# Flagstaff County

Part of the Battle River Basin
Parts of Tp 039 to 046, R 09 to 17, W4M
Regional Groundwater Assessment

Prepared for

Flagstaff County

In conjunction with

Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

Prairie Farm Rehabilitation Administration | Administration du rétablisseme agricole des Prairies

Canada

Prepared by
hydrogeological consultants ltd.
1-800-661-7972
Our File No.: **96-193**

August 1998
(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

1 PROJECT OVERVIEW....1
1.1 About This Report....1
1.2 The Project....1
1.3 Purpose....2
2 INTRODUCTION....3
2.1 Setting....3
2.2 Climate....3
2.3 Background Information....4
3 TERMS....6
4 METHODOLOGY....7
4.1 Data Collection and Synthesis....7
4.2 Spatial Distribution of Aquifers....8
4.3 Hydrogeological Parameters....9
4.3.1 Risk Criteria....9
4.4 Maps and Cross-Sections....10
4.5 Software....10
5 AQUIFERS....11
5.1 Background....11
5.1.1 Surficial Aquifers....11
5.1.2 Bedrock Aquifers....12
5.2 Aquifers in Surficial Deposits....13
5.2.1 Geological Characteristics of Surficial Deposits....13
5.2.2 Sand and Gravel Aquifer(s)....15
5.2.2.1 Chemical Quality of Groundwater from Surficial Deposits....15
5.2.3 Upper Sand and Gravel Aquifer....16
5.2.3.1 Aquifer Thickness....16
5.2.3.2 Apparent Yield....17
5.2.4 Lower Sand and Gravel Aquifer....17
5.2.4.1 Apparent Yield....17
5.3 Bedrock....18
5.3.1 Geological Characteristics....18
5.3.2 Aquifers....19
5.3.3 Chemical Quality of Groundwater....21
5.3.4 Lower Horseshoe Canyon Aquifer....22
5.3.4.1 Depth to Top....22

5.3.4.2 Apparent Yield ........ 22
5.3.4.3 Quality ........ 22
5.3.5 Bearpaw Aquifer ........ 23
5.3.5.1 Depth to Top ........ 23
5.3.5.2 Apparent Yield ........ 23
5.3.5.3 Quality ........ 23
5.3.6 Oldman Aquifer ........ 24
5.3.6.1 Depth to Top ........ 24
5.3.6.2 Apparent Yield ........ 24
5.3.6.3 Quality ........ 24
*5.3.7 Continental* Foremost Aquifer ........ 25
5.3.7.1 Depth to Top ........ 25
5.3.7.2 Apparent Yield ........ 25
5.3.7.3 Quality ........ 25
6 GROUNDWATER BUDGET ........ 26
6.1 Hydrographs ........ 26
6.2 Groundwater Flow ........ 27
6.2.1 Recharge/Discharge ........ 27
6.2.1.1 Surficial Deposits/Upper Bedrock Aquifers ........ 27
6.3 Bedrock Aquifers ........ 28
7 POTENTIAL FOR GROUNDWATER CONTAMINATION ........ 29
7.1.1 Risk of Contamination Map ........ 30
8 RECOMMENDATIONS ........ 31
9 REFERENCES ........ 33
10 GLOSSARY ........ 34

## LIST OF FIGURES

Figure 1. Index Map ........ 3
Figure 2. Location of Water Wells ........ 4
Figure 3. Depth to Base of Groundwater Protection ........ 5
Figure 4. Generalized Cross-Section (for terminology only) ........ 6
Figure 5. Geologic Column ........ 6
Figure 6. Cross-Section A - A' ........ 11
Figure 7. Cross-Section B - B' ........ 12
Figure 8. Bedrock Topography ........ 13
Figure 9. Amount of Sand and Gravel in Surficial Deposits ........ 14
Figure 10. Apparent Yield for Water Wells Completed through Sand and Gravel Aquifer(s) ........ 15
Figure 11. Total Dissolved Solids in Groundwater from Surficial Deposits ........ 16
Figure 12. Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer ........ 17
Figure 13. Apparent Yield for Water Wells Completed through Lower Sand and Gravel Aquifer ........ 17

Figure 14. Bedrock Geology ........ 18
Figure 15. Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s) ........ 20
Figure 16. Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s) ........ 21
Figure 17. Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer ........ 22
Figure 18. Apparent Yield for Water Wells Completed through Bearpaw Aquifer ........ 23
Figure 19. Apparent Yield for Water Wells Completed through Oldman Aquifer ........ 24
Figure 20. Apparent Yield for Water Wells Completed through continental Foremost Aquifer ........ 25
Figure 21. Hydrographs - AEP Observation Water Wells ........ 26
Figure 22. Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s) ........ 28
Figure 23. Recharge/Discharge Areas between Surficial Deposits and Oldman Aquifer ........ 28
Figure 24. Risk of Groundwater Contamination ........ 30

## LIST OF TABLES

Table 1. Risk of Groundwater Contamination Criteria ........ 9
Table 2. Bedrock Aquifer Completion ........ 19
Table 3. Risk of Groundwater Contamination Criteria ........ 30

## APPENDICES

A HYDROGEOLOGICAL MAPS AND FIGURES
B MAPS AND FIGURES ON CD-ROM
C GENERAL WATER WELL INFORMATION
D MAPS AND FIGURES INCLUDED AS LARGE PLOTS

# 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 the 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 Flagstaff 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, maps showing 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 and cross-sections. 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 water-well 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 and the accompanying maps represent Modules 2 and 3.

### 1.3 Purpose

This project is a regional groundwater assessment of Flagstaff 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 Flagstaff 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.

[1] See glossary
[2] See glossary

# 2 INTRODUCTION

## 2.1 Setting

Flagstaff County is situated in east-central Alberta. This area is part of the Alberta Plains region. The County exists within the Battle River basin. The southern boundary of the County is the Battle River. The other boundaries follow township or section lines. The area includes some or all of townships 039 to 046, ranges 09 to 17, west of the 4th Meridian.

The ground elevation varies between 565 and 790 metres above mean sea level (AMSL). Regionally the topographic surface generally decreases from southwest to northeast. However, local drainage is toward the Battle River.

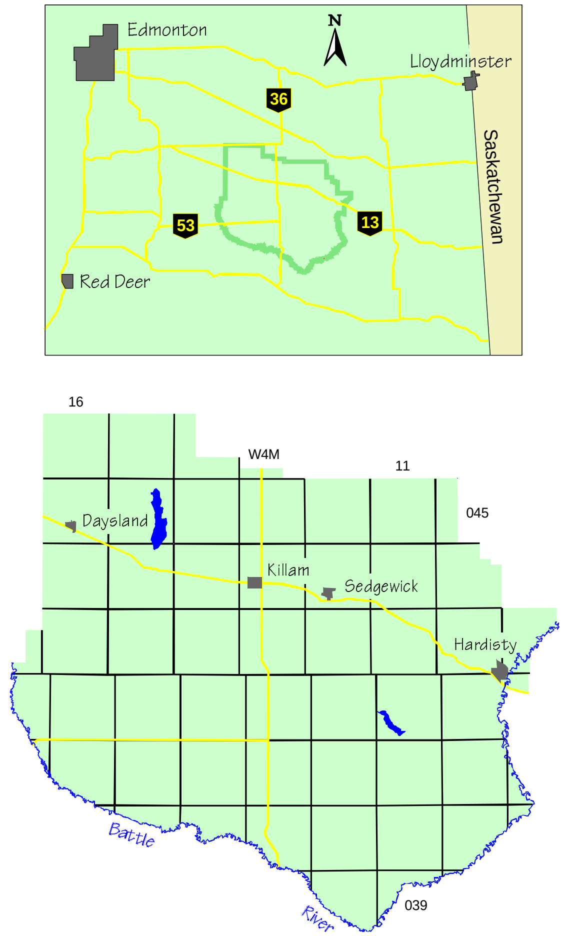


*Figure 1. Index Map*

## 2.2 Climate

Flagstaff County lies within the transition zone between a humid, continental Dfb climate and a semiarid Bsk climate. 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 the Aspen Parkland region, a transition between boreal forest and grassland environments.

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. A Bsk climate is characterized by its moisture deficiency, where mean annual potential evapotranspiration exceeds the mean annual precipitation.

The mean annual precipitation averaged from four meteorological stations within the County measured 415 millimetres (mm), based on data from 1914 to 1990. The mean annual temperature averaged 2.9 °C, with the mean monthly temperature reaching a high of 17.1 °C in July, and dropping to a low of -14.5 °C in January. The calculated annual potential evapotranspiration is 530 millimetres.

## 2.3 Background Information

There are records available for 3,926 water wells in the groundwater database for Flagstaff County. Of the 3,926 water wells, 3,456 are for domestic/stock purposes. The remaining 470 water wells were completed for a variety of uses, including municipal and industrial purposes, and small irrigation projects. Based on a rural population of 4,015, there are 3.4 domestic/stock water wells per family of four. The domestic or stock water wells vary in depth from less than 1 metre to 181 metres below ground level. Lithologic details are available for 1,921 water wells.

There are 1,542 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 823. The adjacent map shows that these water wells are mainly in the buried bedrock valley and the southeastern part of the County. Approximately 48% of the water wells completed in the surficial aquifers have a completion depth of less than 30 metres and 52% have a completion depth of more than 30 metres.

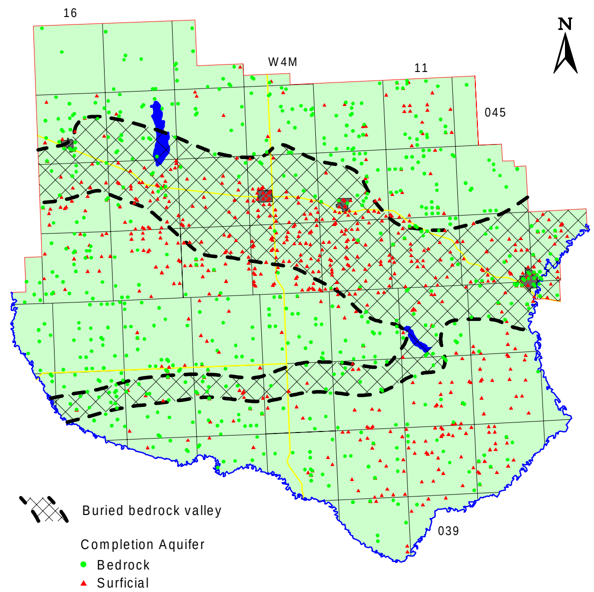



***Figure 2. Location of Water Wells***

The remaining 719 water wells have the top of their completion interval deeper than the depth to the bedrock surface. From the adjacent map, it can be seen that water wells completed in bedrock aquifers occur mainly outside the areas where surficial water wells are completed.

Water wells not used for domestic needs must be licensed. At the end of 1996, 134 groundwater diversions were licensed in the County. The total maximum authorized diversion from these 134 water wells is 4,554 cubic metres per day ($m^3$/day); 63 percent of the authorized groundwater diversion is allotted for agricultural use. The largest licensed groundwater diversion within the County not used for industrial purposes is for the Town of Killam, having a combined diversion of 585 $m^3$/day from two water supply wells.

The largest licensed industrial groundwater diversion within the County is 400 $m^3$/day for a PanCanadian Petroleum (PCP) water source well. The water source well is completed at a depth of 872 metres below ground surface. This water source well, in 01-06-045-11 W4M, is completed 600 metres below the depth to the top of the Lea Park Formation.

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, there is only one aquifer that is being used. The area where the greatest differences between the minimum and maximum depth occur most often is in areas where water wells completed in aquifers in the surficial deposits are most common.

Groundwaters from the surficial deposits can be expected to be chemically hard with a high dissolved iron content. The total dissolved solids (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 bedrock aquifers frequently are chemically soft with generally low concentrations of dissolved iron. The chemically soft groundwater is high in sodium concentration. Approximately 25% of the chemical analyses indicate a fluoride concentration above 1.0 mg/L.

Alberta Environmental Protection (AEP) defines the Base of Groundwater Protection as the elevation below which the groundwater is expected to have more than 4,000 mg/L of total dissolved solids. By using the ground elevation, the bedrock surface and the Base of Groundwater Protection, a depth to the Base of Groundwater Protection can be determined. This depth would be for the most part the maximum drilling depth for a water supply well. Over approximately 80% of the County, the depth to the Base of Groundwater Protection is more than 150 metres. The areas where the depth to the Base of Groundwater Protection is less than 150 metres are mainly in the northwestern and east-central parts of the County.

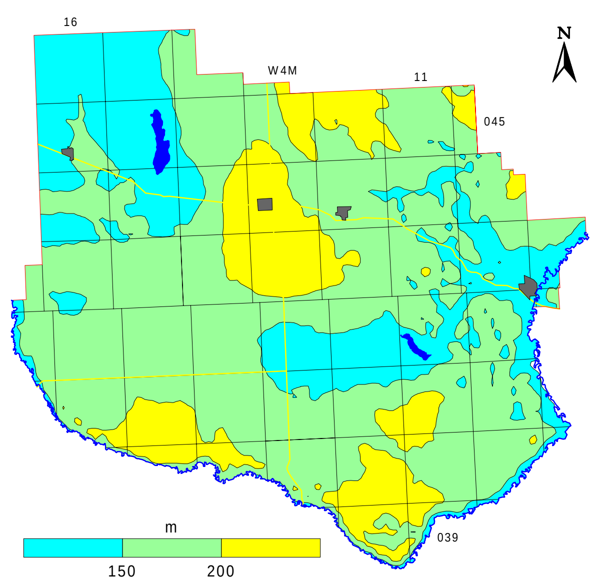



***Figure 3. Depth to Base of Groundwater Protection***

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 seven **Alberta Environmental Protection** (AEP)-operated observation water wells within Flagstaff 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

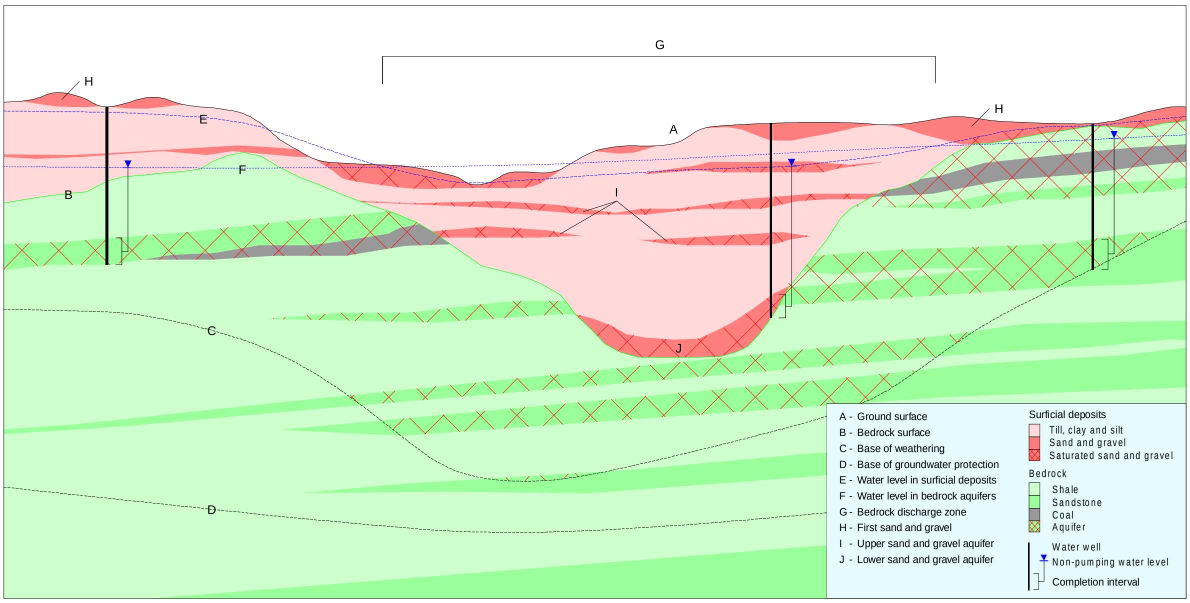



***Figure 4. Generalized Cross-Section (for terminology only)***

Depth (m): 0, 100, 200, 300, 400, 500, 600, 700, 800

| Lithology | Lithologic Description | Group and Formation: Thickness | Group | Group and Formation: Designation | Member: Thickness | Member: Designation | Zone: Thickness | Zone: Designation |
|---|---|---|---|---|---|---|---|---|
| | sand, gravel, till, clay, silt | <60 | | Surficial Deposits | <60 | Upper | <30 | First Sand and Gravel |
| | | | | | <30 | Lower | | |
| | shale, sandstone, coal, bentonite, limestone, ironstone | ~170 | Edmonton Group | Horseshoe Canyon Formation | ~170 | Lower | | |
| | shale, sandstone, siltstone | 60-120 | | Bearpaw Formation | | | | |
| | sandstone, siltstone, shale, coal | 40-80 | Belly River Group | Oldman Formation | <30 | Dinosaur Member | <25 | Lethbridge Coal Zone |
| | | | | | <20 | Upper Siltstone Member | | |
| | | | | | 8-20 | Comrey Member | | |
| | shale, sandstone, coal | 10-220 | | *continental* Foremost Formation | | | <20 | Taber Coal Zone |
| | | | | | | | <20 | McKay Coal Zone |
| | sandstone, shale | <200 | | *marine* Foremost Formation (Basal Belly River Sandstone) | <30 | Birch Lake Member | | Milan Aquifer |
| | | | | | <30 | Ribstone Creek Member | | |
| | | | | | <30 | Victoria Member | | |
| | | | | | <30 | Brosseau Member | | |
| | shale, siltstone | 100-200 | | Lea Park Formation | | | | |

***Figure 5. Geologic Column***

# 4 METHODOLOGY

## 4.1 Data Collection and Synthesis

The AEP groundwater database is the main source of 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 SW ¼ of section 09, township 044, range 12, W4M would have a horizontal coordinate with an Easting of 223,158 metres and a Northing of 5,849,730 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 then 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 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

[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

| 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***

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.

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 NPWL 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 NPWLs. 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

[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 is 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 30 metres thick, except in areas of linear bedrock lows where the thickness of surficial deposits can exceed 60 metres. The Buried Wainwright Valley is one of the main linear bedrock lows in the County. This linear low is present in the northern part of the County and trends from west to east. Cross-section A-A’ passes across the Buried Wainwright Valley approximately six kilometres west of Hardisty, and shows the thickness of the surficial deposits as being approximately 100 metres.

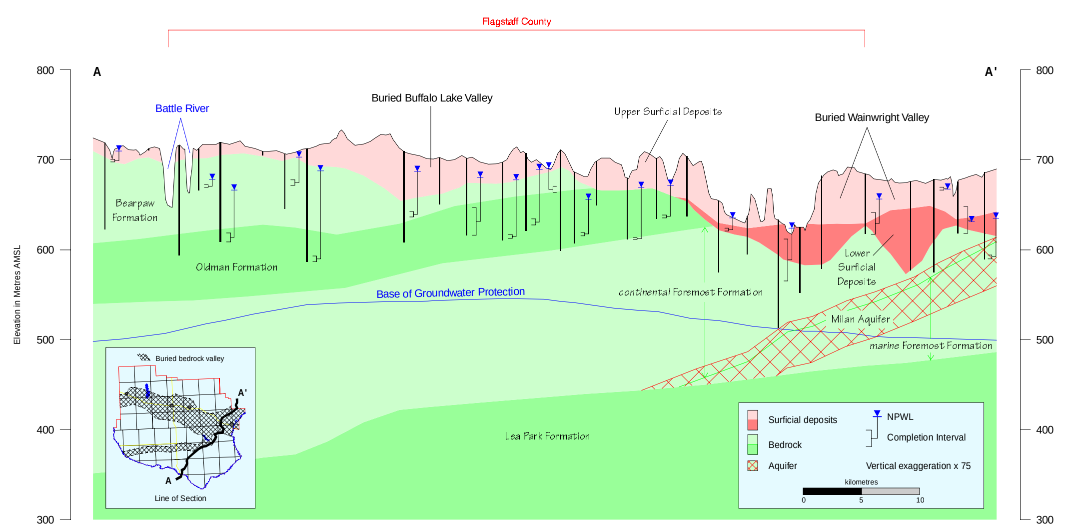



***Figure 6. Cross-Section A - A'***

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 of the 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, 24% of the water wells completed in the surficial deposits have a casing diameter of greater than 275 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, permeable and saturated rocks that have a structure that is permeable enough for the rock to be an aquifer. Water wells completed in bedrock aquifers may not require a water well screen, though some of the sandstones are friable and water well screens are a necessity. The groundwater from the bedrock aquifers is usually chemically soft. The data for 719 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 719 water wells, more than 99% have surface casing diameters of less than 275 mm and 50% of these water wells have been completed with water well screens.

