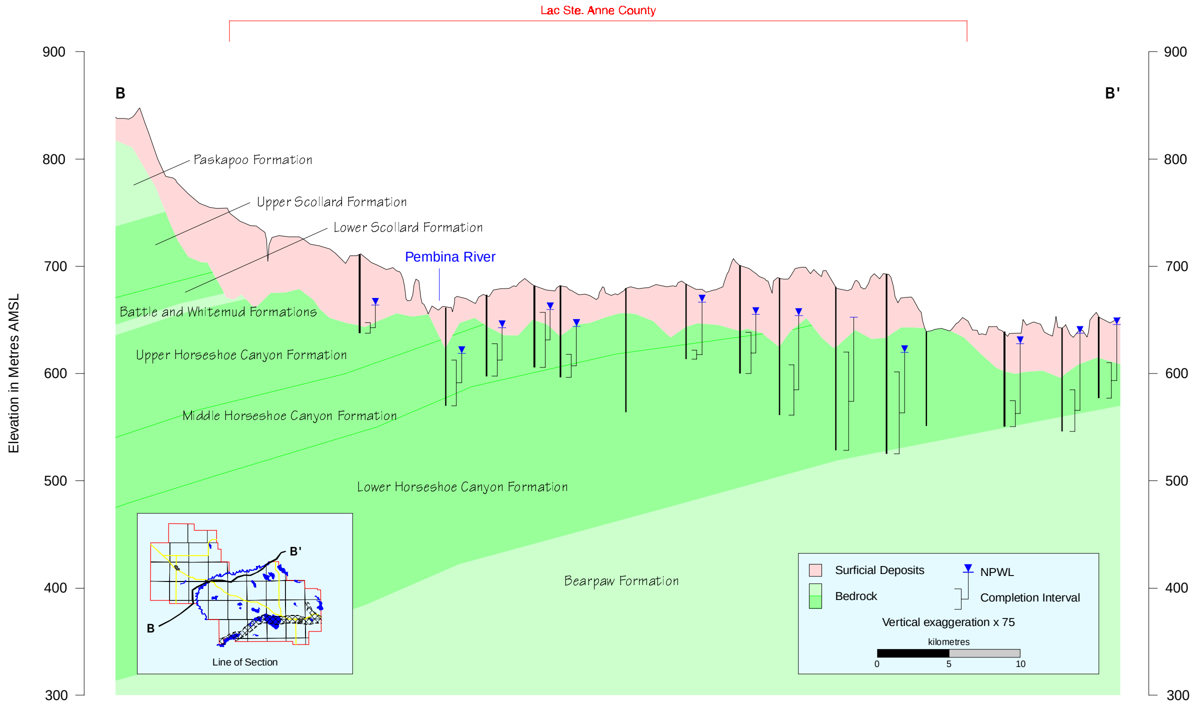

Figure 8. Cross-Section B - B'

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[8] See glossary

5.2 Aquifers in Surficial Deposits

The surficial deposits are the sediments above the bedrock surface. This includes pre-glacial materials, which were deposited before glaciation, and materials deposited directly or indirectly by glaciation. The lower surficial deposits include the pre-glacial fluvial[9] and lacustrine[10] deposits. The lacustrine deposits include clay, silt, fine-grained sand and coal. The upper surficial deposits include the more traditional glacial deposits of till and meltwater deposits.

5.2.1 Geological Characteristics of Surficial Deposits

While the surficial deposits are treated as one hydrogeological unit, they consist of three hydraulic parts. The first is the sand and gravel deposits of the lower surficial deposits, the second is the saturated sand and gravel deposits of the upper surficial deposits and third is the sand and gravel close to ground level, which is usually unsaturated. Sand and gravel deposits in the upper part of the surficial deposits can extend above the upper limit of the saturation zone and because they are not saturated, they are not an aquifer. However, these sand and gravel deposits are significant since they provide a pathway for liquid contaminants to move downward into the groundwater. Because of the significance of the shallow sand and gravel deposits, they have been mapped where they are present within one metre of the ground surface and are referred to as the “first sand and gravel”.

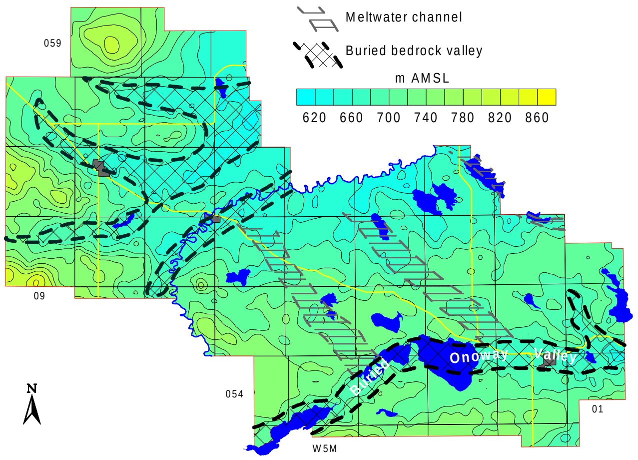

Figure 9. Bedrock Topography

Over the majority of the County, the surficial deposits are less than 40 metres thick. The exceptions are mainly in association with the linear lows in the bedrock surface, which occur throughout the County. Three of the buried valleys are noted on the adjacent map. The main linear bedrock low has been designated as the Buried Onoway Valley. This Valley, shown on the adjacent map, trends from west to east and underlies Isle Lake and Lac Ste. Anne in the southern part of the County. A second buried valley trends from west to east and underlies the Town of Mayerthorpe. The Town of Mayerthorpe developed the sand and gravel aquifer associated with the buried valley for its water supply in 1959. A third buried valley trends from west to east and is south of the Town of Mayerthorpe, and generally follows the present-day Pembina River.

In addition to the Buried Onoway Valley, there are minor linear bedrock lows that are believed to be associated with meltwater channels. Three of these channels are noted on the above map. These meltwater channels trend perpendicular to the Buried Onoway Valley. Their location and orientation is a direct influence of glaciation.

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[9] See glossary
[10] See glossary

The lower surficial deposits are composed mostly of fluvial and lacustrine deposits. The total thickness of the lower surficial deposits is mainly less than 30 metres. The lowest part of the lower surficial deposits includes pre-glacial sand and gravel deposits. These deposits would generally be expected to directly overlie the bedrock surface in the Buried Onoway Valley. The lowest sand and gravel deposits are of fluvial origin and are usually no more than a few metres thick.

The upper surficial deposits are either directly or indirectly a result of glacial activity. The deposits include till, with minor sand and gravel deposits of meltwater origin, which occur as isolated pockets. The thickness of the upper surficial deposits can exceed 30 metres. The greatest thickness of upper surficial deposits occurs in the areas of the buried bedrock valleys.

Sand and gravel deposits can occur throughout the entire unconsolidated section. The total thickness of sand and gravel deposits is generally less than 10 metres throughout the County. The greatest thickness of sand and gravel deposits occurs in the areas of the buried bedrock lows and meltwater channels. The combined thickness of all sand and gravel deposits has been determined as a function of the total thickness of the surficial deposits.

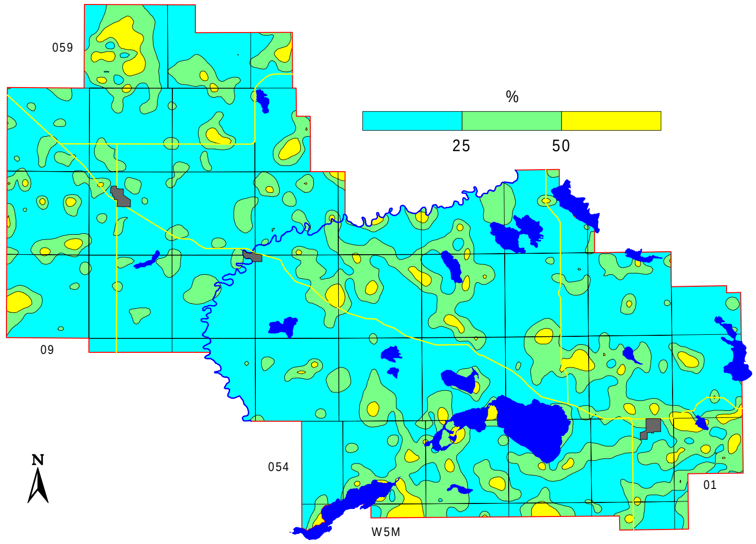

Figure 10. Amount of Sand and Gravel in Surficial Deposits

Over approximately 80% of the County, the sand and gravel deposits are less than 25% of the total thickness of the surficial deposits. The areas where the sand and gravel percentage is higher are associated with the buried bedrock lows and meltwater channels.

5.2.2 Sand and Gravel Aquifer(s)

One source of groundwater in the County includes aquifers in the surficial deposits. The actual aquifer that is developed is usually dictated by which aquifer is present. Some water wells are completed in aquifers in the lower surficial deposits and some are completed in aquifers in the upper surficial deposits.

The adjacent map shows water well yields that are expected in the County, based on the surficial aquifers that have been developed by existing water wells. These data show that water wells with yields of more than 100 m³/day from sand and gravel aquifer(s) can be expected in only a few areas of the County. The most notable areas where higher yields are expected include the towns of Mayerthorpe and Onoway, south of the community of Cherhill, and in the vicinity of Lac Ste. Anne. Over approximately 25% of the County, the sand and gravel deposits are not present or if present, are not saturated.

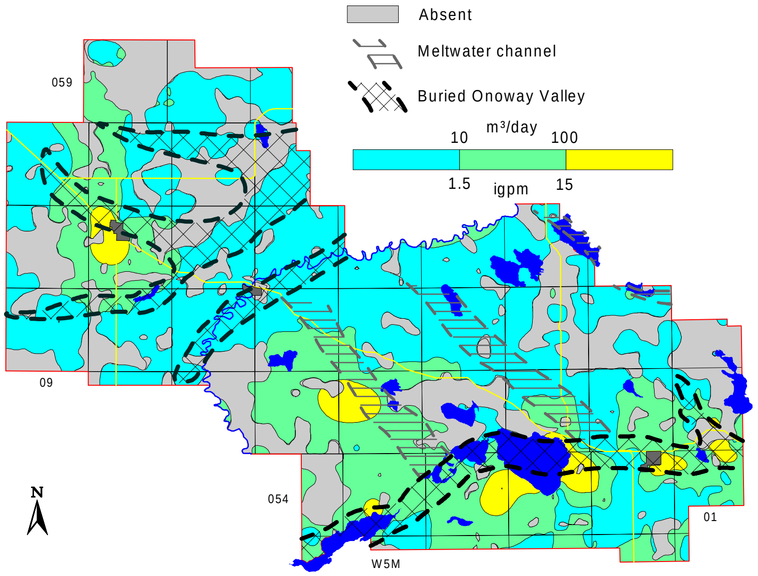

Figure 11. Apparent Yield for Water Wells Completed through Sand and Gravel Aquifer(s)

The main groundwater supply from surficial deposits that has been developed in the County is for the Town of Mayerthorpe. The Town uses a sand and gravel aquifer associated with a linear bedrock low. In 1997, the Town of Mayerthorpe used more than 800 m³/day of groundwater. However, the water level in this aquifer has declined more than 25 metres between 1962 and 1996 (Hydrogeological Consultants Ltd., 1998).

5.2.2.1 Chemical Quality of Groundwater from Surficial Deposits

The chemical analysis results of groundwaters from the surficial deposits have not been differentiated based on aquifers in the upper or lower surficial deposits. The main reason for not separating the chemical analysis results is that there appears to be no major chemical difference between groundwater from the upper and lower sand and gravel aquifers. The groundwaters from these aquifers are generally chemically hard and high in dissolved iron.

The Piper tri-linear diagrams show that the majority of the groundwaters are sodium-bicarbonate-type or calcium-magnesium-bicarbonate-type waters; however, some are groundwaters from the surficial deposits are sodium-sulfate-type waters.

Eighty percent of the groundwaters from the surficial aquifers have a chemical hardness of more than 50 mg/L. The total dissolved solids (TDS) concentrations in the groundwaters from the surficial deposits range from less than 500 to over 2,000 mg/L, with 70% of the groundwaters having a TDS of less than 1,000 mg/L. The groundwaters with a TDS of more than 1,500 mg/L occur mainly in the northern part of the County. Groundwaters with sulfate concentrations of greater than 400 mg/L occur in areas where TDS values exceed 1,100 mg/L.

There are very few groundwaters with appreciable concentrations of the chloride ion and in most of the County the chloride ion concentration is less than 100 mg/L.

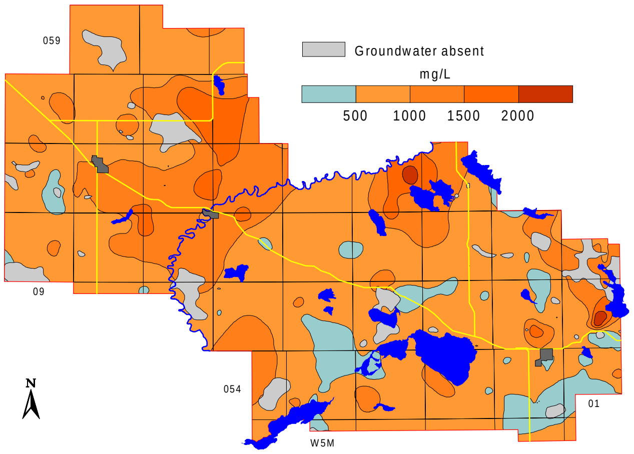

Figure 12. Total Dissolved Solids in Groundwater from Surficial Deposits

There are very few water wells completed in sand and gravel aquifers within the surficial deposits. This is mainly because the groundwaters from these aquifers tend to be chemically hard and high in dissolved iron. The most significant water wells completed in sand and gravel aquifers are those used by the Town of Mayerthorpe (Hydrogeological Consultants Ltd., 1996).

5.2.3 Upper Sand and Gravel Aquifer

The Upper Sand and Gravel Aquifer includes saturated sand and gravel deposits in the upper surficial deposits. These aquifers typically occur above an elevation of 660 metres AMSL. The saturated sand and gravel deposits are not continuous and are expected to be present over approximately 50% of the County.

5.2.3.1 Aquifer Thickness

The thickness of the Upper Sand and Gravel Aquifer is in part a function of the elevation of the non-pumping water level associated with the upper surficial deposits and in part a result of the depth to the bedrock surface. Since the non-pumping water level tends to be a subdued replica of the bedrock surface, the thickness of the Upper Sand and Gravel Aquifer tends to be directly proportional to the thickness of the surficial deposits.

While the sand and gravel deposits in the upper surficial deposits are not continuous, the Upper Sand and Gravel Aquifer includes all of the aquifers present in the upper surficial deposits. The Upper Sand and Gravel Aquifer is more than ten metres thick in some areas, but over the majority of the County, is less than five metres thick or absent. Most of the greater thickness in the Upper Sand and Gravel Aquifer occurs in the areas of linear bedrock lows.

5.2.3.2 Apparent Yield

The permeability of the Upper Sand and Gravel Aquifer can be high. The high permeability combined with significant thickness leads to an extrapolation of water wells with high yields; however, because the sand and gravel deposits occur mainly as hydraulically discontinuous pockets, the long-term yield of the water wells is limited. The apparent yields for water wells completed in this Aquifer are expected to be mainly less than 100 m³/day. Where the Upper Sand and Gravel Aquifer is absent and where the yields are low, the development of water wells for the domestic needs of single families may not be possible.

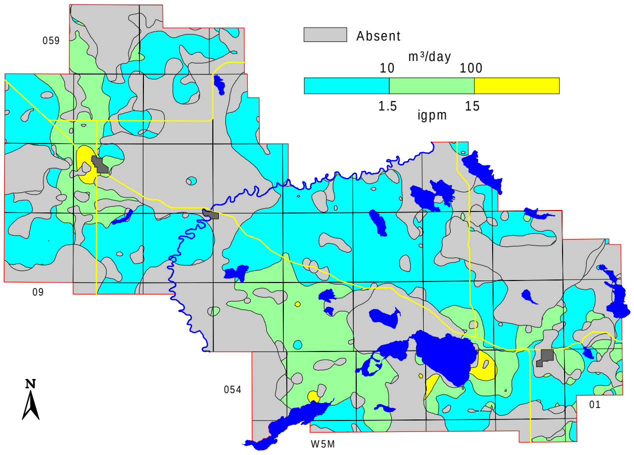

Figure 13. Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer

5.2.4 Lower Sand and Gravel Aquifer

The Lower Sand and Gravel Aquifer is a saturated sand and gravel deposit that occurs at or near the base of the surficial deposits in the deepest part of the pre-glacial linear bedrock lows. Coal fragments are frequently associated with the Lower Sand and Gravel Aquifer in the southern part of the County. During well development, the presence of the coal deposits can create a problem by plugging the water well screen. The Lower Sand and Gravel Aquifer may be a continuous aquifer in the Buried Onoway Valley, where the thickness of the sand and gravel deposits may reach five metres. In all, the Lower Sand and Gravel Aquifer is present in less than 50% of the County.

5.2.4.1 Apparent Yield

Water wells completed in the Lower Sand and Gravel Aquifer may have yields in excess of 100 m³/day. The highest yields are expected in the Buried Onoway Valley east of Lac Ste. Anne. In this area, the projected long-term yields from individual water wells could be more than 150 m³/day. The yields for water wells completed in the Lower Sand and Gravel Aquifer are expected to be less than 10 m³/day in the majority of the County.

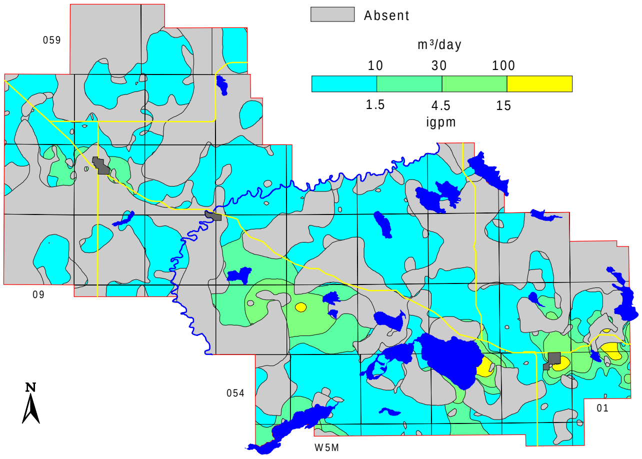

Figure 14. Apparent Yield for Water Wells Completed through Lower Sand and Gravel Aquifer

5.3 Bedrock

5.3.1 Geological Characteristics

The upper bedrock in the County is the Paskapoo Formation and the Edmonton Group. The Paskapoo Formation consists of cycles of thick, tablular sandstones, siltstone and mudstone layers (Glass, D. J.[editor], 1990). The Edmonton Group consists of fresh and brackish-water deposits of fine-grained sandstone and silty shale, thick coal seams, and numerous bentonite beds (Carrigy, 1971). The thickness of the Paskapoo Formation can be up to 800 metres. The thickness of the Edmonton Group varies from 300 to 500 metres, and is underlain by the Bearpaw Formation. The Edmonton Group in the County includes the Scollard, Battle, Whitemud and Horseshoe Canyon formations.

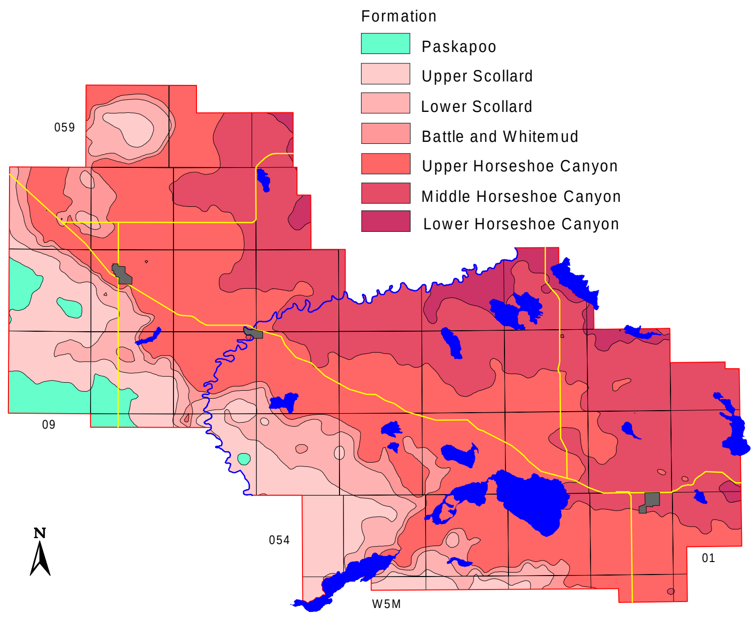

Figure 15. Bedrock Geology

The Paskapoo Formation is the upper bedrock and subcrops in the southwestern part of the County. The total thickness of the Paskapoo Formation within the County is mainly less than 100 metres.

The Scollard Formation underlies the Paskapoo Formation and also subcrops in the southwestern part of the County. The Scollard Formation has a maximum thickness of 120 metres within the County and includes the Upper and Lower Scollard formations. The Upper Scollard consists mainly of sandstone, siltstone, shale and coal seams or zones. Two prominent coal zones within the Upper Scollard are the Ardley Coal (up to 20 metres thick) and the Nevis Coal (up to 3.5 metres thick). The bottom of the Nevis Coal Seam is the border between the Upper and Lower Scollard formations. The Lower Scollard Formation has a maximum thickness of 40 metres and is composed mainly of shale and sandstone.

Beneath the Scollard Formation are two formations having a maximum thickness of 30 metres: the two are the Battle and Whitemud formations. The Battle and Whitemud formations are also present only in the southwestern part of the County. The Battle Formation is composed mainly of claystone, tuff, shale and bentonite, and includes the Kneehills Member, a 2.5- to 30-cm thick tuff bed. The Whitemud Formation is composed mainly of shale, siltstone, sandstone and bentonite. The Battle and Whitemud formations are considered to be significant geologic markers, and were used to prepare the structural maps and hydrostratigraphy classifications. Because of the ubiquitous nature of the bentonite in the Battle and Whitemud formations, there is very little significant permeability within these two formations.

The Horseshoe Canyon Formation is the lower part of the Edmonton Group and is the upper bedrock in the remainder of the County. The Horseshoe Canyon Formation has a maximum thickness of 350 metres and within the County includes the Upper, Middle and Lower Horseshoe Canyon formations. The Upper Horseshoe Canyon, which can be up to 100 metres thick, is the upper bedrock in the central third of the County where the Scollard Formation is absent. The Middle Horseshoe Canyon, which is up to 70 metres thick, is the upper bedrock in the northeastern part of the County. The Lower Horseshoe Canyon, which is up to 180 metres thick, is the upper bedrock in a few areas of the northeastern part of the County.

The Horseshoe Canyon Formation consists of deltaic[11] and fluvial sandstone, siltstone and shale with interbedded coal seams, bentonite and thin nodular beds of ironstone. Because of the low-energy environment in which deposition occurred, the sandstones, when present, tend to be finer grained. The lower 60 to 70 metres and the upper 30 to 50 metres of the Horseshoe Canyon Formation can include coarser grained sandstone deposits.

The Bearpaw Formation underlies the Horseshoe Canyon Formation and is in the order of 80 metres thick within the County. The Bearpaw Formation includes transgressive, shallow marine (shoreface) and open marine facies[12] deposits. In Lac Ste. Anne County, the Bearpaw Formation is composed mainly of shale and as such is a regional aquitard.

5.3.2 Aquifers

In general, water wells in the bedrock aquifer(s) in Lac Ste. Anne County can be expected to provide only limited quantities of groundwater. The adjacent map shows water well yields that are based on the upper bedrock aquifer(s) that have been developed. Over approximately 50% of the County, water wells completed in the upper bedrock aquifer(s) have apparent yields of less than 10 m^3/day. The higher yields are mainly in the western and southern part of the County.

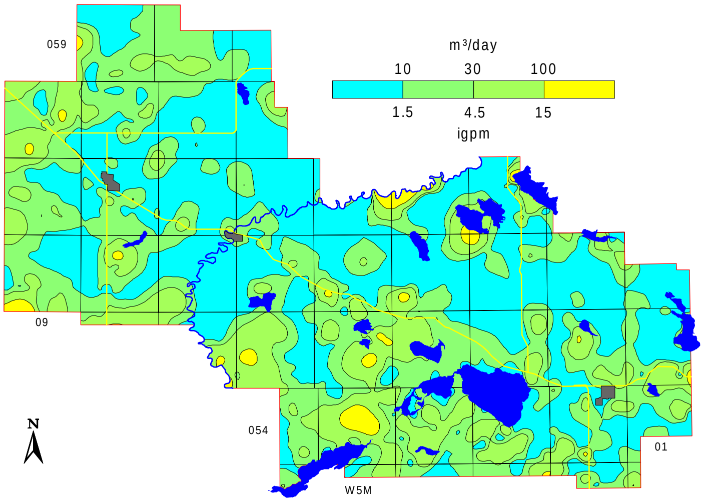

Figure 16. Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)

The water wells completed in the Upper Scollard and Upper Horseshoe Canyon Aquifers generally have higher yields than in the Middle Horseshoe Canyon Aquifer.

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[11] See glossary
[12] See glossary

5.3.3 Chemical Quality of Groundwater

The TDS concentrations in the groundwaters from the upper bedrock aquifer(s) range from less than 500 to more than 2,000 mg/L. In more than 60% of the area, TDS values are less than 1,000 mg/L.

A relationship between TDS and sulfate concentrations shows that when TDS values in the upper bedrock aquifer(s) exceed 1,200 mg/L, the sulfate concentration exceeds 400 mg/L.

The Piper tri-linear diagrams show that all chemical types of groundwater occur in the bedrock aquifer(s). However, the majority of the groundwaters are sodium-bicarbonate or sodium-sulfate types.

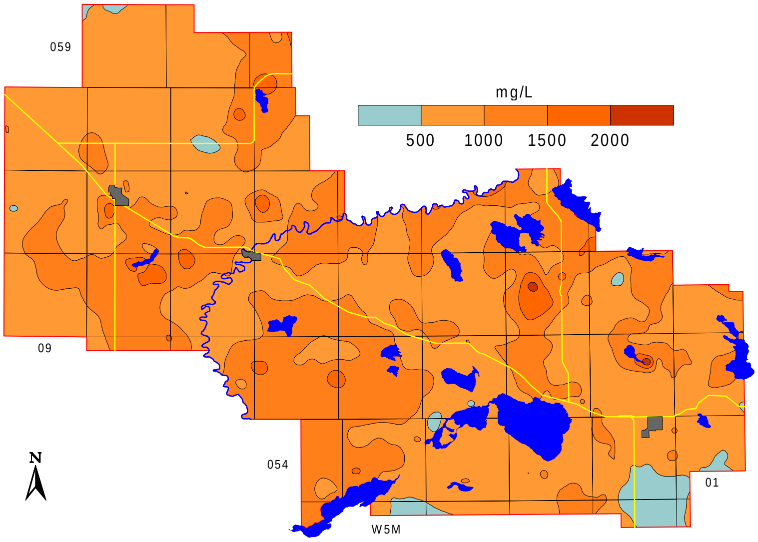

Figure 17. Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)

In 60% of the County, the fluoride ion concentration in the groundwater from the upper bedrock aquifer(s) is less than 1.0 mg/L.

5.3.4 Paskapoo Aquifer

The Paskapoo Aquifer is part of the Paskapoo Formation that mainly underlies parts of townships 056 and 057, ranges 08 and 09, W5M in the southwestern part of the County. The thickness of the Paskapoo Formation is generally less than 100 metres; in most of the County, the Paskapoo Formation has been eroded.

5.3.4.1 Depth to Top

The depth to the top of the Paskapoo Formation is mainly less than 20 metres below ground level.

5.3.4.2 Apparent Yield

The projected long-term yield for individual water wells completed through the Paskapoo Aquifer is mainly 10 to 100 m³/day. The areas where water wells with higher yields are expected within the Paskapoo Aquifer are mainly in the extreme southwestern part of the County.

5.3.4.3 Quality

The TDS concentrations for groundwater from the Paskapoo Aquifer are mainly more than 500 mg/L. The sulfate concentrations are less than 100 mg/L in over 60% of the County where the Paskapoo subcrops.

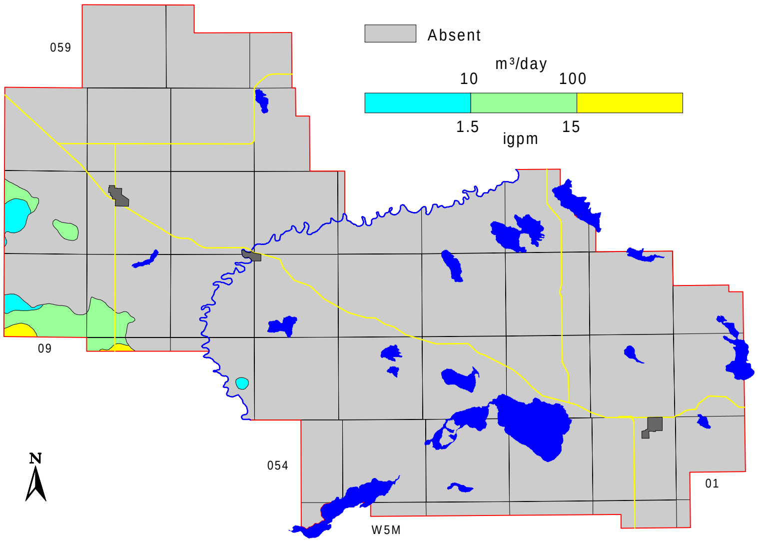

Figure 18. Apparent Yield for Water Wells Completed through Paskapoo Aquifer

The chloride concentration from the Paskapoo Aquifer can be expected to be less than 10 mg/L.

5.3.5 Upper Scollard Aquifer

The Upper Scollard Aquifer is part of the Upper Scollard Formation that underlies the southwestern part of the County. The thickness of the Scollard Formation is generally less than 80 metres; in most of the County, the Scollard Formation has been eroded.

5.3.5.1 Depth to Top

The depth to the top of the Upper Scollard Formation is mainly less than 40 metres below ground level. The greatest depth is in the area(s) where the Paskapoo Formation is present.

5.3.5.2 Apparent Yield

The projected long-term yield for individual water wells completed through the Upper Scollard Aquifer is mainly 10 to 100 m³/day. The lower yields are expected where the Aquifer is thinner near its eastern edge.

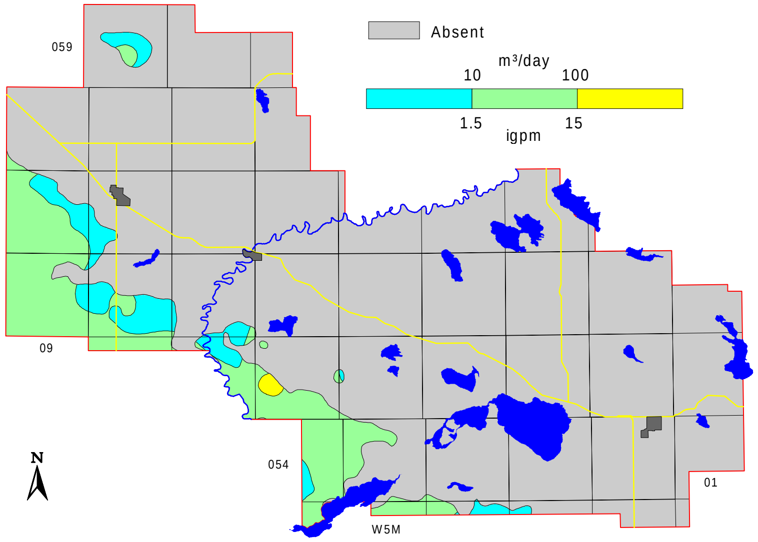

Figure 19. Apparent Yield for Water Wells Completed through Upper Scollard Aquifer

5.3.5.3 Quality

The TDS concentrations for groundwater from the Upper Scollard Aquifer are mainly less than 1,500 mg/L, with 50% of the values being less than 1,000 mg/L. The sulfate concentrations are generally less than 250 mg/L.

The chloride concentration of the groundwater from the Upper Scollard Aquifer can be expected to be less than 10 mg/L except in the area(s) where the Paskapoo Formation is present.

5.3.6 Lower Scollard Aquifer

The Lower Scollard Aquifer is part of the Lower Scollard Formation that underlies the southwestern part of the County. The thickness of the Lower Scollard Formation is generally less than 40 metres; in most of the County, the Lower Scollard Formation has been eroded.

5.3.6.1 Depth to Top

The depth to the top of the Lower Scollard Formation is mainly less than 100 metres below ground level, increasing toward its southwestern extent.

5.3.6.2 Apparent Yield

The projected long-term yields for individual water wells completed through the Lower Scollard Aquifer range from less than 1.0 to more than 5.0 m³/day. An extended aquifer test conducted with a water test hole completed in the Lower Scollard Aquifer for the Town of Mayerthorpe (Hydrogeological Consultants Ltd., 1998) indicated a long-term yield of 325 m³/day. The water test hole site was chosen on the basis of a lineament analysis.

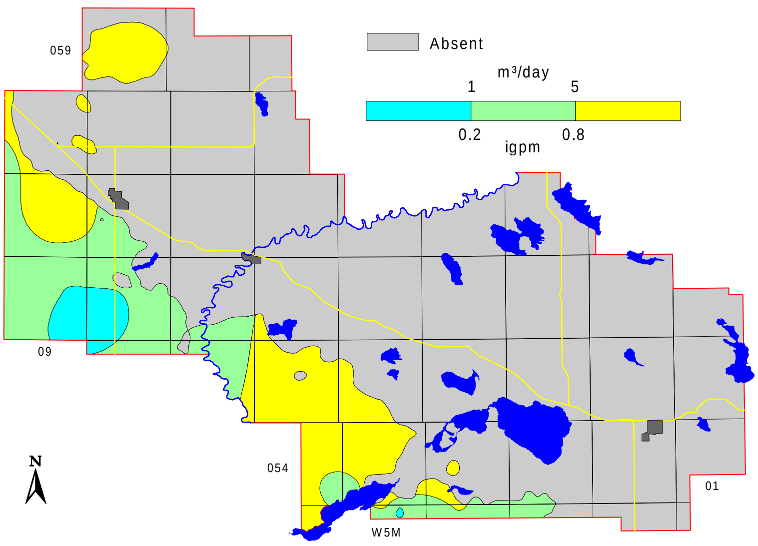

Figure 20. Apparent Yield for Water Wells Completed through Lower Scollard Aquifer

5.3.6.3 Quality

The TDS concentrations for groundwater from the Lower Scollard Aquifer are mainly less than 1,500 mg/L. Due to the paucity of data available, establishing meaningful trends between TDS and sulfate concentrations is not practical.

A groundwater sample collected from a water test hole in November 1997 (Hydrogeological Consultants Ltd., 1998) completed in the Lower Scollard Aquifer had a TDS concentration of 1,050 mg/L, a sulfate concentration of 58.4 mg/L, a chloride concentration of 1.2 mg/L, and a fluoride concentration of 1.03 mg/L.

5.3.7 Upper Horseshoe Canyon Aquifer

The Upper Horseshoe Canyon Aquifer is the upper part of the Horseshoe Canyon Formation and subcrops under the central part of the County. The thickness of the Upper Horseshoe Canyon Aquifer increases to the southwest and can reach 100 metres in the southern part of the County. In general terms, the permeability of the Upper Horseshoe Canyon Aquifer is very low. Higher local permeability can be expected when the depth of burial is less than 100 metres and fracturing or weathering has occurred.

5.3.7.1 Depth to Top

The depth to the top of the Upper Horseshoe Canyon Aquifer is variable, ranging from less than 20 to more than 220 metres. The largest area where the top of the Upper Horseshoe Canyon Aquifer is more than 80 metres below ground level is in the southwestern part of the County, where the Upper Horseshoe Canyon Aquifer underlies the Scollard Aquifer.

5.3.7.2 Apparent Yield

The projected long-term yields for water wells completed through the Upper Horseshoe Canyon Aquifer are mainly less than 30 m³/day. The higher yields occur along the western side of the County and north of the Buried Onoway Valley. These higher yields may be related to a shallow depth of burial, fracturing or weathering.

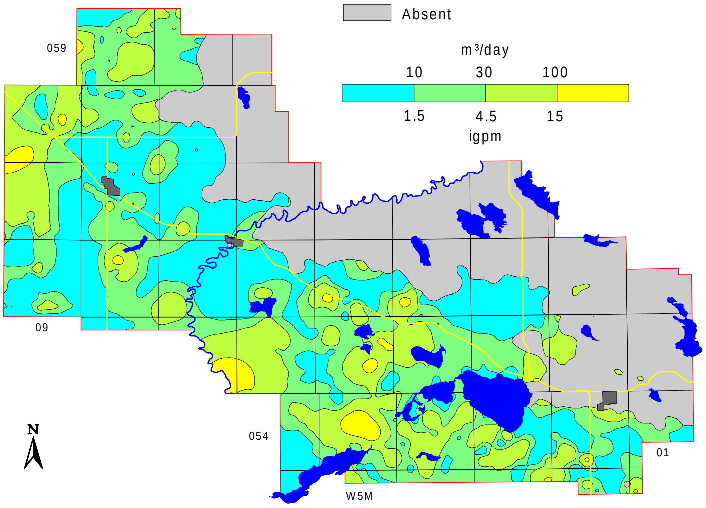

Figure 21. Apparent Yield for Water Wells Completed through Upper Horseshoe Canyon Aquifer

5.3.7.3 Quality

The Piper tri-linear diagrams show that sodium-bicarbonate and sodium-sulfate are the dominant types of groundwater that occur in the Upper Horseshoe Canyon Aquifer. The TDS concentrations in groundwater from the Upper Horseshoe Canyon Aquifer mainly range from 500 to 1,500 mg/L. The higher TDS values tend to be highest in the central part of the County. When TDS values exceed 1,200 mg/L, the sulfate concentrations exceed 400 mg/L.

Chloride concentrations in the groundwater from the Upper Horseshoe Canyon Aquifer are mainly less than 10 mg/L. The exceptions occur along the southwestern extent of the County. In this area, chloride concentrations can exceed 100 mg/L.

5.3.8 Middle Horseshoe Canyon Aquifer

The Middle Horseshoe Canyon Aquifer is part of the Middle Horseshoe Canyon Formation and subcrops under the northeastern part of the County. The thickness of the Middle Horseshoe Canyon Aquifer increases to the southwest and can reach 70 metres in the western part of the County. In general terms, the permeability of the Middle Horseshoe Canyon Aquifer is very low. Higher local permeability can be expected when the depth of burial is less than 100 metres and fracturing or weathering has occurred.

5.3.8.1 Depth to Top

The depth to the top of the Middle Horseshoe Canyon Aquifer is variable, ranging from less than 20 to more than 340 metres. The largest area where the top of the Middle Horseshoe Canyon Aquifer is more than 80 metres below ground level is in the southwestern part of the County, where the Middle Horseshoe Canyon underlies the Upper Horseshoe Canyon Aquifer.

5.3.8.2 Apparent Yield

The projected long-term yields for water wells completed through the Middle Horseshoe Canyon Aquifer are mainly less than 10 m³/day. The adjacent map indicates that apparent yields of more than 30 m³/day are expected mainly in the vicinity of the Village of Onoway.

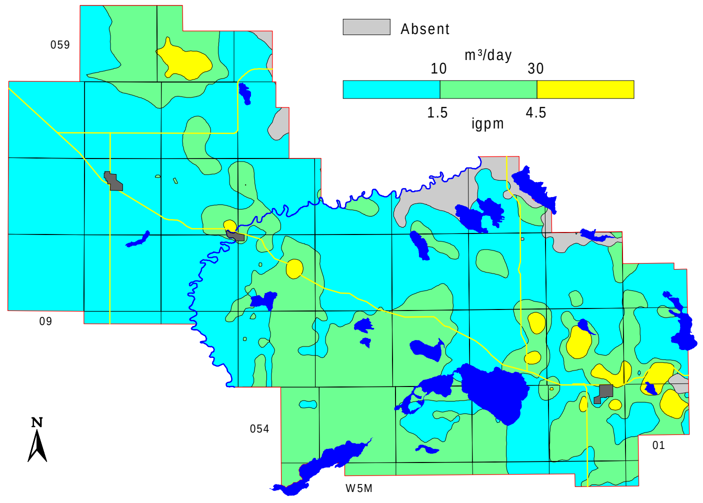

Figure 22. Apparent Yield for Water Wells Completed through Middle Horseshoe Canyon Aquifer

5.3.8.3 Quality

The Piper tri-linear diagrams show that groundwaters in the Middle Horseshoe Canyon Aquifer are mainly a sodium-bicarbonate-type. The TDS concentrations in groundwater from the Middle Horseshoe Canyon Aquifer mainly range from less than 1,000 to more than 1,500 mg/L. The higher TDS values tend to be in the northeastern part of the County where the Middle Horseshoe Canyon is present as the upper bedrock. When TDS values exceed 1,300 mg/L, the sulfate concentrations exceed 400 mg/L.

Chloride concentrations in the groundwater from the Middle Horseshoe Canyon Aquifer are mainly less than 10 mg/L.

5.3.9 Lower Horseshoe Canyon Aquifer

The Lower Horseshoe Canyon Aquifer is part of the Lower Horseshoe Canyon Formation and subcrops under the northeasternmost part of the County. The thickness of the Lower Horseshoe Canyon Aquifer is generally 170 metres. Higher local permeability can be expected in the lowest part of the Lower Horseshoe Canyon Formation.

5.3.9.1 Depth to Top

The depth to the top of the Lower Horseshoe Canyon Aquifer ranges from less than 20 metres in the northeastern part of the County where the Aquifer subcrops, to more than 360 metres in the southwestern part of the County where the Paskapoo Formation is present.

5.3.9.2 Apparent Yield

The projected long-term yields for individual water wells completed in the Lower Horseshoe Canyon Aquifer are mainly less than 50 m³/day. The adjacent map indicates that apparent yields of more than 50 m³/day are expected mainly north and south of the Town of Mayerthorpe; however, there is little or no data for the Aquifer for the southern and western parts of the County due to the large depth to the Aquifer.

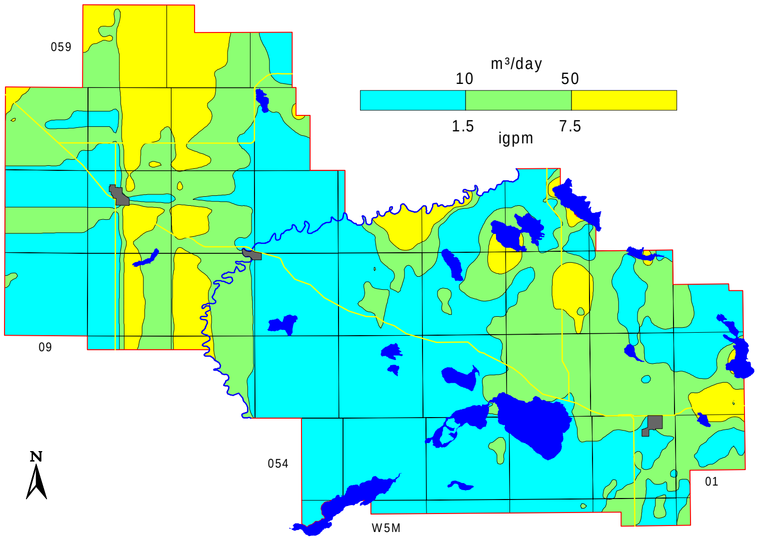

Figure 23. Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer

5.3.9.3 Quality

Groundwaters from the Lower Horseshoe Canyon Aquifer are mainly sodium-bicarbonate or sodium-sulfate-type waters. TDS concentrations are expected to be in the order of 500 to 1,500 mg/L where the Aquifer is present, although there is a paucity of data for the southern and western parts of the County.

Chloride concentrations in the groundwater from the Lower Horseshoe Canyon Aquifer are mainly less than 250 mg/L.

6 GROUNDWATER BUDGET

6.1 Hydrographs

There are two observation water wells in the County where water levels are being measured and recorded with time. These observation water wells are part of the AEP groundwater-monitoring network. Both of the observation water wells, located approximately 10 kilometres south of the Town of Mayerthorpe in the Paddle River Valley, are completed in the Lower Sand and Gravel Aquifer.

The water level rose more than two metres from 1987 to 1989 in the two observation water wells, with one metre of water-level rise occurring in 1987. This rise in water level corresponds to the filling of the Paddle River Dam.

The Town of Mayerthorpe has been using groundwater from water supply wells completed in the Lower Sand and Gravel Aquifer since 1959. The available data indicate that between 1962 and 1996, the water level in the aquifer has declined more than 25 metres. The water-level decline indicates that recharge to the Aquifer is less than the 800 m^3/day that is being used by the Town.

In general, the hydrographs show local hydraulic conditions and are not applicable to a regional groundwater budget analysis.

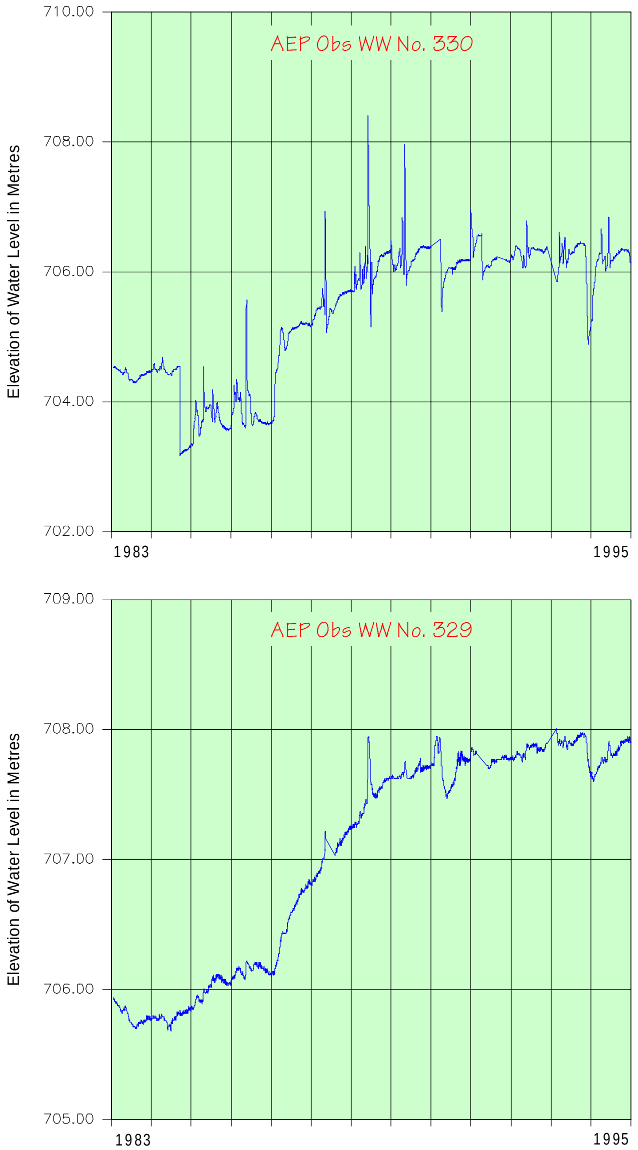

Figure 24. Hydrographs - AEP Observation Water Wells

6.2 Groundwater Flow

A direct measurement of groundwater recharge or discharge is not possible from the data that are presently available for the County. One indirect method of measuring recharge is to determine the quantity of groundwater flowing through each individual aquifer. This method assumes that there is sufficient recharge to the aquifer to maintain the flow through the aquifer and the discharge is equal to the recharge. However, even the data that can be used to calculate the quantity of flow must be averaged and estimated. To determine the flow requires a value for the average transmissivity of the aquifer, an average hydraulic gradient and an estimate for the width of the aquifer. For the present program, the flow has been estimated for those parts of the various aquifers within the County. The aquifers include the Buried Onoway Valley, the Upper Scollard Aquifer, the Upper Horseshoe Canyon Aquifer, the Middle Horseshoe Canyon Aquifer and the Lower Horseshoe Canyon Aquifer. Due to the paucity of data from surficial water wells completed outside the Buried Onoway Valley, the groundwater flow has not been estimated from the surficial deposits.

The flow through each aquifer assumes that by taking a large area, an aquifer can be considered as homogeneous, the average gradient can be estimated from the non-pumping water-level surface, and flow takes place through the entire width of the aquifer. Based on these assumptions, the estimated groundwater flow through the individual aquifers can be summarized as follows:

Aquifer Designation	Transmissivity (m^2/day)	Gradient (m/m)	Width (km)	Main Direction of Flow	Quantity (m^3/day)
Buried Onoway Valley	30	0.0035	4	East	420
Upper Scollard	3	0.003	70	Northeast	630
Upper Horseshoe Canyon	1.5	0.004	90	Southeast/North/Northeast	540
Middle Horseshoe Canyon	0.7	0.004	90	Southeast/North	250
Lower Horseshoe Canyon	1	0.003	90	Southeast/North/Northeast	270

The recharge to these aquifers would be restricted to Lac Ste. Anne County.

6.2.1 Quantity of Groundwater

An estimate of the volume of groundwater stored in the sand and gravel aquifers in the surficial deposits is 0.5 to 3.0 cubic kilometres. This volume is based on an areal extent of 3,100 square kilometres and a saturated sand and gravel thickness of three metres. The variation in the total volume is based on the value of porosity that is used for the sand and gravel. One estimate of porosity is 5%, which gives the low value of the total volume. The high estimate is based on a porosity of 30% (Ozoray, Dubord and Cowen, 1990).

The adjacent water-level map has been prepared by considering water wells completed in aquifers in the surficial deposits. The map shows the highest level of groundwater in surficial deposits, and this level was used for calculation of saturated surficial deposits and for calculations of recharge/discharge areas.

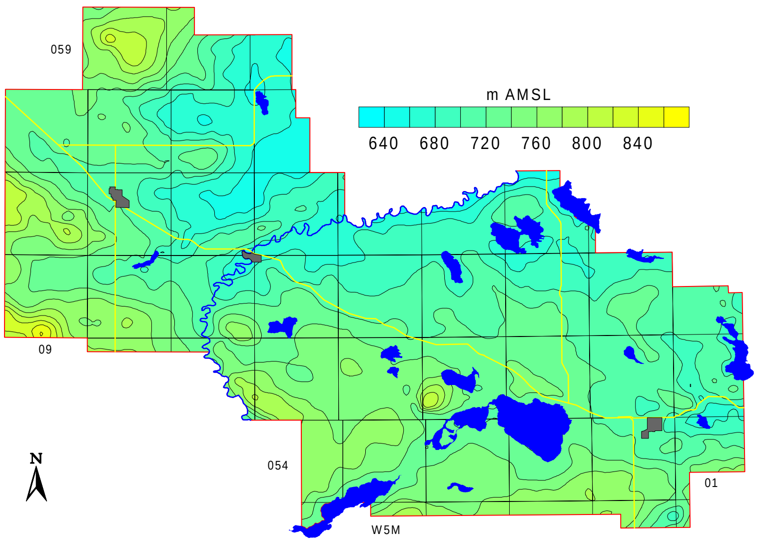

Figure 25. Non-Pumping Water-Level Surface in Water Wells Completed in Surficial Aquifer(s)

6.2.2 Recharge/Discharge

The hydraulic relationship between the groundwater in the surficial deposits and the groundwater in the bedrock aquifers is given by the non-pumping water-level surface associated with each of the hydraulic units. Where the water level in the surficial deposits is at a higher elevation than the water level in the bedrock aquifers, there is the opportunity for groundwater to move from the surficial deposits into the bedrock aquifers. This condition would be considered as an area of recharge to the bedrock aquifers and an area of discharge from the surficial deposits. The amount of groundwater that would move from the surficial deposits to the bedrock aquifers is directly related to the vertical permeability of the sediments separating the two aquifers.

When the hydraulic gradient is from the bedrock aquifers to the surficial deposits, the condition is a discharge area, relative to the bedrock aquifers.

6.2.2.1 Surficial Deposits/Bedrock Aquifers

The hydraulic gradient between the surficial deposits and the upper bedrock aquifers has been determined by subtracting the non-pumping water-level surface, determined for all water wells in the surficial deposits, from the non-pumping water-level surface associated with all water wells completed in bedrock aquifers. The recharge classification on the adjacent map includes those areas where the water level in the surficial deposits is more than five metres above the water level in the upper bedrock aquifer(s). The discharge areas are where the water level in the surficial deposits is more than five metres lower than the water level in the bedrock. When the elevation of the water level in the surficial deposits is between five metres above and five metres below the elevation of the water level in the bedrock, the area is classified as a transition.

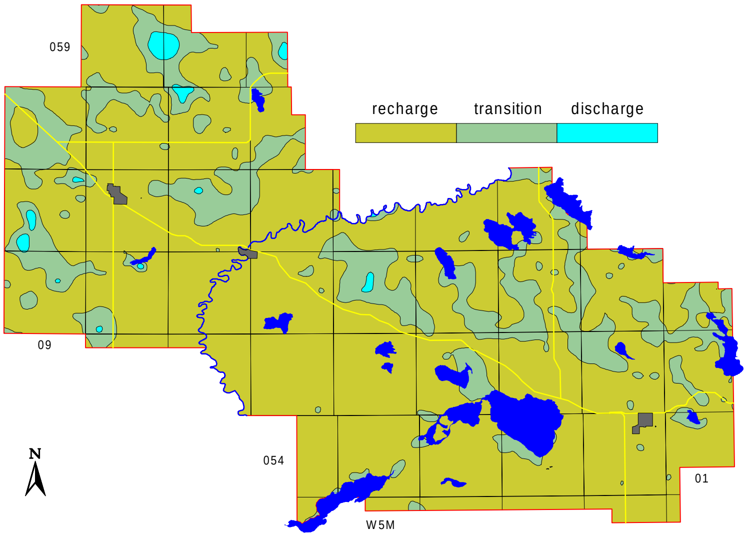

Figure 26.Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)

The adjacent map shows that in more than 80% of the County there is a downward hydraulic gradient between the surficial deposits and the upper bedrock aquifer(s). Areas where there is an upward hydraulic gradient, discharge from the bedrock, are very few. The areas of discharge from the bedrock are mainly in the northwestern part of the County. The remaining parts of the County are areas where there is a transition condition. The extensive areas of transition conditions may be a result of the topographic relief and/or the limited amount of data for both aquifer conditions generally and specifically for the surficial deposits.

Because of the paucity of data, a calculation of the volumes of groundwater entering and leaving the surficial deposits has not been attempted.

6.3 Bedrock Aquifers

Recharge to the bedrock aquifers within the County takes place from the overlying surficial deposits and from flow in the aquifer from outside the County. The recharge/discharge maps show that generally for most of the County, there is a downward hydraulic gradient from the surficial deposits to the bedrock. On a regional basis, calculating the quantity of water involved is not possible because of the complexity of the geological setting and the limited amount of data. However, because of the generally low permeability of the upper bedrock materials, the volume of water is expected to be small.

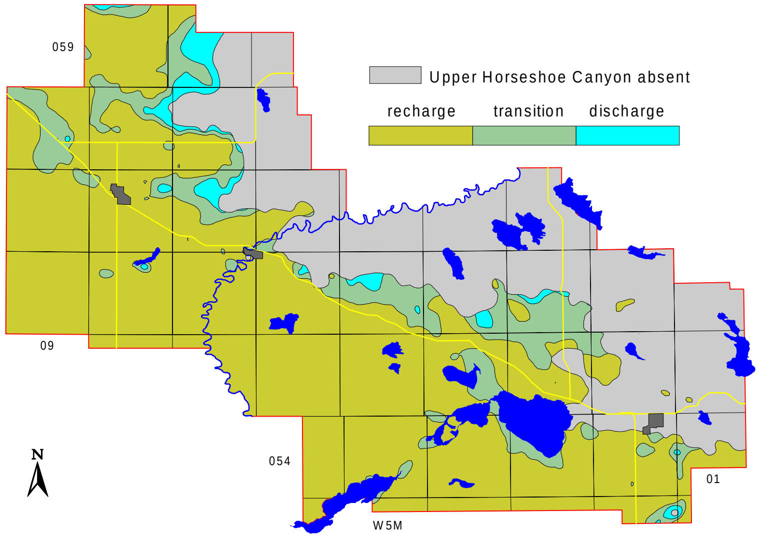

Figure 27. Recharge/Discharge Areas between Surficial Deposits and Upper Horseshoe Canyon Aquifer

The hydraulic relationship between the surficial deposits and the Paskapoo Aquifer indicates that in 50% of the County where the Paskapoo is present, there is a downward hydraulic gradient. Discharge areas are present at the northern and easternmost edges of the Paskapoo Formation.

The hydraulic relationship between the surficial deposits and the Upper and Lower Scollard Aquifer indicates that in 90% of the County where the Aquifer is present, there is a downward hydraulic gradient. Discharge or transition areas are present mainly at the eastern edges of the Formation.

The recharge/discharge configuration for each of the Upper, Middle and Lower Horseshoe Canyon formations and the surficial deposits shows that, generally, discharge from the bedrock occurs over an area of less than 10% of the central and northwestern parts of the County. The discharge in these parts of the County is associated with the edges of each of the Horseshoe Canyon formations.

7 POTENTIAL FOR GROUNDWATER CONTAMINATION

The most common sources of contaminants that can impact groundwater originate on or near the ground surface. The contaminant sources can include leachate from landfills, effluent from leaking lagoons or from septic fields, and petroleum products from storage tanks or pipeline breaks. The agricultural activities that generate contaminants include spreading of fertilizers, pesticides, herbicides and manure. The spreading of highway salt can also degrade groundwater quality.

When activities occur that do or can produce a liquid which could contaminate groundwater, it is prudent (from a hydrogeological point of view) to locate the activities where the risk of groundwater contamination is minimal. Alternatively, if the activities must be located in an area where groundwater can be more easily contaminated, the necessary action must be taken to minimize the risk of groundwater contamination.

The potential for groundwater contamination is based on the concept that the easier it is for a liquid contaminant to move downward, the easier it is for the groundwater to become contaminated. In areas where there is groundwater discharge, liquid contaminants cannot enter the groundwater flow systems to be distributed throughout the area. When there are groundwater recharge areas, low-permeability materials impede the movement of liquid contaminants downward. Therefore, if the soils develop on a low-permeability parent material of till or clay, the downward migration of a contaminant is slower relative to a high-permeability parent material such as sand and gravel of fluvial origin. Once a liquid contaminant enters the subsurface, the possibility for groundwater contamination increases if it coincides with a higher permeability material within one metre of the land surface.

To determine the nature of the materials on the land surface, the surficial geology map prepared by the Alberta Research Council (Shetsen, 1990) has been reclassified based on the relative permeability. The classification of materials is as follows:

1. high permeability - sand and gravel;
2. moderate permeability - silt, sand with clay, gravel with clay, and bedrock; and
3. low permeability - clay and till.