The upper bedrock includes parts of the Lower Horseshoe Canyon, the Bearpaw and the Belly River Group. The Lea Park Formation underlies the Belly River Group. The Lea Park Formation is not considered part of the upper bedrock in the Flagstaff area, even though in some areas it is less than 200 metres below the bedrock surface. The present-day Battle River has eroded down almost to the base of the Lower Horseshoe Canyon Formation in the southwestern part of the County, and near the base of the Bearpaw Formation in the southern part of the County.

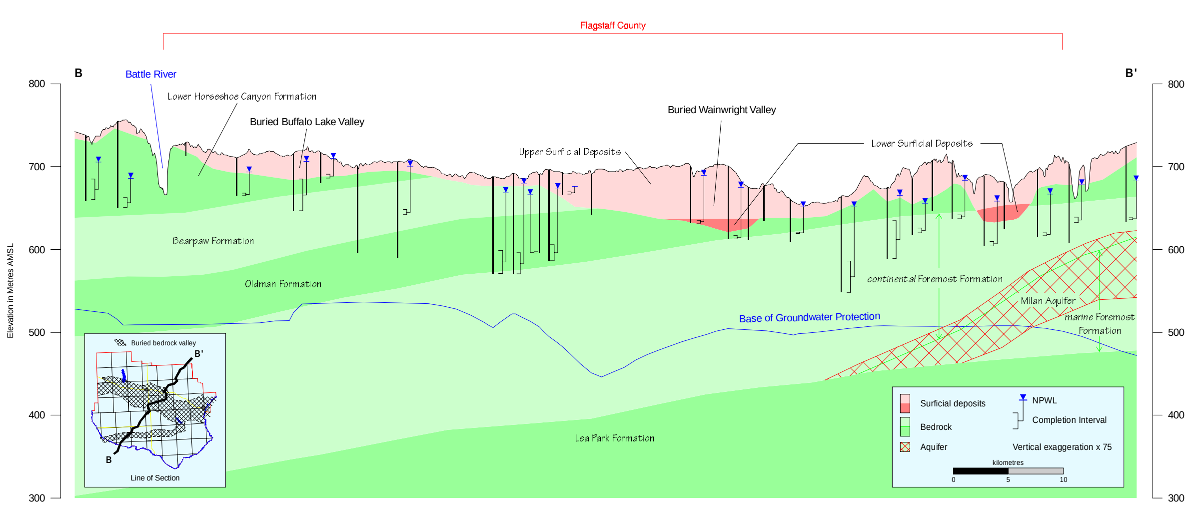



***Figure 7. Cross-Section B - B'***

## 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 pre-glacial fluvial[8] and lacustrine[9] deposits. The lacustrine deposits include clay, silt and fine-grained sand. The upper surficial deposits include the more traditional glacial deposits of till and meltwater deposits. In Flagstaff County, pre-glacial material is reported to be present in association with the Buried Wainwright Valley.

### 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. The 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”.

Over the majority of the County, the surficial deposits are less than 30 metres thick. The exceptions are mainly in association with the linear bedrock lows where the deposits can have a thickness of more than 60 metres. The main linear bedrock low in the County has been designated as the Buried Wainwright Valley, as shown on the adjacent map. This Valley trends from northwest to southeast through the County and underlies or is close to the towns of Daysland, Killam, Sedgewick and Hardisty. The Buried Wainwright Valley is approximately 8 to 15 kilometres wide, with local bedrock relief being less than 60 metres. Sand and gravel deposits can be expected to be present in association with this bedrock low, but the thickness of the sand and gravel deposits is expected to be mainly less than 30 metres. The above-mentioned towns obtain their municipal water from water supply wells completed in the sand and gravel aquifer associated with the buried valley.

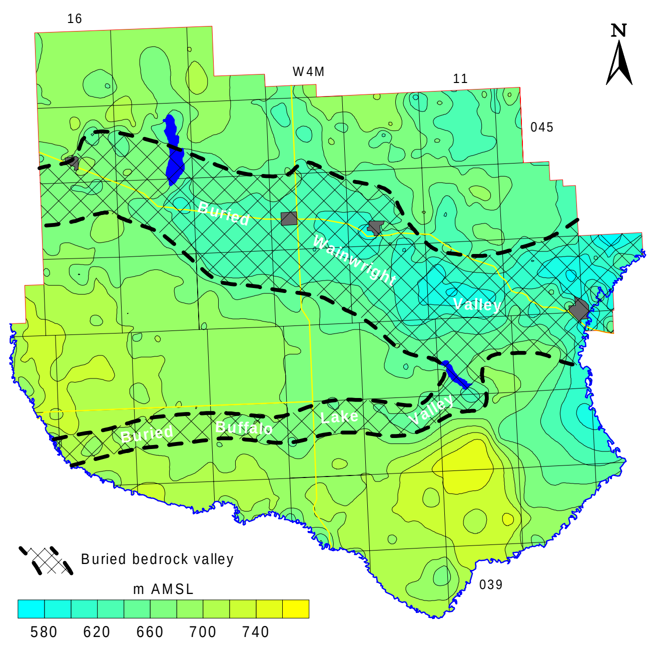



*Figure 8. Bedrock Topography*

---

8 See glossary
9 See glossary

The second linear bedrock low is designated as the Buried Buffalo Lake Valley. The Buried Buffalo Lake Valley trends from west to east and is a tributary valley to the Buried Wainwright Valley. The Buried Buffalo Lake Valley is approximately five kilometres wide, with local relief being less than 40 metres. Sand and gravel deposits can be expected to be present in association with this bedrock low, with the thickness of the deposits expected to be less than 30 metres.

In addition to the linear bedrock lows, there is a significant low in the bedrock surface in the southeastern part of the County. In the eastern part of the County, the bedrock surface is poorly understood. The difficulty in defining the bedrock surface is a result of friable sandstones in the bedrock that can be identified as “sand” by the drillers and the presence of ice-thrusted blocks of bedrock. For example, the bedrock high between the two parts of the Buried Wainwright Valley on cross-section A-A’ may be a result of a block of bedrock having been thrusted into the valley, overlying fluvial deposits at depth.

Sand and gravel deposits can occur throughout the entire unconsolidated section. The combined thickness of all sand and gravel deposits has been determined as a function of the total thickness of the surficial deposits. Over approximately 25% of the County, the sand and gravel deposits are more than 50% of the total thickness of the surficial deposits. The main areas where the sand and gravel percentages are higher are in the southeastern part of the County and in association with linear bedrock lows. The other areas where sand and gravel deposits constitute more than 50% of the surficial deposits may be areas of meltwater channels or areas where linear bedrock lows exist but have not been identified due a shortage of accurate bedrock control points.

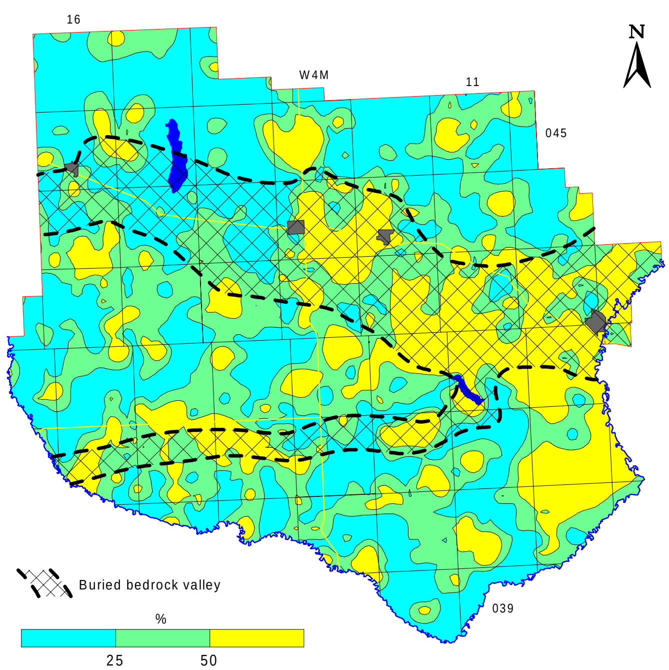



***Figure 9. Amount of Sand and Gravel in Surficial Deposits***

### 5.2.2 Sand and Gravel Aquifer(s)

One significant 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.

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. Based on these data, water wells with yields of more than 100 m³/day from sand and gravel aquifer(s) can be expected in more than 25% of the County. Over approximately 15% of the County, the sand and gravel deposits are not present or, if present, are not saturated.

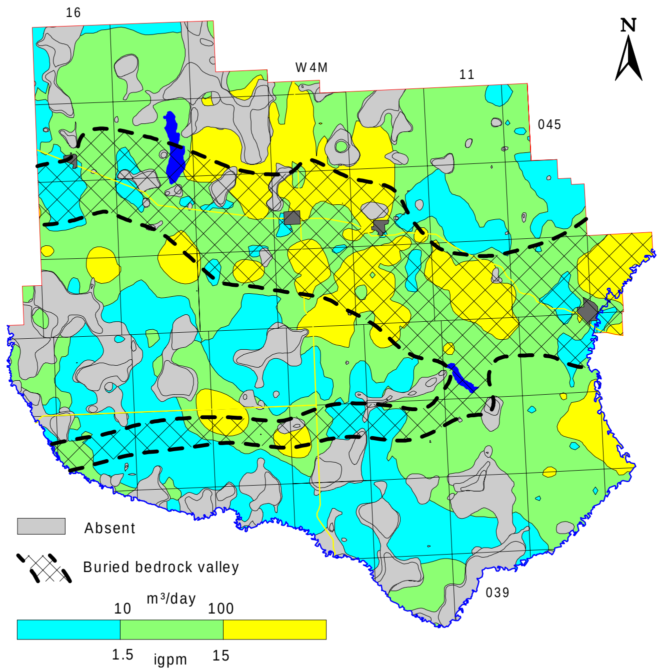



***Figure 10. Apparent Yield for Water Wells Completed through Sand and Gravel Aquifer(s)***

The highest yield from surficial deposits that has been developed in the County for towns along Highway 13 was for the Town of Hardisty. The Town uses a sand and gravel aquifer associated with the Buried Wainwright Valley. Extensive studies of this aquifer indicated a long-term supply of more than 500 m³/day (AEP, 1979). Studies of this aquifer from water wells completed for the Town of Daysland indicated a long-term yield of 330 m³/day (Geoscience, March 1976); and for the Town of Killam, a long-term yield of 420 m³/day (Geoscience, April 1976). Studies for the Town of Sedgewick were not available.

#### *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 calcium-magnesium-bicarbonate-type waters; however, there are groundwaters from the surficial deposits that are calcium-magnesium-sulfate, sodium-bicarbonate or sodium-sulfate-type waters.

Fifty percent of the groundwaters from the surficial aquifers have a chemical hardness of less than 400 mg/L. The TDS concentrations in the groundwaters from the surficial deposits range from less than 200 to over 2,000 mg/L, with 60% of the groundwaters having a TDS of less than 1,000 mg/L. The groundwaters with a TDS of more than 2,000 mg/L occur mainly in the northern part of the County. The groundwaters with elevated levels of sulfate occur in areas where there are elevated levels of total dissolved solids. When TDS values exceed 1,200 mg/L, sulfate concentrations exceed 400 mg/L.

There are very few groundwaters with appreciable concentrations of the chloride ion. All of the groundwaters from the surficial deposits are expected to have concentrations of dissolved iron of greater than 1 mg/L.

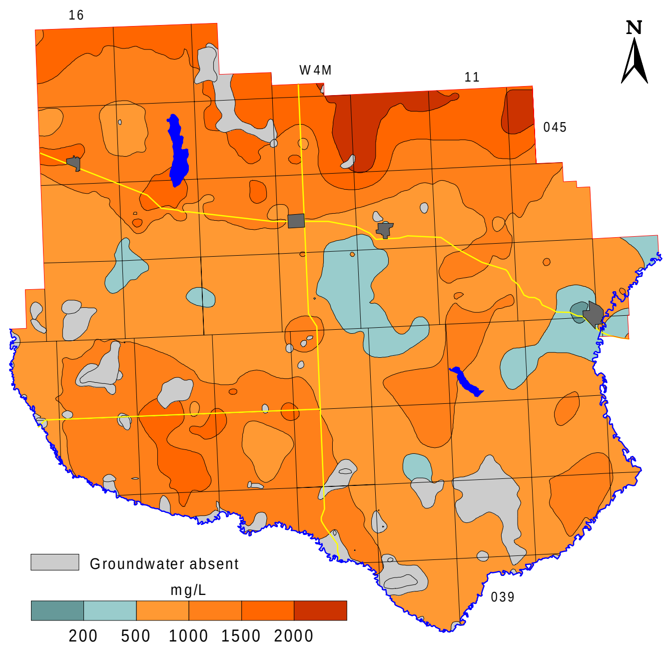



***Figure 11. Total Dissolved Solids in Groundwater from Surficial Deposits***

### 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 670 metres AMSL. Saturated sand and gravel deposits are not continuous but are expected over approximately 90% of the County.

#### *5.2.3.1 Aquifer Thickness*

The non-pumping water level in the surficial deposits tends to be a subdued replica of the bedrock surface. Consequently, 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 30 metres thick in a few areas, but over the majority of the County, is less than ten metres thick; over 10% of the County, the Aquifer is absent. Most of the greater thickness in the Upper Sand and Gravel Aquifer occurs in the areas of linear bedrock lows and in the southeastern part of the County. The major bedrock low in the southeastern part of the County is not presently associated with a linear bedrock low.

#### *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 yields of the water wells are 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.

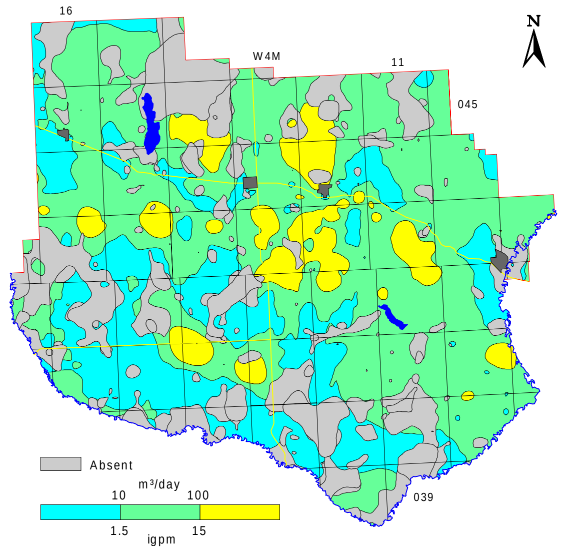



***Figure 12. Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer***

### 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 where the bedrock surface is below a depth of 670 metres AMSL. The Lower Sand and Gravel Aquifer may be a continuous aquifer in the Buried Wainwright Valley, where the thickness of the sand and gravel deposits is mainly less than 10 metres. The Lower Sand and Gravel Aquifer does not appear to extend west of range 15. In all, the Lower Sand and Gravel Aquifer is mostly restricted to the northeastern and eastern parts 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 Wainwright Valley in the vicinity of the Town of Hardisty; in township 043, range 11, W4M; and in the eastern part of township 041, range 10, W4M. The results of detailed studies for the individual towns suggest that long-term yields for some water wells are more than 300 m³/day.

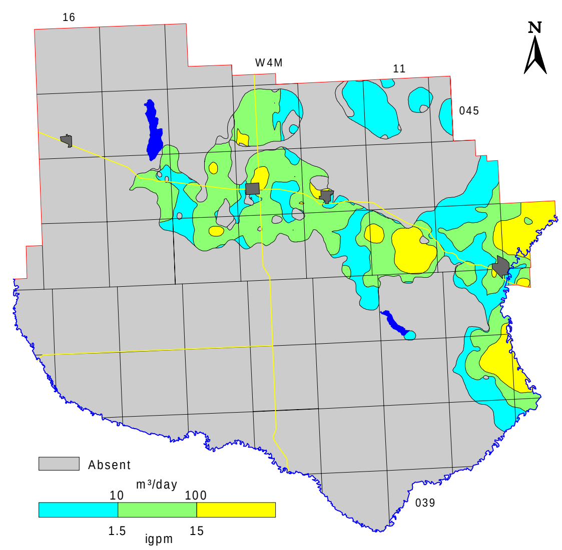



***Figure 13. Apparent Yield for Water Wells Completed through Lower Sand and Gravel Aquifer***

## 5.3 Bedrock

### 5.3.1 Geological Characteristics

The upper bedrock in the County includes the Lower Horseshoe Canyon Formation, the Bearpaw Formation and the Belly River Group. The Lea Park underlies the Belly River Group.

The Lower Horseshoe Canyon Formation is the lower part of the Edmonton Group and is the upper bedrock in the western part of the County. There are also subcrops of the Lower Horseshoe Canyon Formation that occur as outliers within the area of the Bearpaw Formation. The Lower Horseshoe Canyon Formation has a maximum thickness of 170 metres. The Upper and the Middle Horseshoe Canyon formations are absent within the County.

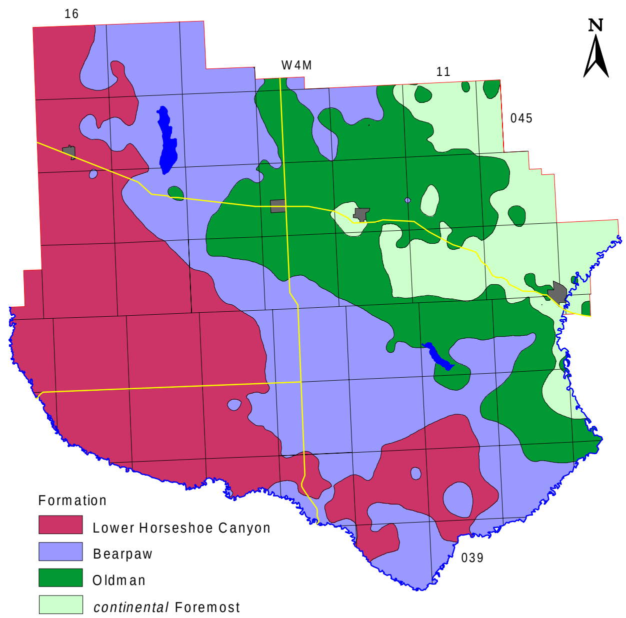



***Figure 14. Bedrock Geology***

The Lower Horseshoe Canyon Formation consists of deltaic[10] and fluvial sandstone, siltstone and shale layers 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 of the Lower Horseshoe Canyon can include coarser grained sandstone deposits. The Lower Horseshoe Canyon Formation is underlain by the Bearpaw Formation.

The Bearpaw Formation is the upper bedrock in the west-central part of the County and has been eroded in the northeastern half of the County. The Bearpaw Formation is generally less than 100 metres thick in the County. “The Bearpaw Formation consists of marine shale, siltstone and minor sandstone, and represents the final widespread marine unit in the Western Canada Foreland Basin” (Catuneanu et al, 1997). The border between the bottom of the Bearpaw Formation and the uppermost part of the Belly River Group was used as a geological marker in the e-log interpretation.

The Belly River Group in the County has a maximum thickness of 250 metres and includes the Oldman Formation, and both the *continental* and *marine* facies[11] of the Foremost Formation. There are zones of higher permeability that occur in the *marine* facies of the Belly River Group. These porous and permeable zones are present in the northeastern one quarter of the County but there are very few areas where they are within 100 metres of the ground surface. Where the porous and permeable zones are present, the fluids in the aquifers may be hydrocarbons or groundwater. However, the groundwater could be expected to have total dissolved solids concentrations of 15,000 mg/L.

---

[10] See glossary
[11] See glossary

The Oldman Formation is the upper bedrock in the east-central part of the County. There are also subcrops of the Oldman Formation that occur as outliers within the area of the *continental* Foremost Formation. The Oldman Formation has a maximum thickness of 75 metres within the County and is composed of sandstone, siltstone, shale and coal deposited in a continental environment. The Oldman Formation is the upper part of the Belly River Group and is composed of three parts: the Comrey, the Upper Siltstone and the Dinosaur members. The uppermost part of the Dinosaur Member is the Lethbridge Coal Zone. Sandstone is predominant in the Comrey Member, the Upper Siltstone is mainly siltstone, and the Dinosaur Member includes shale and coal deposits.

The *continental* Foremost Formation underlies the Oldman Formation and subcrops under the surficial deposits in the northeastern part of the County. The *continental* Foremost Formation, a backshore deposit, consists mainly of shale deposits with minor amounts of sandstone present. Coal zones occur within the *continental* Foremost Formation, with the main ones referred to as the McKay and the Taber Coal Zones. There are also minor amounts of ironstone, a chemical deposit, in the *continental* Foremost Formation. Where the *continental* Foremost Formation is close to the bedrock surface, it can be fractured or weathered and can have significant local permeability. The *marine* Foremost Formation, which includes up to five sandstone members and has a maximum thickness of 50 metres within the County, underlies the *continental* Foremost Formation.

The upper part of the *marine* Foremost Formation is present in the eastern part of the County. The sandstones in the *marine* Foremost Formation cannot always be separated into individual members that are identified east of Flagstaff County. This situation occurs because the sandstone members of the *marine* Foremost Formation thicken and the intervening shale layers thin toward the western edge of the *marine* facies. With this change, distinguishing between the individual sandstone members is not possible. Even though the individual members cannot be distinguished, the sandstone occurrence can be a significant aquifer and has been designated the “Milan Aquifer”. The top of the Milan Aquifer extends up to 10 metres into the overlying *continental* Foremost Formation and can occupy the upper 40 metres of the *marine* Foremost Formation. The westward extent of the Milan Aquifer coincides with the position where the Basal Belly River Sand can be distinguished. In the Flagstaff County, both the *marine* Foremost Formation and the Milan Aquifer are present under the *continental* Foremost Formation in the northeastern part of the County but do not subcrop in the County.

The Lea Park Formation is mostly composed of shale, with only minor amounts of bentonitic sandstone present in some areas. Regionally, the Lea Park Formation is an aquitard[12].

### 5.3.2 Aquifers

Of the 3,926 water wells in the database, 719 were defined as being completed in bedrock aquifers. This designation is based on the top of the completion interval being below the bedrock surface. The completion depth is available for the majority of water wells. In order to make use of additional information within the groundwater database, it was statistically determined that water wells typically have completion intervals

| Bedrock Aquifer | No. of Water Wells |
| --- | --- |
| Lower Horseshoe Canyon | 570 |
| Bearpaw | 390 |
| Oldman | 416 |
| *continental* Foremost | 389 |
| *marine* Foremost | 8 |
| Milan | 6 |
| Lea Park | 0 |

***Table 2. Bedrock Aquifer Completion***

12 See glossary

equivalent to one quarter of their completed depth. This relationship was used to increase the number of water wells identified as completed in bedrock aquifers to 2,092 from 719. With the use of geological surfaces that were determined from the interpretation of geophysical logs, it has been possible to assign the water wells completed in bedrock aquifers to specific aquifers based on their completion intervals. The bedrock water wells are mainly completed in the Lower Horseshoe Canyon, the Bearpaw, the Oldman, and the *continental* Foremost aquifers as shown in the adjacent table; 313 bedrock water wells are completed in more than one aquifer. The discussions related to specific aquifers, later in this report, do not include the Milan or *marine* Foremost Aquifers. However, maps associated with these two aquifers are included on the CD-ROM.

The records for the existing water wells completed in bedrock aquifer(s) indicate that, in Flagstaff County, water well yields can be expected to be mainly less than 30 m³/day, with large areas having expected long-term yields of less than 10 m³/day. The adjacent map shows that water well yields in the eastern part of the County are generally higher. In some of the eastern area, projected long-term yields are greater than 100 m³/day. These higher yields may be a result of fracturing caused by ice thrusting of bedrock blocks.

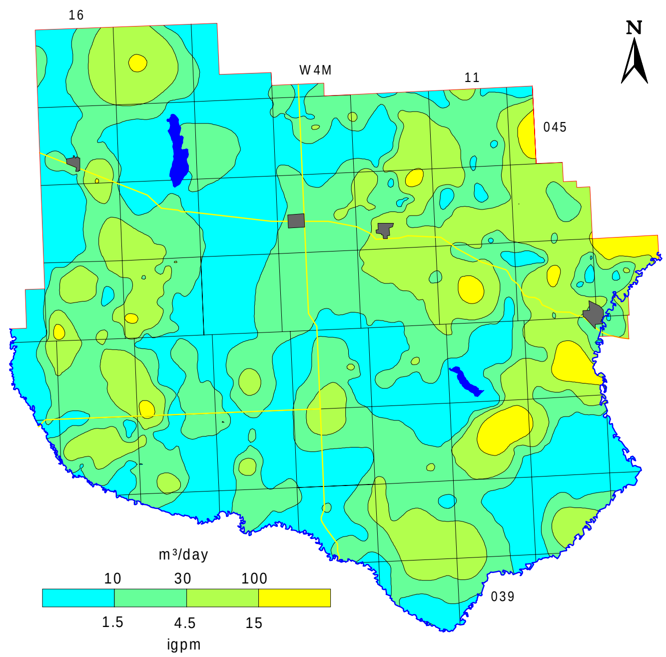



***Figure 15. Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)***

The general area of lower projected yields in the central part of the County corresponds to the subcrop area of the Bearpaw Formation. Immediately west of the Bearpaw Formation subcrop is the subcrop of the Lower Horseshoe Canyon Formation. And in this area, water well yields tend to be higher. Further east, water well yields decline as the lower part of the Lower Horseshoe Canyon Formation is at a greater depth and the upper bedrock is the upper part of the Lower Horseshoe Canyon Formation.

### 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 50% of the area, TDS values are less than 1,000 mg/L, with only a few areas having TDS concentrations of less than 500 mg/L. In general terms, the lowest values for TDS are expected in the central part of the County, with the higher values along the northern and southern parts of the County, a pattern that is similar to the TDS concentrations in the groundwaters from the surficial deposits.

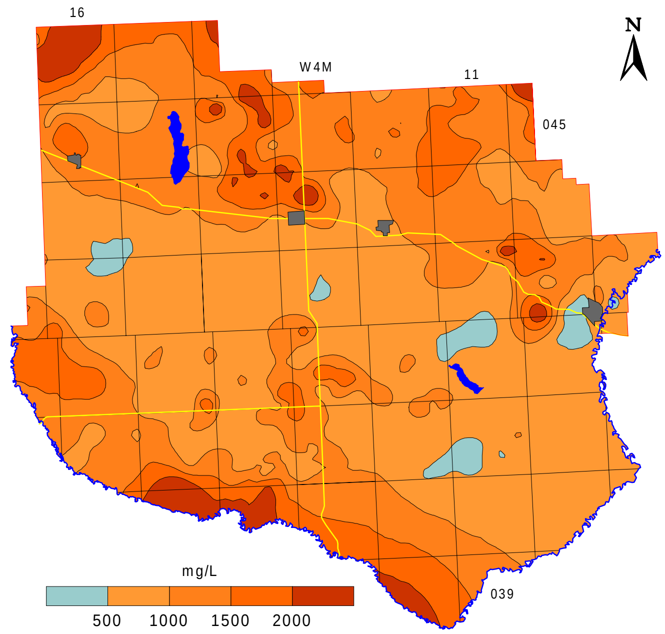



***Figure 16. Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)***

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 chloride concentration in groundwater from the upper bedrock aquifer(s) does exceed 250 mg/L in some areas, most noticeably in the northwestern segment of the County.

In 80% of the County, the fluoride ion concentration in the groundwater from the upper bedrock aquifer(s) is less than 1.0 mg/L. The higher values of fluoride are associated with the areas where the Bearpaw Formation subcrops.

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

### 5.3.4 Lower Horseshoe Canyon Aquifer

The Lower Horseshoe Canyon Aquifer is part of the Lower Horseshoe Canyon Formation that underlies 300 square kilometres in the western and southern parts of the County. The thickness of the Lower Horseshoe Canyon Formation is generally less than 80 metres; in the northern and eastern two-thirds of the County, the Lower Horseshoe Canyon Formation has been eroded. The lowest 70 metres of the Horseshoe Canyon Formation tend to contain the more porous and permeable materials.

#### *5.3.4.1 Depth to Top*

The depth to the top of the Lower Horseshoe Canyon Formation is mainly less than 40 metres below ground level and is a reflection of the thickness of the surficial deposits. Close to the western edge of the County, the Lower Horseshoe Canyon Formation is approximately 100 metres thick. In these areas, water well depths would need to be greater that 60 metres to encounter the lower part of the Formation, assuming a thickness of 20 metres for the surficial deposits.

#### *5.3.4.2 Apparent Yield*

The projected long-term yield for individual water wells completed through the Lower Horseshoe Canyon Aquifer is mainly in the range of 10 to 100 m³/day. The areas where water wells with higher yields are expected are mainly in the west-central part of the County in townships 041 to 044. There is no apparent relationship between expected water well yield and thickness of the Aquifer. Some of the higher yields are expected close to the erosional edge of the Aquifer.

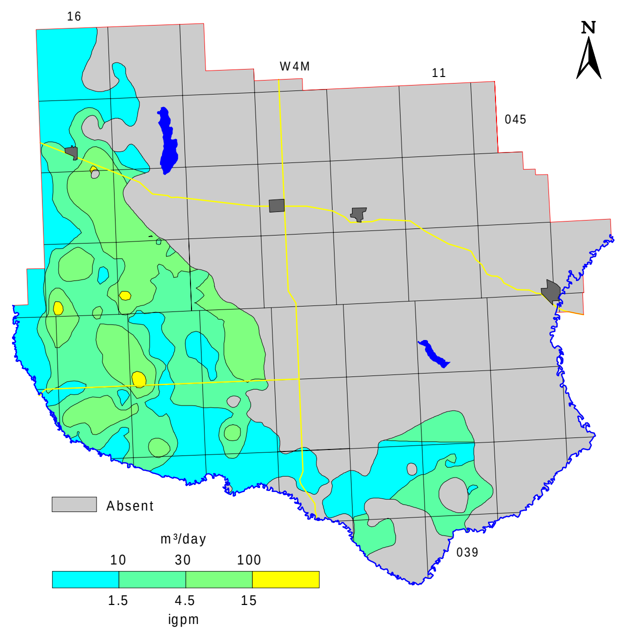



***Figure 17. Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer***

#### *5.3.4.3 Quality*

The TDS concentrations for groundwater from the Lower Horseshoe Canyon Aquifer range mainly from less than 1,000 to more than 2,000 mg/L. There are a few small areas in the County where the TDS of groundwater from the Lower Horseshoe Canyon Aquifer is less than 500 mg/l. The higher values of TDS occur in the extreme northwestern part of the area in township 046, range 16, W4M and in the extreme southern part of the County next to the Battle River in ranges 14 and 15, W4M. When TDS values in the groundwater from the Lower Horseshoe Canyon Aquifer exceed 1,300 mg/L, the sulfate concentrations exceed 400 mg/L.

The chloride concentration of the groundwater from the Lower Horseshoe Canyon Aquifer can be expected to be less than 100 mg/L. In a few small areas, mainly in the southwestern part of the County, the chloride concentration exceeds 250 mg/L.

### 5.3.5 Bearpaw Aquifer

The Bearpaw Aquifer is the upper part of the Bearpaw Formation and subcrops under the west-central part of the County. The thickness of the Bearpaw Formation is generally less than 80 metres and is present only in the western part of the County; in the remainder of the County, the Bearpaw Formation has been eroded.

#### *5.3.5.1 Depth to Top*

The depth to the top of the Bearpaw Formation is mainly less than 60 metres below ground level. The largest area where the top of the Bearpaw Formation is more than 60 metres below ground level is in the southwestern part of the County, where the Bearpaw Formation underlies the Lower Horseshoe Canyon Formation and the depth to the top can exceed 140 metres.

#### *5.3.5.2 Apparent Yield*

The projected long-term yields for water wells completed through the Bearpaw Aquifer are mainly less than 10 m³/day. The higher yields occur in townships 039 and 040, ranges 11 and 12, W4M. These higher yields may be related to inaccurate classification due to poor stratigraphic control.

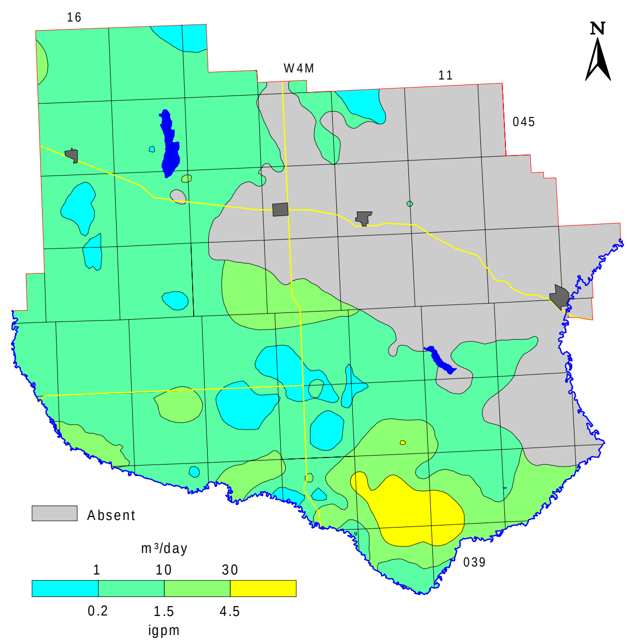



***Figure 18. Apparent Yield for Water Wells Completed through Bearpaw Aquifer***

#### *5.3.5.3 Quality*

The Piper tri-linear diagrams show that sodium-bicarbonate and sodium-sulfate are the dominant types of groundwater in the Bearpaw Aquifer. The TDS concentrations in groundwater from the Bearpaw Aquifer range mainly from 500 to more than 2,000 mg/L. The lower TDS values tend to be in the southern half 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 Bearpaw Aquifer are mostly less than 100 mg/L. The exceptions occur in the northwestern and the southern parts of the County, where chloride concentrations can exceed 250 mg/L.

Fluoride maps have not been made for individual bedrock aquifers. However, the average fluoride concentration in the Bearpaw Aquifer is 0.5 mg/L, with individual values being over 1 mg/L in some areas.

### *5.3.6* Oldman Aquifer

The Oldman Aquifer is part of the Oldman Formation that underlies the Bearpaw Formation and subcrops in the east-central part of the County. The thickness of the Oldman Aquifer is generally 60 metres in the eastern part of the County. In the western part of the County, the thickness can be more than 100 metres.

#### *5.3.6.1 Depth to Top*

The depth to the top of the Oldman Formation is mainly less than 20 metres in the northeastern part of the County where it subcrops. In the western part of the County where the Oldman is below the Bearpaw and the Lower Horseshoe Canyon formations, the depth to the top of the Oldman Formation can be more than 160 metres.

#### *5.3.6.2 Apparent Yield*

The projected long-term yields for individual water wells completed in the Oldman Aquifer are mainly less than 30 m³/day. However, the large expanse of low expected yields may be a reflection of the limited amount of data rather than the hydraulic properties of the Aquifer. The adjacent map indicates that water wells with apparent yields of more than 100 m³/day are expected toward the eastern edge of the Oldman Formation. There are little or no data for the Aquifer in the western parts of the County. In these areas, the Oldman Aquifer would be at a depth of more than 160 metres.

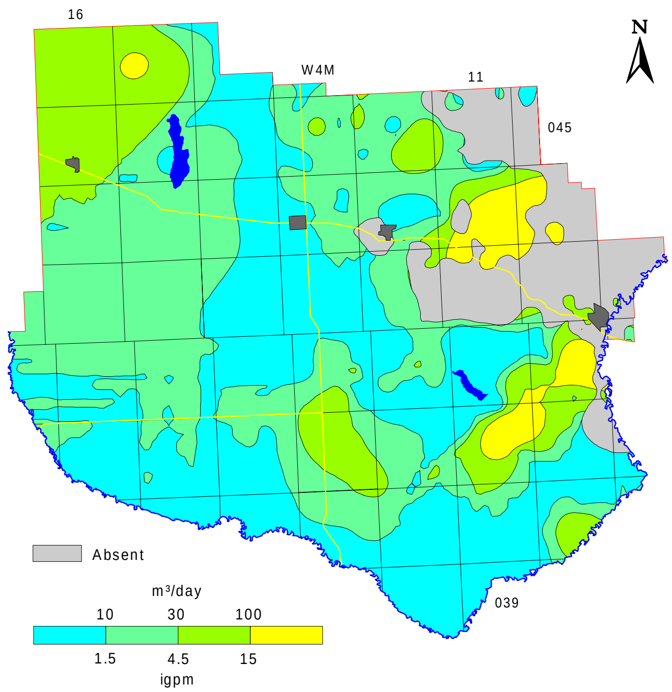



***Figure 19. Apparent Yield for Water Wells Completed through Oldman Aquifer***

#### *5.3.6.3 Quality*

Groundwaters from the Oldman Aquifer are mainly sodium-bicarbonate or sodium-sulfate type waters. TDS concentrations are expected to be between 500 and 2,000 mg/L. In the western part of the County, there is a paucity of data. When TDS values exceed 1,200 mg/L, the sulfate concentrations exceed 400 mg/L.

Chloride concentrations in the groundwater from the Oldman Aquifer are mainly less than 250 mg/L in the eastern part of the County and more than 250 mg/L in the western part of the County. The high values in the western part of the County are based on very little control.

### 5.3.7 *Continental* Foremost Aquifer

The *continental* Foremost Aquifer is part of the *continental* Foremost Formation and subcrops under the northeastern part of the County. The thickness of the *continental* Foremost Aquifer can be up to 180 metres in the western part of the County. The *continental* Foremost Aquifer does not include that part of the Formation attributed to the Milan Aquifer.

#### *5.3.7.1 Depth to Top*

The *continental* Foremost Formation is present under the entire County. The depth to the top of the Formation is variable, ranging from less than 20 metres where it subcrops in the eastern part of the County, to more than 280 metres in the western part of the County. In the western and southern parts of the County, the depth to the top of the Formation is more than 100 metres.

#### *5.3.7.2 Apparent Yield*

The projected long-term yields for individual water wells completed in the *continental* Foremost Aquifer are mainly between 10 and 50 m³/day. The adjacent map indicates that apparent yields of more than 50 m³/day are expected where the Aquifer subcrops and there could be increased permeability as a result of weathering processes. There are little or no data for the Aquifer in the western third of the County, and the map indicates that expected water well yields are less than 10 m³/day. The low yields presented in the western third of the County could be a result of the gridding procedure used to process a very limited number of data points.

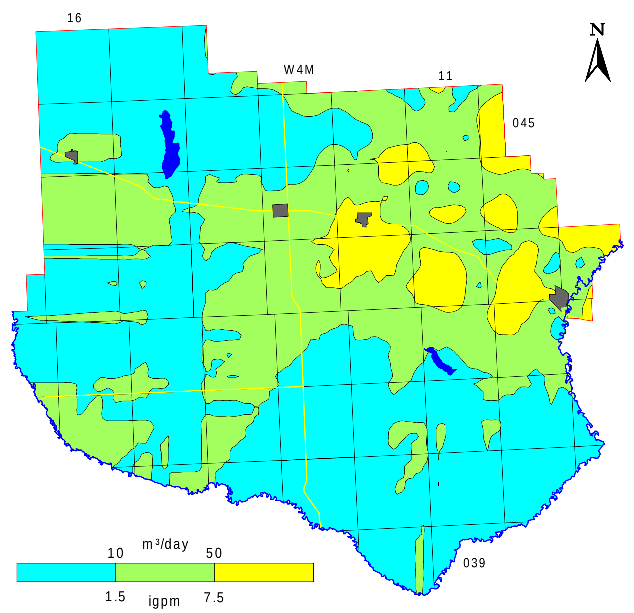



***Figure 20. Apparent Yield for Water Wells Completed through continental Foremost Aquifer***

#### *5.3.7.3 Quality*

Groundwaters from the *continental* Foremost Aquifer are mainly sodium-bicarbonate or sodium-sulfate type waters. TDS concentrations are expected to be in the order of 500 to 2,000 mg/L although there is a paucity of data from the western and southern parts 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 *continental* Foremost Aquifer are mainly less than 250 mg/L where the Formation subcrops. The indications are that in the western part of the County where the Aquifer is deeper, the chloride concentration is expected to be over 250 mg/L.

There is no detailed discussion for the Milan and *marine* Foremost Aquifers. However, maps are provided on the CD-ROM for each of the Aquifers.

# 6 GROUNDWATER BUDGET

## 6.1 Hydrographs

There are seven 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. Three of the observation water wells are located in the vicinity of the Town of Hardisty; their hydrographs are shown in the adjacent graphs.

Obs WW Nos. 142 and 143 are located in 01-043-10 W4M, 700 metres from the nearest Town of Hardisty water supply well. The water level in both of these observation water wells has declined 0.8 metres over the last eight years. The nature of the yearly fluctuation in the water level in the observation water wells is indicative of a municipal use of groundwater. The similarity of the water-level fluctuations is unusual because Obs WW No. 143 is completed in the Lower Sand and Gravel Aquifer and Obs WW No. 142 is completed in the *continental* Foremost Aquifer. Also, there is a difference in the NPWL of the two observation water wells of 4.3 metres, with the NPWL in Obs WW No. 142 being the lower water level. (The water-level elevations given by AEP are incorrect).

AEP Obs WW No. 139 is completed in the Oldman Aquifer. The water level in this observation water well has risen more than 0.5 metres over the last 12 years. This observation water well is 4.7 kilometres from the nearest Town of Hardisty water supply well.

Hydrographs for the other four observation water wells are available on the CD-ROM.

In general, all of the hydrographs reflect local hydrogeological conditions, and have not been used for the regional budget analysis.