To identify the areas where sand and gravel can be expected within one metre of the ground surface, all groundwater database records with lithologies were reviewed. From a total of 4,071 records in the area of the County with lithology descriptions, 467 have sand and gravel within one metre of ground surface. In the remaining 3,604 records, the first sand and gravel is deeper or not present. This information was gridded to prepare a distribution of where the first sand and gravel deposit could be expected within one metre of ground level.

7.1.1 Risk of Groundwater Contamination Map

The information from the reclassification of the surficial geology map is the basis for preparing the initial risk map. The depth to the first sand and gravel is then used to modify the initial map and to prepare the final map. The criteria used for preparing the final Risk of Groundwater Contamination map are outlined in the adjacent table.

Surface Permeability	Sand or Gravel Present Top Within One Metre Of Ground Surface	Groundwater Contamination Risk
Low	No	Low
Moderate	No	Moderate
High	No	High
Low	Yes	High
Moderate	Yes	High
High	Yes	Very High

Table 2. Risk of Groundwater Contamination Criteria

The Risk of Groundwater Contamination map shows that, in less than 35% of the County, there is a high or very high risk of the groundwater being contaminated. These areas would be considered the least desirable ones for a development that has a product or by-product that could cause groundwater contamination. However, because the map has been prepared as part of a regional study, the designations are a guide only; detailed hydrogeological studies must be completed at any proposed development site to ensure the groundwater is protected from possible contamination. At all locations, good environmental practices should be exercised in order to ensure that groundwater contamination would not affect groundwater quality.

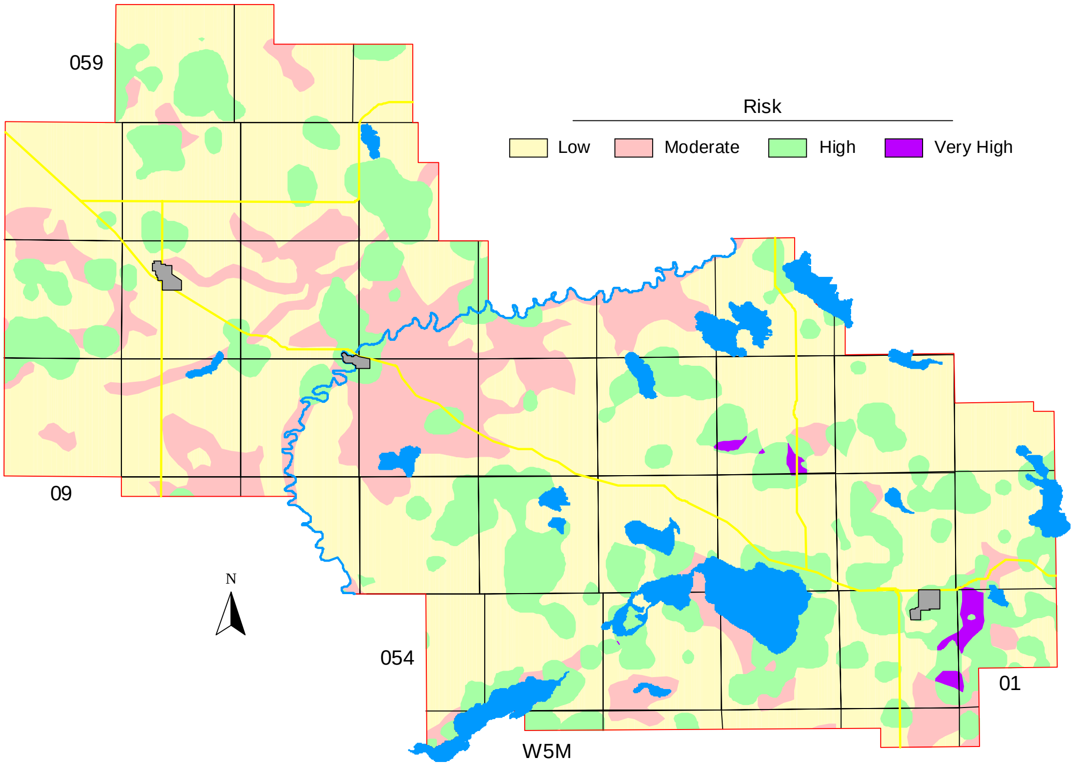

Figure 28. Risk of Groundwater Contamination

8 RECOMMENDATIONS

The present study has been based on information available from the groundwater database. The database has three problems:

1) the quality of the data;
2) the coordinate system used for the horizontal control; and
3) the distribution of the data.

The quality of the data in the groundwater database is affected by two factors: a) the technical training of the persons collecting the data; and b) the quality control of the data. The possible options to upgrade the database include the creation of a “super” database, which includes only verified data. The level of verification would have to include identifying the water well in the field, obtaining meaningful horizontal coordinates for the water well and the verification of certain parameters such as water level and completed depth. An attempt to update the quality of the entire database is not recommended.

The results of the present study indicate that the only readily identifiable aquifers in the surficial deposits are the sand and gravel deposits associated with the Buried Onoway Valley and the buried valley that underlies the Town of Mayerthorpe. It is recommended that the surficial deposits along the linear bedrock lows be further investigated.

There are indications that significant aquifers may be present in the bedrock where fracturing has occurred. This is most evident in the western part of the County where the Scollard Formation subcrops. The results of water test holes drilled for the Town of Mayerthorpe indicated that high yields can be expected from water wells completed in the Lower Scollard Aquifer. However, because of the generally low permeability that is characteristic of the Lower Scollard Aquifer, it is recommended that lineament analyses be conducted prior to any drilling program in the area where the Scollard Aquifer subcrops.

Another area where insufficient data are available is for the determination of a groundwater budget. There are only two observation water-well data sources in the County from which to obtain water levels for the groundwater budget. One method to obtain additional water-level data is to solicit the assistance of the water well owners who are stakeholders in the groundwater resource. In the M.D. of Rocky View, water well owners are being provided with a tax credit if they accurately measure the water level in their water well once per week for a year. A pilot project indicated that approximately five years of records are required to obtain a reasonable data set. The cost of a five-year project involving 50 water wells would be less than the cost of one drilling program that may provide two or three observation water wells.

In general, for the next level of study, the database needs updating. It requires more information from existing water wells, and additional information from new ones.

Before an attempt is made to upgrade the level of interpretation provided in this report and the accompanying maps and groundwater query, it is recommended that all water wells for which water well drilling reports are available be subjected to the following actions:

1. The horizontal location of the water well should be determined within 10 metres. The coordinates must be in 10TM NAD 27 or some other system that will allow conversion to 10TM NAD 27 coordinates.

2. A four-hour aquifer test should be performed with the water well to obtain a realistic estimate for the transmissivity of the aquifer in which the water well is completed.
3. Water samples should be collected for chemical analysis after 5 and 115 minutes of pumping, and analyzed for major and minor ions.

In addition to the data collection associated with the existing water wells, all available geophysical logs should be interpreted to establish a more accurate spatial definition of individual aquifers.

There is also a need to provide the water well drillers with feedback on the reports they are submitting to the regulatory agencies. The feedback is necessary to allow for a greater degree of uniformity in the reporting process. This is particularly true when trying to identify the bedrock surface. The water well drilling reports should be submitted to the AEP Resource Data Division in an electronic form. The money presently being spent by AEP and Prairie Farm Rehabilitation Administration (PFRA) to transpose the paper form to the electronic form should be used to allow for a technical review of the data and follow-up discussions with the drillers.

An effort should be made to form a partnership with the petroleum industry. The industry spends millions of dollars each year collecting information relative to water wells. Proper coordination of this effort could provide significantly better information from which future regional interpretations could be made. This could be accomplished by the County taking an active role in the activities associated with the drilling of hydrocarbon wells and conducting of seismic programs.

Groundwater is a renewable resource and it must be managed.

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10 GLOSSARY

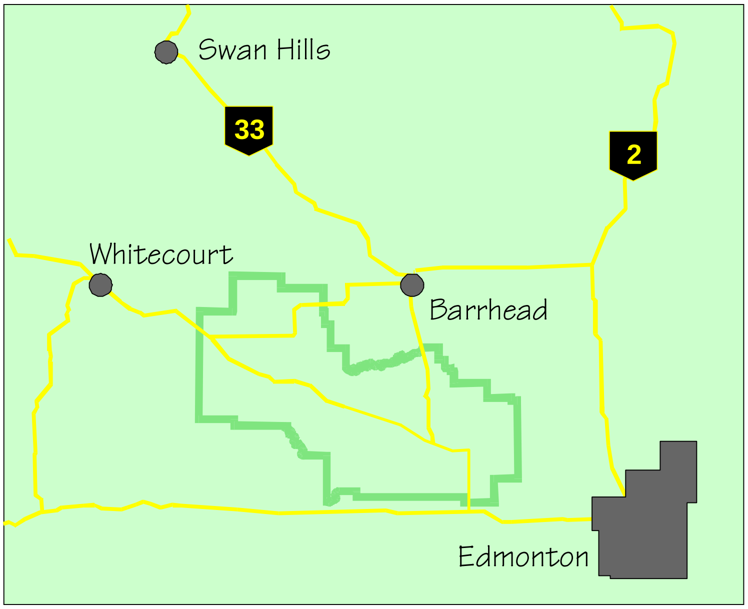
Apparent Yield	a regional analysis term referring to the rate a properly completed water well could be pumped, if fully penetrating the aquifer.
Aquifer	a formation, group of formations, or part of a formation that contains saturated permeable rocks capable of transmitting groundwater to water wells or springs in economical quantities.
Aquitard	a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer.
Available Drawdown	in a confined aquifer, the distance between the non-pumping water level and the top of the aquifer.
	in an unconfined aquifer (water table aquifer), two thirds of the saturated thickness of the aquifer.
Deltaic	a depositional environment in standing water near the mouth of a river.
Facies	the aspect or character of the sediment within beds of one and the same age (Pettijohn, 1957).
Fluvial	produced by the action of a stream or river.
Hydraulic Conductivity	the rate of flow of water through a unit cross-section under a unit hydraulic gradient; units are length/time.
Kriging	a geo-statistical method for gridding irregularly-spaced data.
Lacustrine	fine-grained sedimentary deposits associated with a lake environment and not including shore-line deposits.
Surficial Deposits	includes all sediments above the bedrock.
Transmissivity	the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient: a measure of the ease with which groundwater can move through the aquifer.
	Apparent Transmissivity: the value determined from a summary of aquifer test data, usually involving only two water-level readings.
	Effective Transmissivity: the value determined from late pumping and/or late recovery water-level data from an aquifer test.
	Aquifer Transmissivity: the value determined by multiplying the hydraulic conductivity of an aquifer by the thickness of the aquifer.

LAC STE. ANNE COUNTY

Appendix A

HYDROGEOLOGICAL MAPS AND FIGURES

Index Map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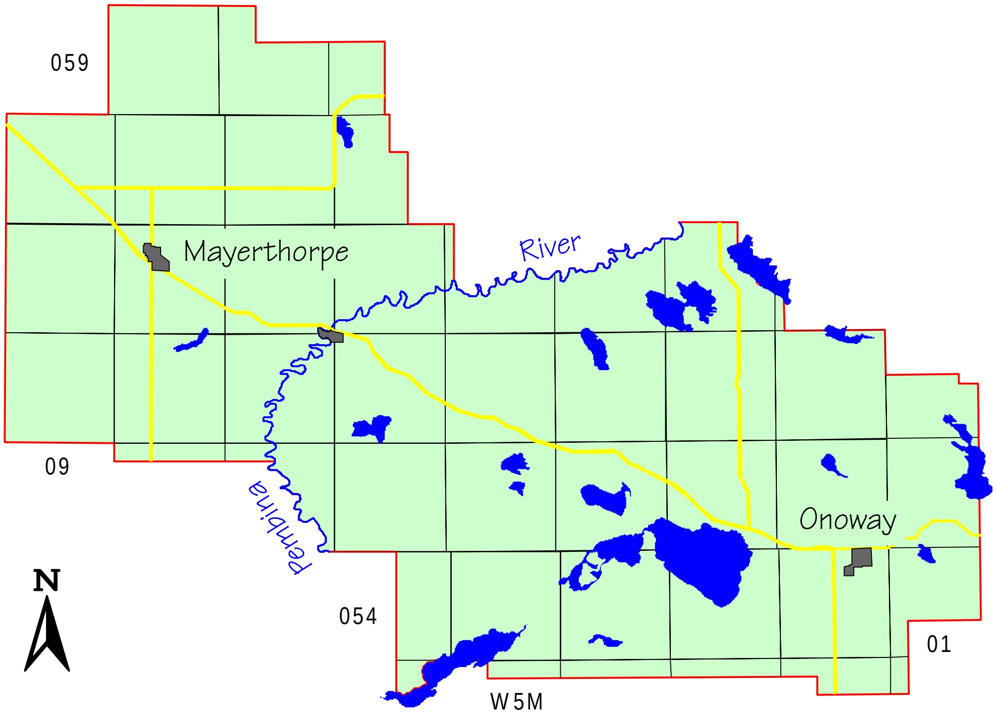
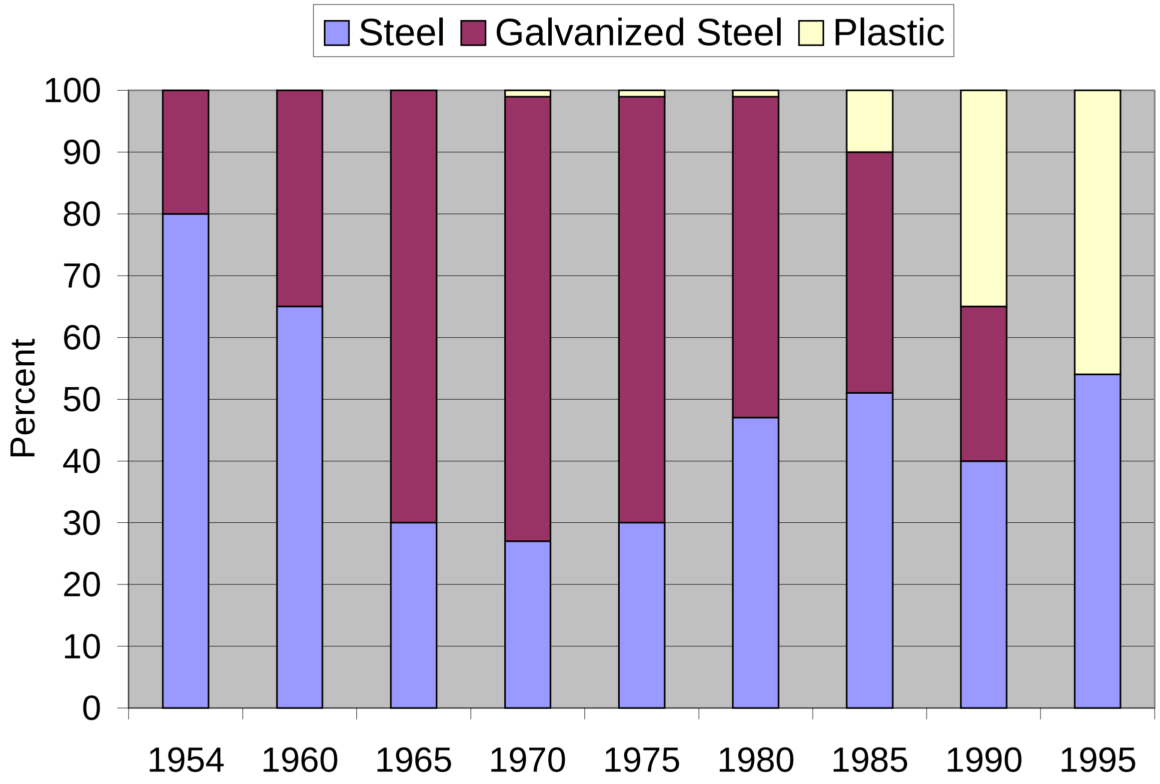
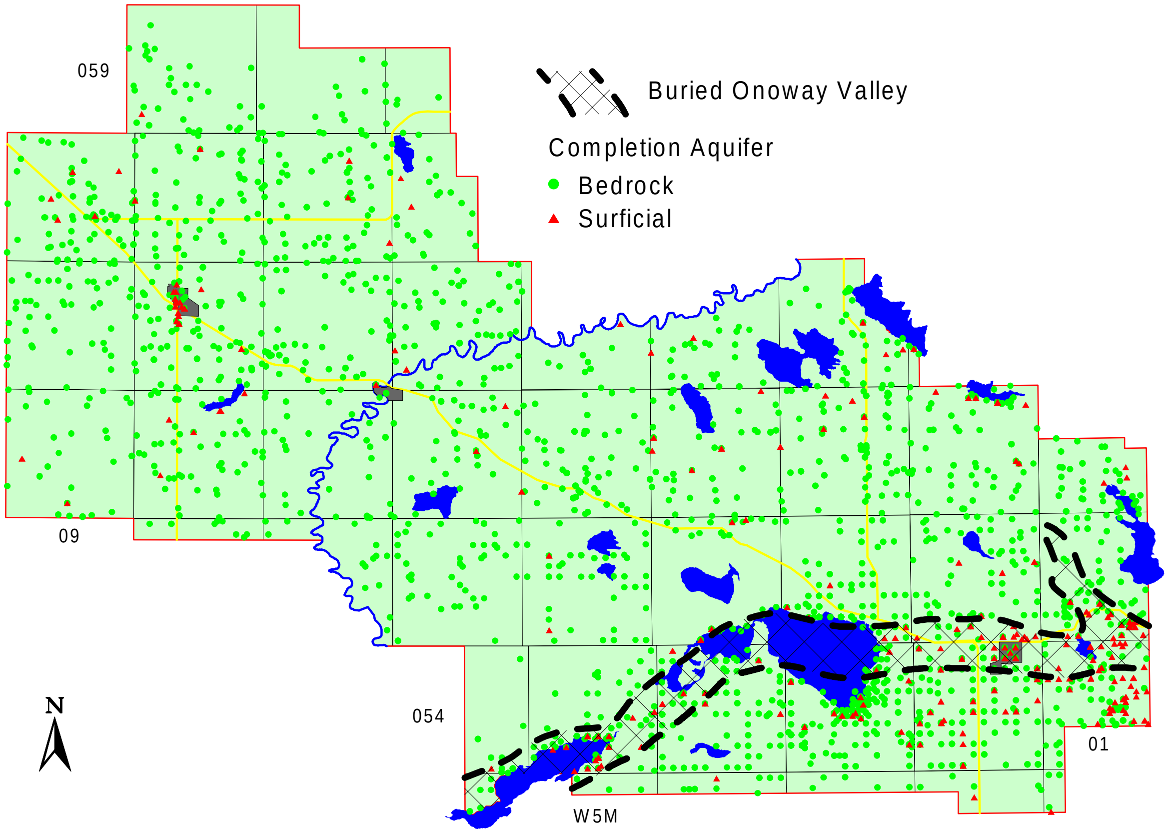
33
2
Whitecourt
Barrhead
Edmonton


059
Mayerthorpe
River
Pembina
09
N
054
Onoway
01
W5M

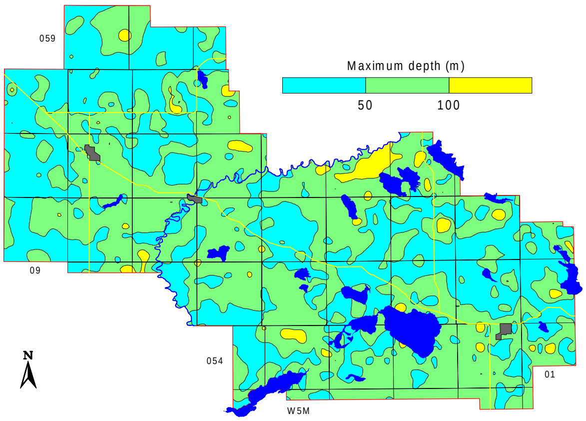
Surface Casing Types used in Drilled Water Wells

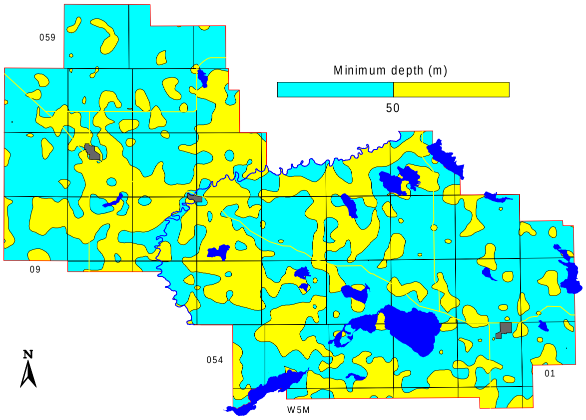


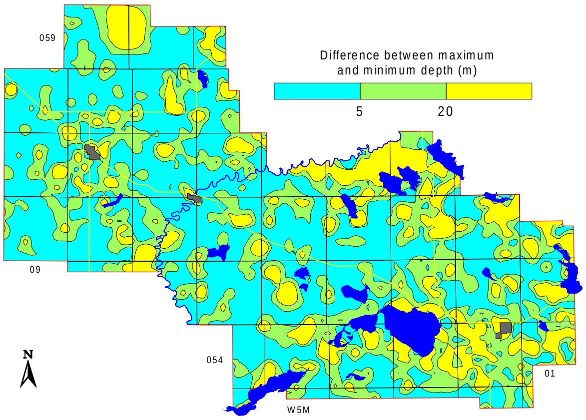
Location of Water Wells

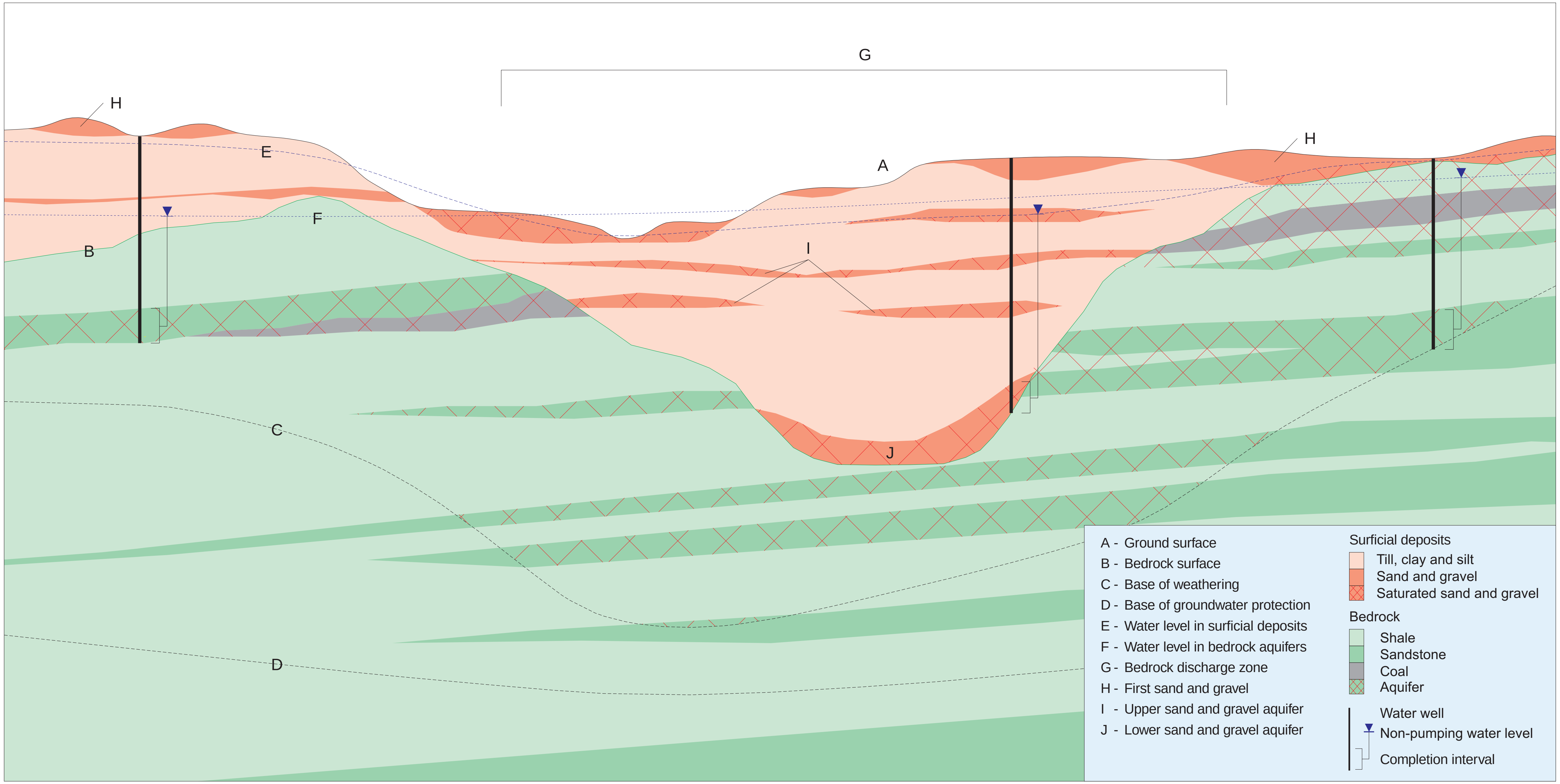


Depth of Existing Water Wells



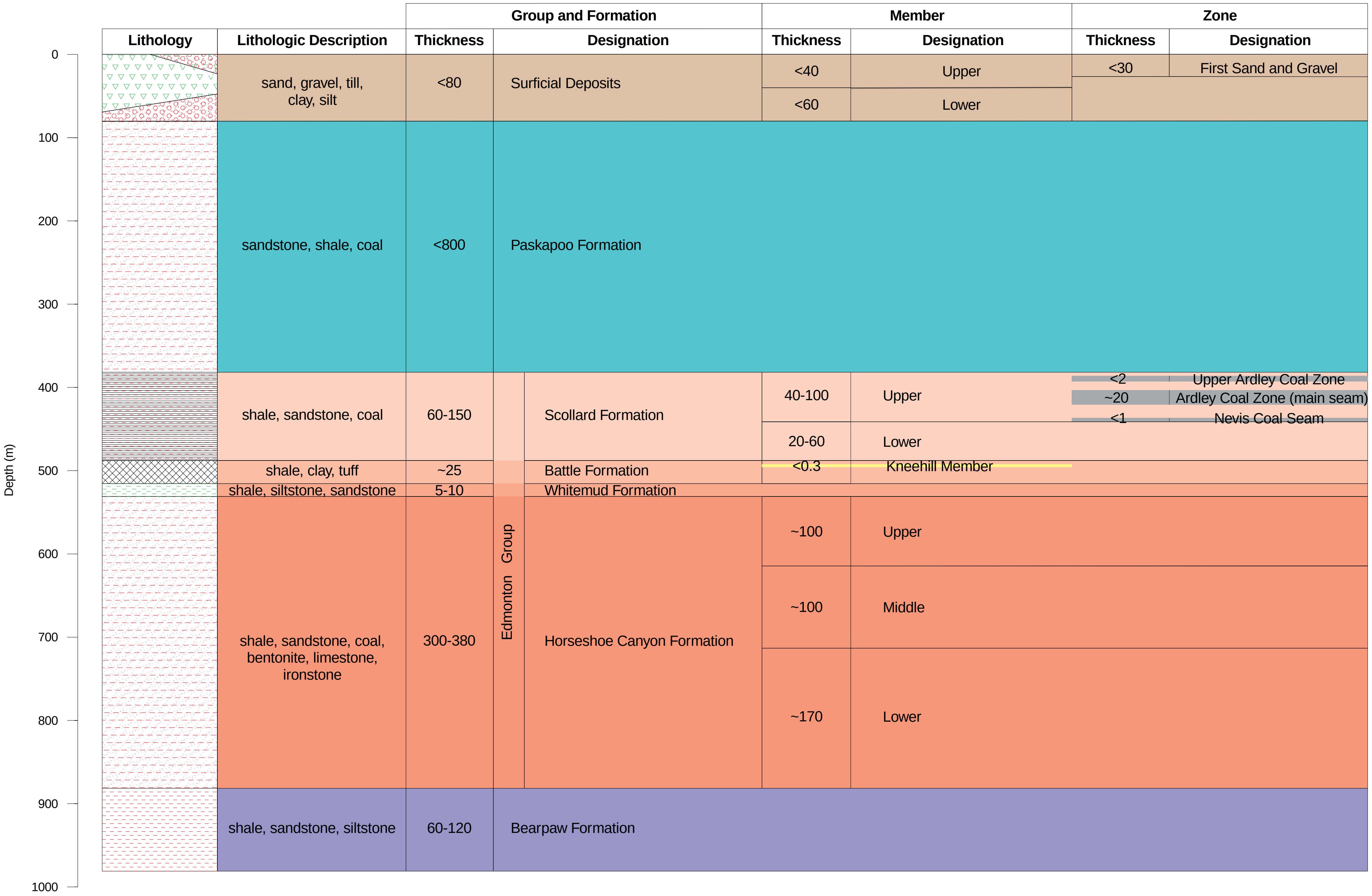






Generalized Cross-Section

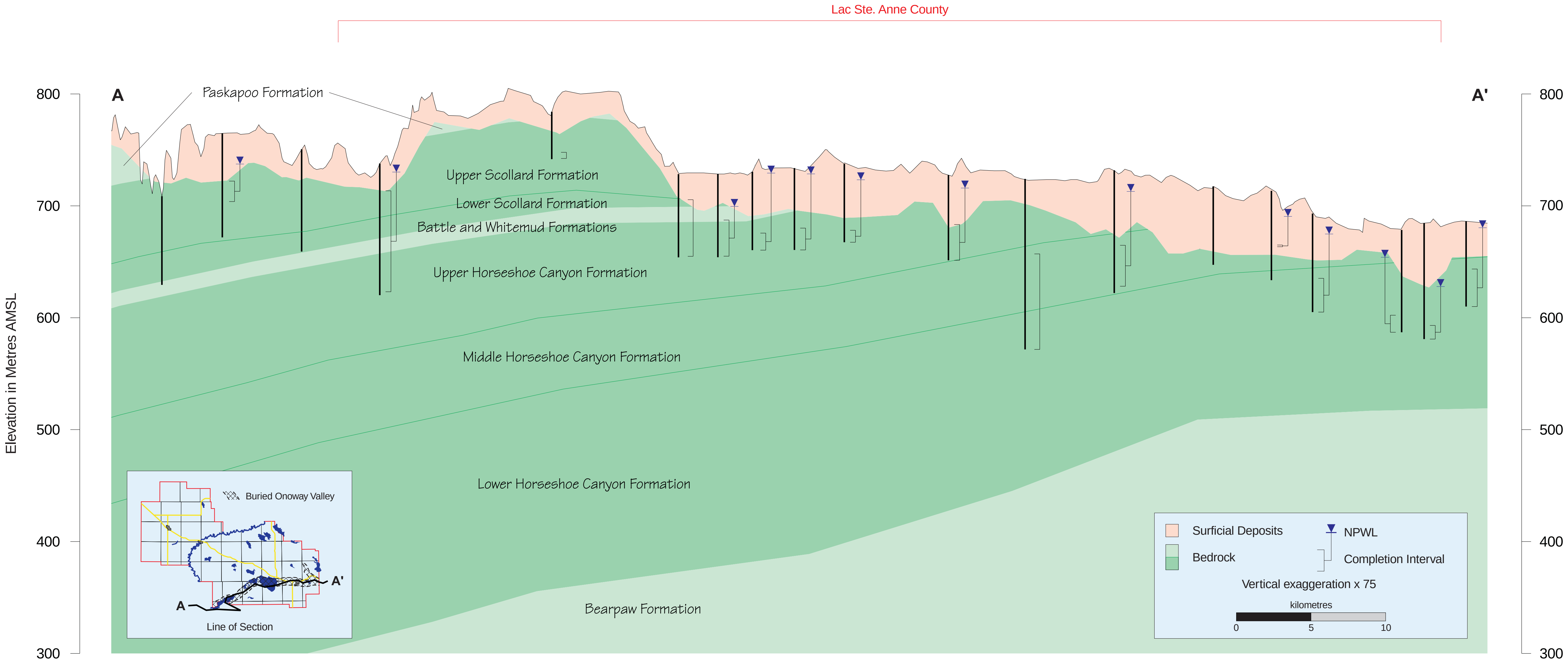
(For terminology only)