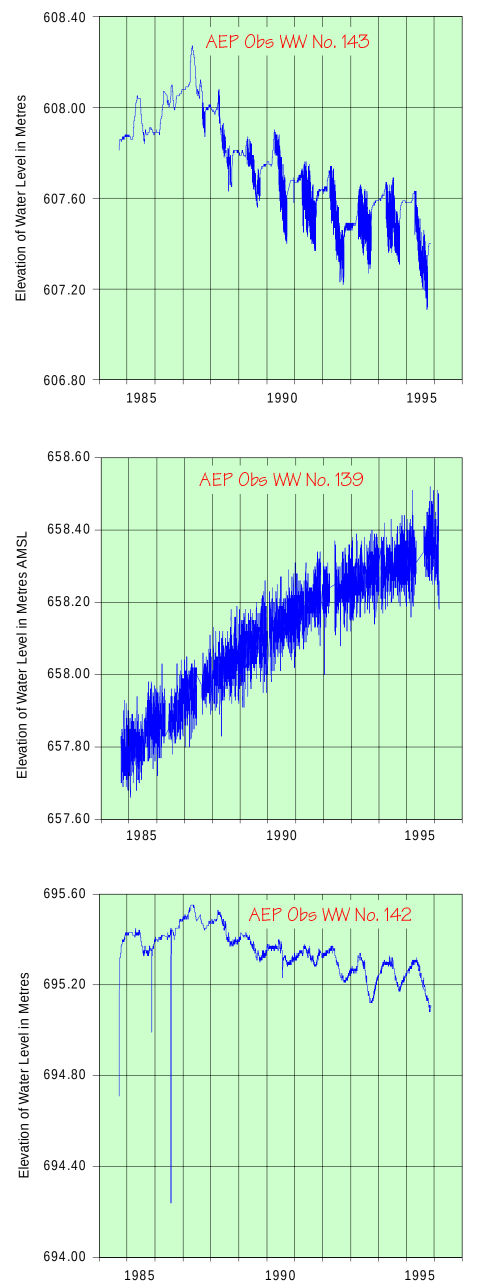



***Figure 21. Hydrographs - AEP Observation Water Wells***

## 6.2 Groundwater Flow

A direct measurement of groundwater recharge or discharge is not possible from the data that are 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 through an aquifer 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 flow through each aquifer assumes that by taking a large enough 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) | Authorized Diversion ($m^3$/day) |
|---|---|---|---|---|---|---|
| Upper Surficial Deposits | | | | | 720 | 917 |
| North part of Buried Wainwright Valley | 3 | 0.002 | 60 | South/Southeast | 360 | |
| South part of Buried Wainwright Valley | 3 | 0.002 | 60 | North/Northeast | 360 | |
| Buried Wainwright Valley | 20 | 0.0025 | 15 | East/Southeast | 750 | 1005 |
| Lower Horseshoe Canyon Formation | 3 | 0.002 | 100 | Southwest/East | 600 | 1176 |
| Bearpaw Formation | 0.6 | 0.002 | 100 | Southwest/East | 120 | 481 |
| Oldman Formation | 3 | 0.002 | 60 | East/Northeast | 360 | 249 |
| *Continental* Foremost Formation | 1 | 0.003 | 50 | East | 150 | 247 |

The Authorized Diversion column is the amount of groundwater diversion that has been authorized by AEP under the Water Resources Act. The authorized diversions are greater than the calculated flow through the aquifers. However, the calculated flow is a very rough estimate and tends to be conservative. The recharge to these aquifers would be restricted mainly to Flagstaff County, except for the Buried Wainwright Valley Aquifer.

### 6.2.1 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.

#### *6.2.1.1 Surficial Deposits/Upper 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, associated with all water wells completed in upper bedrock aquifers from the non-pumping water-level surface determined for all water wells in the surficial deposits,. 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 water level in the surficial deposits is between five metres above and five metres below the water level in the bedrock, the area is classified as a transition.

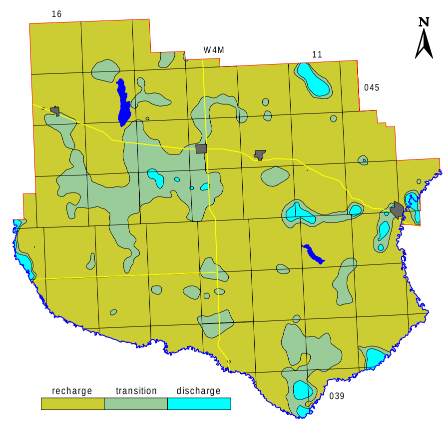



*Figure 22. Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)*

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 along the Battle River in the southeastern part of the County and in the vicinity of lows in the bedrock surface. 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 limited topographic relief and/or limited data for both aquifer conditions.

The limited amount of discharge from the bedrock to the surficial deposits in the linear bedrock lows is the result of relatively high elevations of water levels in the surficial deposits. The high elevation of the water levels in the surficial deposits may be a result of the lower sand and gravel aquifer being discontinuous as a result of ice-thrusted blocks of bedrock. The other reason for the higher elevation of the water level in the surficial deposits may be a result of a limited amount of data.

### 6.3 Bedrock Aquifers

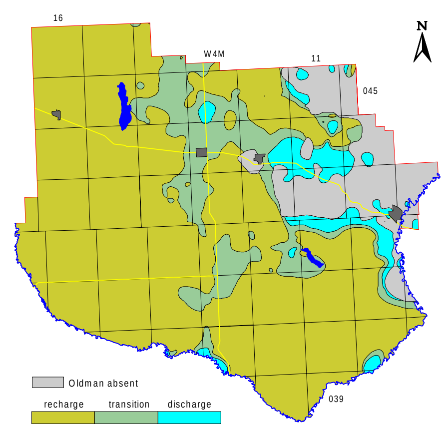



*Figure 23. Recharge/Discharge Areas between Surficial Deposits and Oldman Aquifer*

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.

The hydraulic relationship between the surficial deposits and the Oldman Aquifer indicates that in 80% of the County where the Oldman Formation is present, there is a downward hydraulic gradient. Discharge areas are adjacent to the bedrock low in the east-central part of the County.

# 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 2,101 records in the area of the County with lithology descriptions, 418 have sand and gravel within one metre of ground level. In the remaining 1,683 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 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 3. Risk of Groundwater Contamination Criteria***

The Risk of Groundwater Contamination map shows that, in 40% 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.

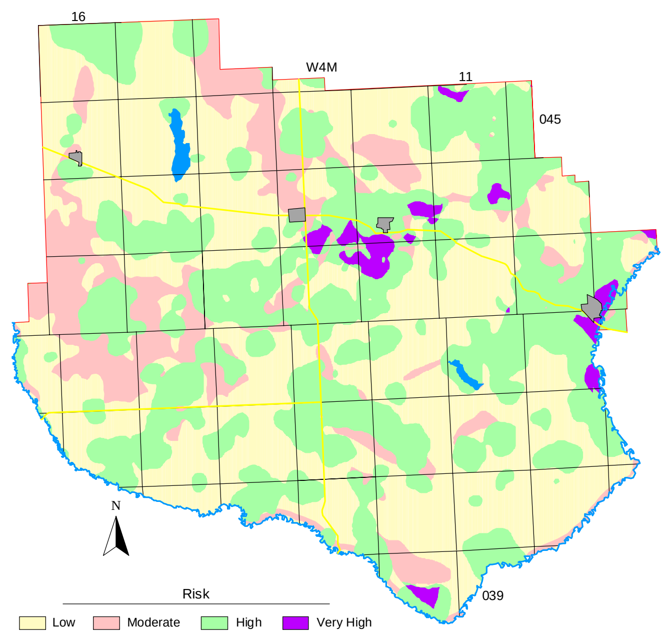



***Figure 24. Risk of Groundwater Contamination***

# 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 main sources of groundwater are in the eastern part of the County. However, in this area there is a very poor understanding of the local hydrogeology. The bedrock surface cannot be defined with confidence, water well yields are significantly different than in other parts of the County, and the groundwater contains fewer dissolved minerals. In order to understand the local hydrogeology in townships 040 to 043, ranges 10 and 11, W4M, it will be necessary to conduct a detailed groundwater study in the area. The program would need to verify as much of the existing data as possible, synthesize the data to determine locations for the drilling of water test holes, and conduct the necessary drilling.

Another area where insufficient data are available is for the determination of a groundwater budget. There are only seven 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 (two hours of pumping and 2 hours of recovery) 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 construction of lease sites for the drilling of hydrocarbon wells and conducting of seismic programs.

**Groundwater is a renewable resource and it must be managed.**

# 9 REFERENCES

Alberta Environmental Protection. June 1979. Hardisty, Groundwater Study. Report Prepared by Environmental Protection Services.

Carrigy, M. A. 1971. Lithostratigraphy of the Uppermost Cretaceous (Lance) and Paleocene Strata of the Alberta Plains. Research Council of Alberta. Bulletin 27.

Catuneanu, Octavian, Andrew D. Miall and Arthur R. Sweet. 1997. Reciprocal Architecture of Bearpaw T-R Sequences, Uppermost Cretaceous, Western Canada Sedimentary Basin. Bulletin of Canadian Petroleum Geology. Vol. 45, No. 1 (March, 1997), P. 75-94.

Associated Engineering Services Ltd. April 1967. Town of Killam Water Supply Study. Unpublished Contract Report.

Geoscience Consulting Ltd. March 1976. Evaluation of Water Supply. Daysland, Alberta. Prepared for Alberta Environment.

Geoscience Consulting Ltd. April 1976. Evaluation of Water Supply. Killam, Alberta. Prepared for Alberta Environment.

Hackbarth, D. A. 1975. Hydrogeology of the Wainwright area, Alberta. Earth Sciences Report No. 75-1. Alberta Research Council.

Le Breton, E. G. February 1961. Groundwater prospects of the Killam area. Research Council of Alberta.

Le Breton, E. Gordon. 1971. Hydrogeology of the Red Deer Area, Alberta. Research Council of Alberta. Report 71-1.

Mossop, G. and I. Shetsen (co-compilers). 1994. Geological Atlas of the Western Canada Sedimentary Basin. Produced jointly by the Canadian Society of Petroleum Geology, Alberta Research Council, Alberta Energy, and the Geological Survey of Canada.

Ozoray, G., M. Dubord and A. Cowen. 1990. Groundwater Resources of the Vermilion 73E Map Area, Alberta. Alberta Environmental Protection.

Pettijohn, F. J. 1957. Sedimentary Rocks. Harper and Brothers Publishing.

Shetsen, I. 1990. Quaternary Geology, Central Alberta. Produced by the Natural Resources Division of the Alberta Research Council.

Thornthwaite, C. W. and J. R. Mather. 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Drexel Institute of Technology. Laboratory of Climatology. Publications in Climatology. Vol. 10, No. 3, P. 181-289.

## 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.<br><br>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.<br><br>Apparent Transmissivity: the value determined from a summary of aquifer test data, usually involving only two water-level readings.<br><br>Effective Transmissivity: the value determined from late pumping and/or late recovery water-level data from an aquifer test.<br><br>Aquifer Transmissivity: the value determined by multiplying the hydraulic conductivity of an aquifer by the thickness of the aquifer. |

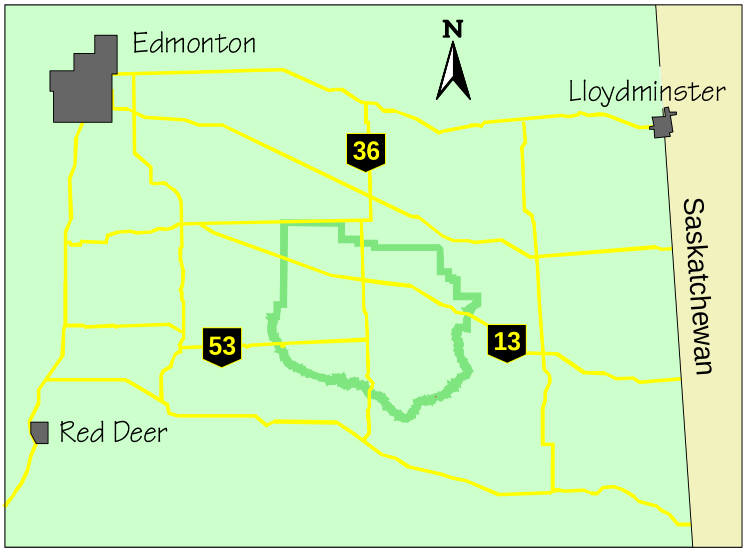
# FLAGSTAFF COUNTY

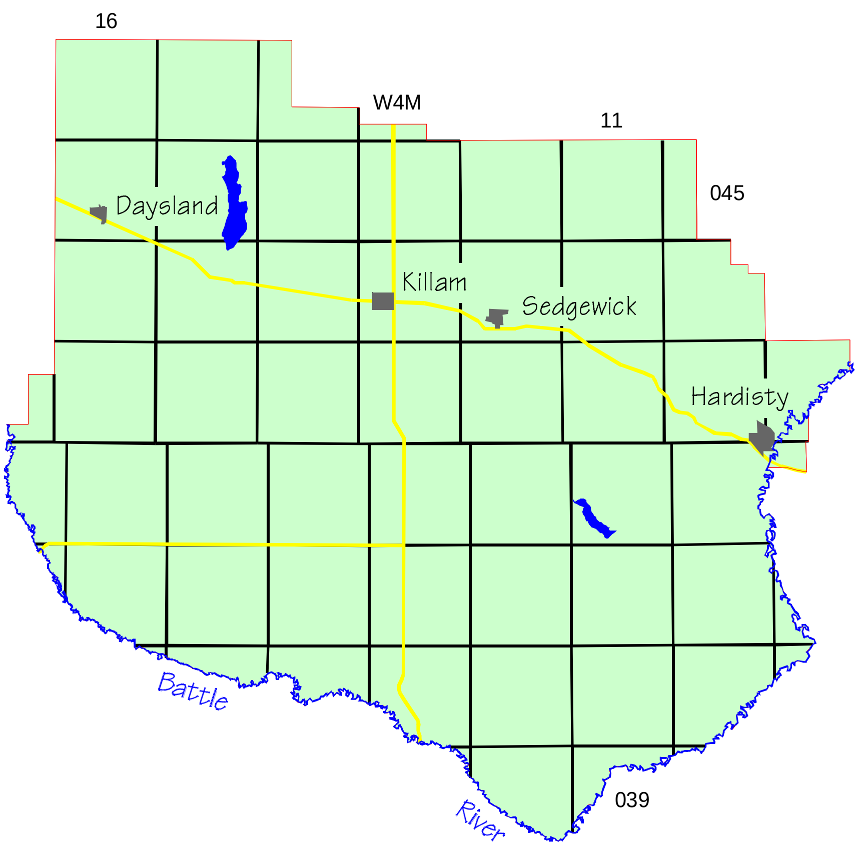
## Appendix A

## HYDROGEOLOGICAL MAPS AND FIGURES

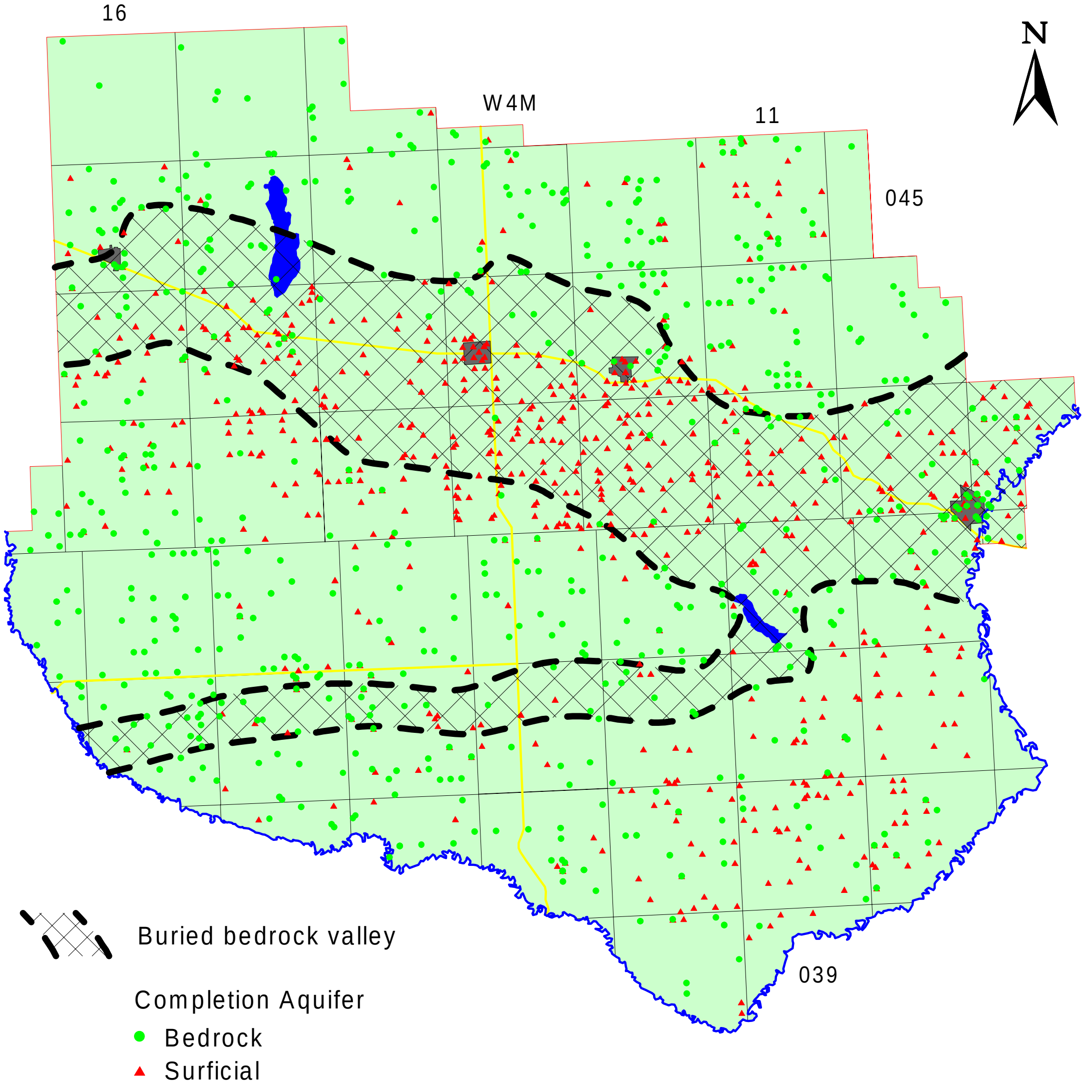

Index Map....2
Location of Water Wells....3
Depth to Base of Groundwater Protection....4
Generalized Cross-Section....5
Geologic Column....6
Cross-Section A - A'....7
Cross-Section B - B'....8
Bedrock Topography....9
Thickness of Surficial Deposits....10
Amount of Sand and Gravel in Surficial Deposits....11
Thickness of Sand and Gravel Aquifer(s)....12
Apparent Yield for Water Wells Completed through Sand and Gravel Aquifer(s)....13
Total Dissolved Solids in Groundwater from Surficial Deposits....14
Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer....15
Apparent Yield for Water Wells Completed through Lower Sand and Gravel Aquifer....16
Bedrock Geology....17
Piper Diagrams....18
Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)....19
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)....20
Fluoride in Groundwater from Upper Bedrock Aquifer(s)....21
Depth to Top of Lower Horseshoe Canyon Formation....22
Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer....23
Depth to Top of Bearpaw Formation....24
Apparent Yield for Water Wells Completed through Bearpaw Aquifer....25
Depth to Top of Oldman Formation....26
Apparent Yield for Water Wells Completed through Oldman Aquifer....27
Depth to Top of continental Foremost Formation....28
Apparent Yield for Water Wells Completed through continental Foremost Aquifer....29
Depth to Top of Milan Formation....30
Apparent Yield for Water Wells Completed through Milan Aquifer....31
Depth to Top of marine Foremost Formation....32
Apparent Yield for Water Wells Completed through marine Foremost Aquifer....33
Depth to Top of Lea Park Aquitard....34
Hydrographs - AEP Observation Water Wells....35
Recharge/Discharge between Surficial Deposits and Upper Bedrock Aquifer(s)....36
Recharge/Discharge between Surficial Deposits and Oldman Aquifer....37
Risk of Groundwater Contamination....38

# Index Map

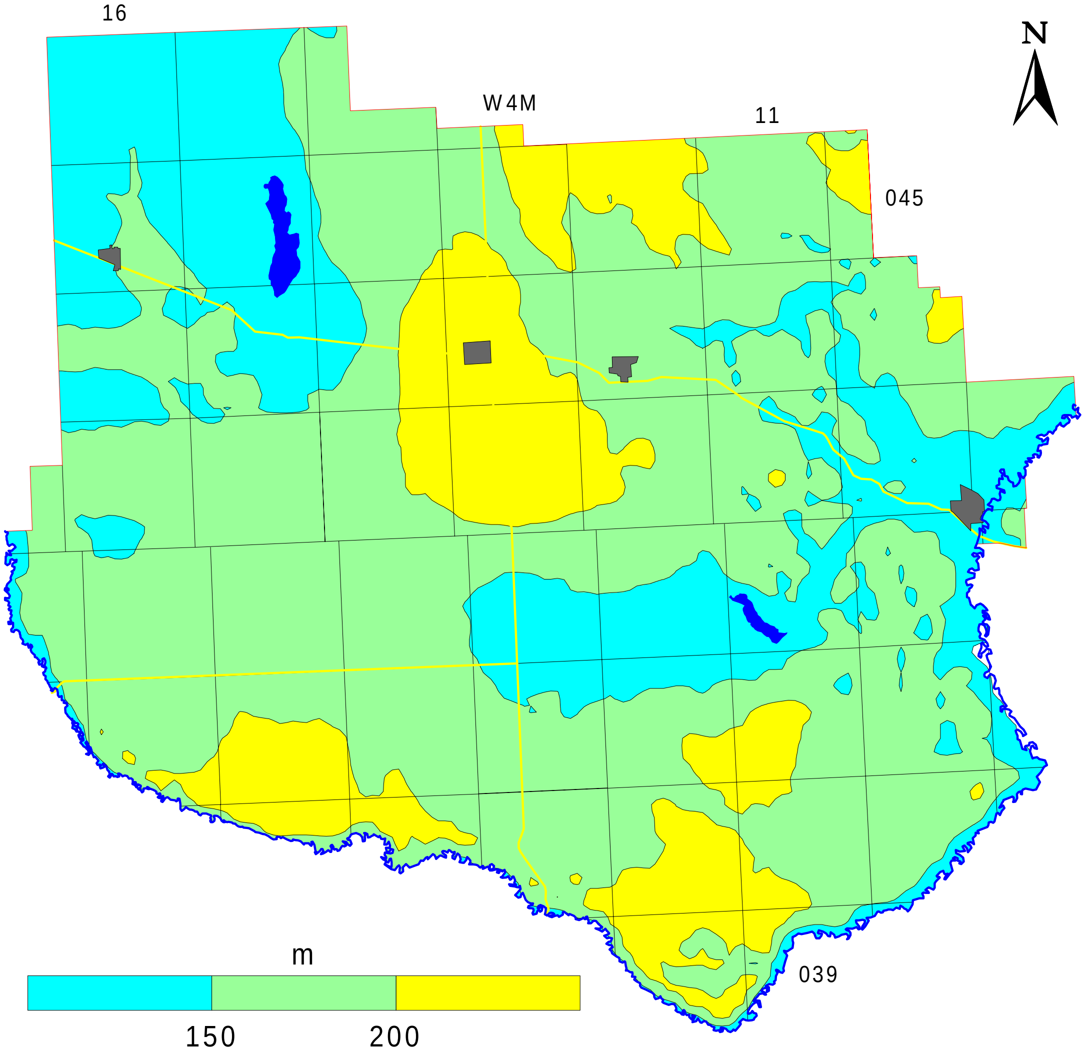

Edmonton
N
Lloydminster
36
Saskatchewan
53
13
Red Deer

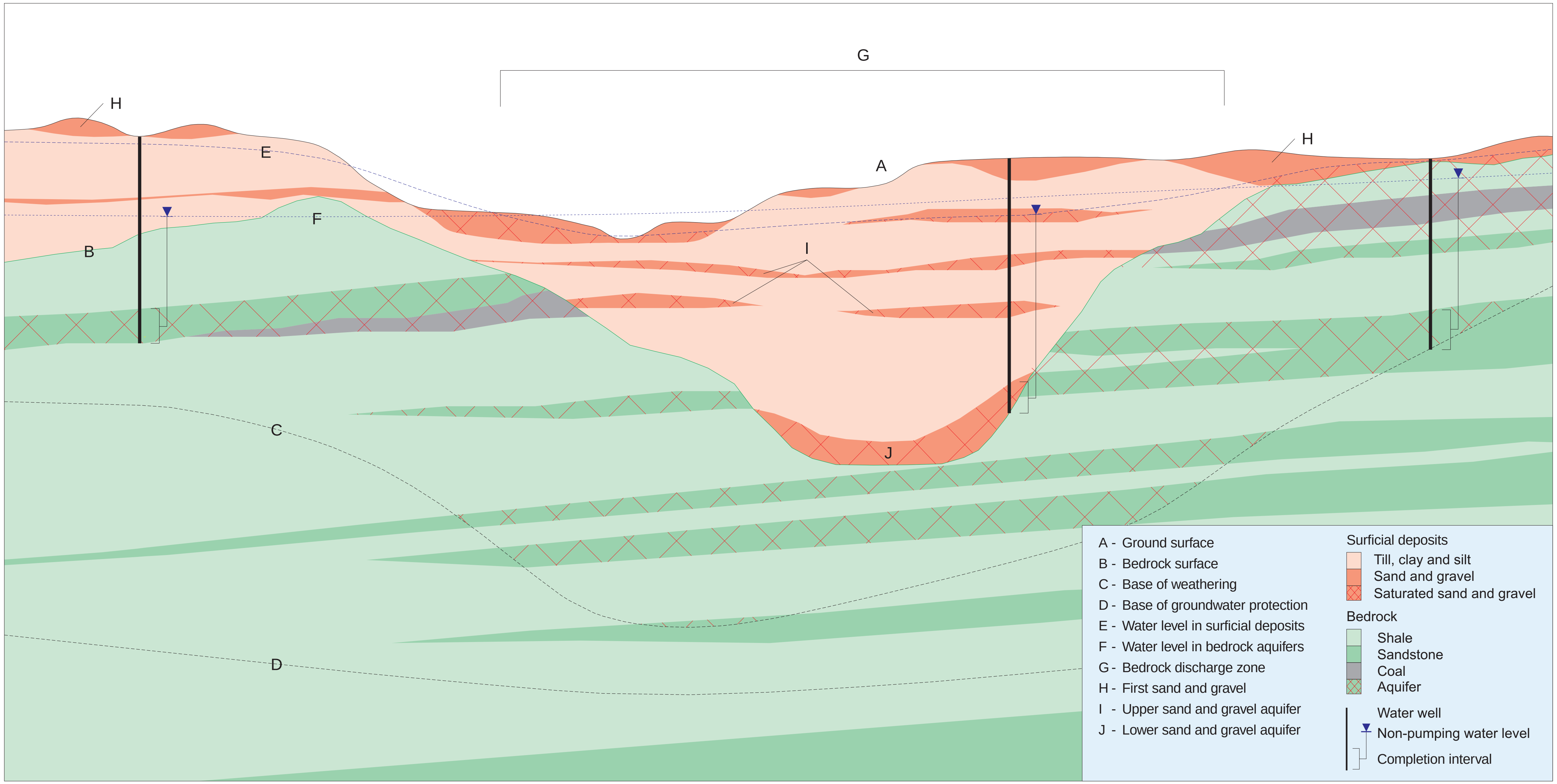

16
W4M
11
045
Daysland
Killam
Sedgewick
Hardisty
Battle
River
039

## Location of Water Wells



## Depth to Base of Groundwater Protection






***Generalized Cross-Section***

*(For terminology only)*



hydrogeological consultants ltd.

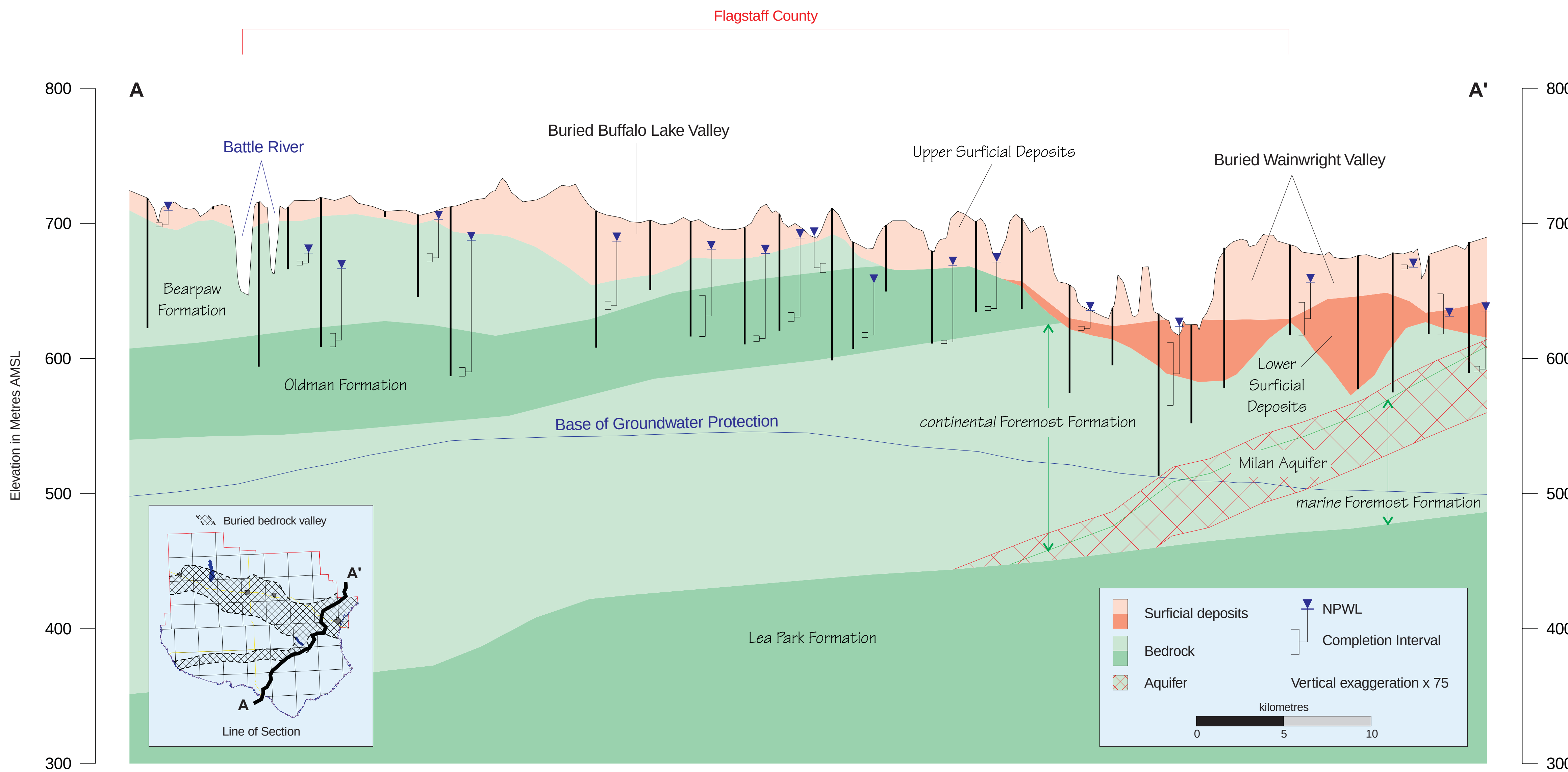
| Lithologic Description | Group and Formation: Thickness | Group | Group and Formation: Designation | Member: Thickness | Member: Designation | Zone: Thickness | Zone: Designation |
|---|---|---|---|---|---|---|---|
| sand, gravel, till, clay, silt | <60 | | Surficial Deposits | <60 | Upper | <30 | First Sand and Gravel |
| | | | | <30 | Lower | | |
| shale, sandstone, coal, bentonite, limestone, ironstone | ~170 | Edmonton Group | Horseshoe Canyon Formation | ~170 | Lower | | |
| shale, sandstone, siltstone | 60-120 | | Bearpaw Formation | | | | |
| sandstone, siltstone, shale, coal | 40-80 | Belly River Group | Oldman Formation | <30 | Dinosaur Member | <25 | Lethbridge Coal Zone |
| | | | | <20 | Upper Siltstone Member | | |
| | | | | 8-20 | Comrey Member | | |
| shale, sandstone, coal | 10-220 | | *continental* Foremost Formation | | | <20 | Taber Coal Zone |
| | | | | | | <20 | McKay Coal Zone |
| sandstone, shale | <200 | | *marine* Foremost Formation (Basal Belly River Sandstone) | <30 | Birch Lake Member | | Milan Aquifer |
| | | | | <30 | Ribstone Creek Member | | |
| | | | | <30 | Victoria Member | | |
| | | | | <30 | Brosseau Member | | |
| shale, siltstone | 100-200 | | Lea Park Formation | | | | |

Depth (m): 0, 100, 200, 300, 400, 500, 600, 700, 800

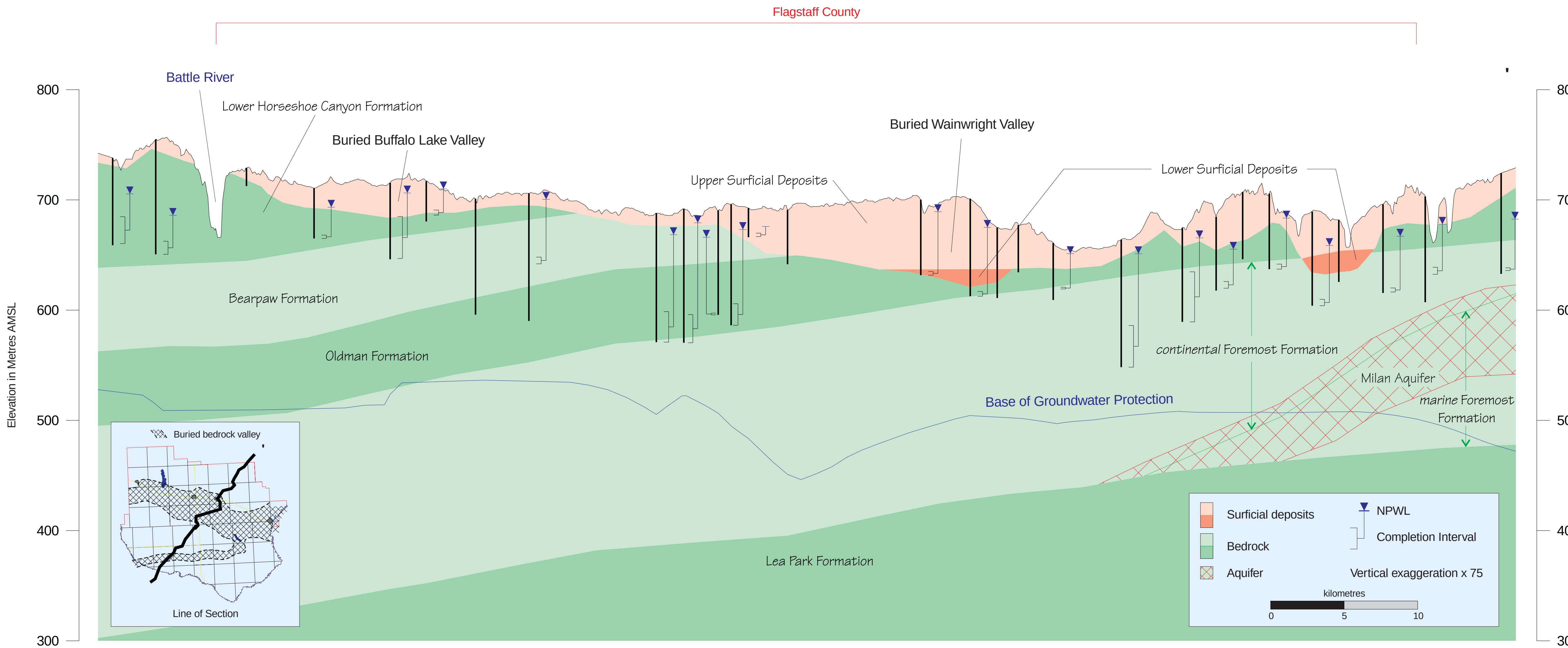
**Geologic Column**



hydrogeological consultants ltd.




**Cross-Section A - A'**

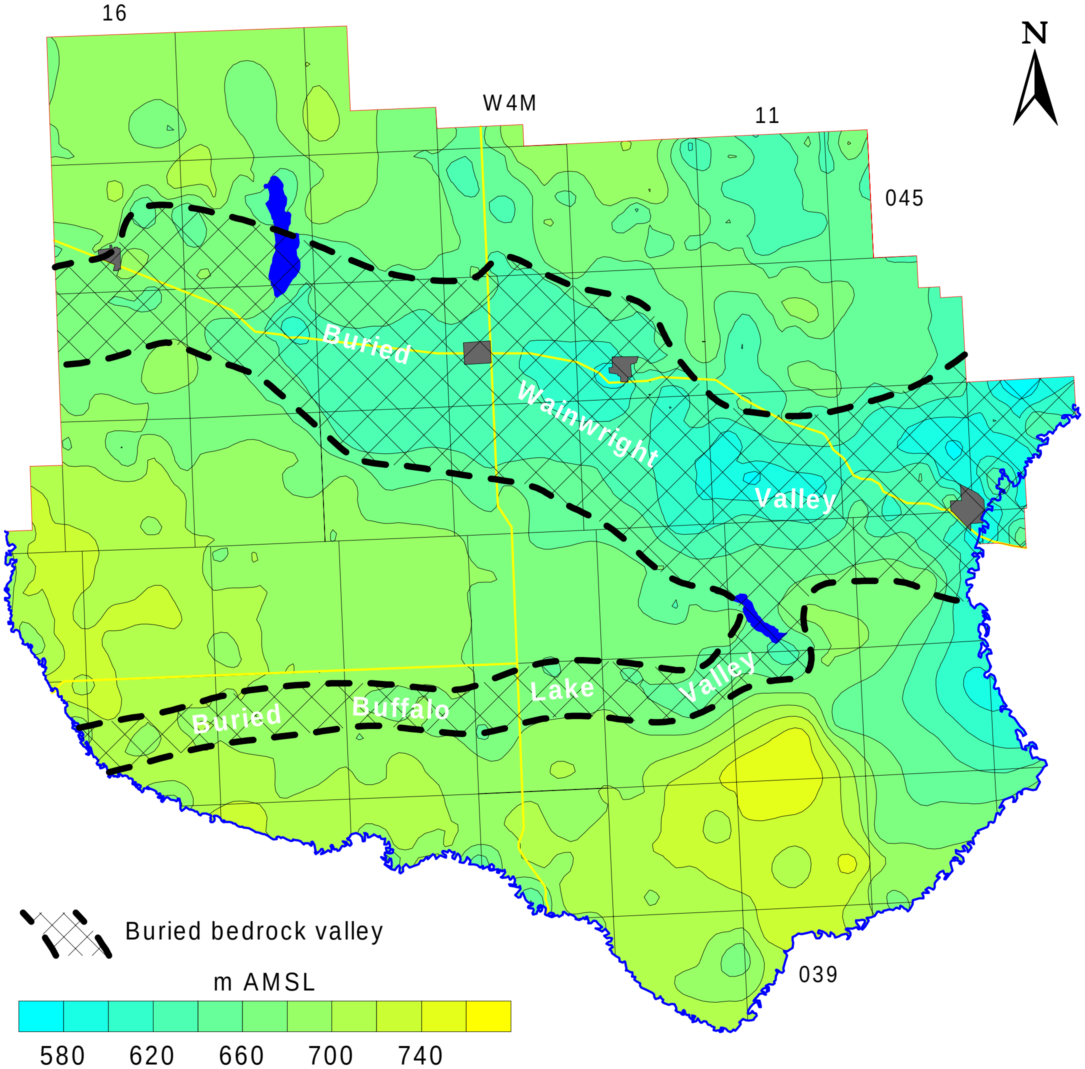



**Cross-Section B - B'**

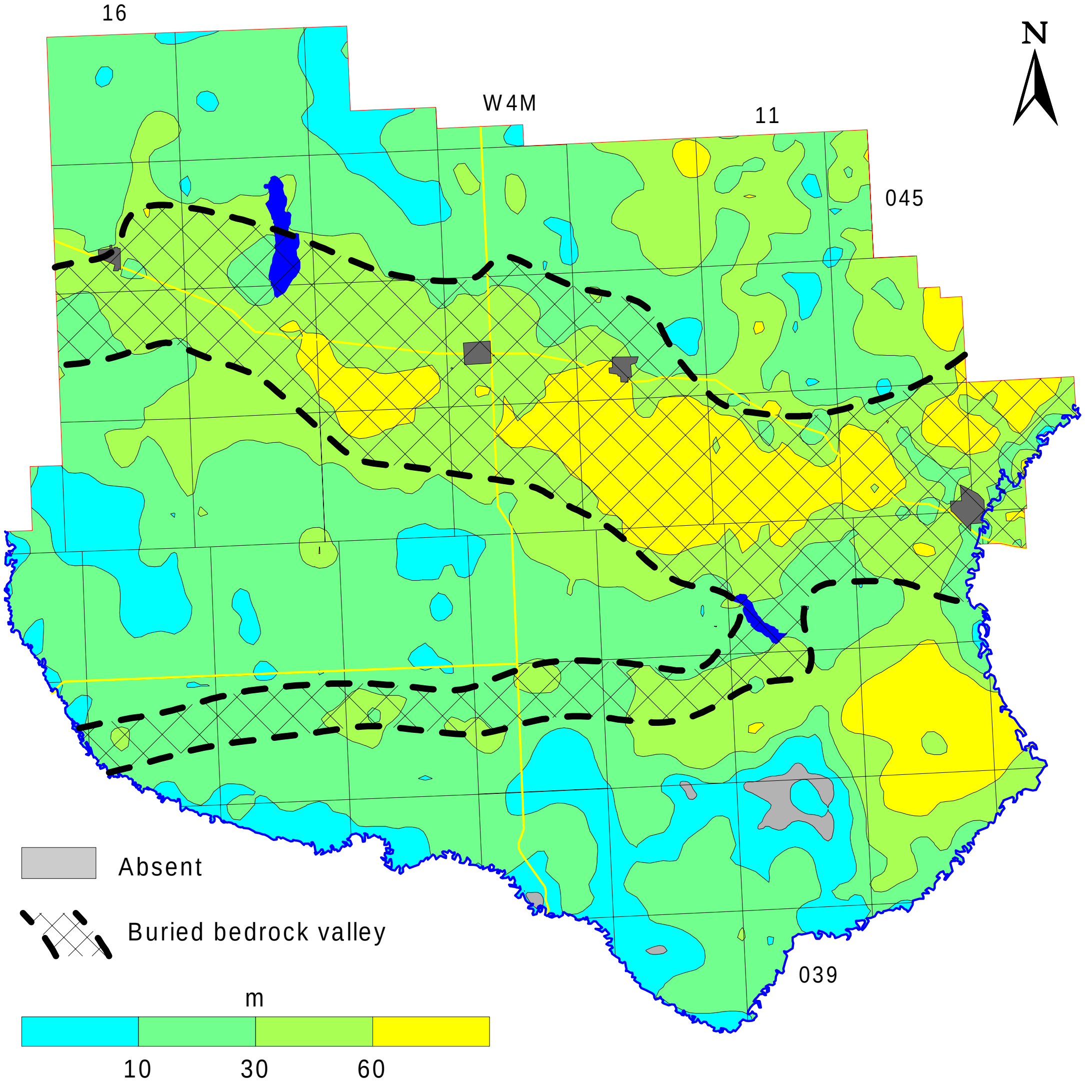


hydrogeological consultants ltd.