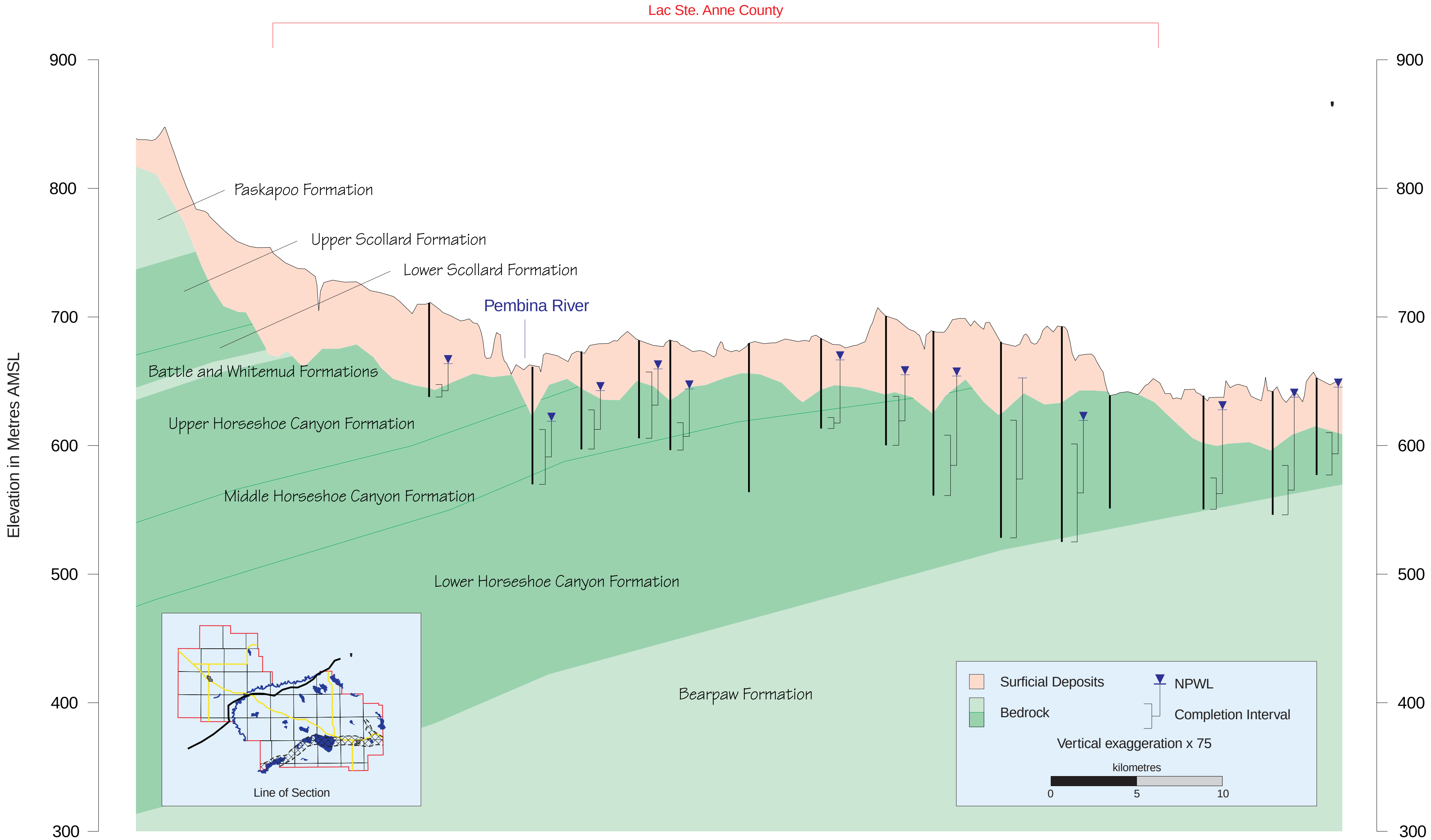
		Group and Formation			Member		Zone	
Lithology	Lithologic Description	Thickness	Designation		Thickness	Designation	Thickness	Designation
	sand, gravel, till, clay, silt	<80	Surficial Deposits		<40	Upper	<30	First Sand and Gravel
					<60	Lower		
	sandstone, shale, coal	<800	Paskapoo Formation					
	shale, sandstone, coal	60-150	Edmonton Group	Scollard Formation	40-100	Upper	<2	Upper Ardley Coal Zone
							~20	Ardley Coal Zone (main seam)
							<1	Nevis Coal Seam
					20-60	Lower		
	shale, clay, tuff	~25		Battle Formation	<0.3	Kneehill Member		
	shale, siltstone, sandstone	5-10		Whitemud Formation				
	shale, sandstone, coal, bentonite, limestone, ironstone	300-380		Horseshoe Canyon Formation	~100	Upper		
					~100	Middle		
					~170	Lower		
	shale, sandstone, siltstone	60-120	Bearpaw Formation					

Geologic Column

hydrogeological consultants ltd.

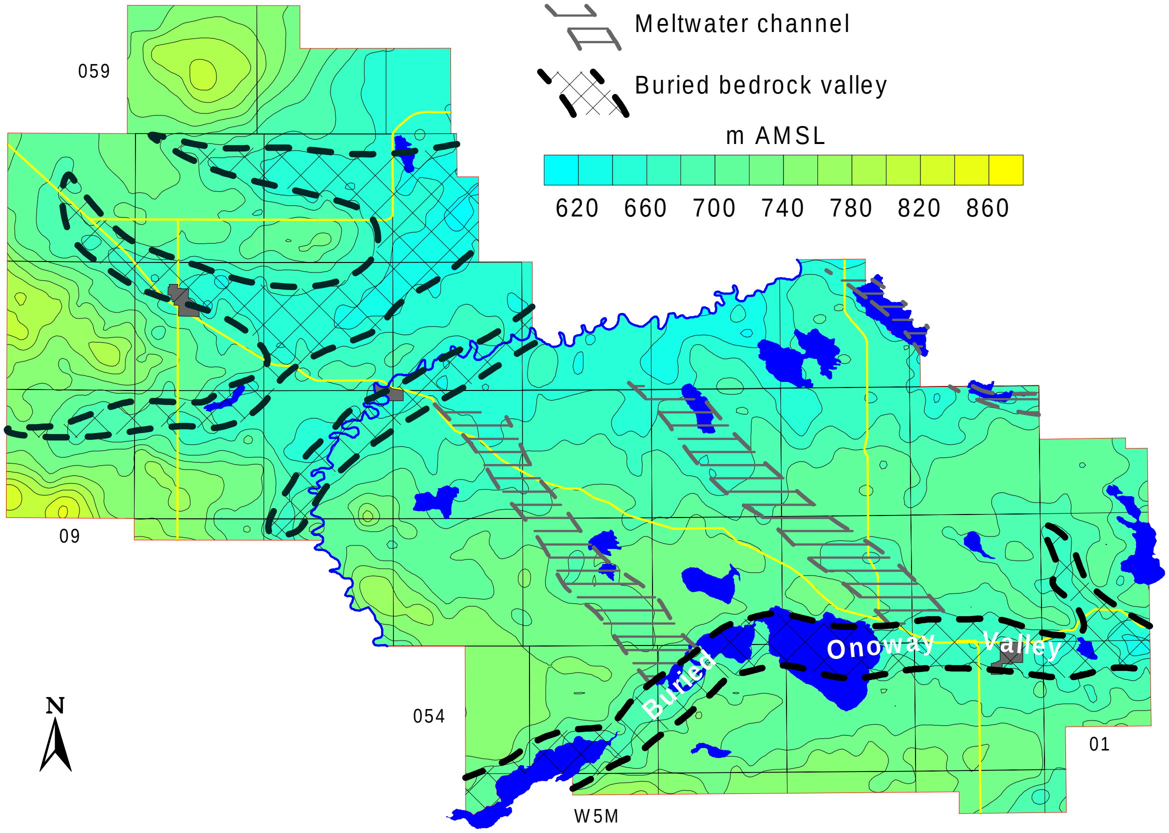


Cross-Section A - A'

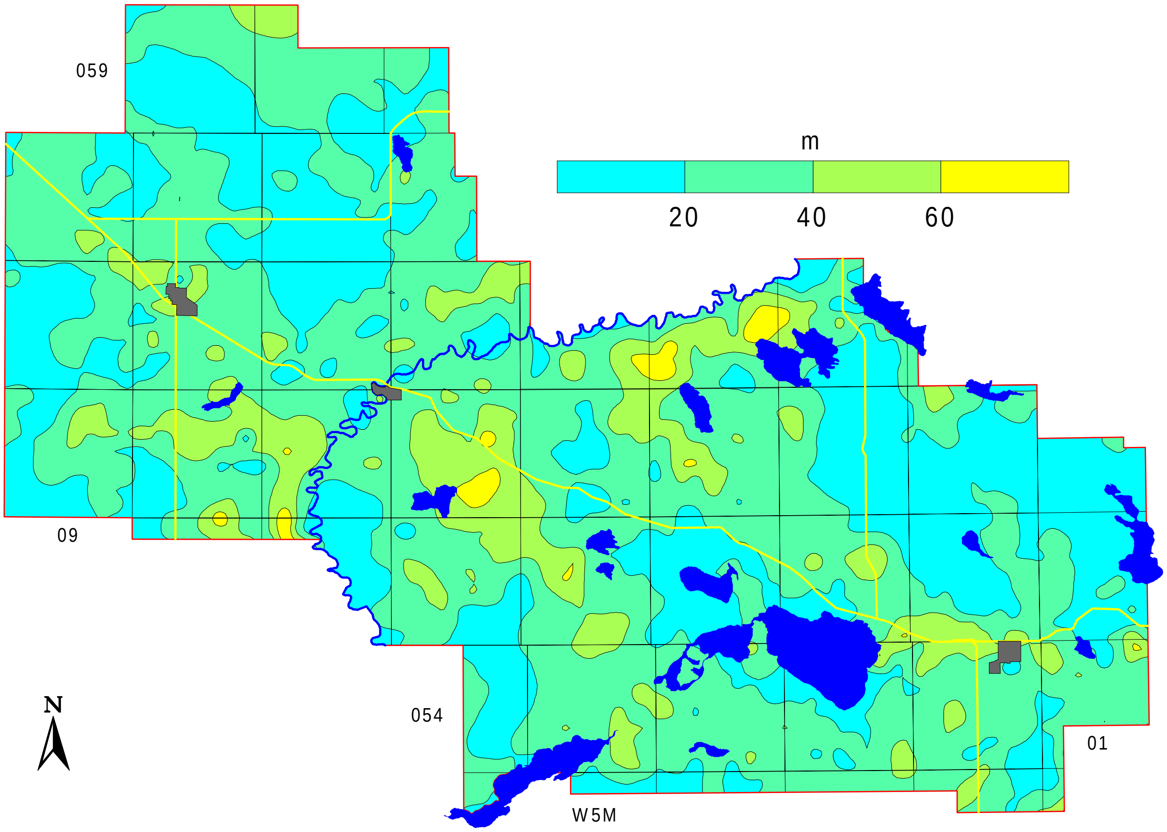


Cross-Section B - B'

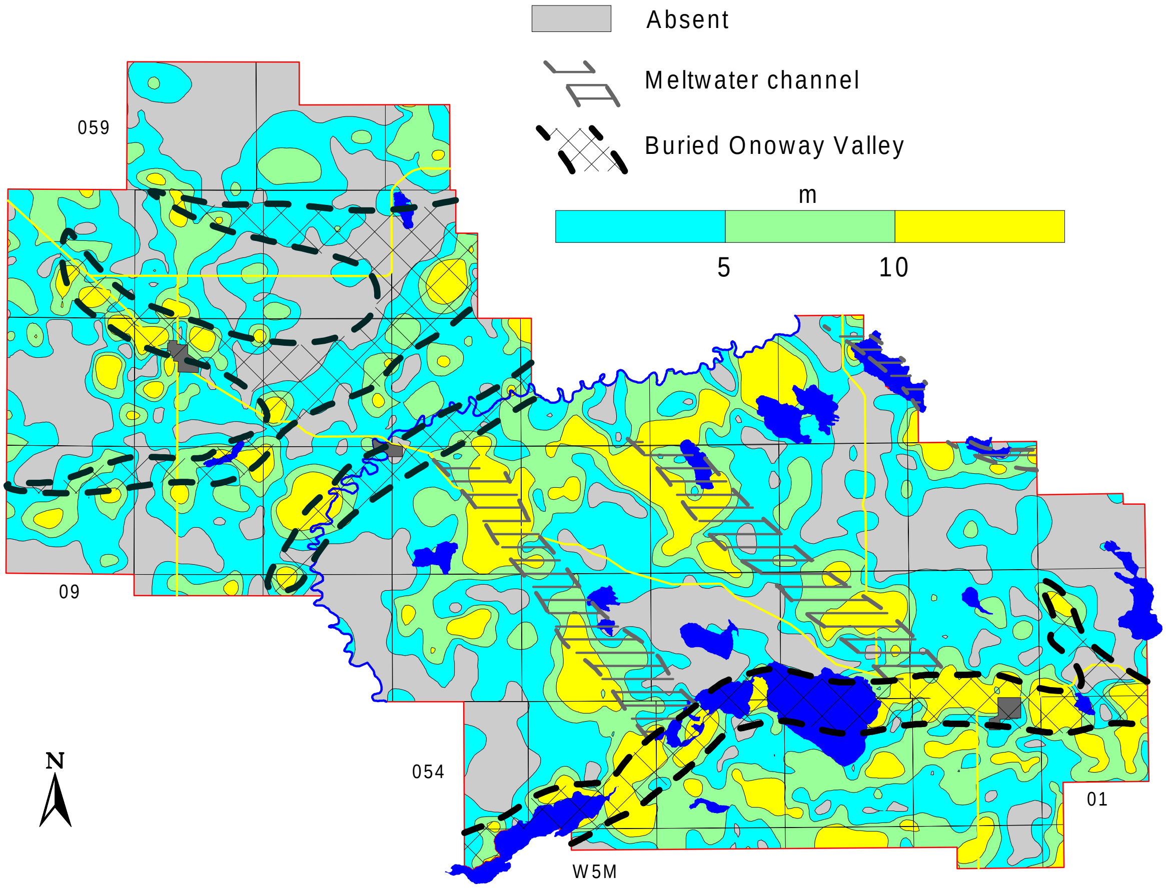
Bedrock Topography



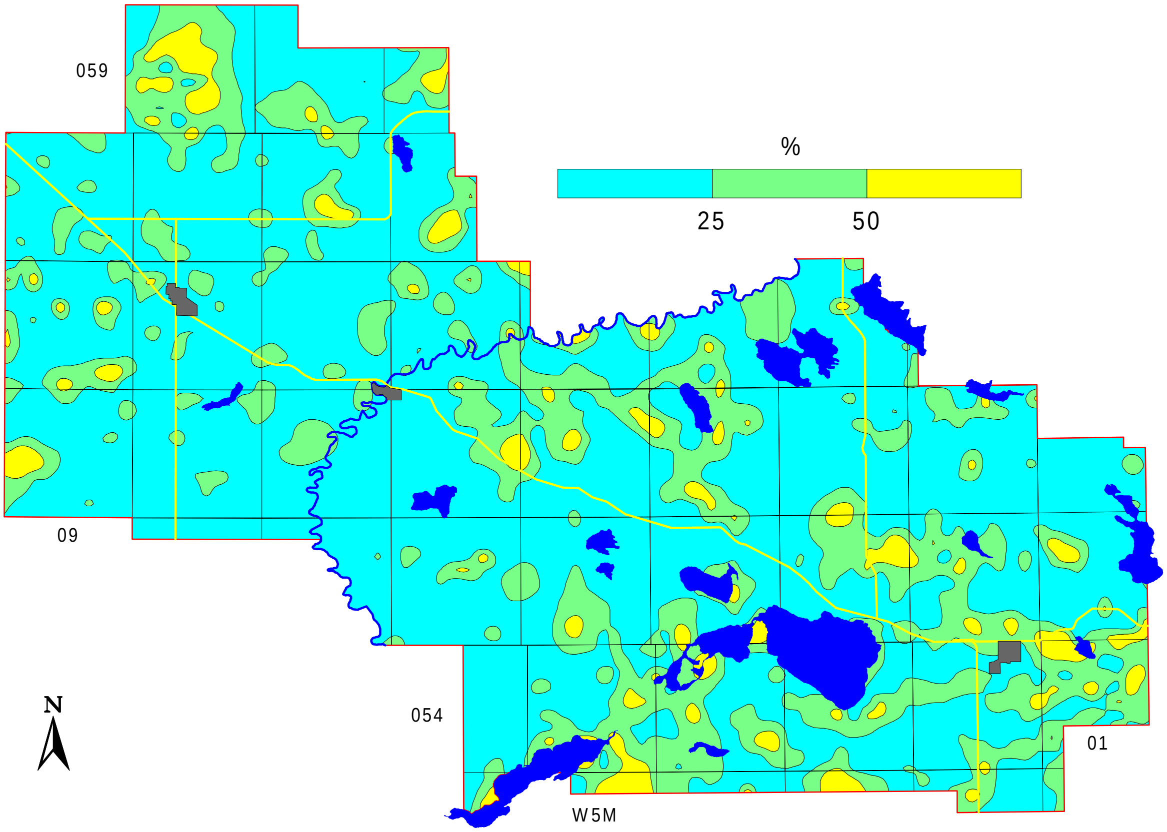
Thickness of Surficial Deposits



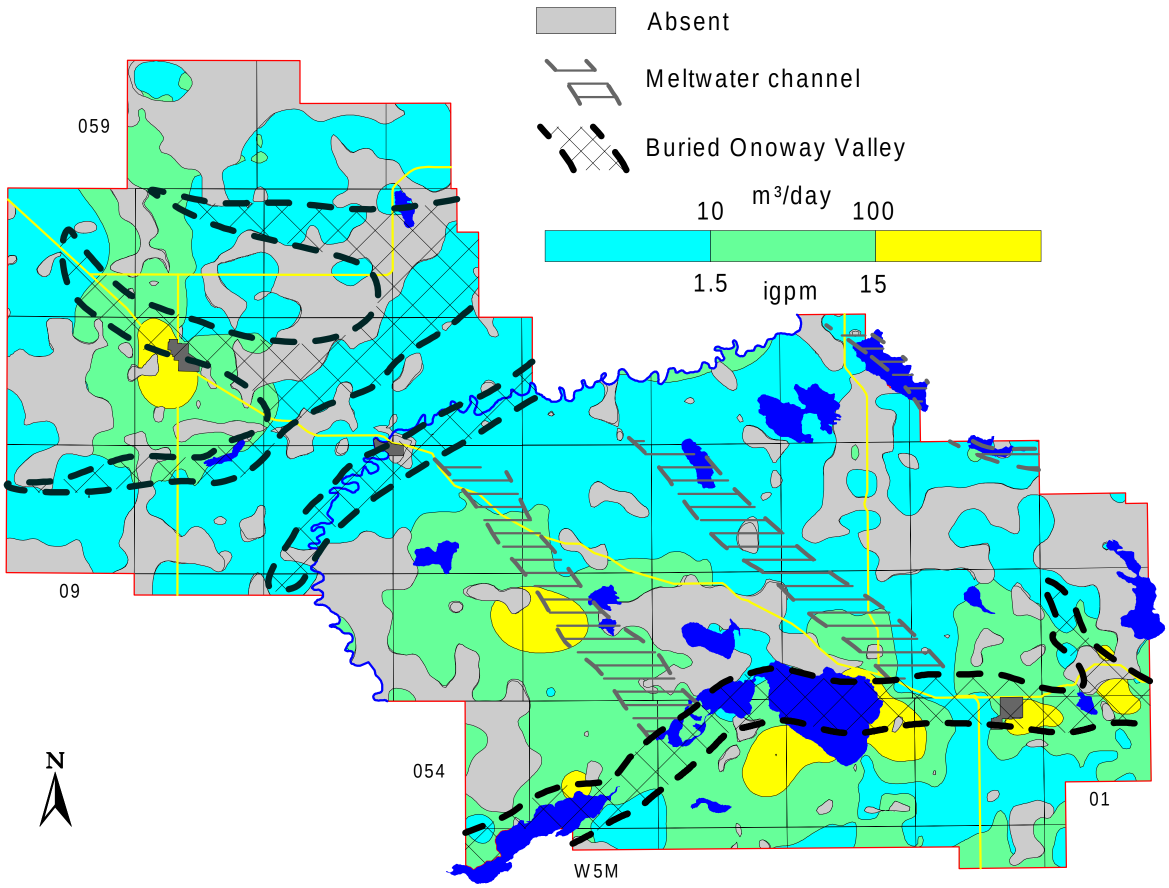
Thickness of Sand and Gravel Aquifer(s)



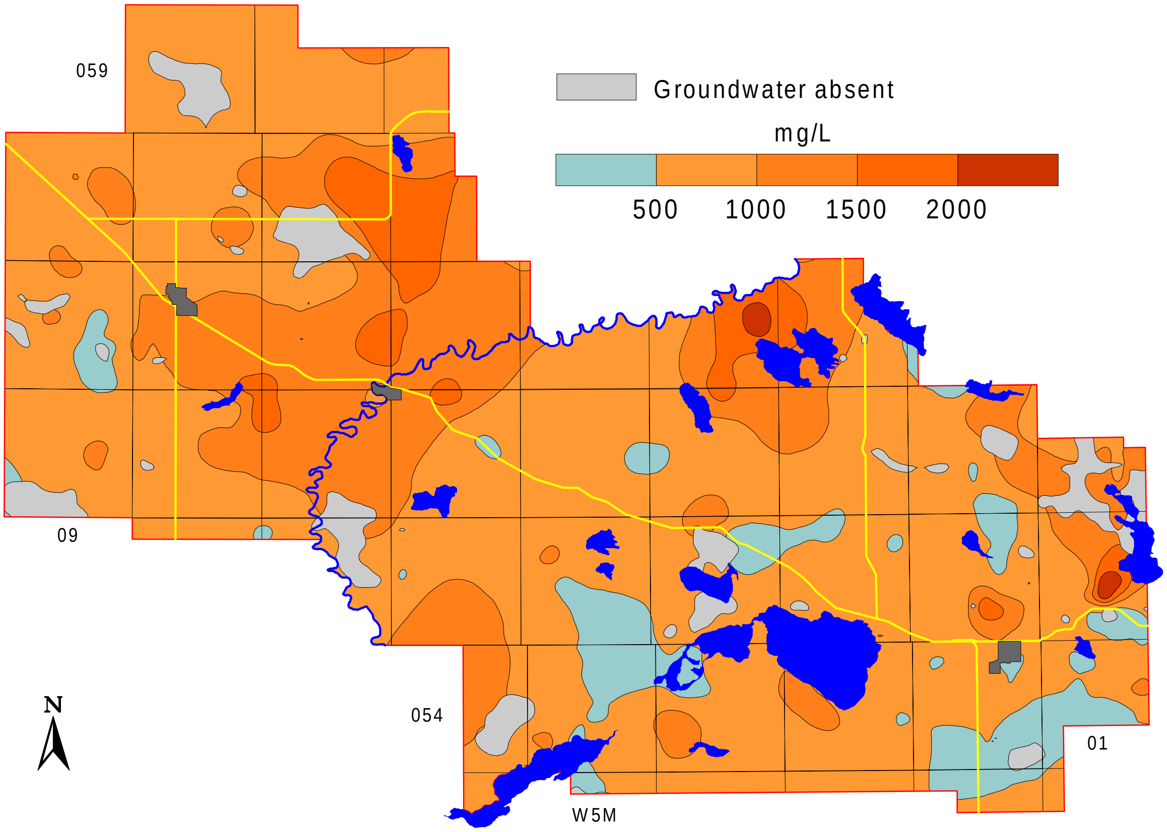
Amount of Sand and Gravel in Surficial Deposits



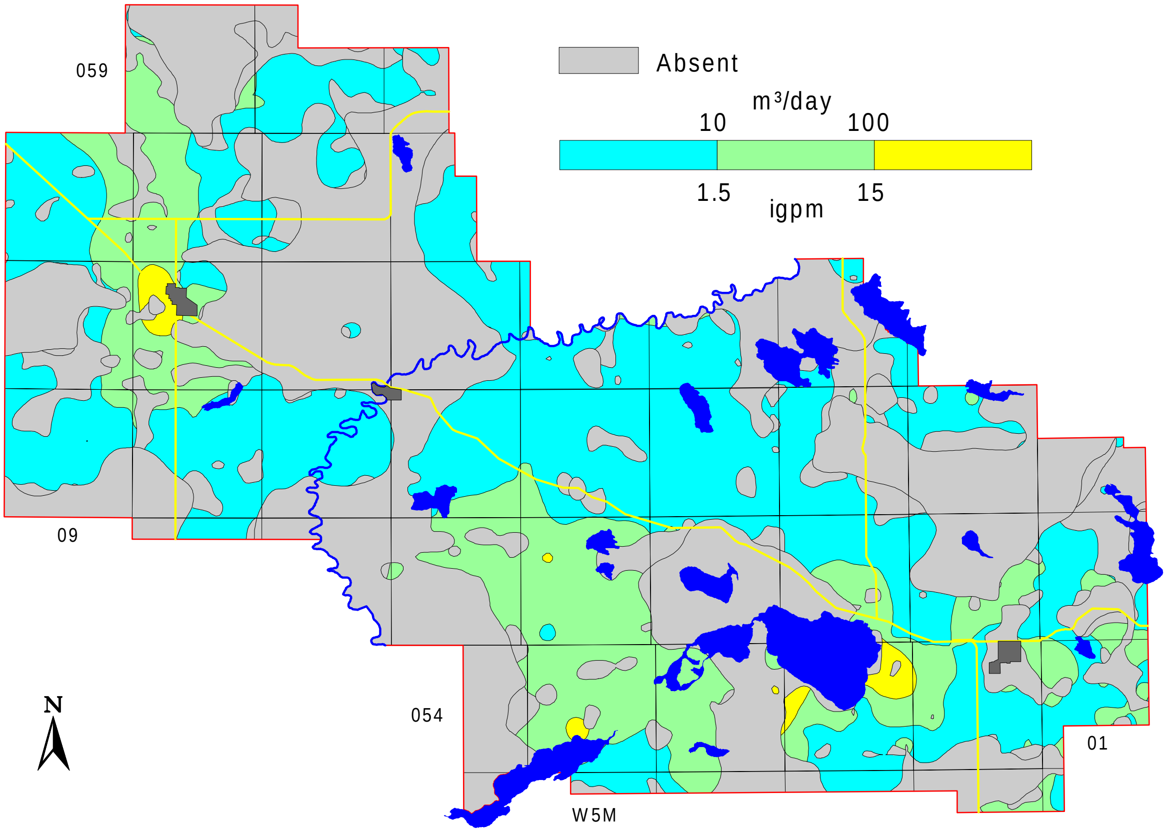
Apparent Yield for Water Wells Completed through Sand and Gravel Aquifer(s)