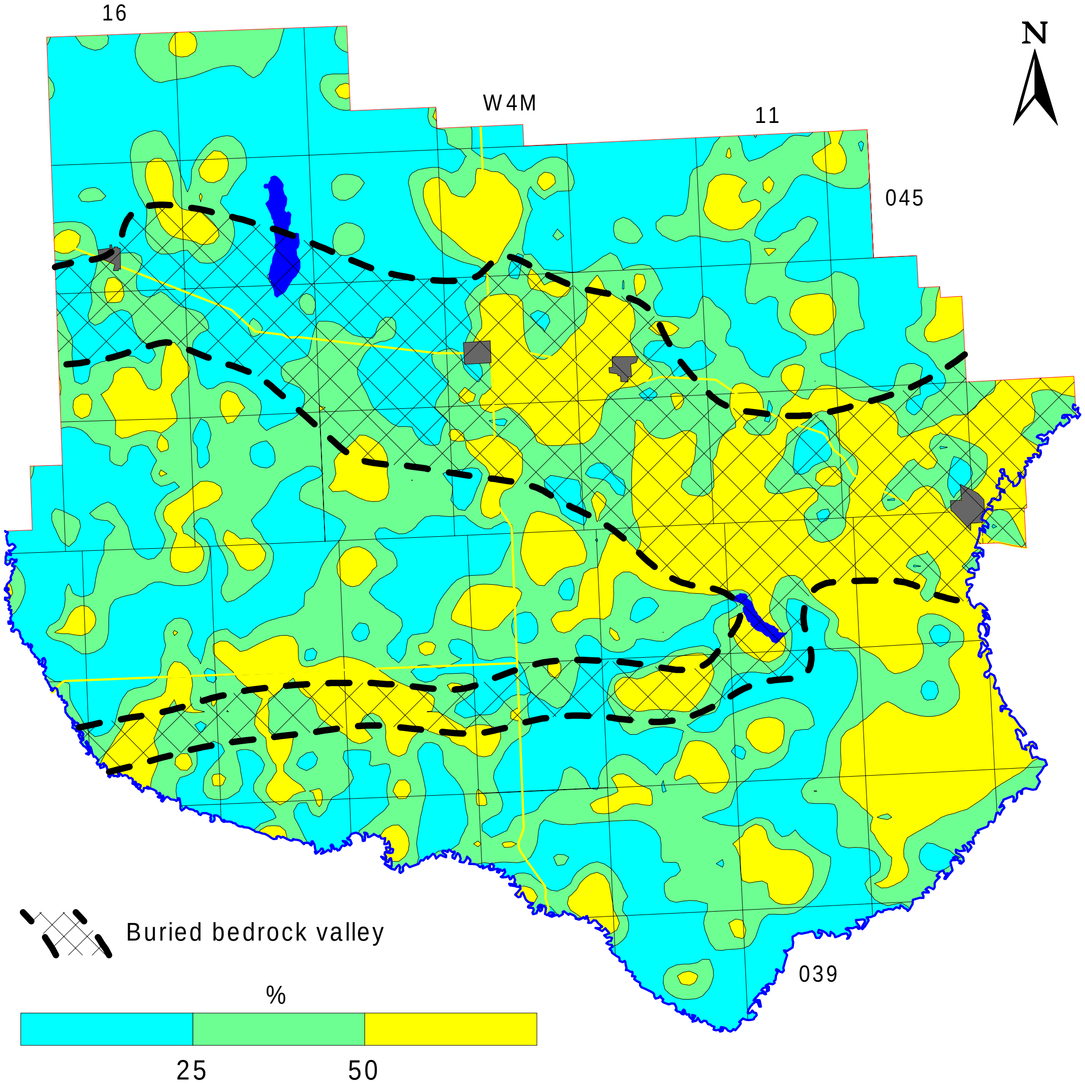
## Bedrock Topography



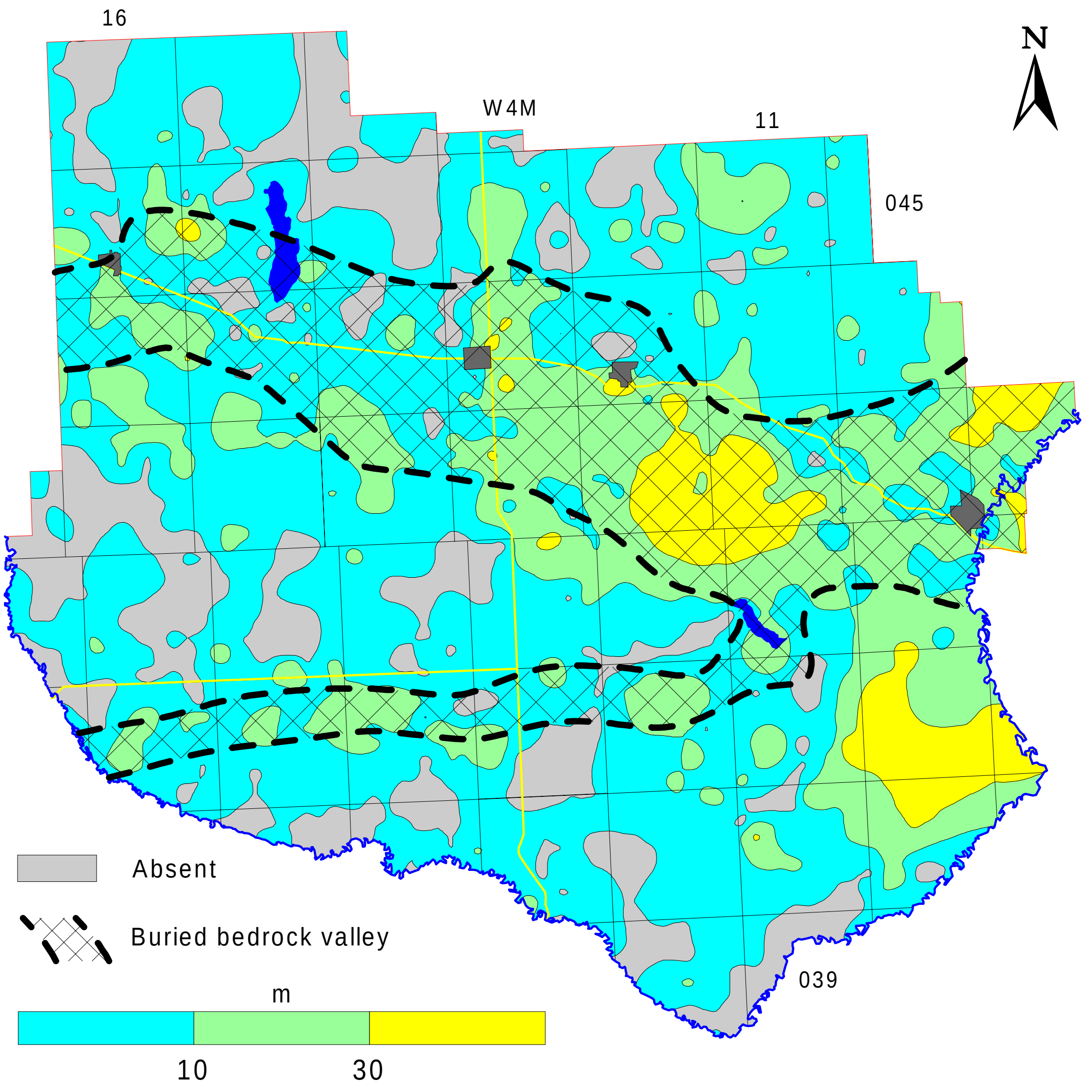
## Thickness of Surficial Deposits



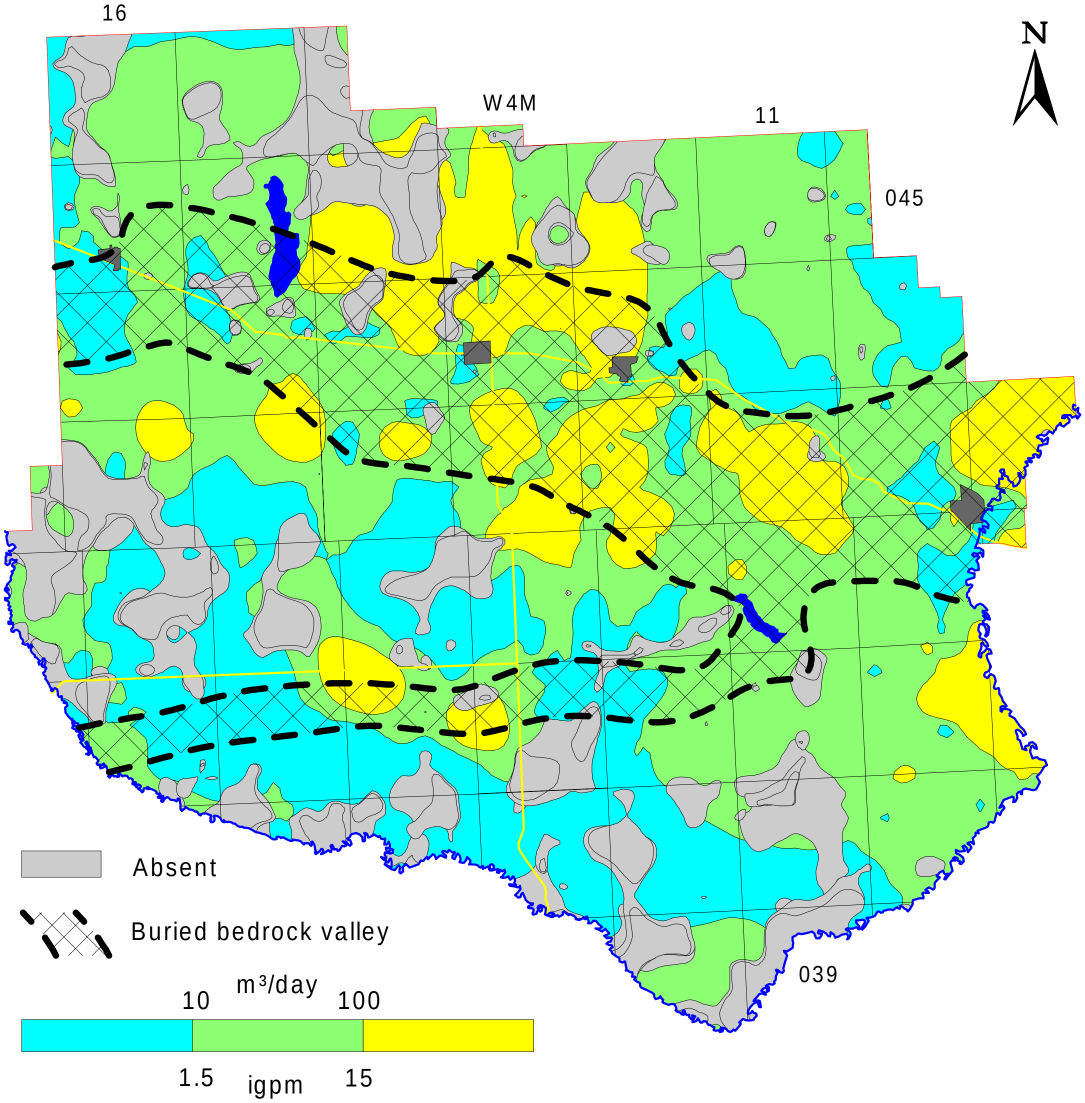
## Amount of Sand and Gravel in Surficial Deposits



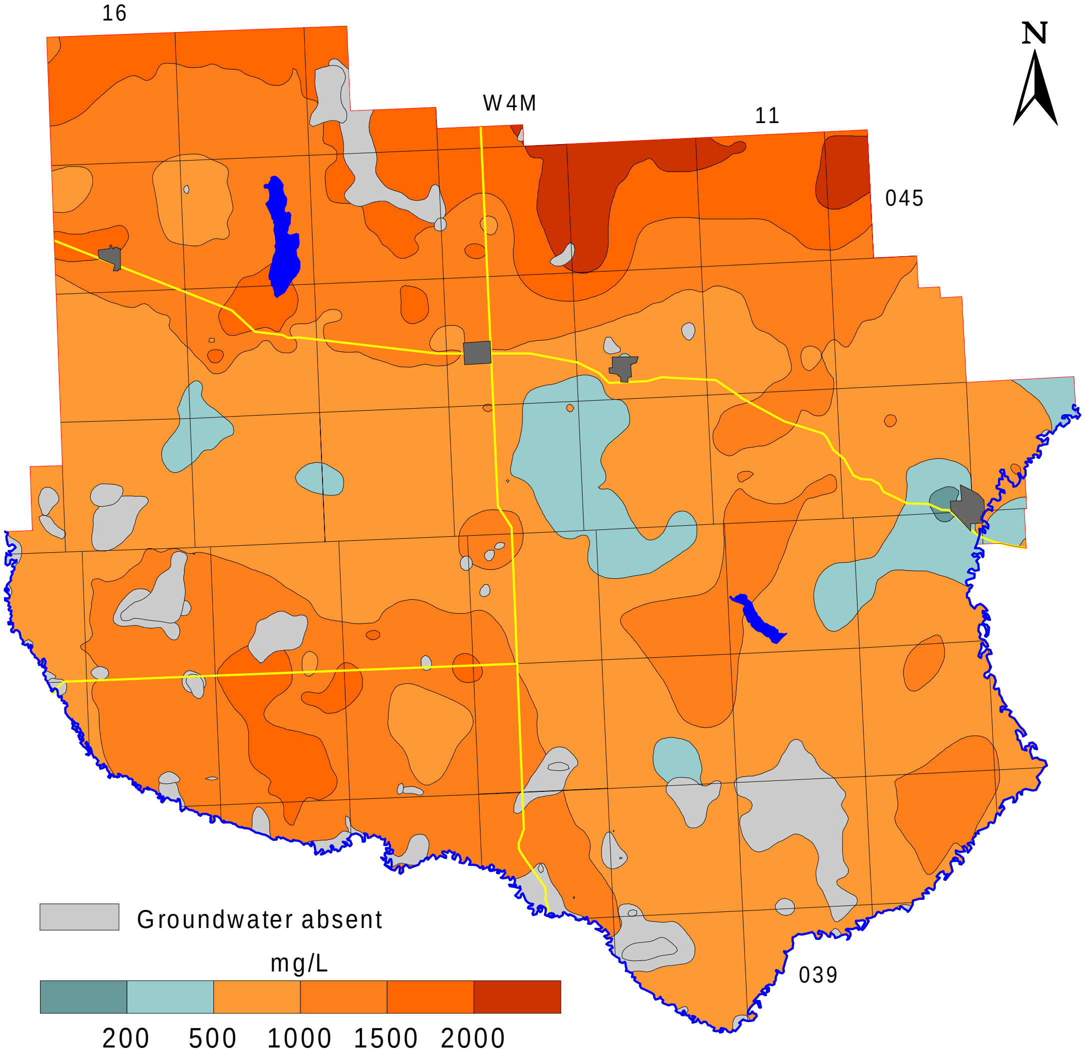
## Thickness of Sand and Gravel Aquifer(s)



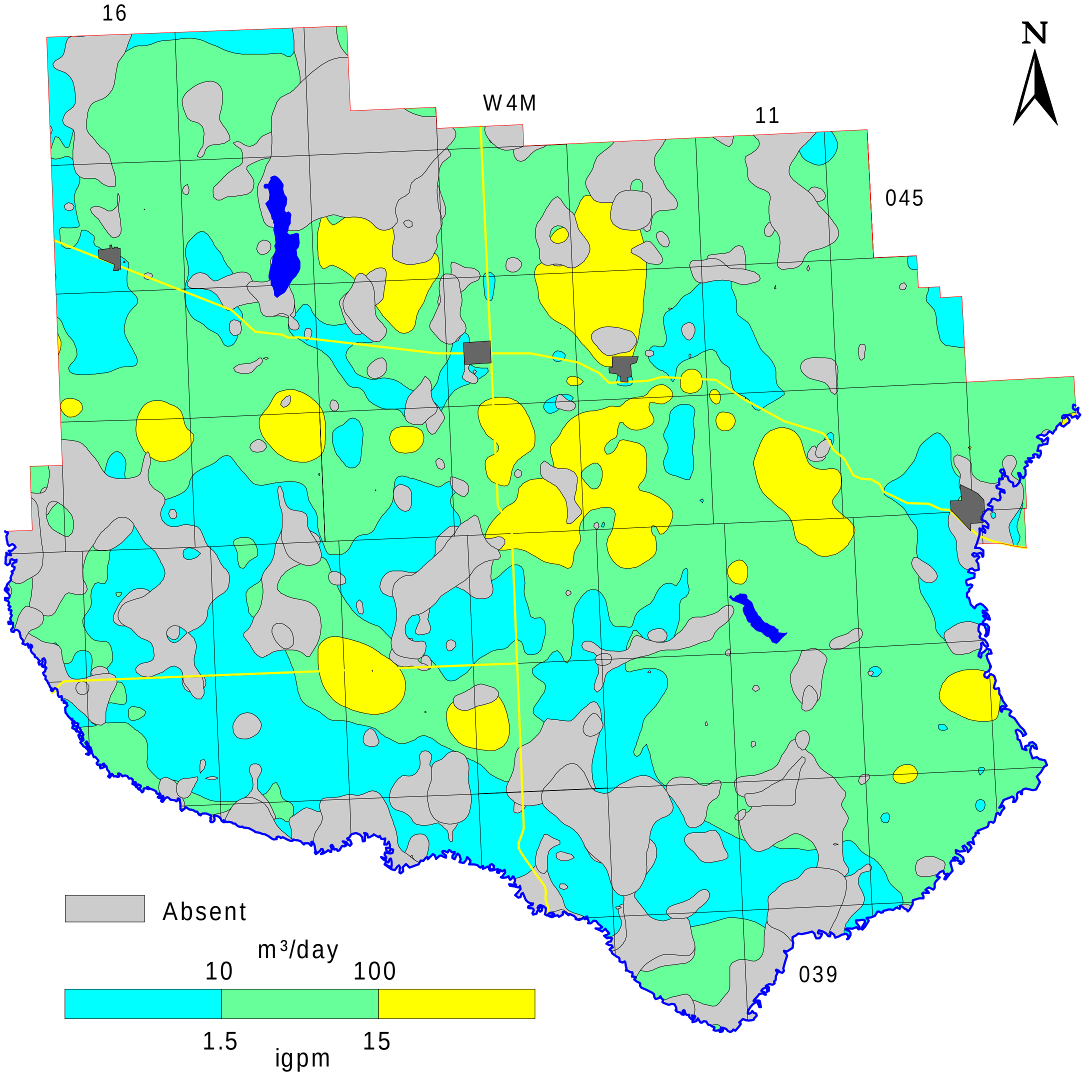
## Apparent Yield for Water Wells Completed through Sand and Gravel Aquifer(s)



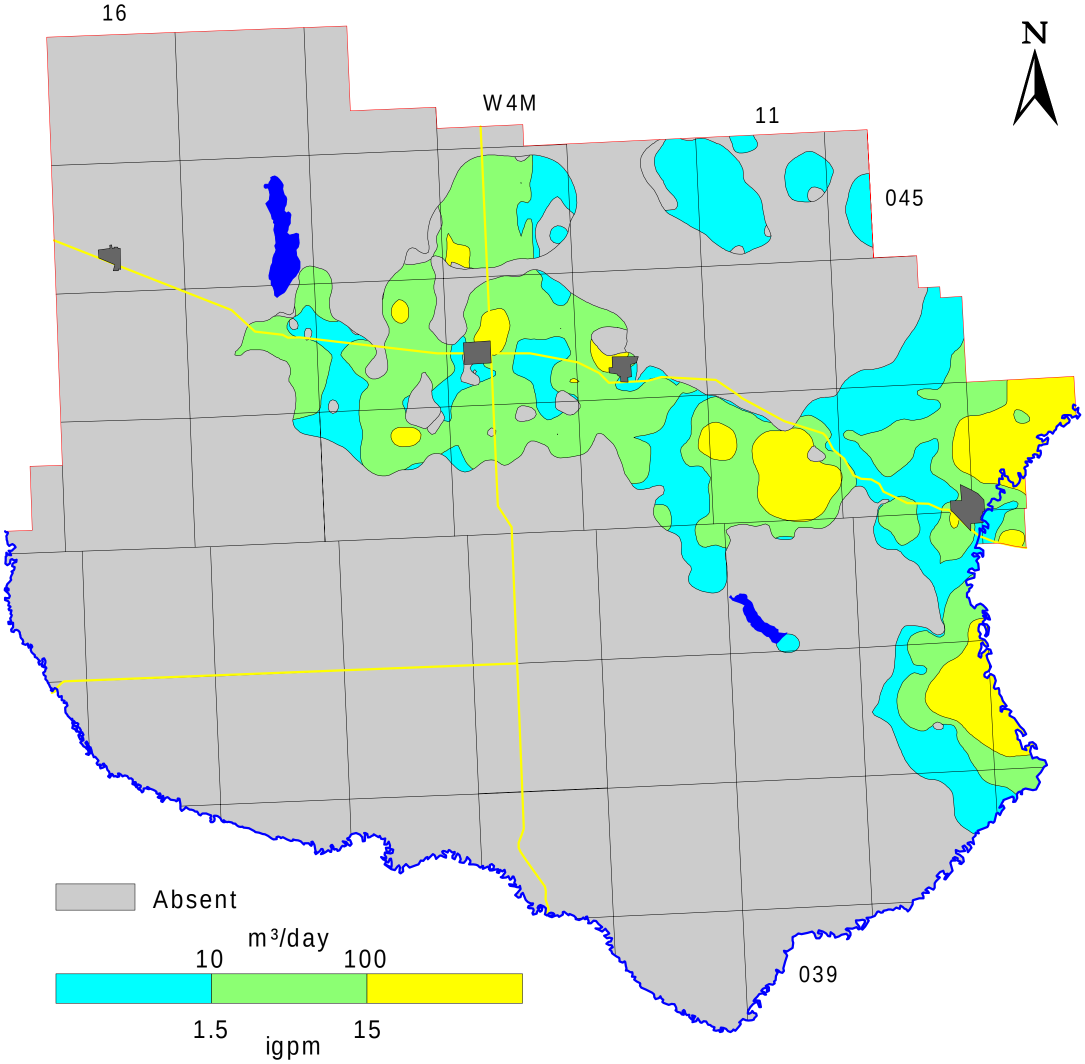
## Total Dissolved Solids in Groundwater from Surficial Deposits



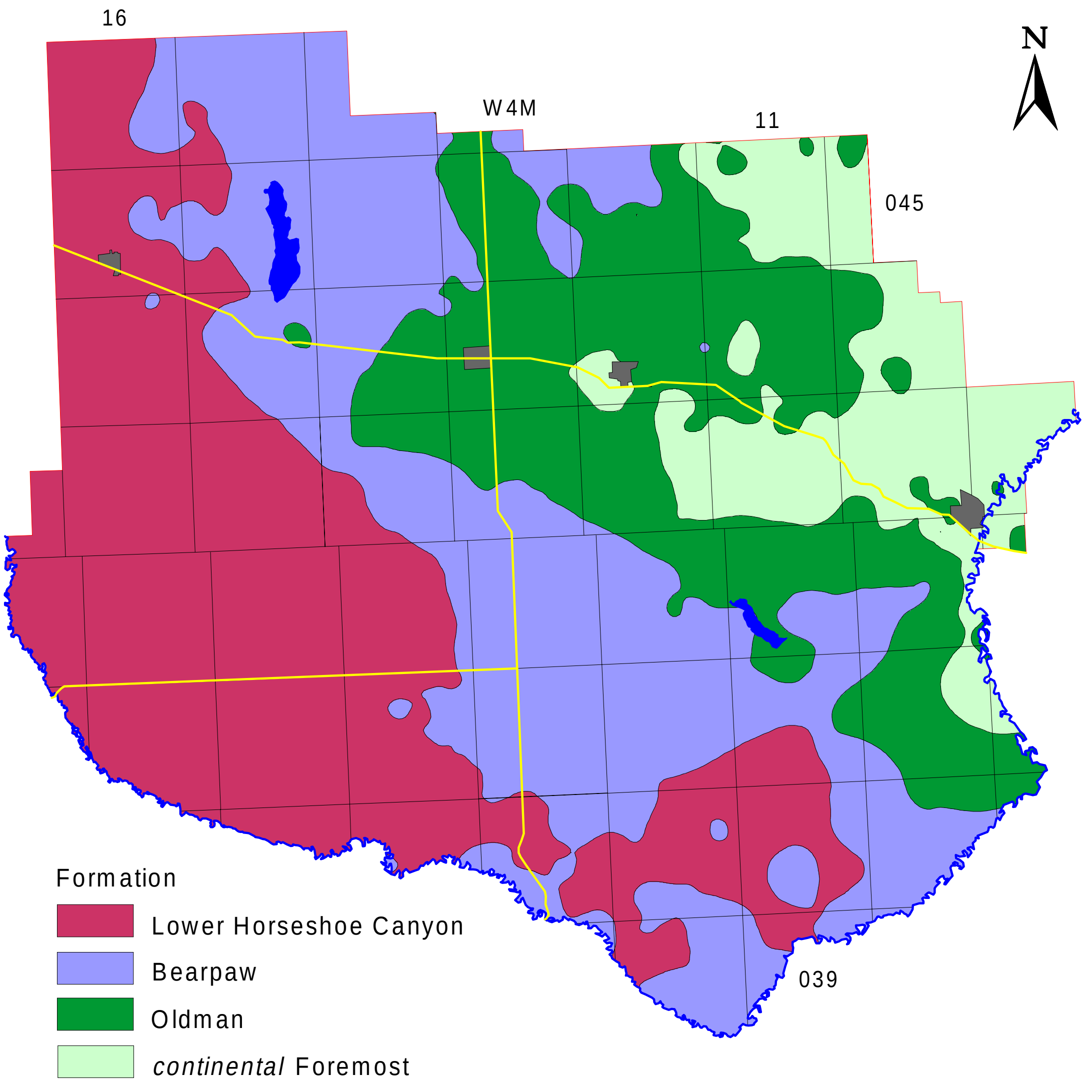
# Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer



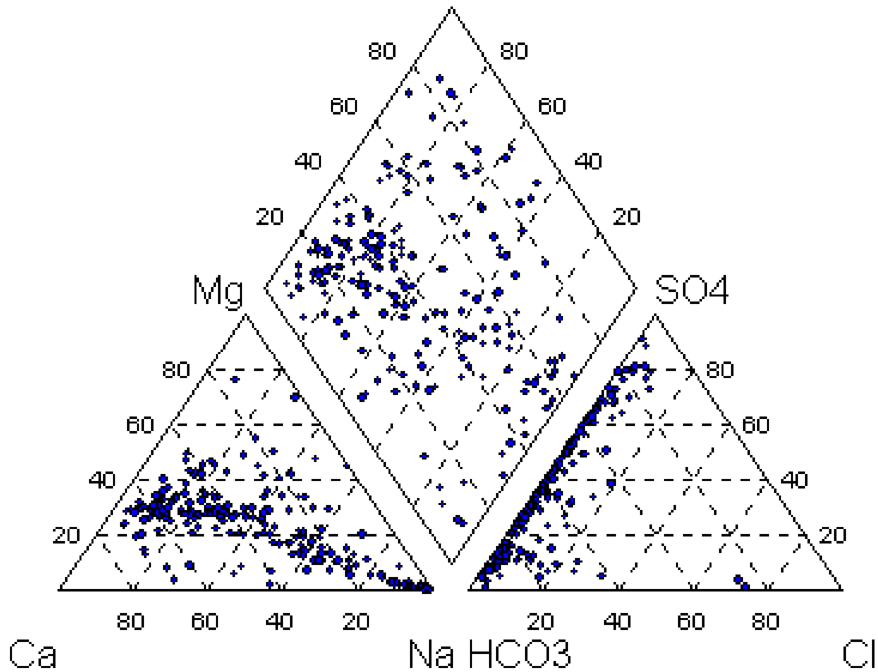
## Apparent Yield for Water Wells Completed through Lower Sand and Gravel Aquifer



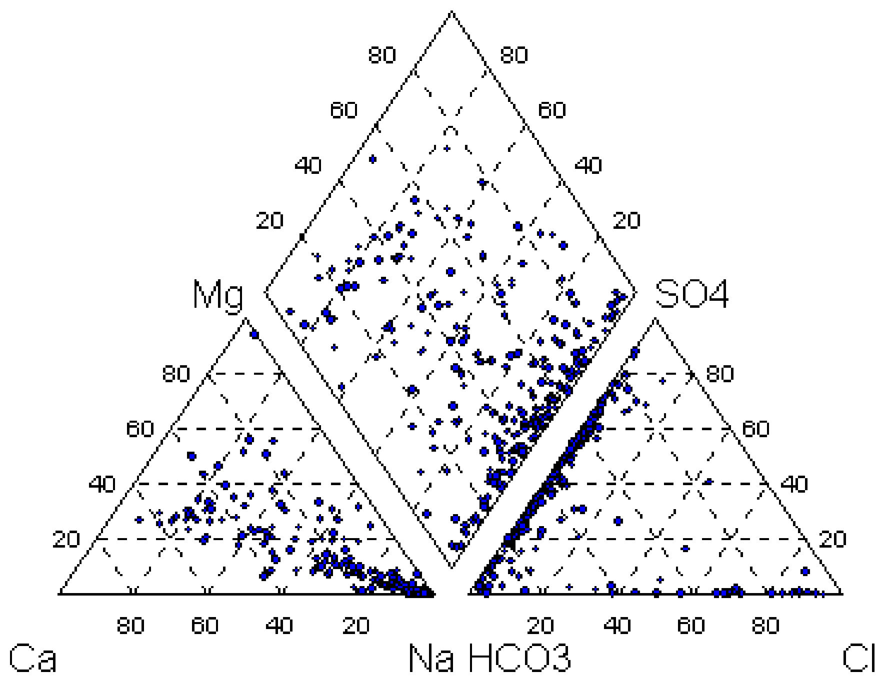
# Bedrock Geology



## Piper Diagrams

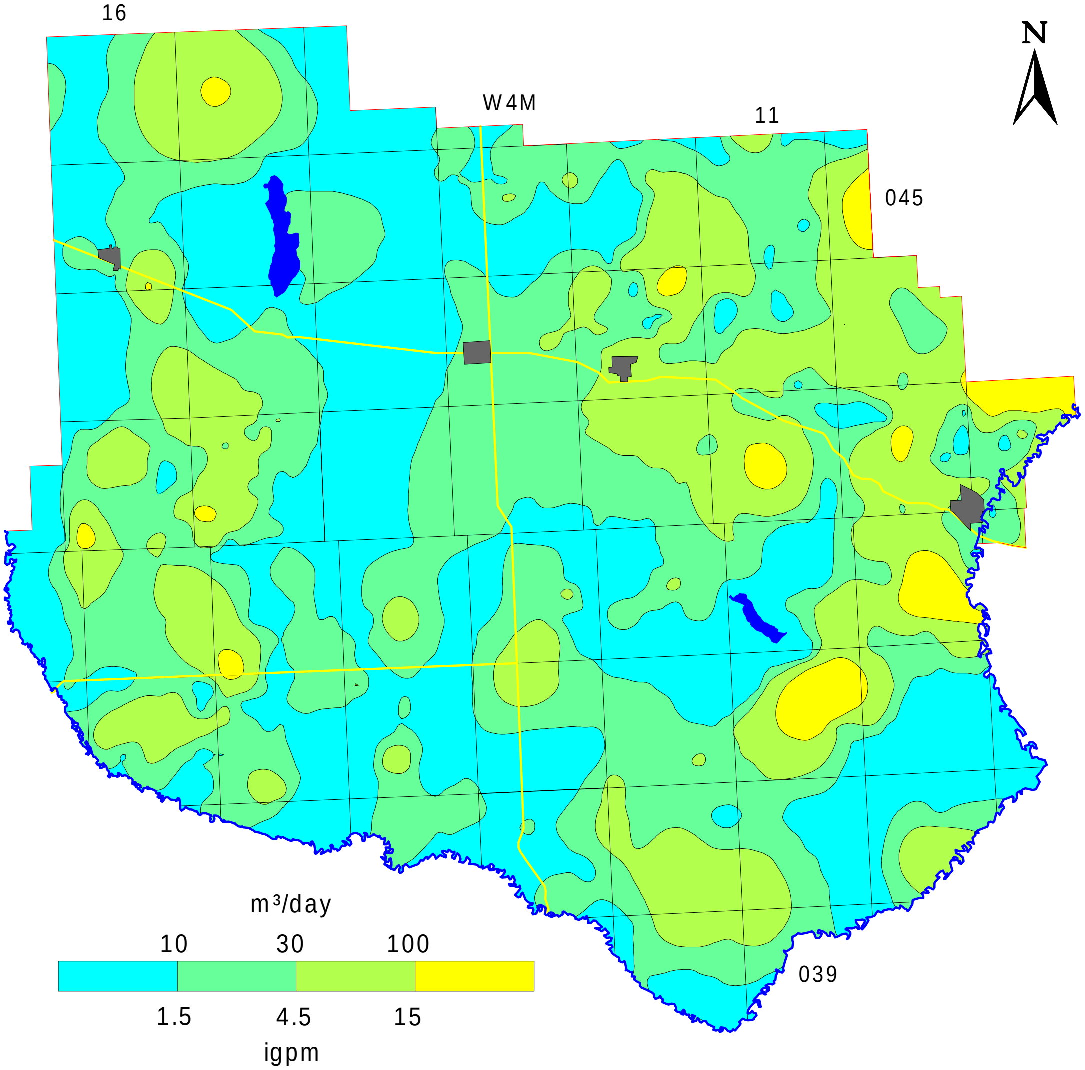



**Surficial Deposits**

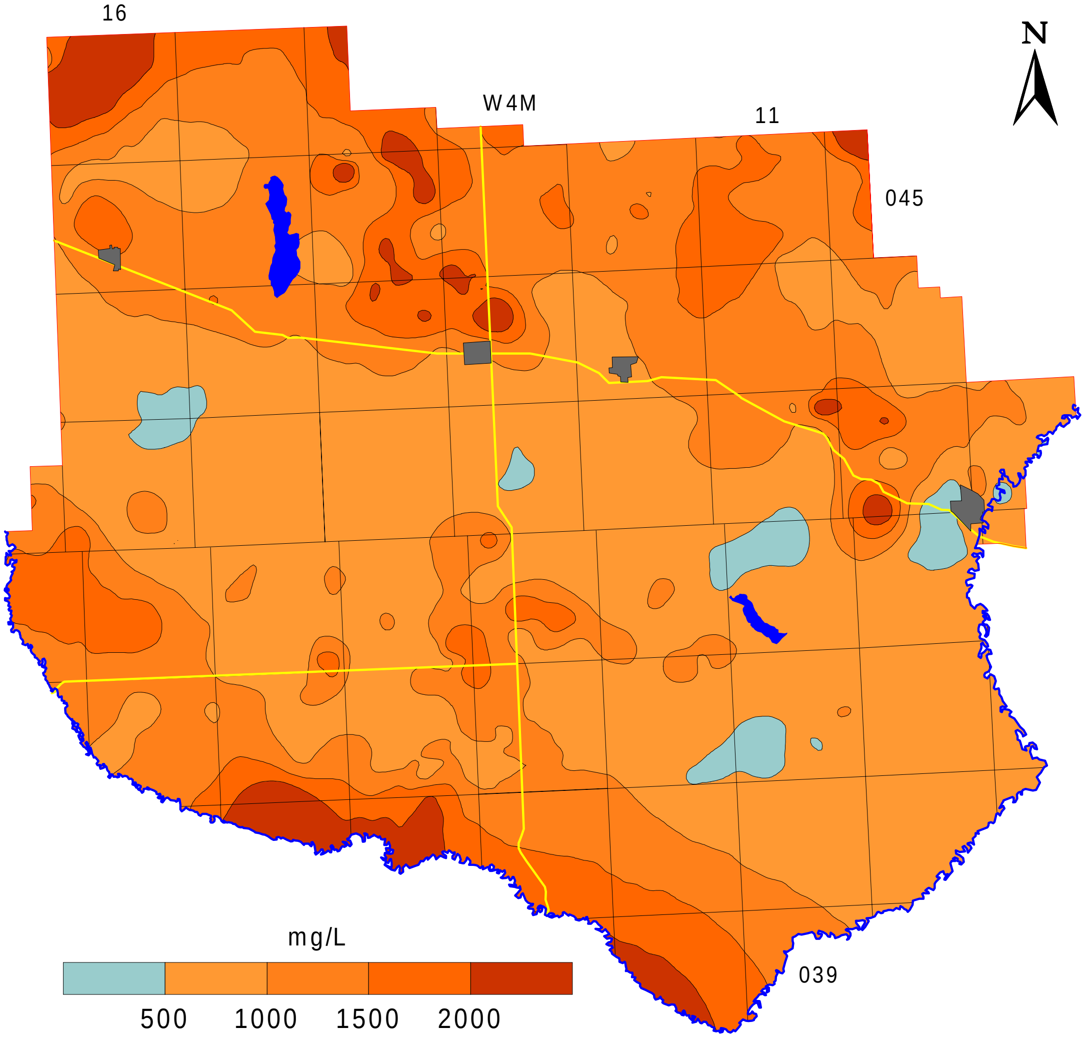



**Bedrock Aquifer(s)**

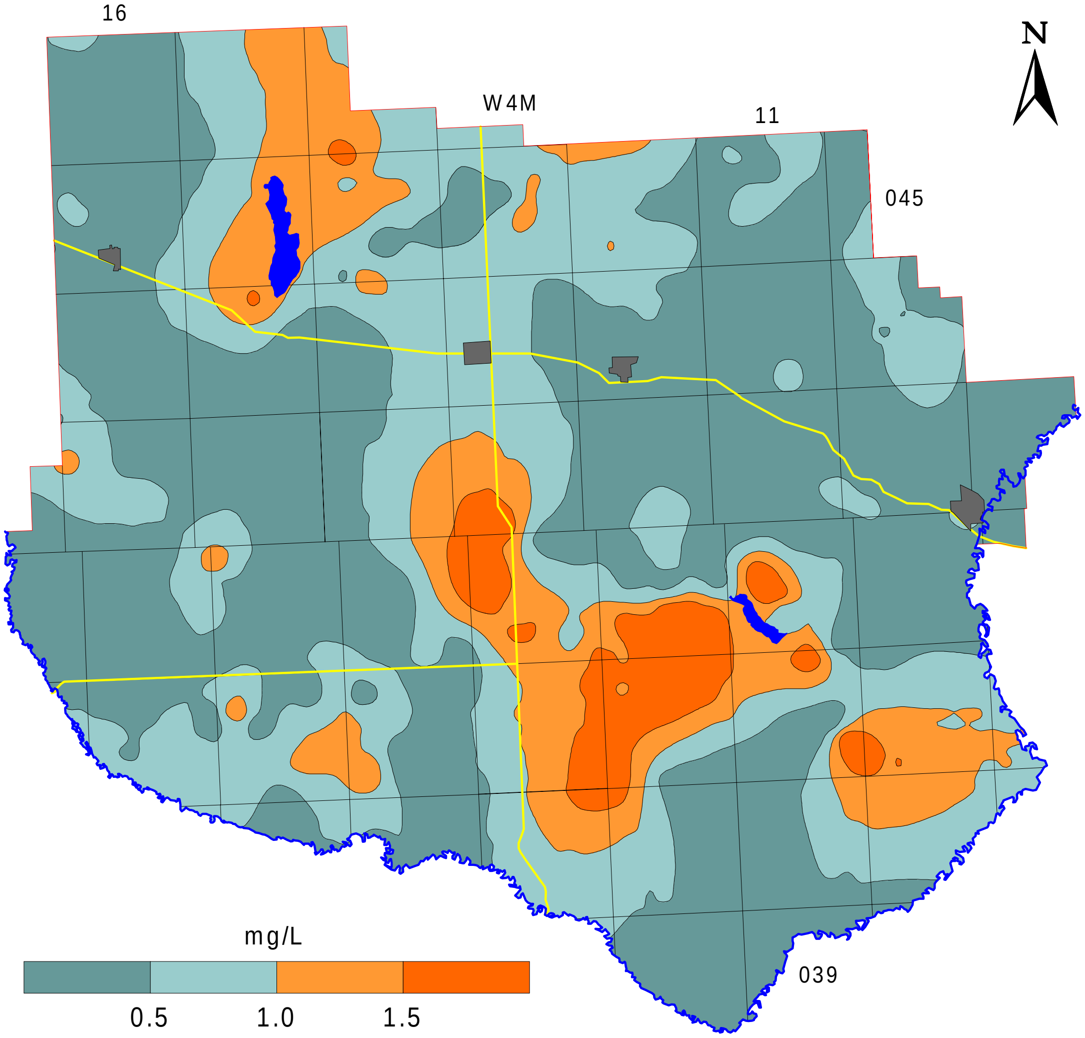
## Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)