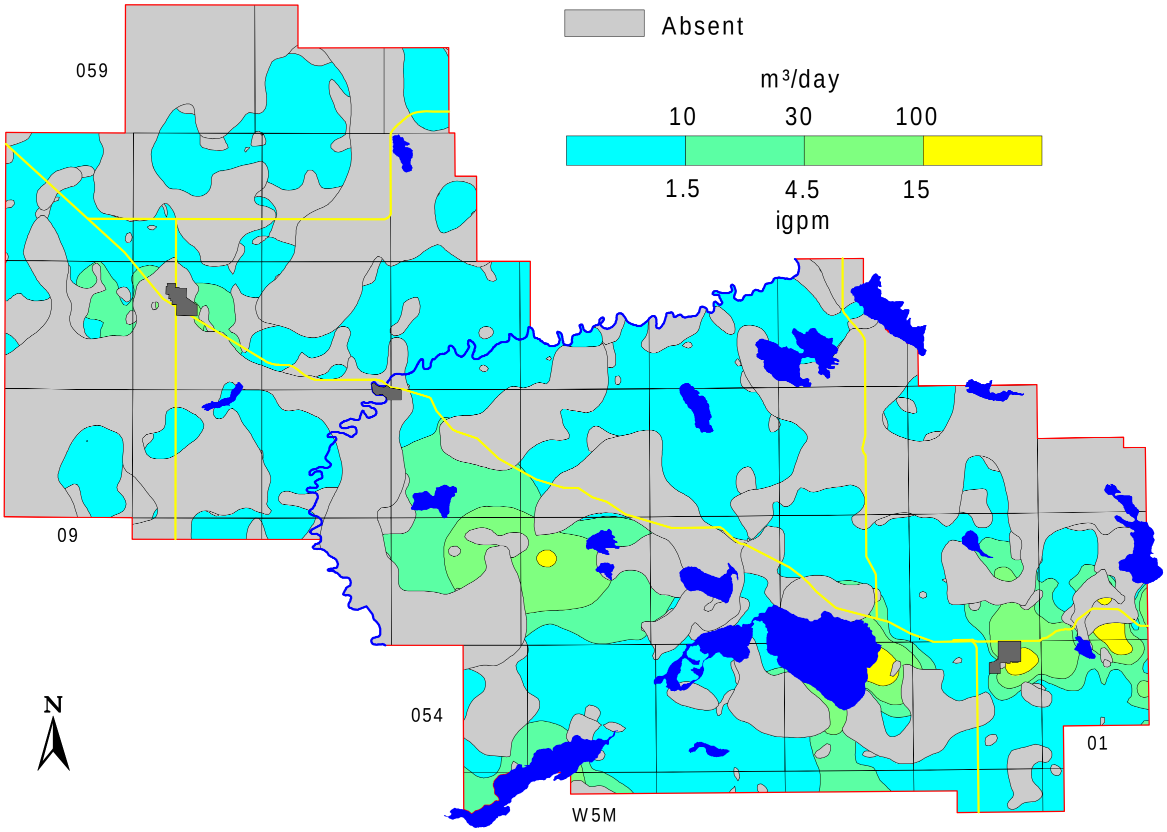
Total Dissolved Solids in Groundwater from Surficial Deposits



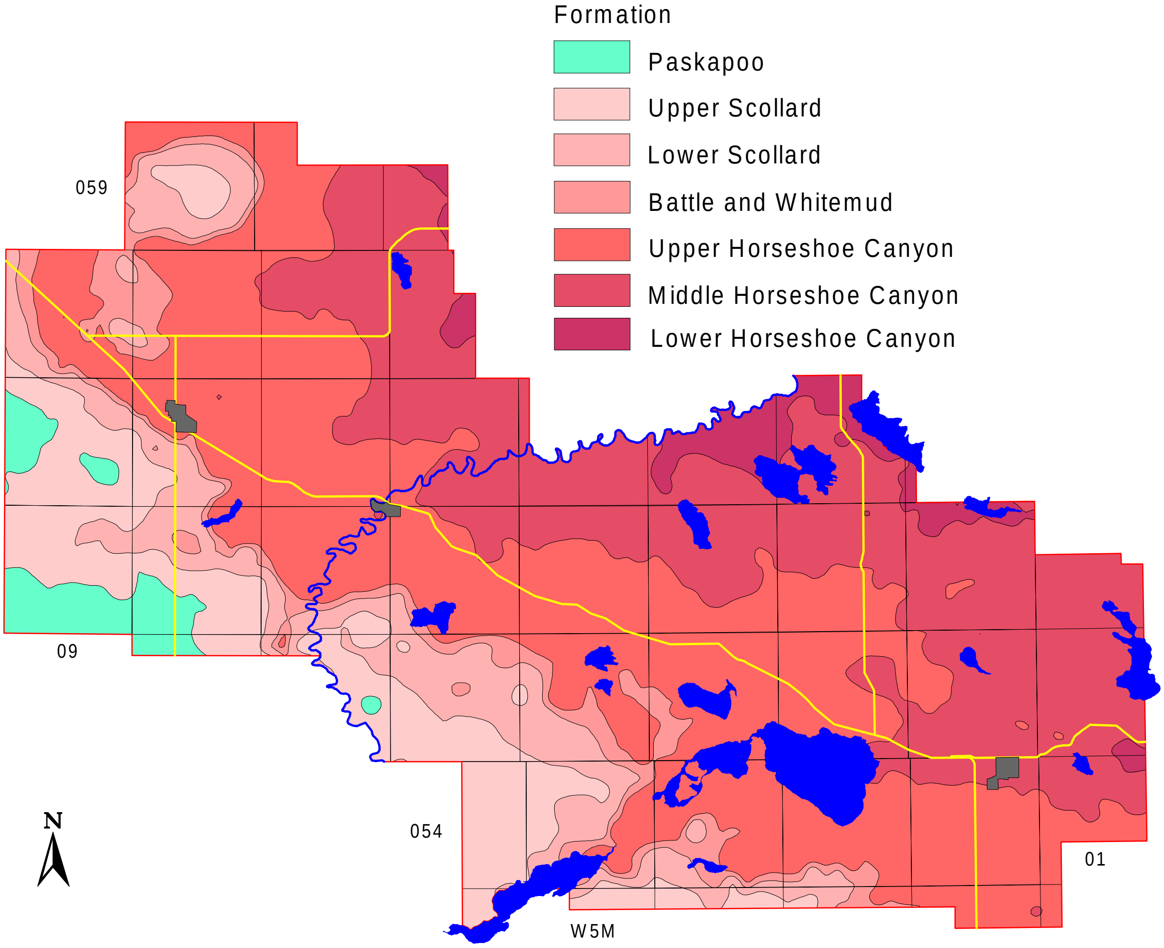
Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer



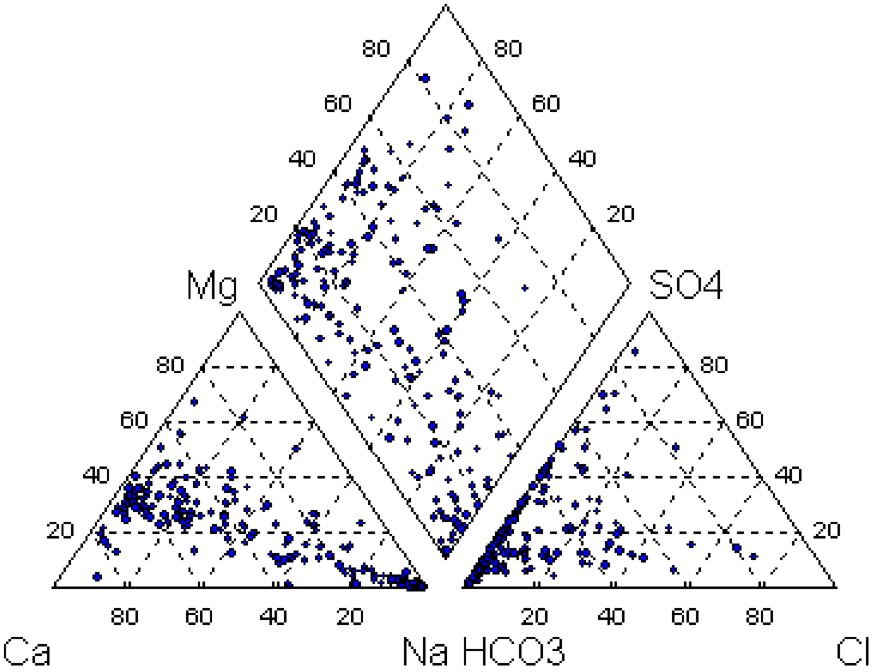
Apparent Yield for Water Wells Completed through Lower Sand and Gravel Aquifer



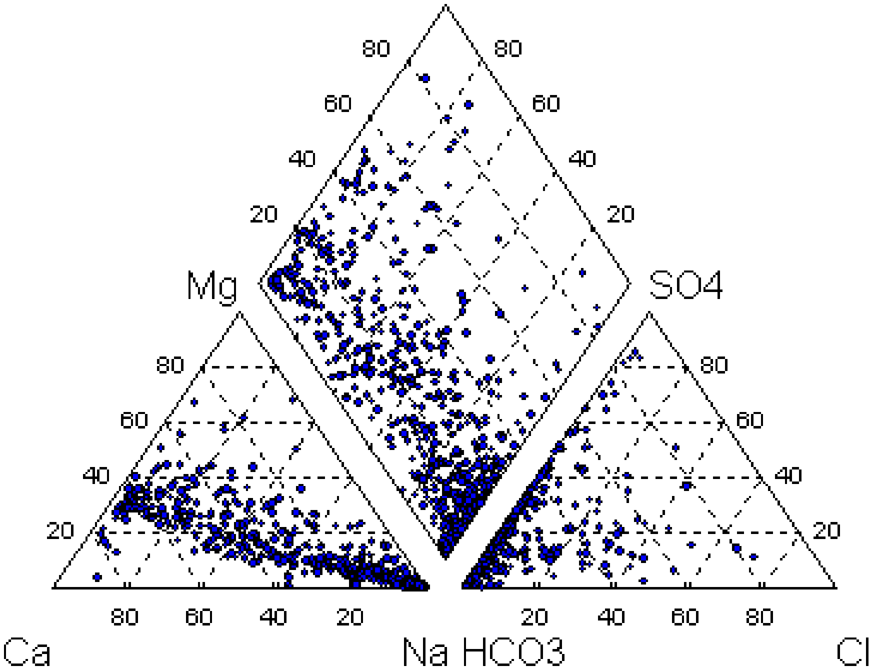
Bedrock Geology



Piper Diagrams

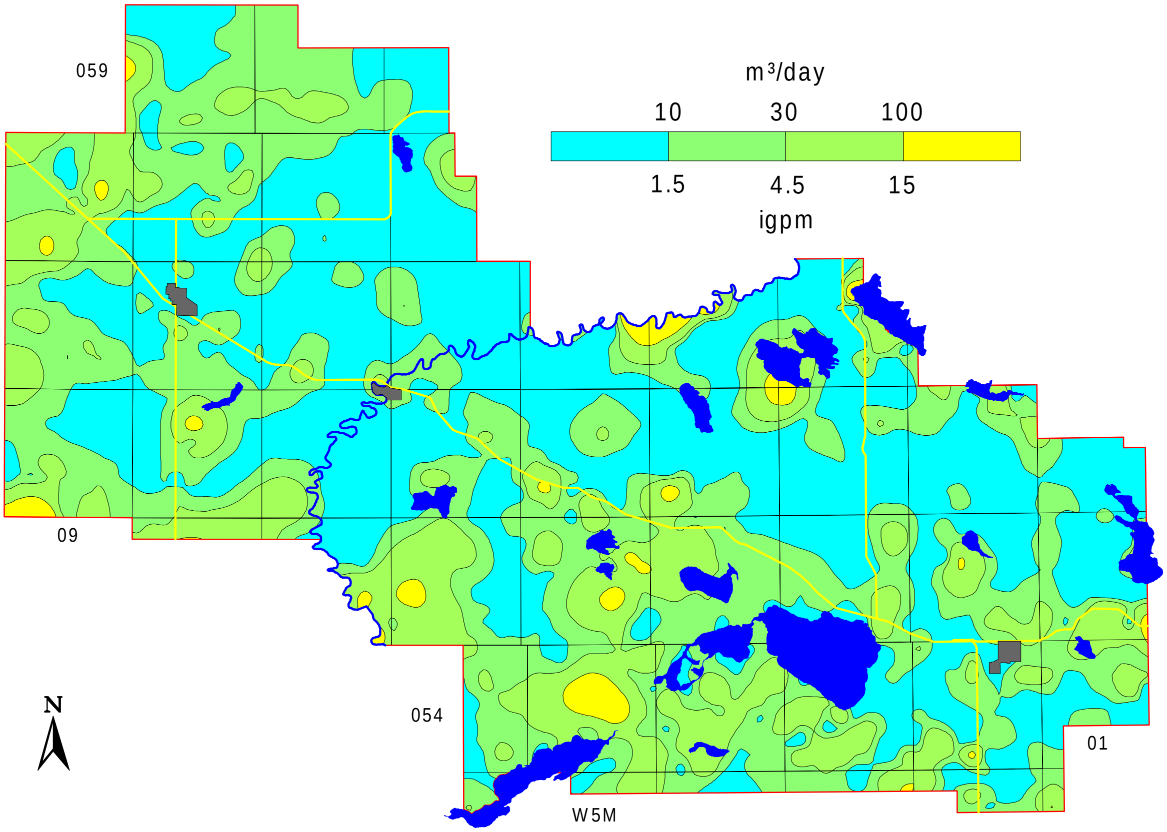


Surficial Deposits

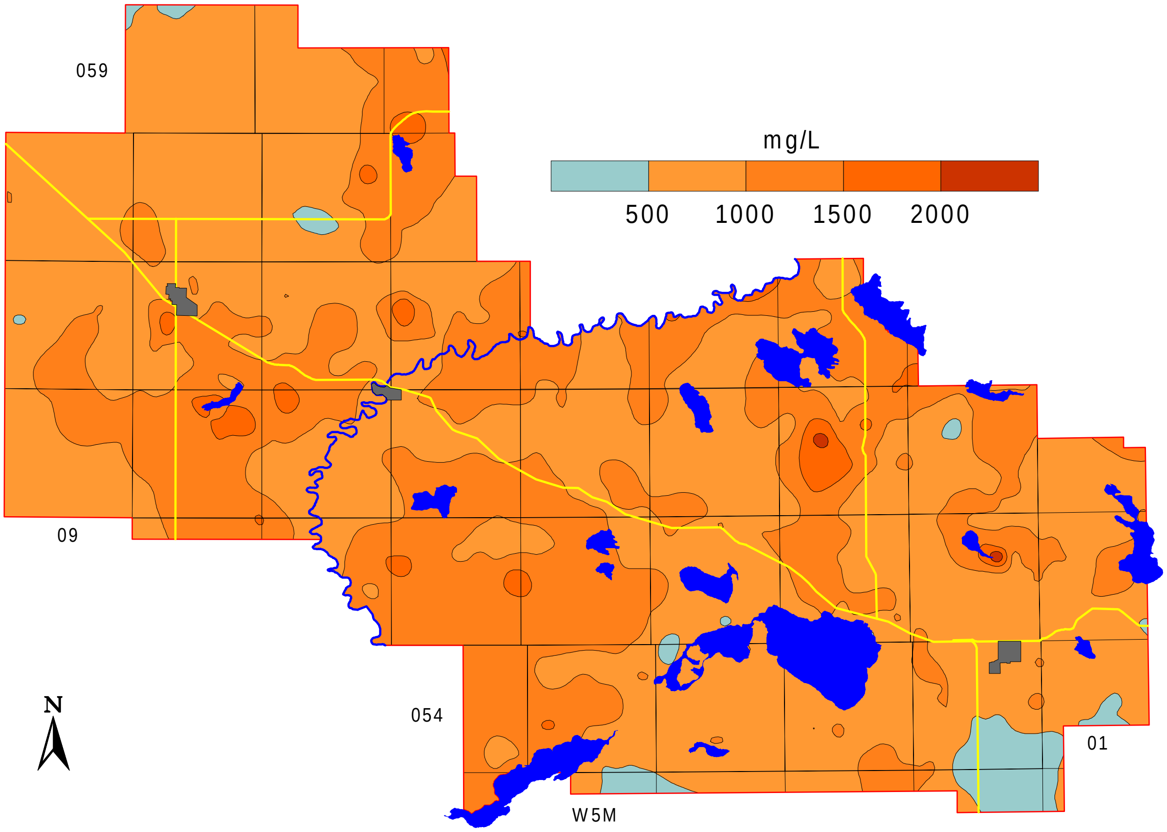


Bedrock Aquifers

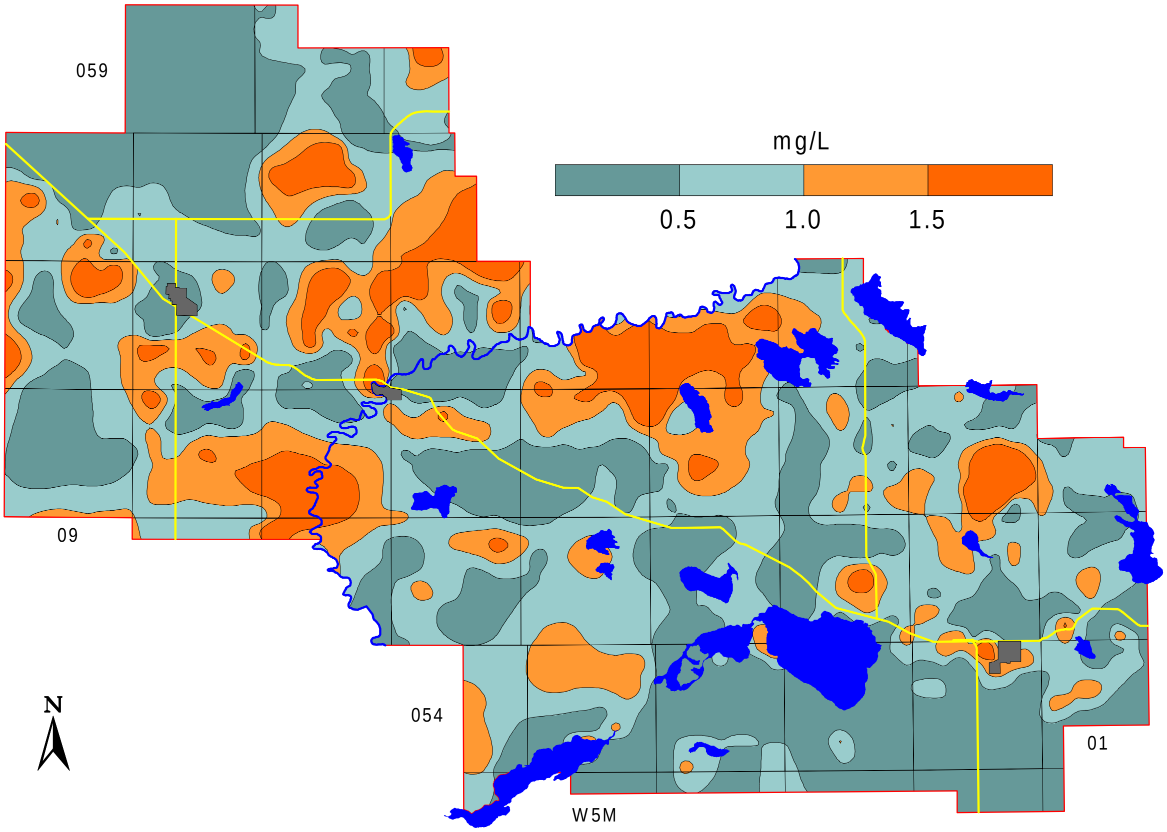
Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)



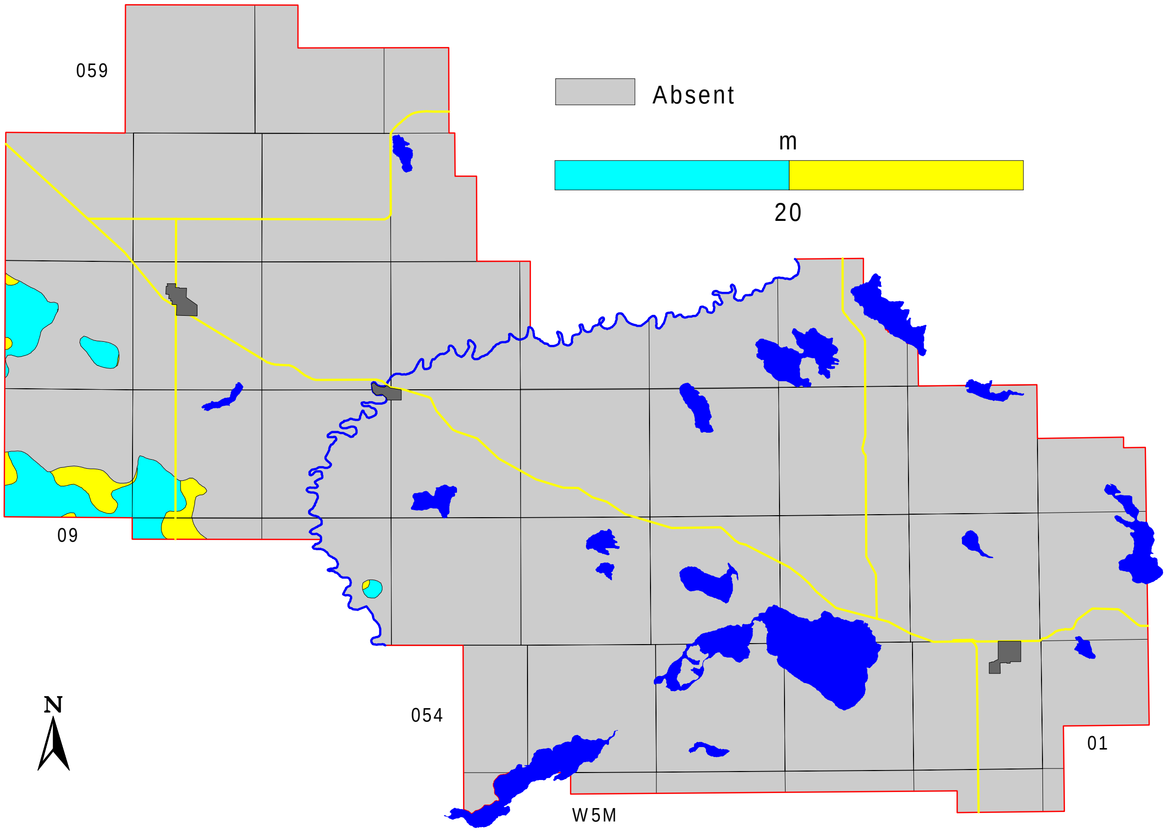
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)



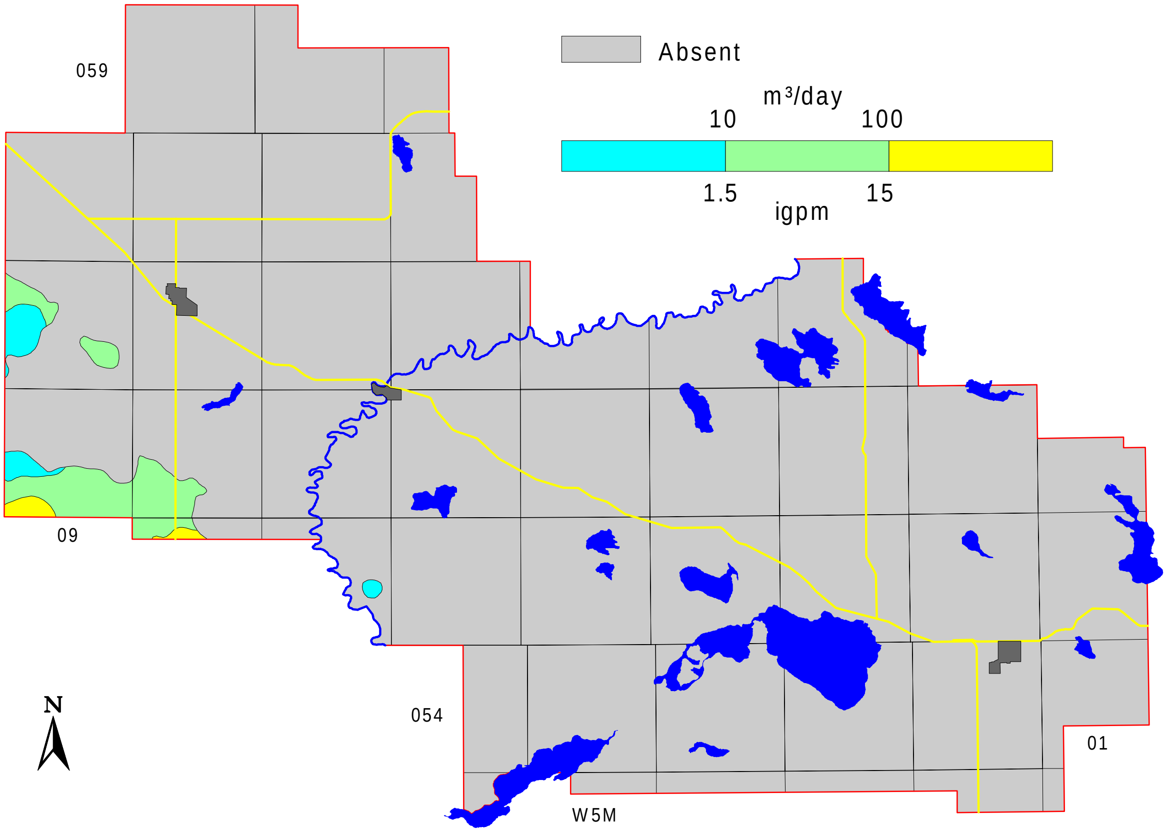
Fluoride in Groundwater from Upper Bedrock Aquifer(s)



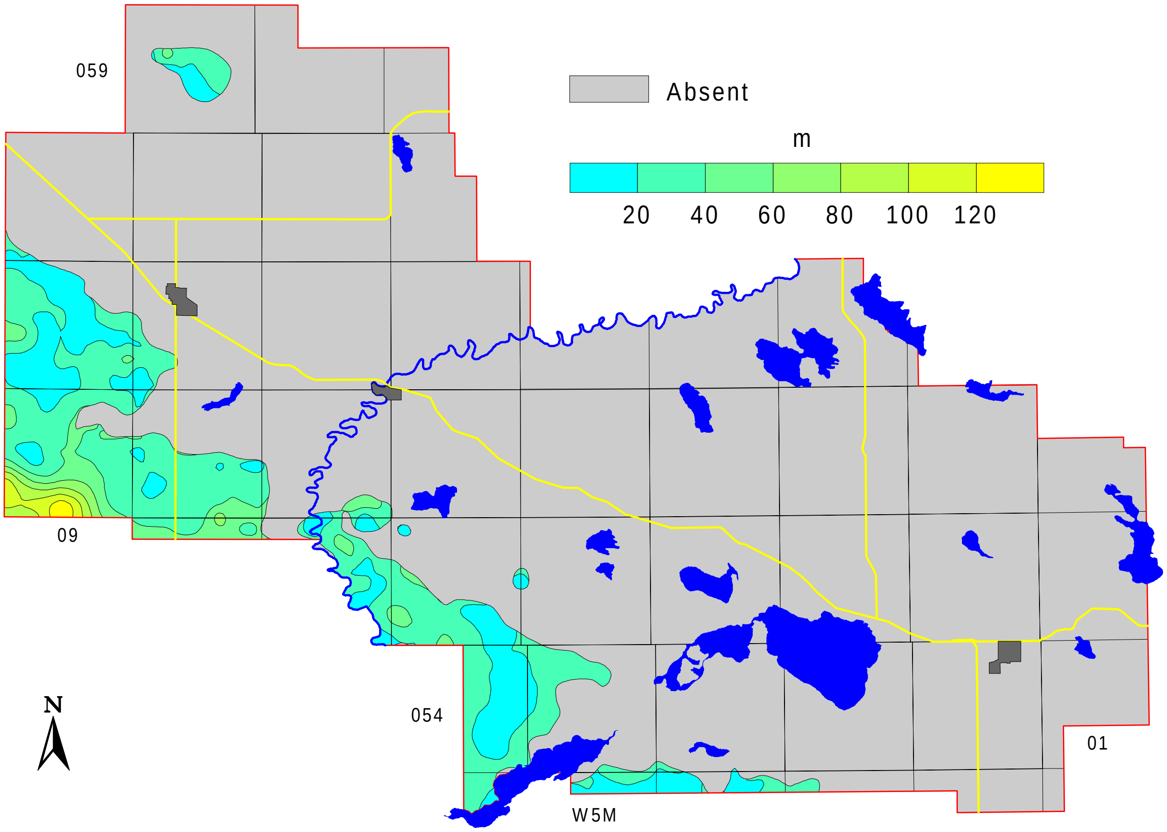
Depth to Top of Paskapoo Formation



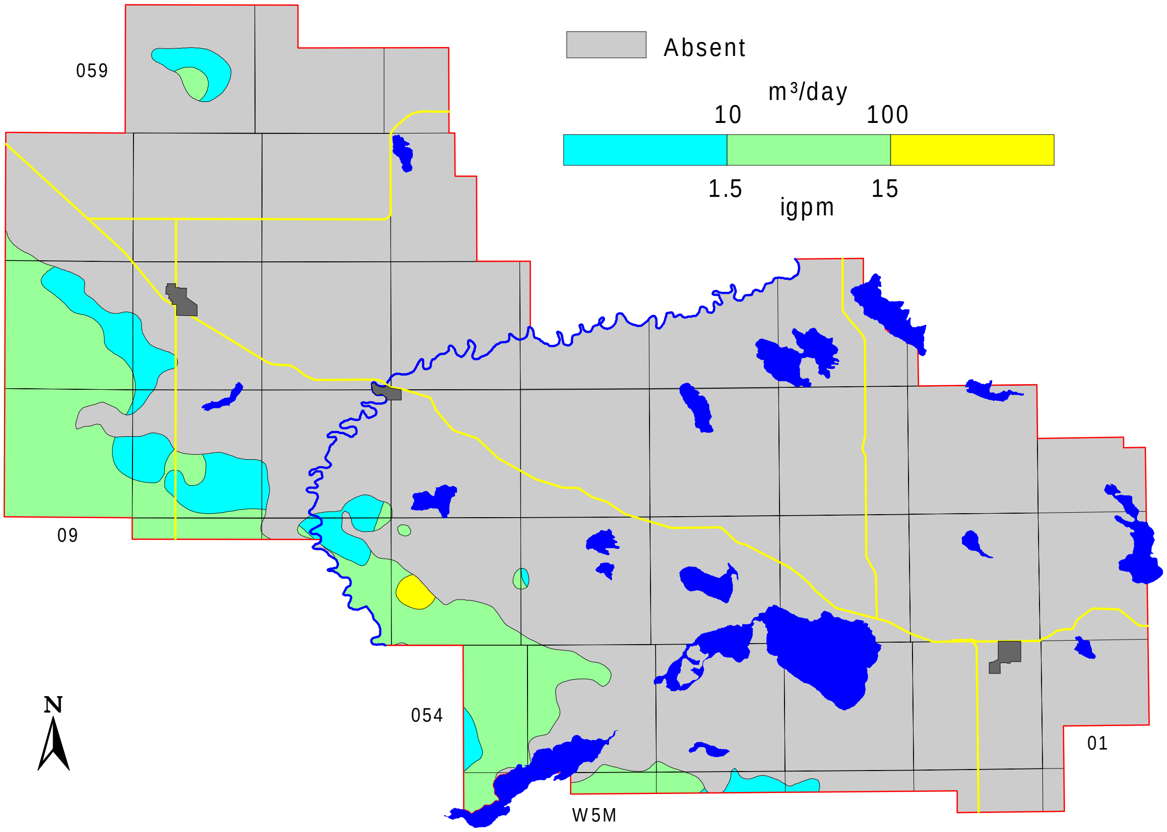
Apparent Yield for Water Wells Completed through Paskapoo Aquifer



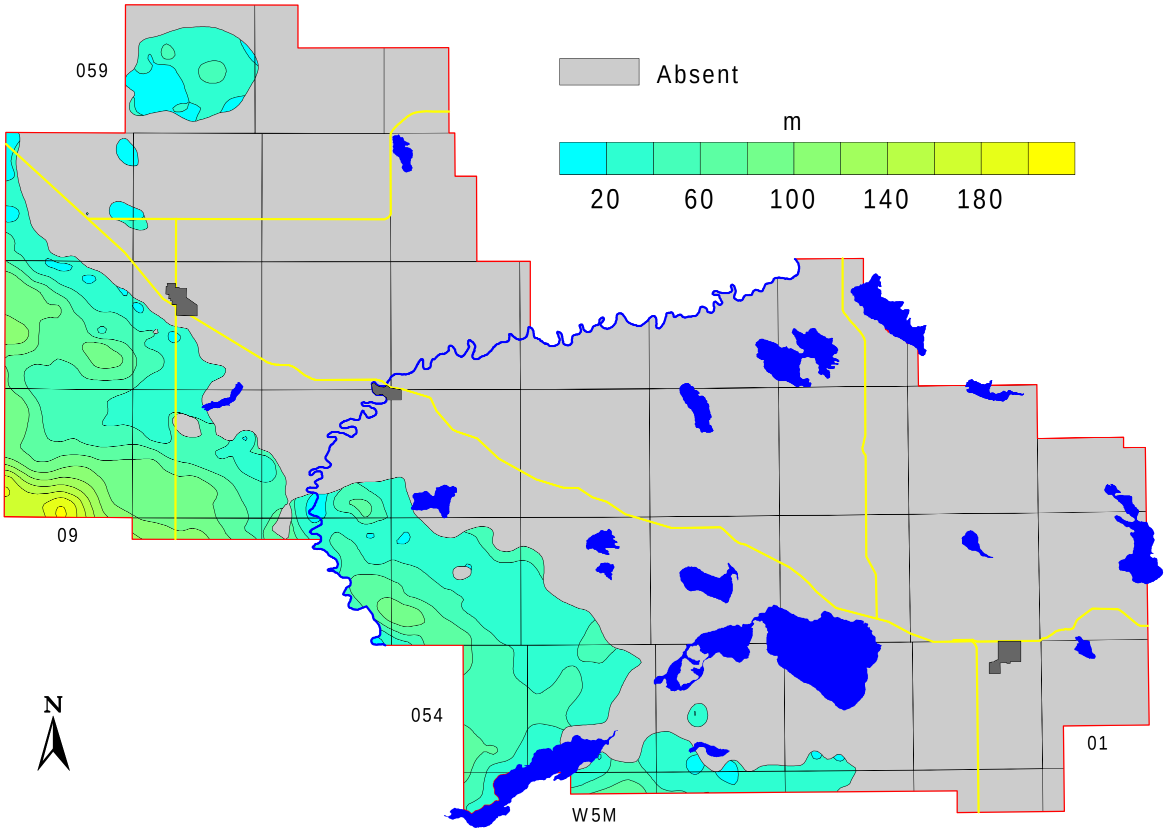
Depth to Top of Upper Scollard Formation



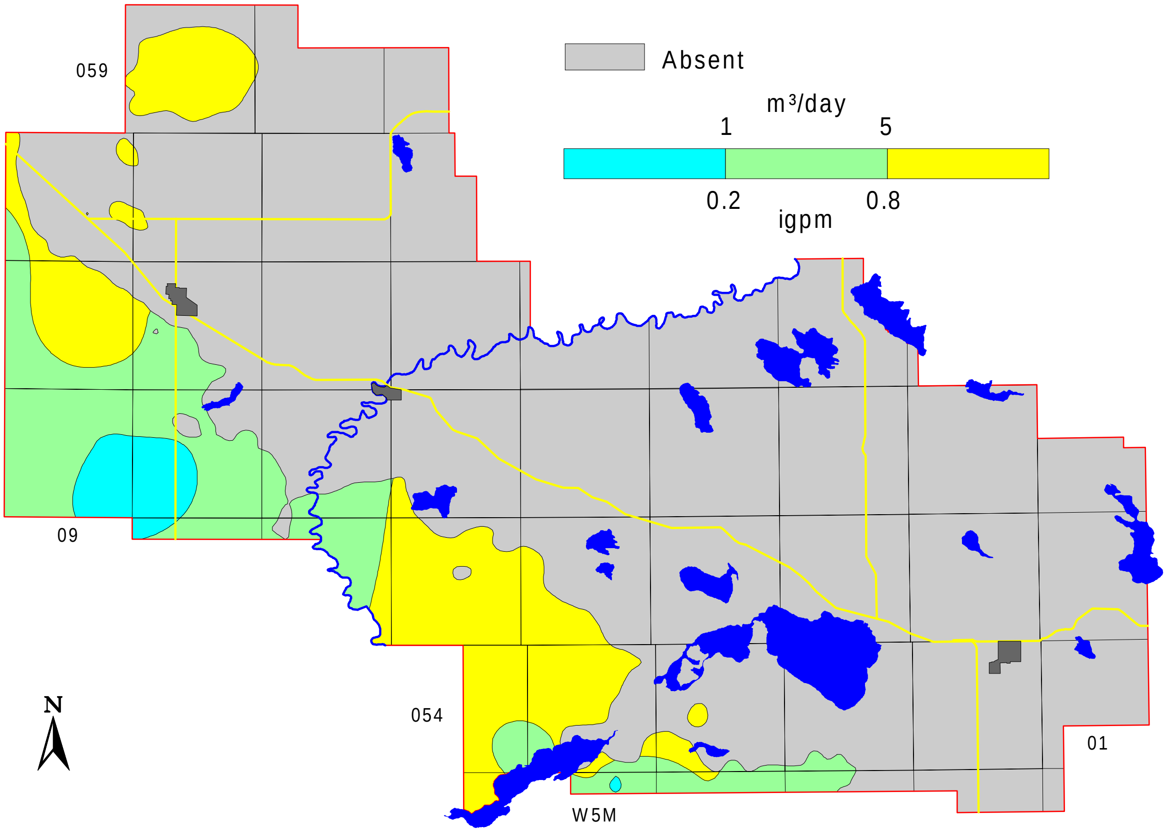
Apparent Yield for Water Wells Completed through Upper Scollard Aquifer



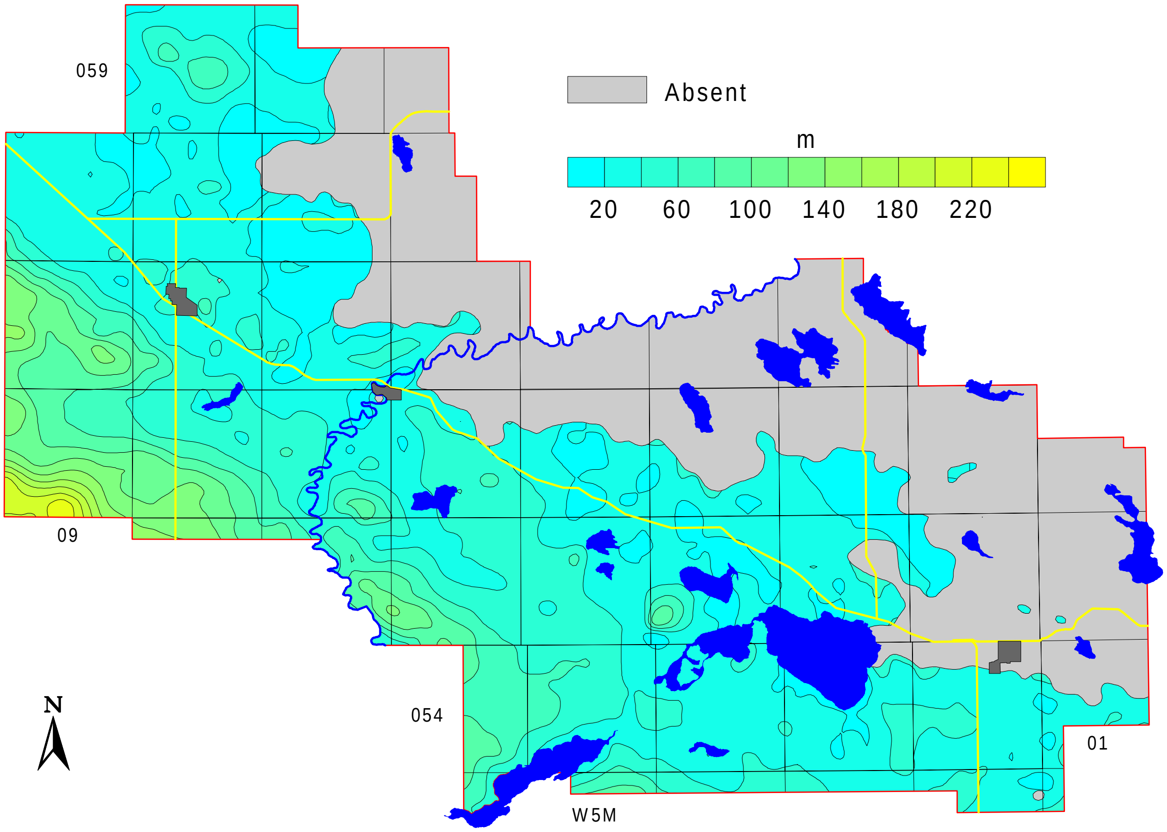
Depth to Top of Lower Scollard Formation



Apparent Yield for Water Wells Completed through Lower Scollard Aquifer



Depth to Top of Upper Horseshoe Canyon Formation



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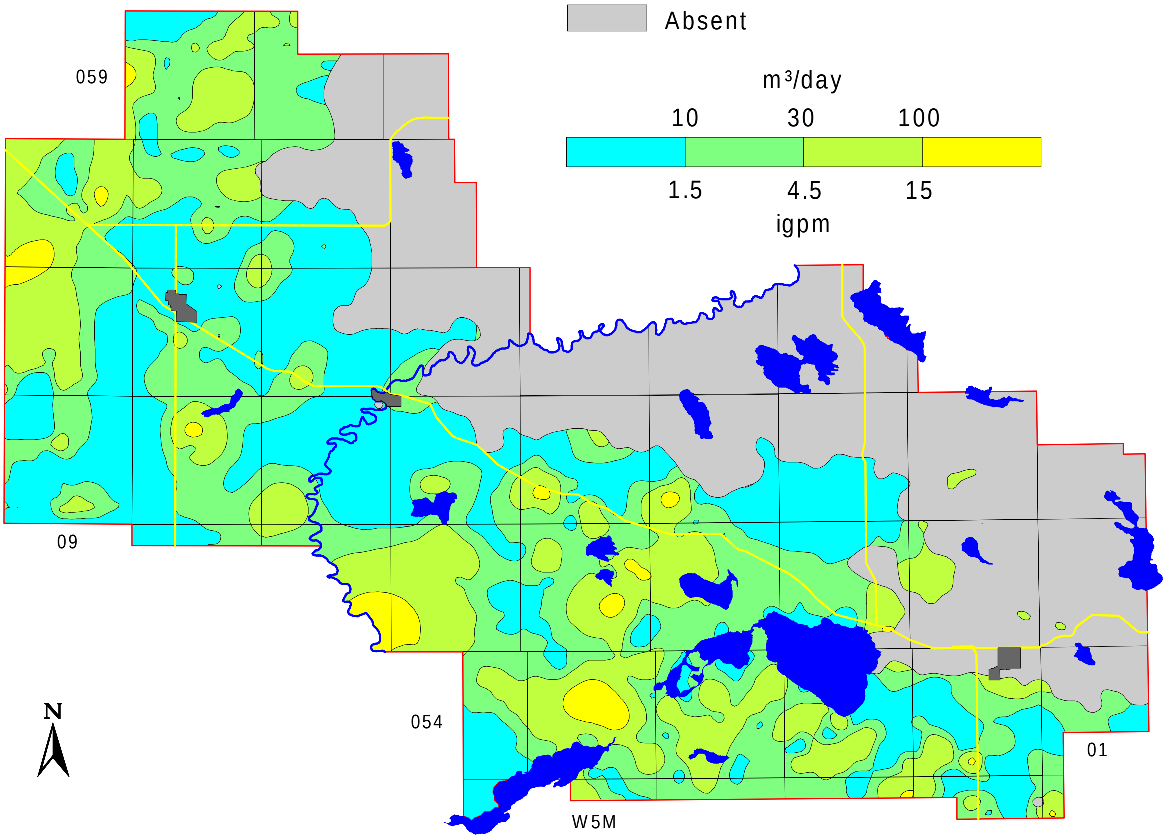

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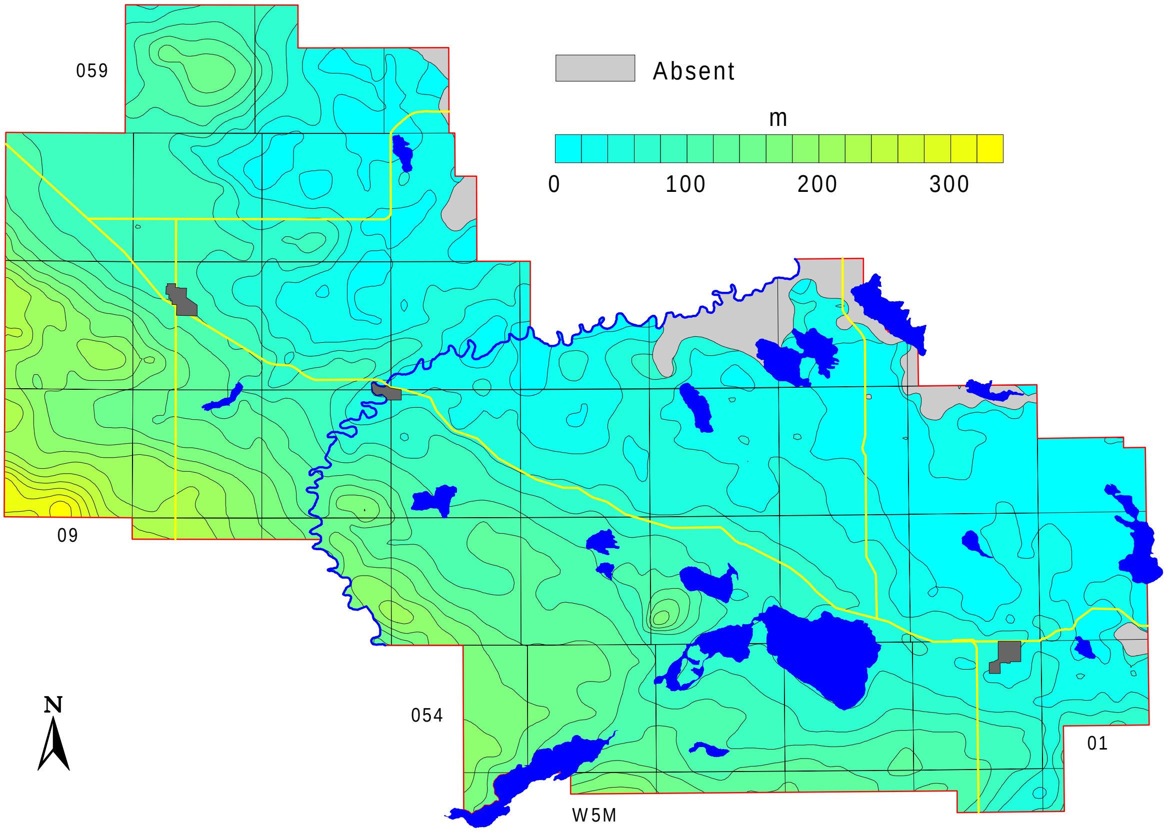

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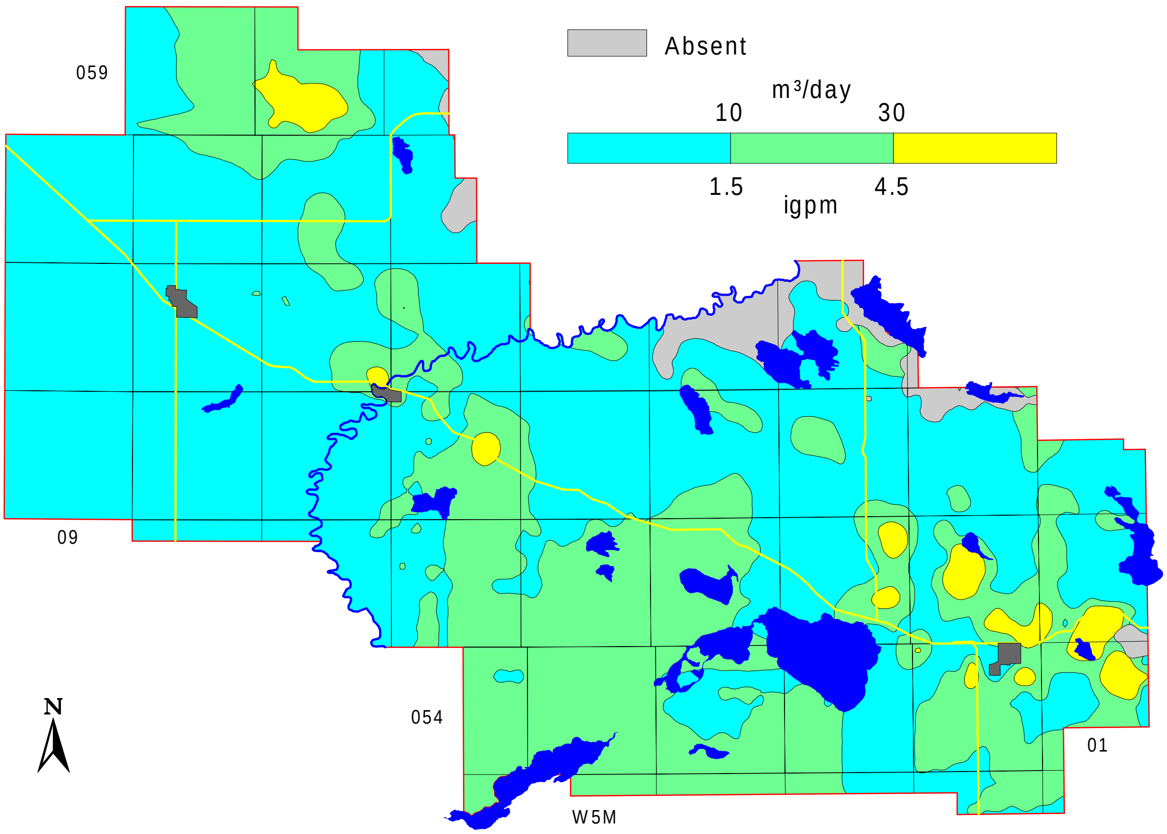

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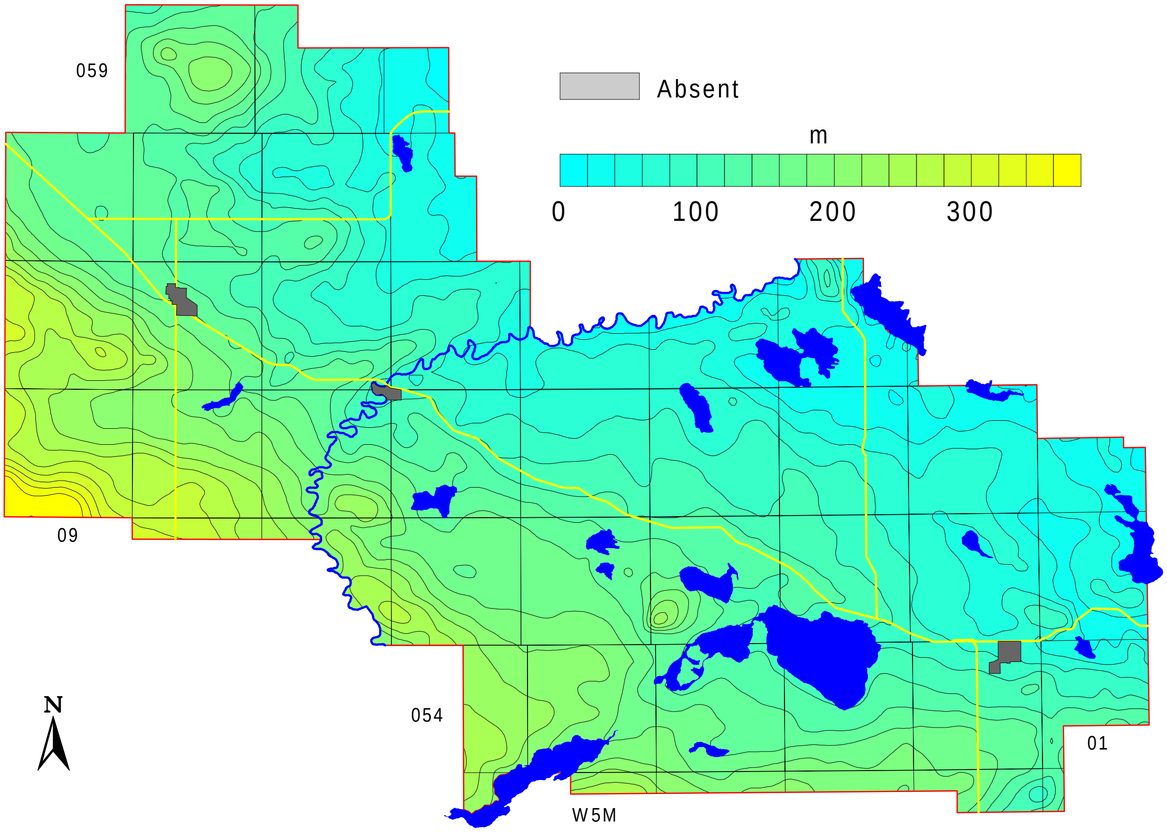
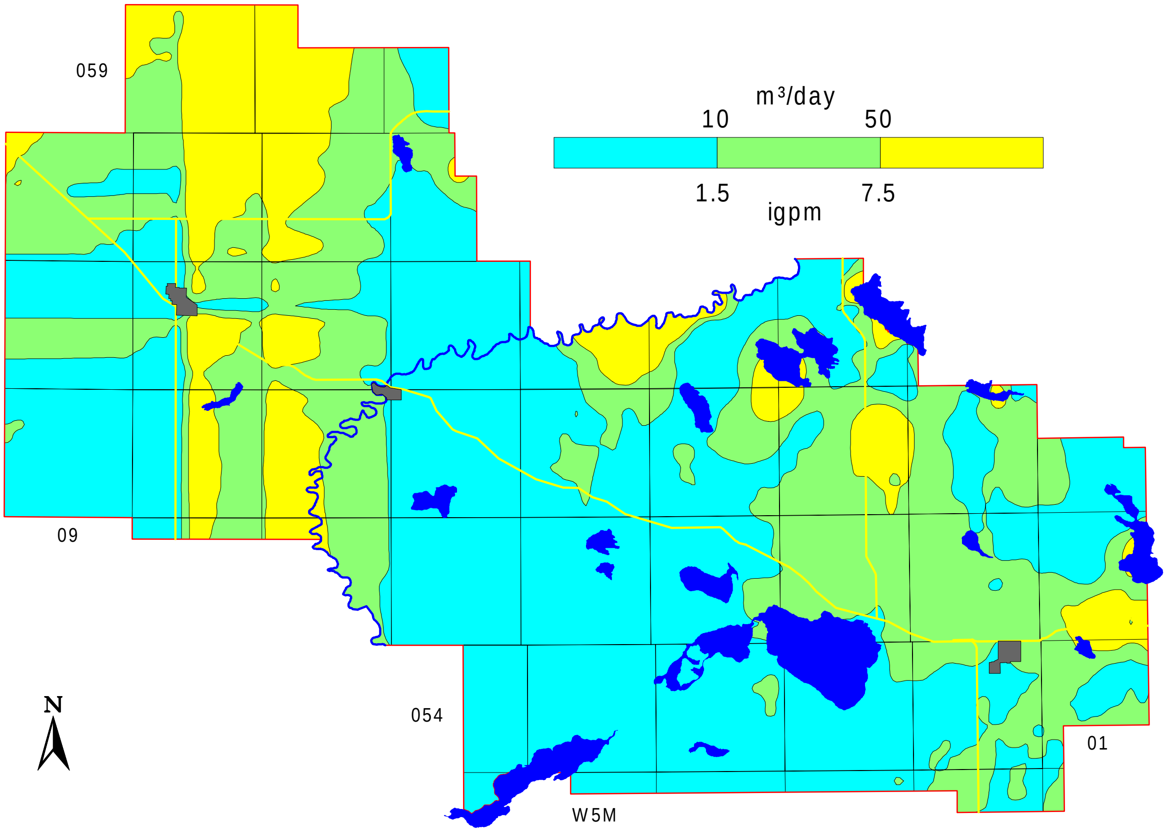
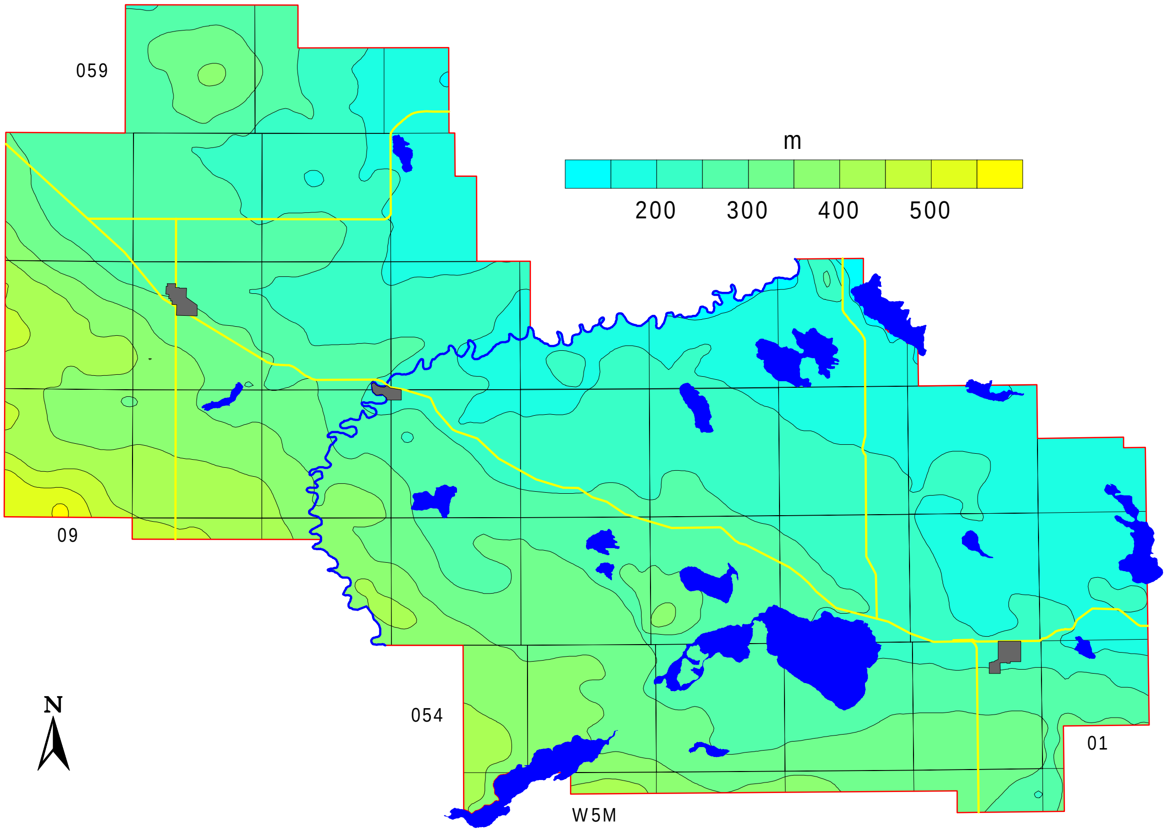


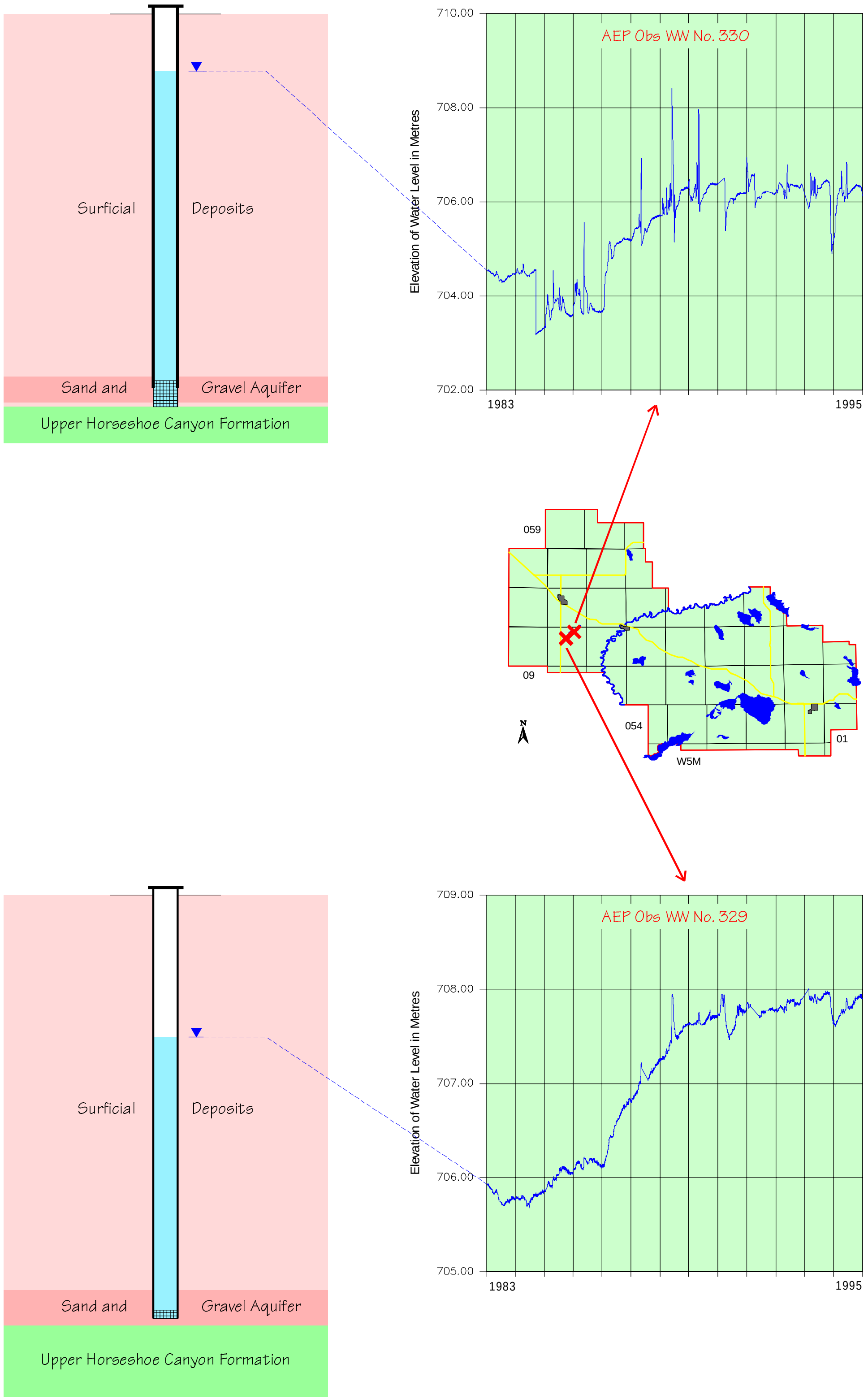
Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer



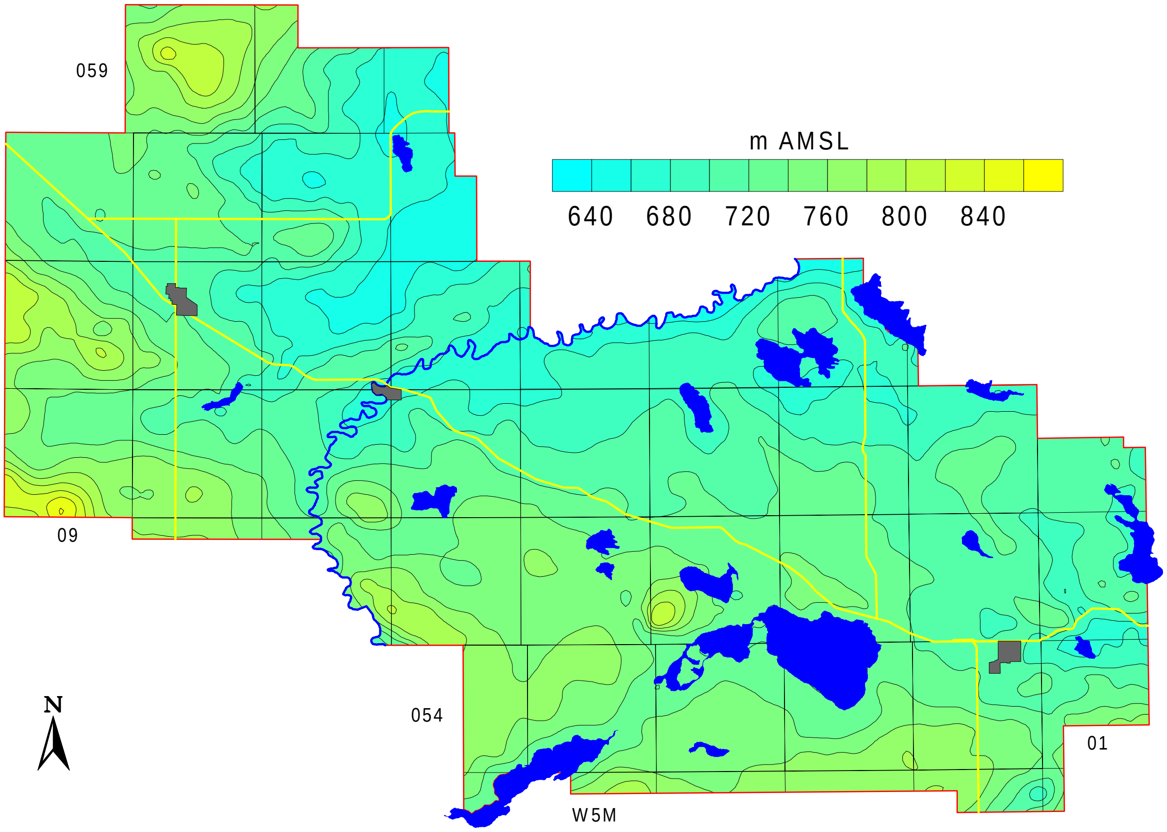
Depth to Top of Bearpaw Aquifer



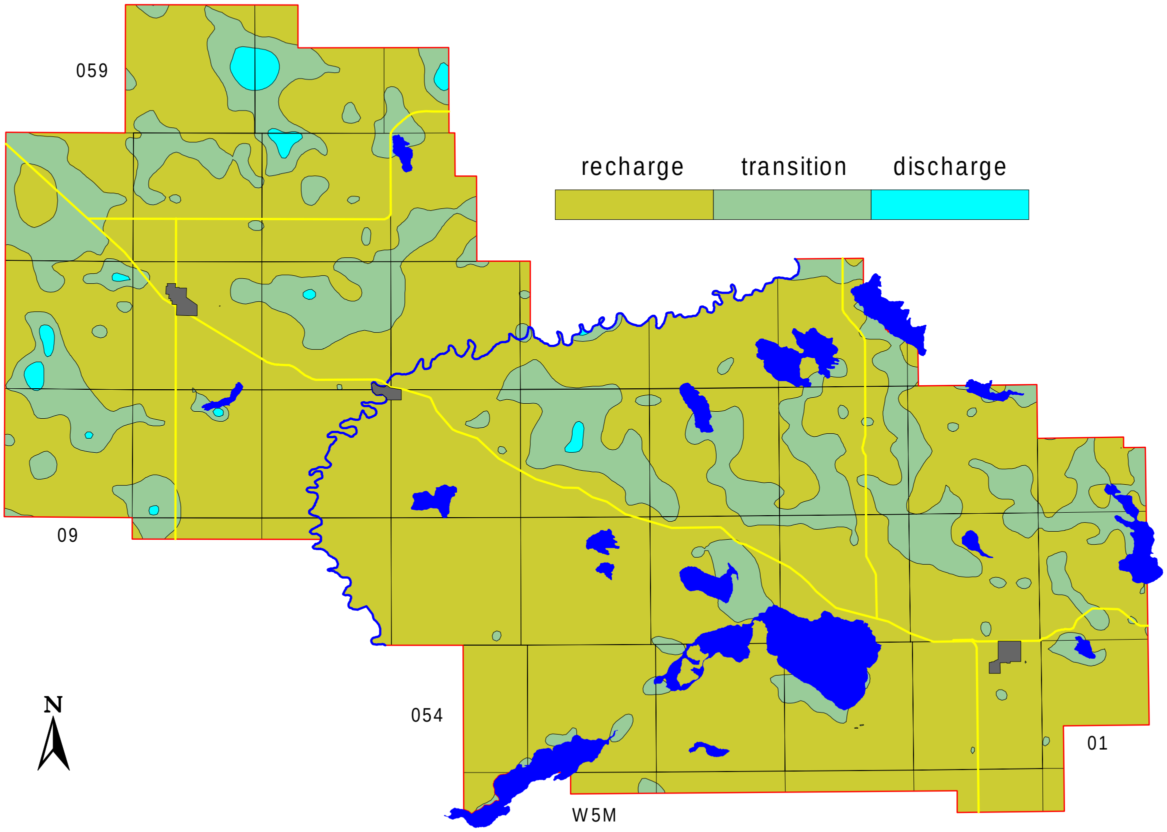
Hydrographs - AEP Observation Water Wells



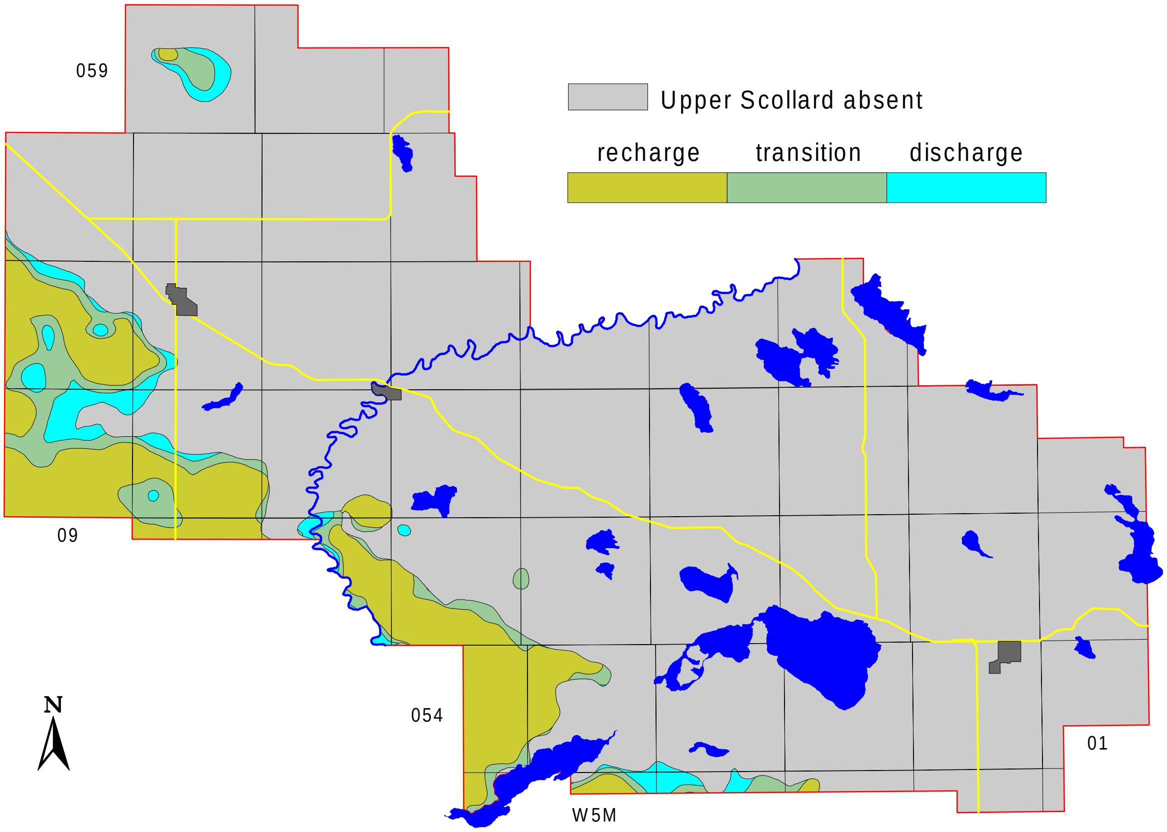
Non-Pumping Water-Level Surface in Water Wells Completed in Surficial Aquifer(s)



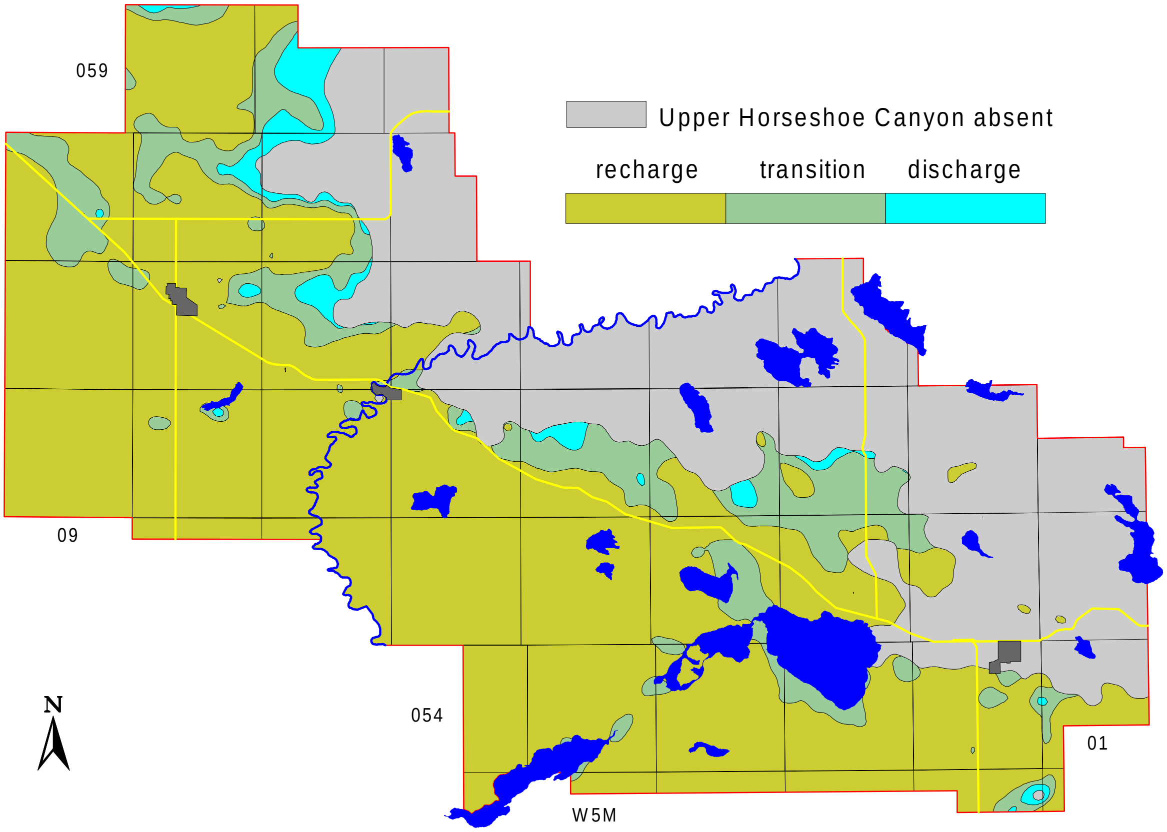
Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)



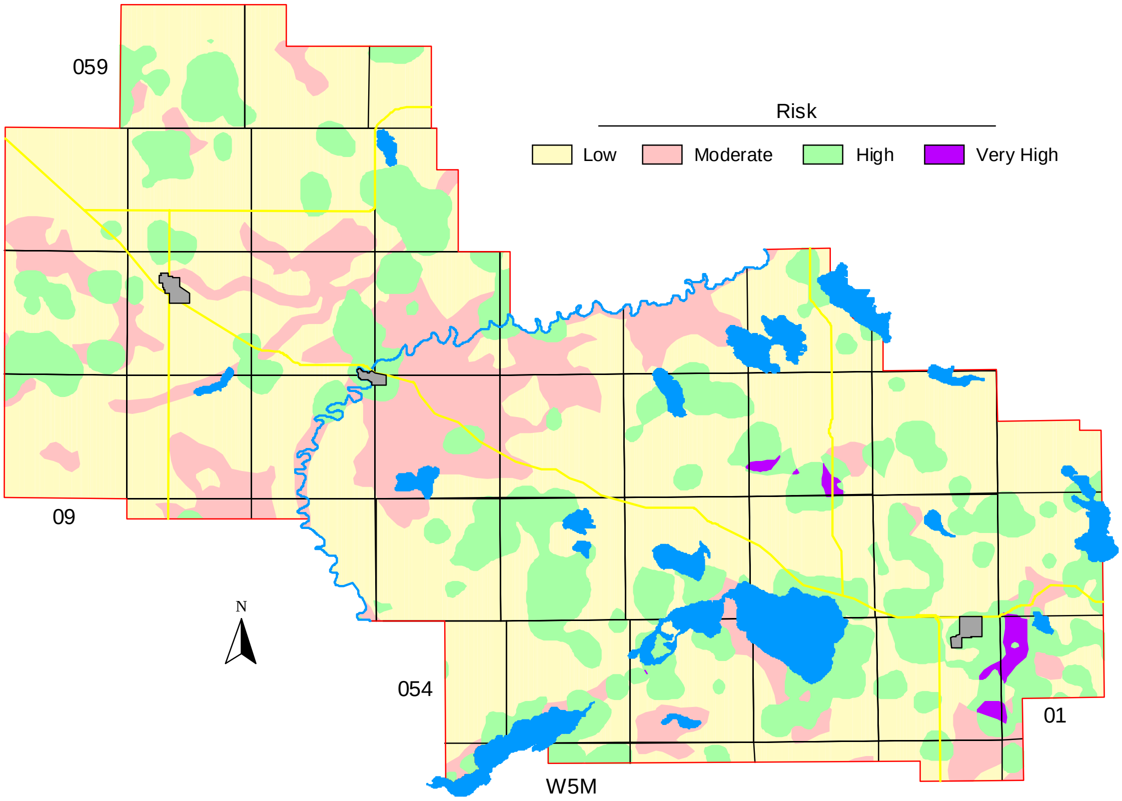
Recharge/Discharge Areas between Surficial Deposits and Upper Scollard Aquifer



Recharge/Discharge Areas between Surficial Deposits and Upper Horseshoe Canyon Aquifer



Risk of Groundwater Contamination



LAC STE. ANNE COUNTY

Appendix B

MAPS AND FIGURES ON CD-ROM

CD-ROM

A) Database
B) ArcView Files
C) Query
D) Maps and Figures

1) General

- Index Map
- Surface Casing Types used in Drilled Water Wells
- Location of Water Wells
- Depth of Existing Water Wells
- Bedrock Topography
- Bedrock Geology
- Cross-Section A - A'
- Cross-Section B - B'
- Geologic Column
- Generalized Cross-Section
- Risk of Groundwater Contamination
- Relative Permeability
- Hydrographs - AEP Observation Water Wells

2) Surficial Aquifers

a) Surficial Deposits

- Thickness of Surficial Deposits
- Non-Pumping Water-Level Surface in Water Wells Completed in Surficial Aquifer(s)
- Total Dissolved Solids in Groundwater from Surficial Deposits
- Sulfate in Groundwater from Surficial Deposits
- Chloride in Groundwater from Surficial Deposits
- Fluoride in Groundwater from Surficial Deposits
- Piper Diagram - Surficial Deposits
- Amount of Sand and Gravel in Surficial Deposits
- Thickness of Sand and Gravel Aquifer(s)
- Apparent Yield for Water Wells Completed through Sand and Gravel Aquifer(s)

b) First Sand and Gravel

- Thickness of First Sand and Gravel
- First Sand and Gravel - Saturation

c) Upper Sand and Gravel

- Thickness of Upper Surficial Deposits
- Thickness of Upper Sand and Gravel
- Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer

d) Lower Sand and Gravel

- Structure-Contour Map - Top of Lower Surficial Deposits
- Depth to Top of Lower Sand and Gravel Aquifer
- Thickness of Lower Surficial Deposits
- Thickness of Lower Sand and Gravel Aquifer
- Apparent Yield for Water Wells Completed through Lower Sand and Gravel Aquifer
- Non-Pumping Water-Level Surface in Lower Sand and Gravel Aquifer

3) Bedrock Aquifers

a) General

- Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)
- Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)
- Sulfate in Groundwater from Upper Bedrock Aquifer(s)
- Chloride in Groundwater from Upper Bedrock Aquifer(s)
- Fluoride in Groundwater from Upper Bedrock Aquifer(s)
- Piper Diagram - Bedrock Aquifers
- Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)
- Non-Pumping Water-Level Surface in Upper Bedrock Aquifer(s)

b) Paskapoo Aquifer

- Depth to Top of Paskapoo Formation
- Structure-Contour Map - Top of Paskapoo Formation
- Non-Pumping Water-Level Surface - Paskapoo Aquifer
- Apparent Yield for Water Wells Completed through Paskapoo Aquifer
- Total Dissolved Solids in Groundwater from Paskapoo Aquifer
- Sulfate in Groundwater from Paskapoo Aquifer
- Chloride in Groundwater from Paskapoo Aquifer
- Piper Diagram - Paskapoo Aquifer
- Recharge/Discharge Areas between Surficial Deposits and Paskapoo Aquifer

c) Upper Scollard Aquifer
- Depth to Top of Upper Scollard Formation
- Structure-Contour Map - Top of Upper Scollard Formation
- Non-Pumping Water-Level Surface - Upper Scollard Aquifer
- Apparent Yield for Water Wells Completed through Upper Scollard Aquifer
- Total Dissolved Solids in Groundwater from Upper Scollard Aquifer
- Sulfate in Groundwater from Upper Scollard Aquifer
- Chloride in Groundwater from Upper Scollard Aquifer
- Piper Diagram - Upper Scollard Aquifer
- Recharge/Discharge Areas between Surficial Deposits and Upper Scollard Aquifer

d) Lower Scollard Aquifer
- Depth to Top of Lower Scollard Formation
- Structure-Contour Map - Top of Lower Scollard Formation
- Non-Pumping Water-Level Surface - Lower Scollard Aquifer
- Apparent Yield for Water Wells Completed through Lower Scollard Aquifer
- Total Dissolved Solids in Groundwater from Lower Scollard Aquifer
- Sulfate in Groundwater from Lower Scollard Aquifer
- Chloride in Groundwater from Lower Scollard Aquifer
- Piper Diagram - Lower Scollard Aquifer
- Recharge/Discharge Areas between Surficial Deposits and Lower Scollard Aquifer

e) Upper Horseshoe Canyon Aquifer
- Depth to Top of Upper Horseshoe Canyon Formation
- Structure-Contour Map - Top of Upper Horseshoe Canyon Formation
- Non-Pumping Water-Level Surface - Upper Horseshoe Canyon Aquifer
- Apparent Yield for Water Wells Completed through Upper Horseshoe Canyon Aquifer
- Total Dissolved Solids in Groundwater from Upper Horseshoe Canyon Aquifer
- Sulfate in Groundwater from Upper Horseshoe Canyon Aquifer
- Chloride in Groundwater from Upper Horseshoe Canyon Aquifer
- Piper Diagram - Upper Horseshoe Canyon Formation
- Recharge/Discharge Areas between Surficial Deposits and Upper Horseshoe Canyon Aquifer

f) Middle Horseshoe Canyon Aquifer
- Depth to Top of Middle Horseshoe Canyon Formation
- Structure-Contour Map - Top of Middle Horseshoe Canyon Formation
- Non-Pumping Water-Level Surface - Middle Horseshoe Canyon Aquifer
- Apparent Yield for Water Wells Completed through Middle Horseshoe Canyon Aquifer
- Total Dissolved Solids in Groundwater from Middle Horseshoe Canyon Aquifer
- Sulfate in Groundwater from Middle Horseshoe Canyon Aquifer
- Chloride in Groundwater from Middle Horseshoe Canyon Aquifer
- Piper Diagram - Middle Horseshoe Canyon Formation
- Recharge/Discharge Areas between Surficial Deposits and Middle Horseshoe Canyon Aquifer

g) Lower Horseshoe Canyon Aquifer
- Depth to Top of Lower Horseshoe Canyon Formation
- Structure-Contour Map - Top of Lower Horseshoe Canyon Formation
- Non-Pumping Water-Level Surface - Lower Horseshoe Canyon Aquifer
- Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer
- Total Dissolved Solids in Groundwater from Lower Horseshoe Canyon Aquifer
- Sulfate in Groundwater from Lower Horseshoe Canyon Aquifer
- Chloride in Groundwater from Lower Horseshoe Canyon Aquifer
- Piper Diagram - Lower Horseshoe Canyon Formation
- Recharge/Discharge Areas between Surficial Deposits and Lower Horseshoe Canyon Aquifer

h) Bearpaw Aquifer
- Depth to Top of Bearpaw Aquifer
- Structure-Contour Map - Top of Bearpaw Formation

LAC STE. ANNE COUNTY

Appendix C

GENERAL WATER WELL INFORMATION

Domestic Water Well Testing

Purpose and Requirements

The purpose of the testing of domestic water wells is to obtain background data related to:

1) the non-pumping water level for the aquifer - Has there been any lowering of the level since the last measurement?
2) the specific capacity of the water well, which indicates the type of contact the water well has with the aquifer;
3) the transmissivity of the aquifer and hence an estimate of the projected long-term yield for the water well;
4) the chemical, bacteriological and physical quality of the groundwater from the water well.

The testing procedure involves conducting an aquifer test and collecting of groundwater samples for analysis by an accredited laboratory. The date and time of the testing are to be recorded on all data collection sheets. A sketch showing the location of the water well relative to surrounding features is required. The sketch should answer the question, "If this water well is tested in the future, how will the person doing the testing know this is the water well I tested?"

The water well should be taken out of service as long as possible before the start of the aquifer test, preferably not less than 30 minutes before the start of pumping. The non-pumping water level is to be measured 30, 10, and 5 minutes before the start of pumping and immediately before the start of pumping which is to be designated as time 0 for the test. All water levels must be from the same designated reference, usually the top of the casing. Water levels are to be measured during the pumping interval and during the recovery interval after the pump has been turned off; all water measurements are to be with an accuracy of ± 0.01 metres.

During the pumping and recovery intervals, the water level is to be measured at the appropriate times. An example of the time schedule for a 4-hour test is as follows, measured in minutes after the pump is turned on and again after the pump is turned off:

1,2,3,4,6,8,10,13,16,20,25,32,40,50,64,80,100,120.

For a four-hour test, the reading after 120 minutes of pumping will be the same as the 0 minutes of recovery. Under no circumstance will the recovery interval be less than the pumping interval.

Flow rate during the aquifer test should be measured and recorded with the maximum accuracy possible. Ideally, a water meter with an accuracy of better than ±1% displaying instantaneous and total flow should be used. If a water meter is not available, then the time required to completely fill a container of known volume should be recorded, noting the time to the nearest 0.5 seconds or better. Flow rate should be determined and recorded often to ensure a constant pumping rate.

Groundwater samples should be collected as soon as possible after the start of pumping and within 10 minutes of the end of pumping. Initially only the groundwater samples collected near the end of the pumping interval need to be submitted to the accredited laboratory for analysis. All samples must be properly stored for transportation to the laboratory and, in the case of the bacteriological analysis, there is a maximum time allowed between the time the sample is collected and the time the sample is delivered to the laboratory. The first samples collected are only analyzed if there is a problem or a concern with the first samples submitted to the laboratory.

Procedure

Site Diagrams

These diagrams are a map showing the distance to nearby significant features. This would include things like a corner of a building (house, barn, garage etc.) or the distance to the half-mile or mile fence. The description should allow anyone not familiar with the site to be able to unequivocally identify the water well that was tested.

In lieu of a map, UTM coordinates accurate to within five metres would be acceptable. If a hand-held GPS is used, the post-processing correction details must be provided.

Surface Details

The type of surface completion must be noted. This will include such things as a pitless adapter, well pit, pump house, in basement, etc. Also, the reference point used for measuring water levels needs to be noted. This would include top of casing (TOC) XX metres above ground level; well pit lid, XX metres above TOC; TOC in well pit XX metres below ground level.

Groundwater Discharge Point

Where was the flow of groundwater discharge regulated? For example was the discharge through a hydrant downstream from the pressure tank; discharged directly to ground either by connecting directly above the well seal or by pulling the pump up out of the pitless adapter; from a tap on the house downstream from the pressure tank? Also note must be made if any action was taken to ensure the pump would operate continuously during the pumping interval and whether the groundwater was passing through any water-treatment equipment before the discharge point.

Water-Level Measurements

How were the water-level measurements obtained? If obtained using a contact gauge, what type of cable was on the tape, graduated tape or a tape with tags? If a tape with tags, when was the; last time the tags were calibrated? If a graduated tape, what is the serial number of the tape and is the tape shorter than its original length (i.e. is any tape missing)?

If water levels are obtained using a transducer and data logger, the serial numbers of both transducer and data logger are needed and a copy of the calibration sheet. The additional information required is the depth the transducer was set and the length of time between when the transducer was installed and when the calibration water level was measured, plus the length of time between the installation of the transducer and the start of the aquifer test.

All water levels must be measured at least to the nearest 0.01 metres.

Discharge Measurements

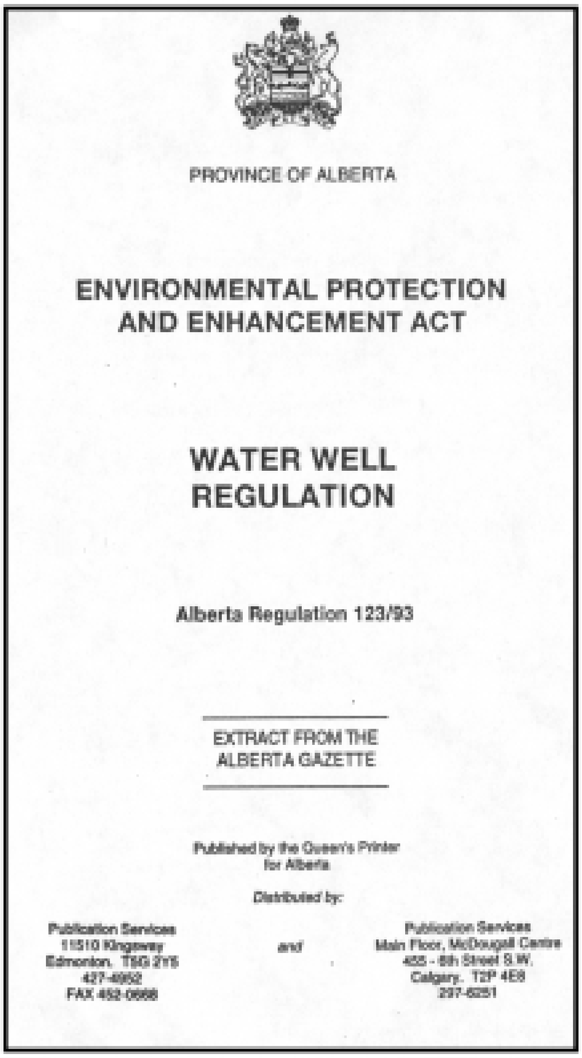
Type of water meter used. This could include such things as a turbine or positive displacement meter. How were the readings obtained from the meter? Were the readings visually noted and recorded or were they recorded using a data logger?

Water Samples

A water sample must be collected between the 4- and 6-minute water-level measurements, whenever there is an observed physical change in the groundwater being pumped, and 10 minutes before the end of the planned pumping interval. Additional water samples must be collected if it is expected that pumping will be terminated before the planned pumping interval.

Environmental Protection and Enhancement Act

Water Well Regulation



PROVINCE OF ALBERTA

ENVIRONMENTAL PROTECTION AND ENHANCEMENT ACT

WATER WELL REGULATION

Alberta Regulation 123/93

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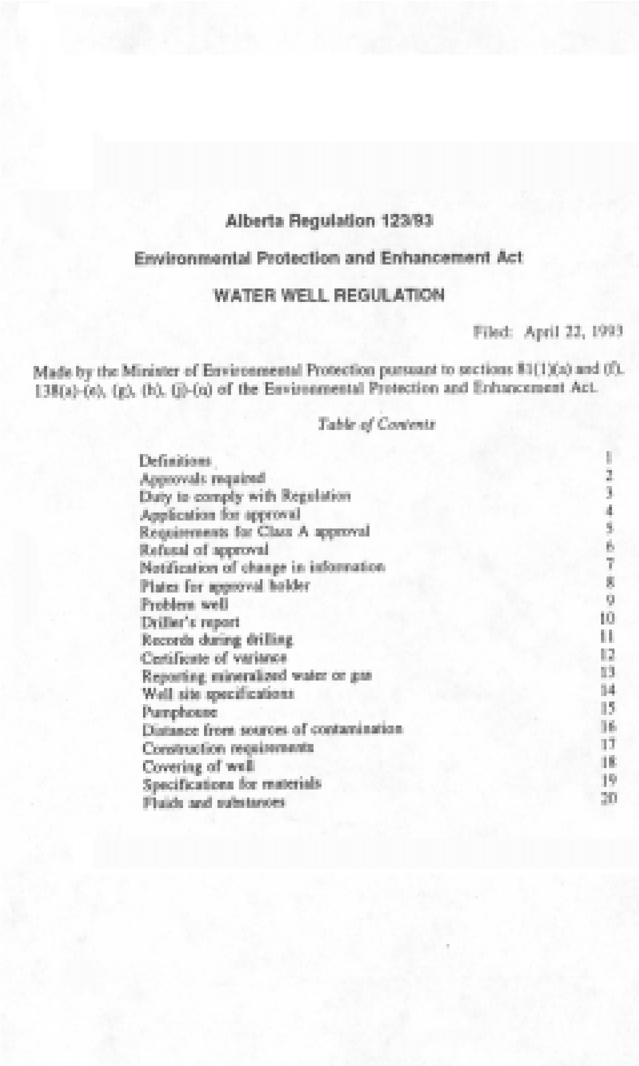

Alberta Regulation 123/93

Environmental Protection and Enhancement Act

WATER WELL REGULATION

Filed: April 22, 1993

Made by the Minister of Environmental Protection pursuant to sections 81(1)(a) and (f), 138(a)-(e), (g), (h), (j)-(u) of the Environmental Protection and Enhancement Act.

Table of Contents

Additional Information

VIDEOS

Will the Well Go Dry Tomorrow? (Mow-Tech Ltd.: 1-800 GEO WELL)
Water Wells that Last (PFRA – Edmonton Office: 403-495-3307)
Ground Water and the Rural Community (Ontario Ground Water Association)

BOOKLET

Water Wells that Last (PFRA – Edmonton Office: 403-495-3307)

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PRAIRIE FARM REHABILITATION ADMINISTRATION

Curtis Snell (Westlock: 403-349-3963)

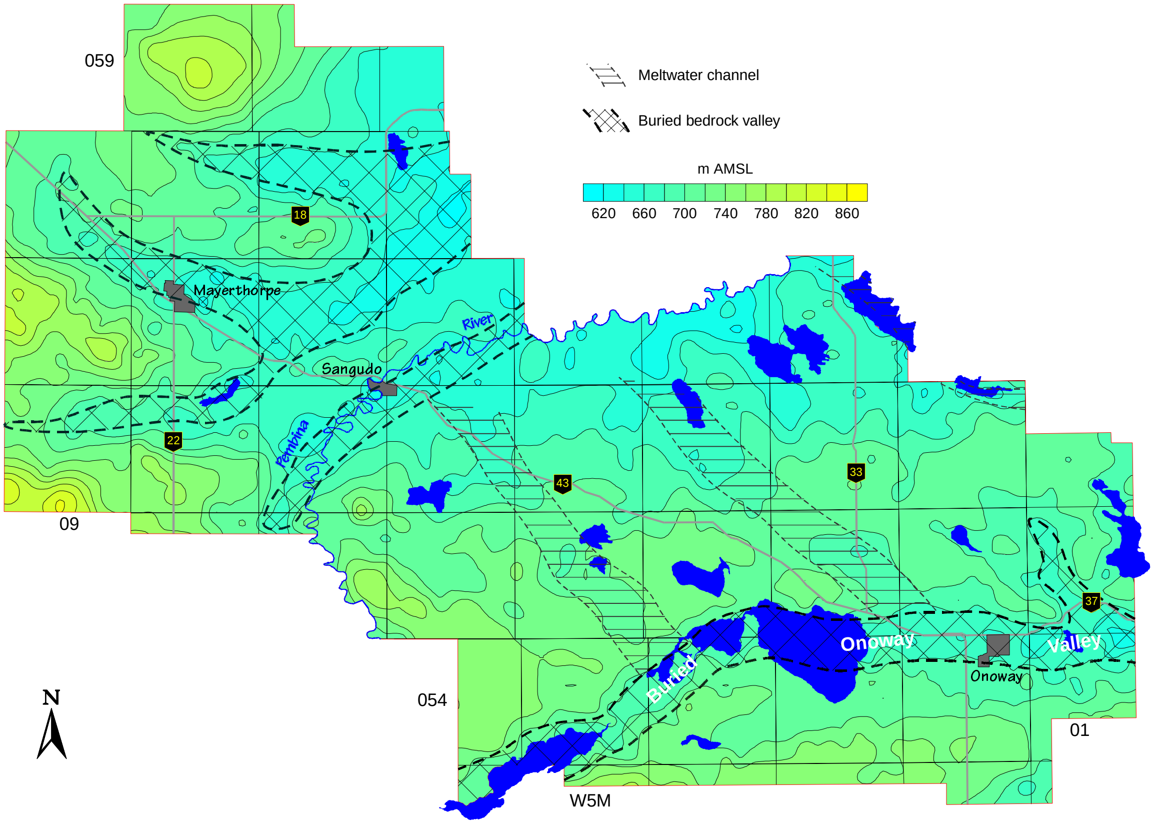
LOCAL HEALTH DEPARTMENTS

LAC STE. ANNE COUNTY

Appendix D

MAPS AND FIGURES INCLUDED AS LARGE PLOTS

Lac Ste. Anne County
Bedrock Topography



Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada

PFRA
Prairie Farm Rehabilitation Administration

Note: This map is based on a regional study and as such, the results are to be used only as a guide. Detailed local studies are required to verify hydrogeological conditions at a given location.

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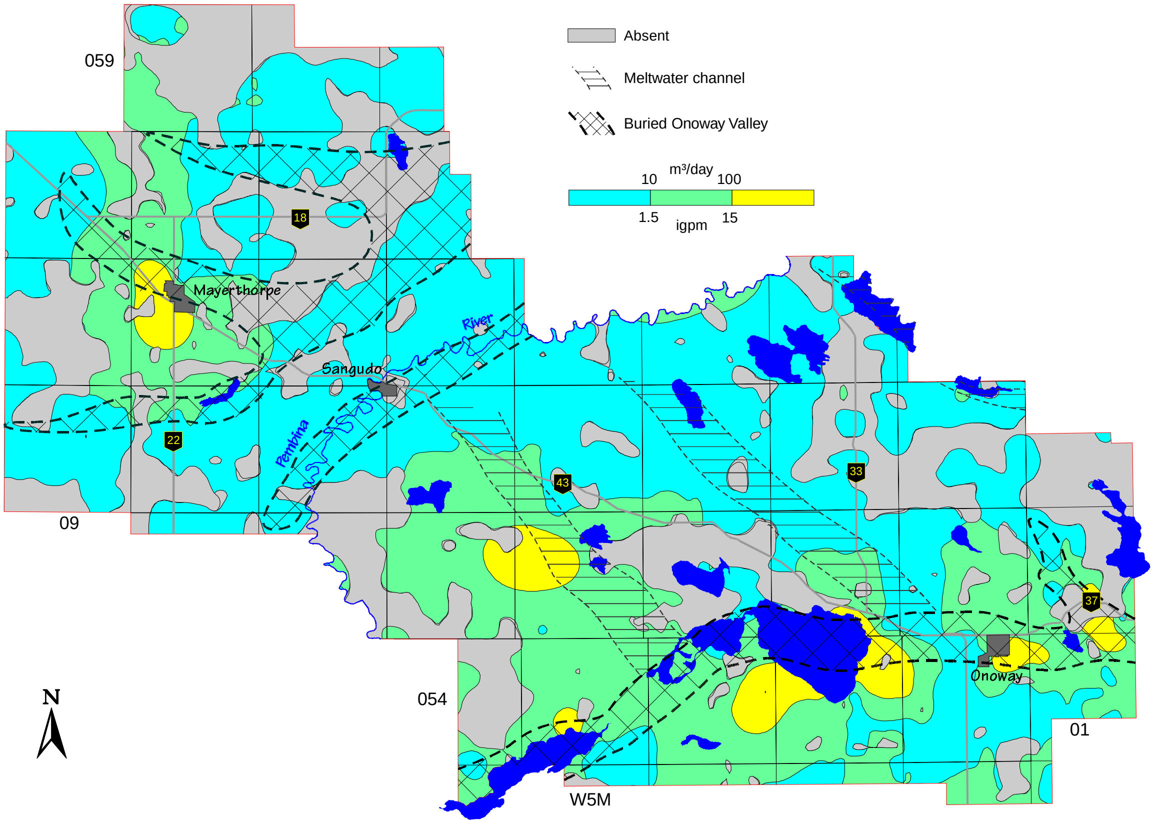
hydrogeological consultants ltd, edmonton, alberta - 1-800-661-7972 - project no. 97-112 - bdrsa.cdr - 24 Jul 98

Lac Ste. Anne County
Apparent Yield for Water Wells Completed through Sand and Gravel Aquifer(s)



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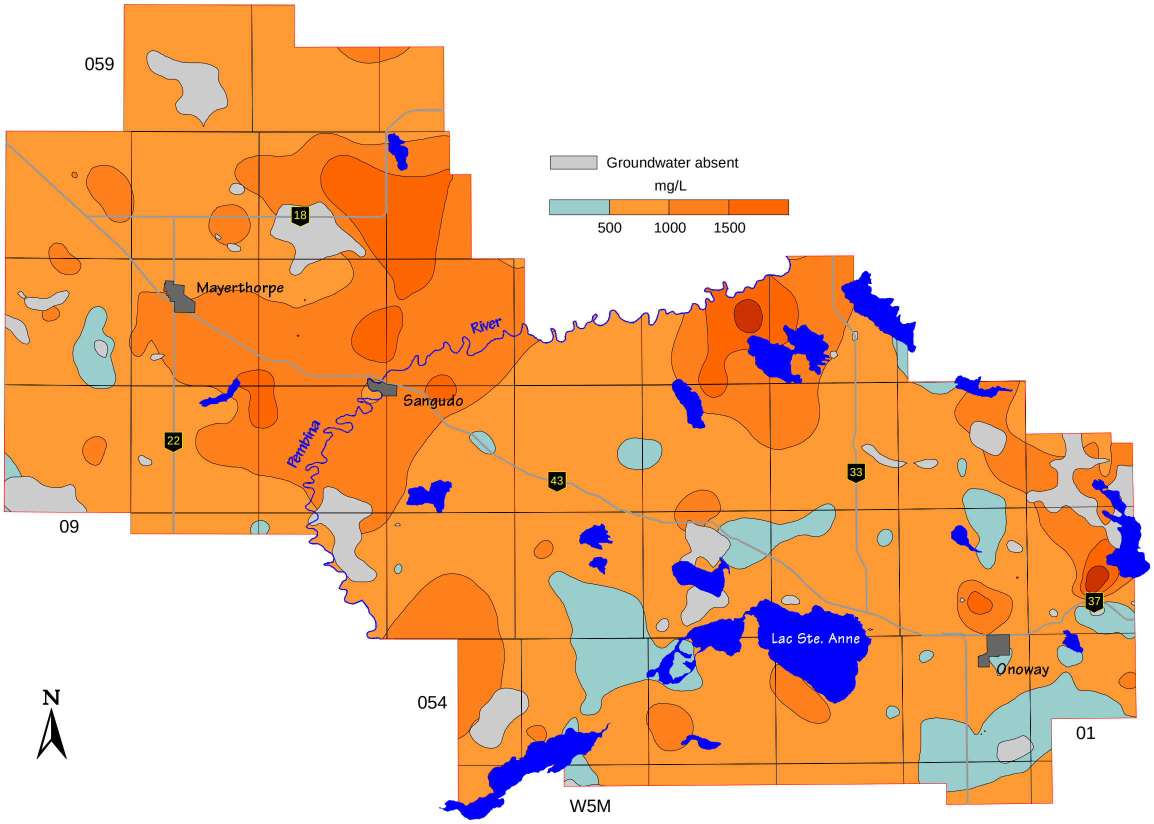
Lac Ste. Anne County
Total Dissolved Solids in Groundwater from Surficial Deposits



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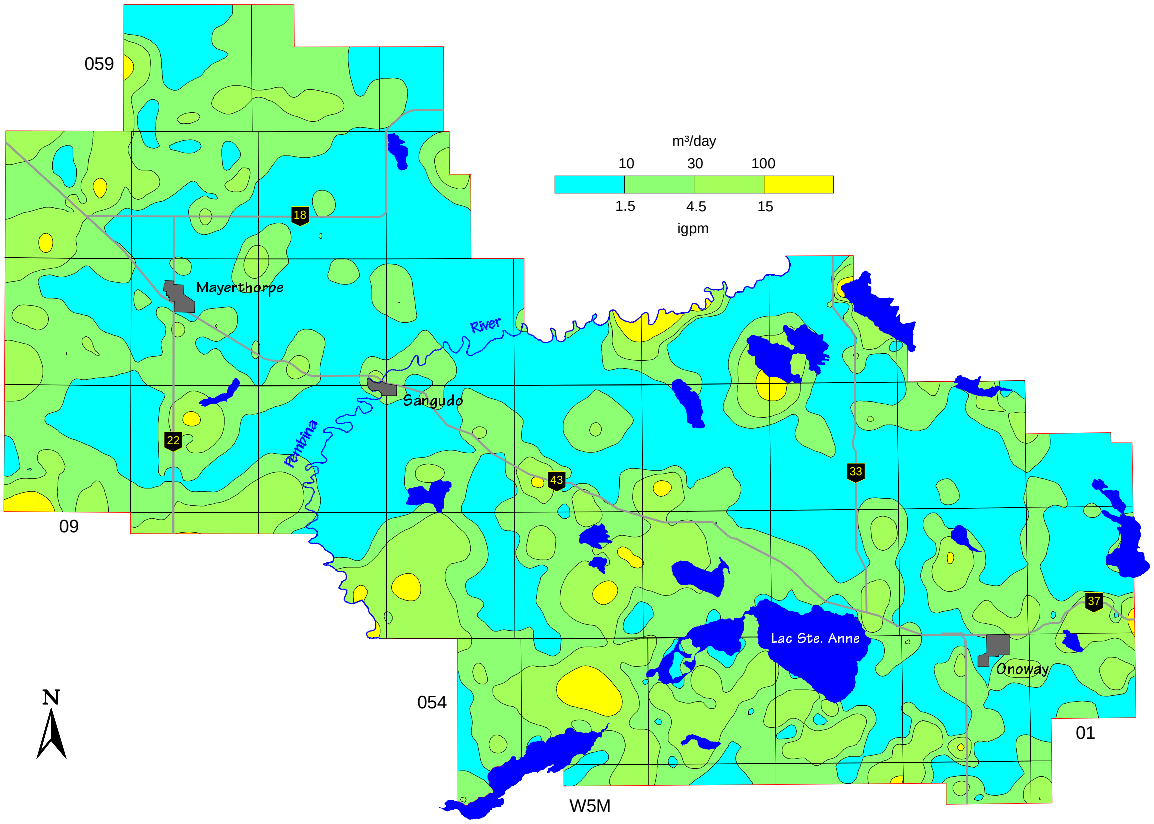
Lac Ste. Anne County
Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)



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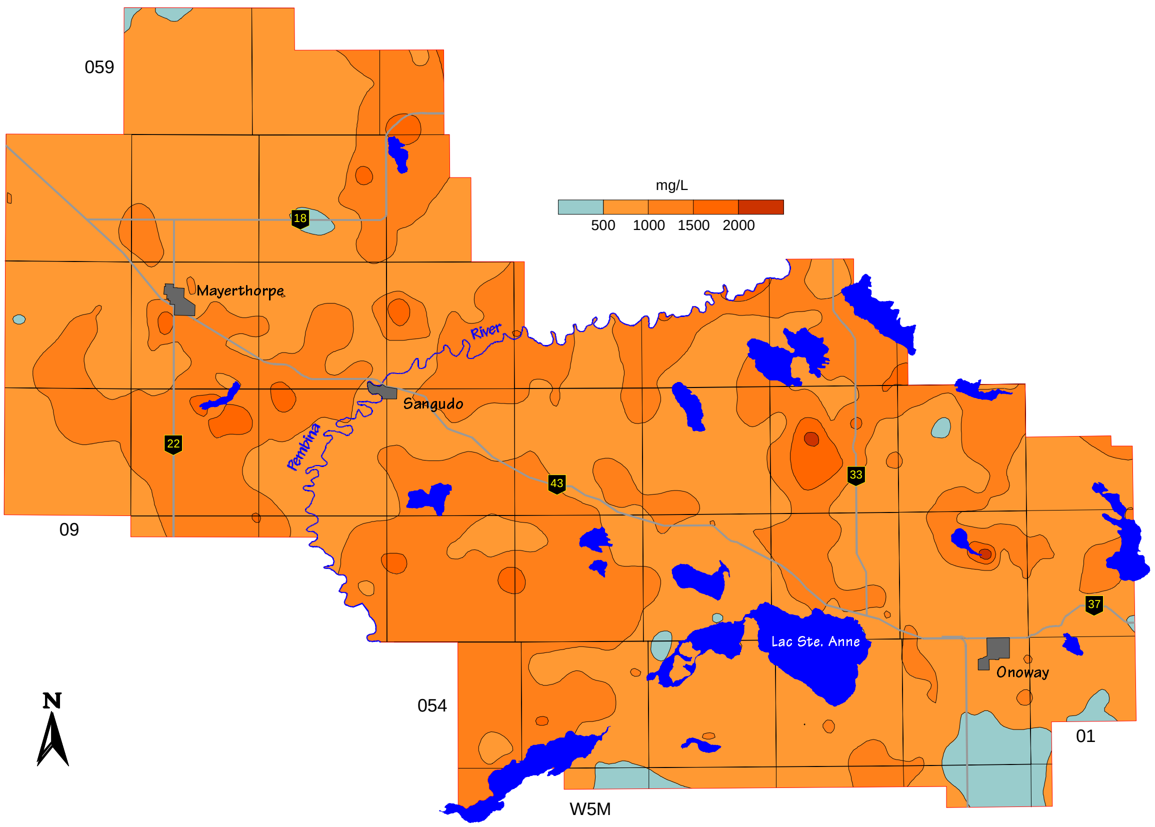
Lac Ste. Anne County
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)



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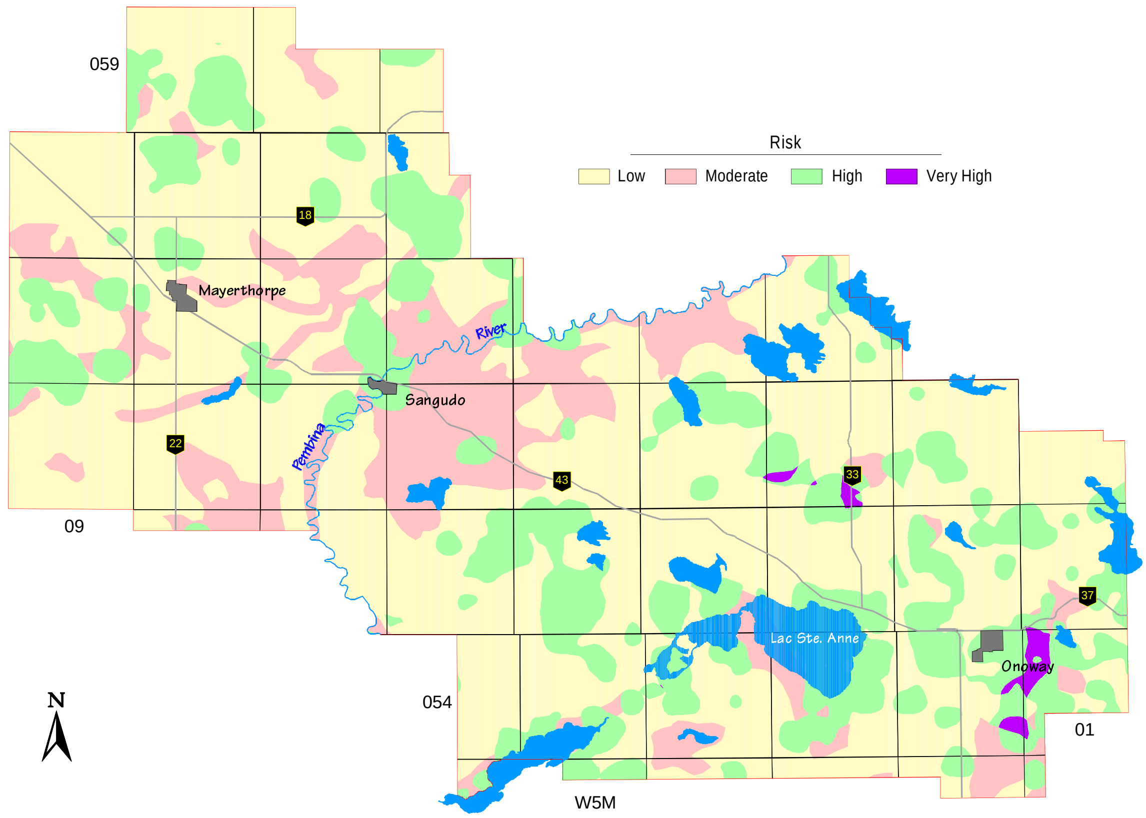
Lac Ste. Anne County
Risk of Groundwater Contamination



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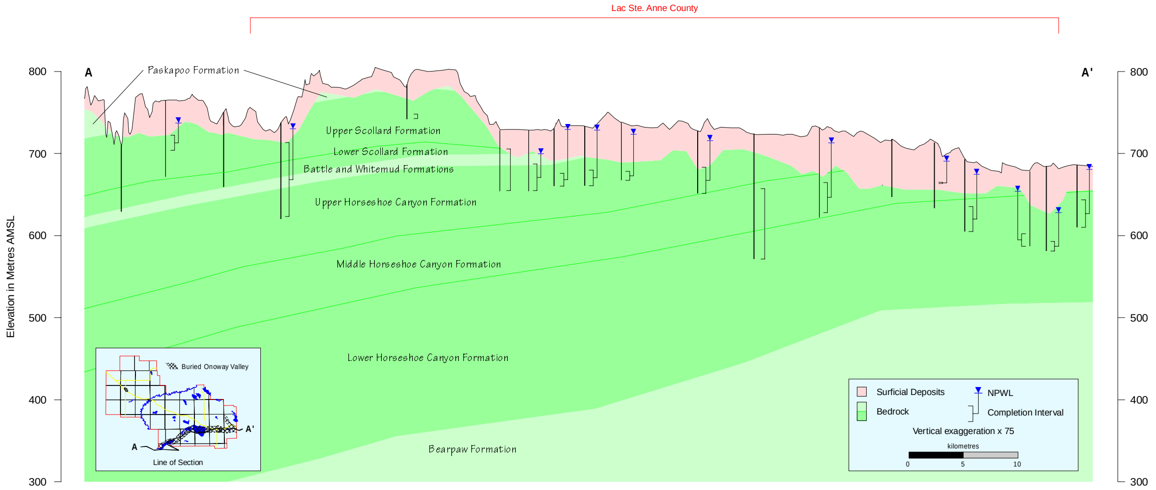
Lac Ste. Anne County
Cross-Section A - A'



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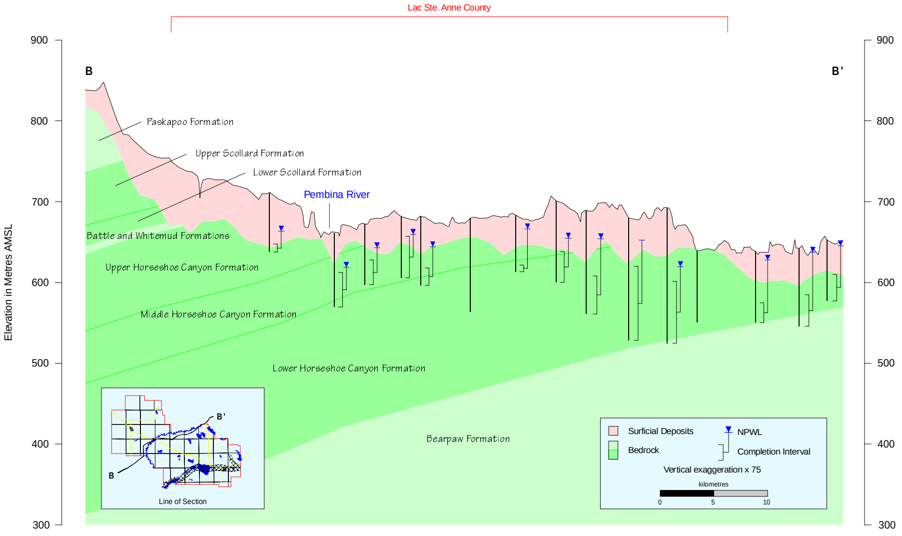
Lac Ste. Anne County
Cross-Section B - B'



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