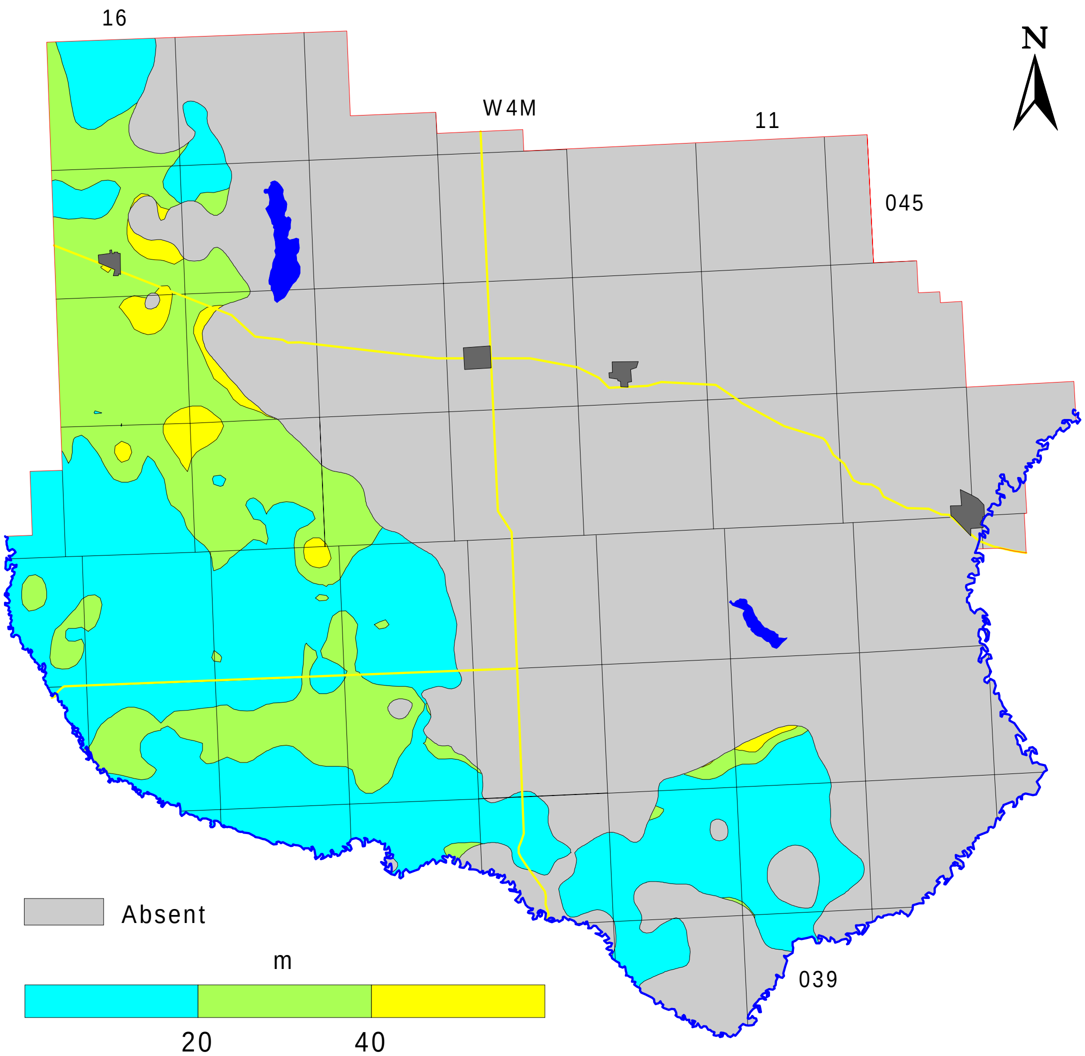
# Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)



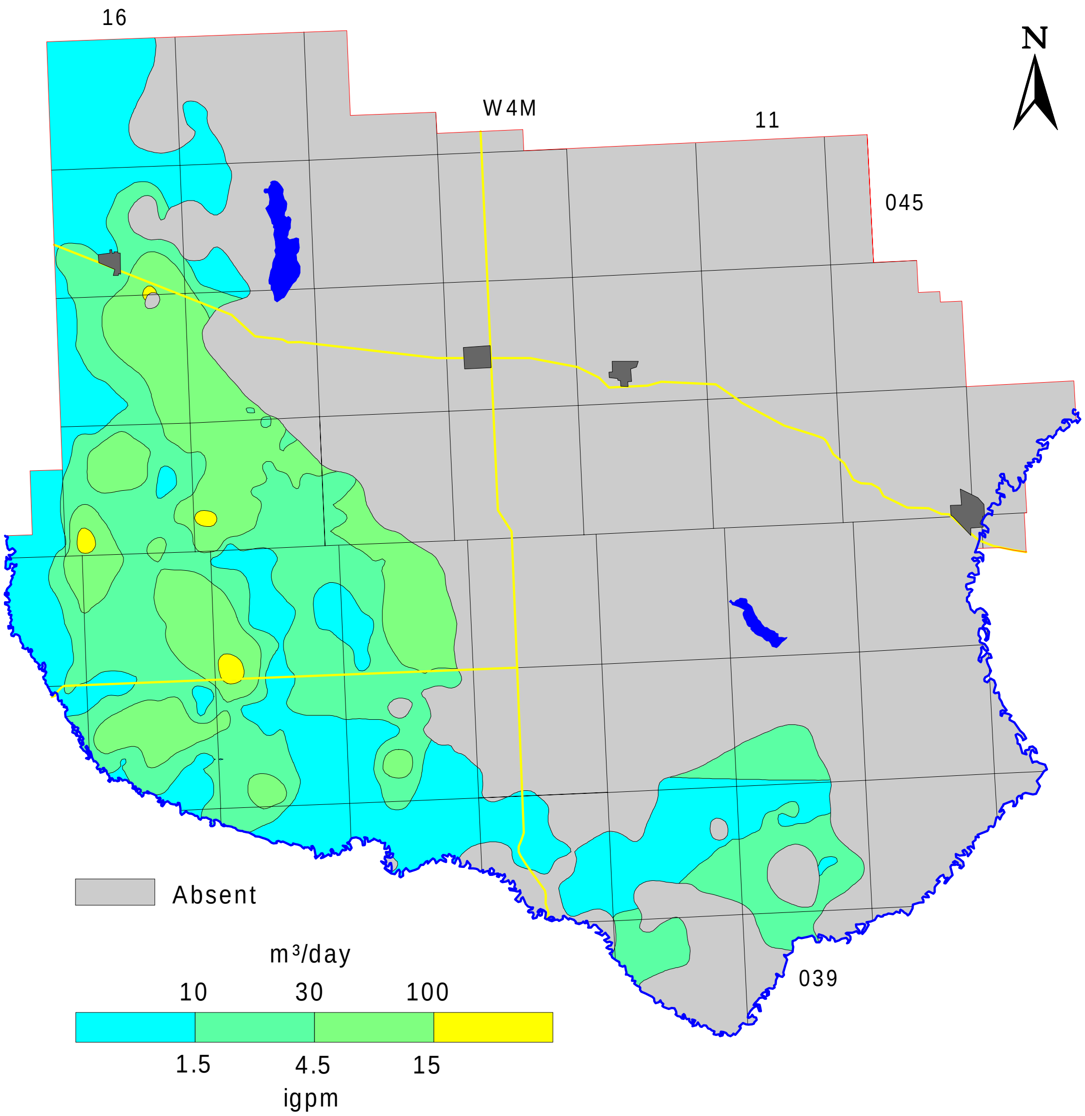
## Fluoride in Groundwater from Upper Bedrock Aquifer(s)



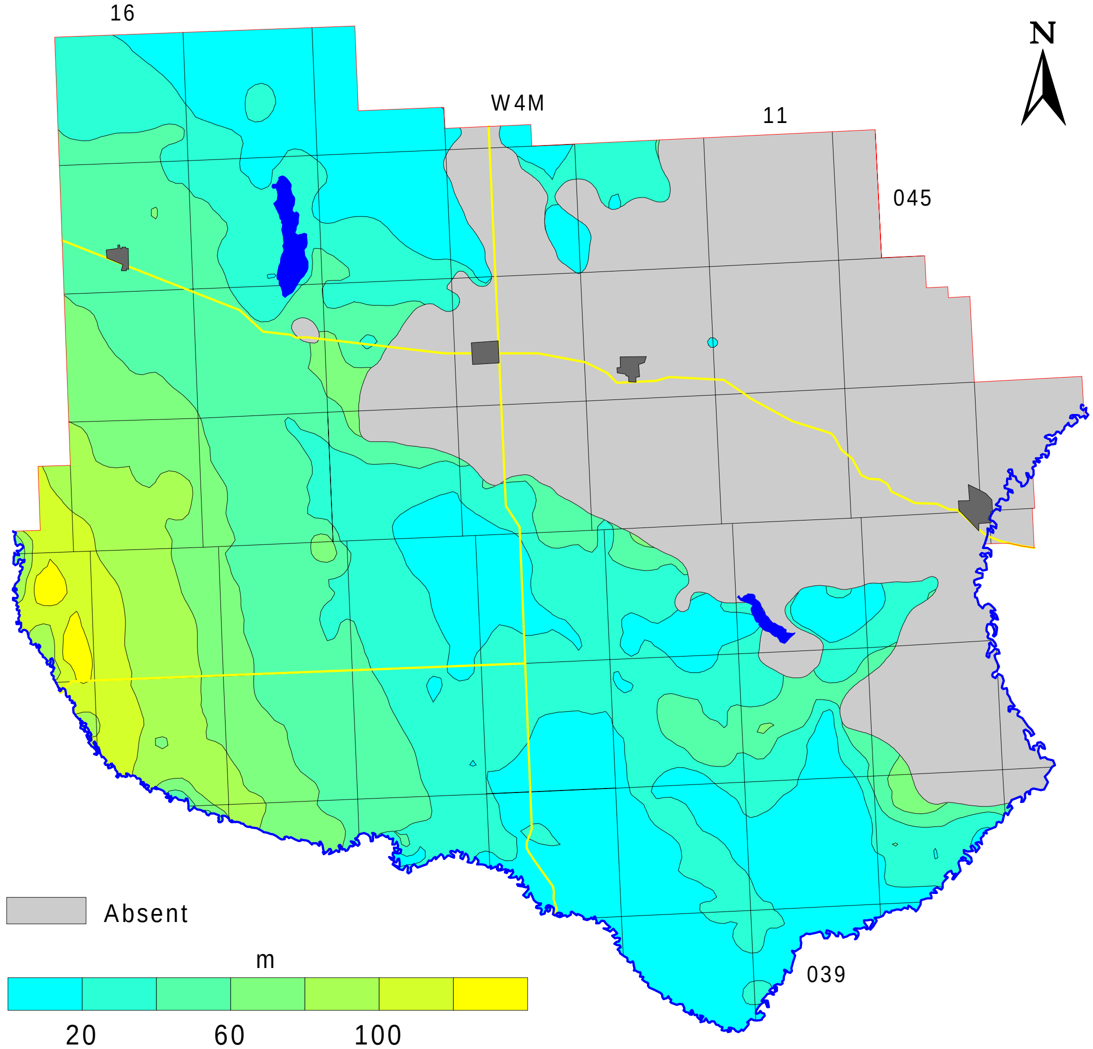
# Depth to Top of Lower Horseshoe Canyon Formation



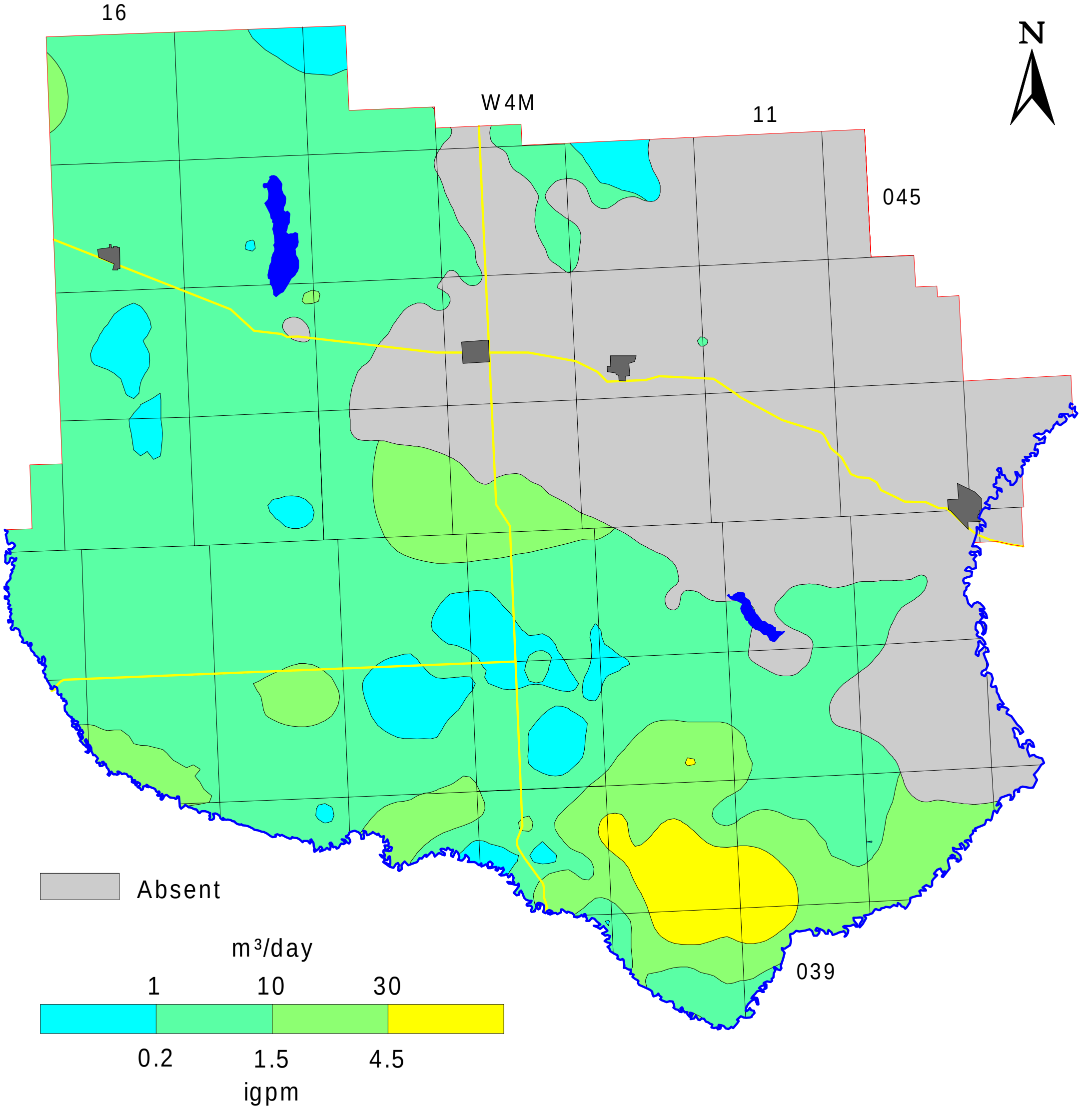
# Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer



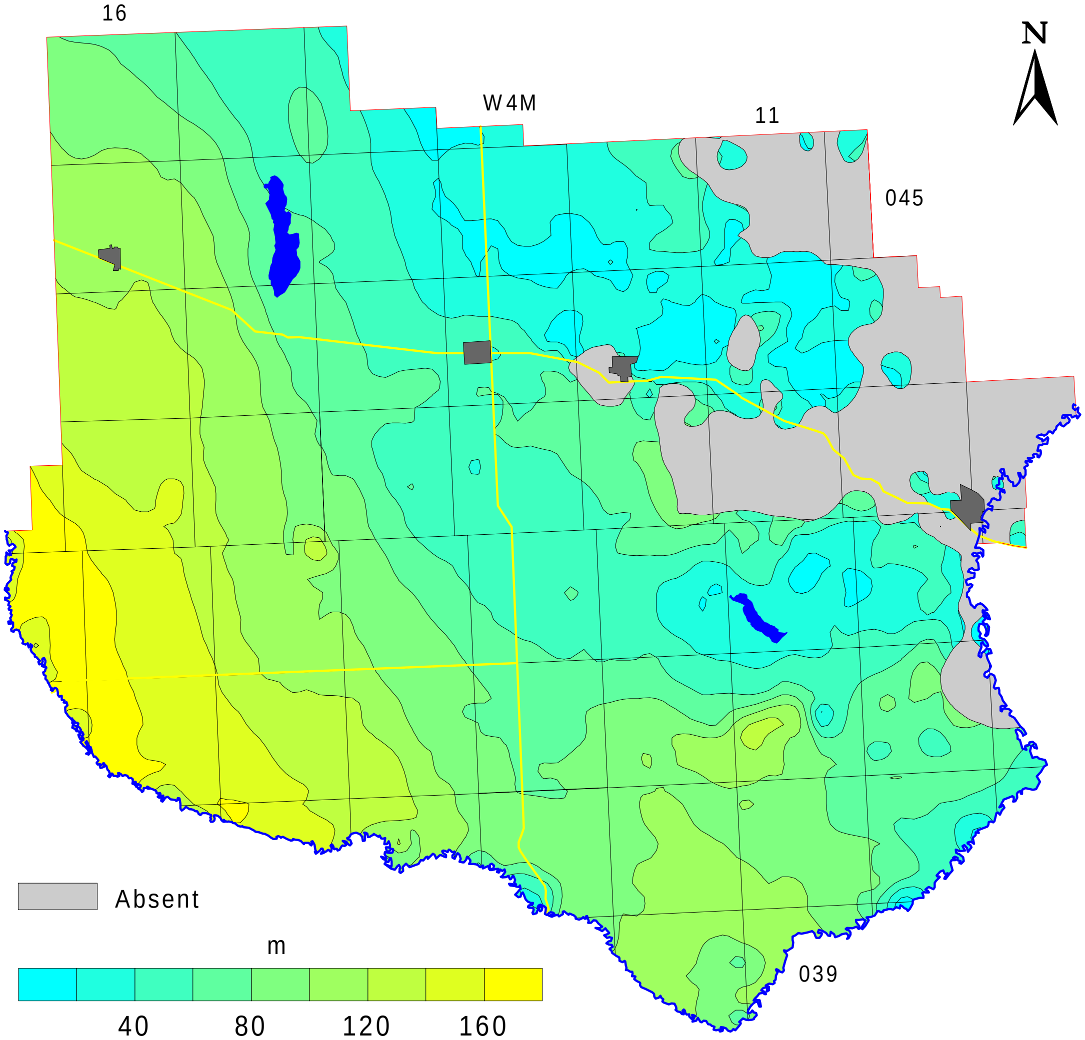
## Depth to Top of Bearpaw Formation



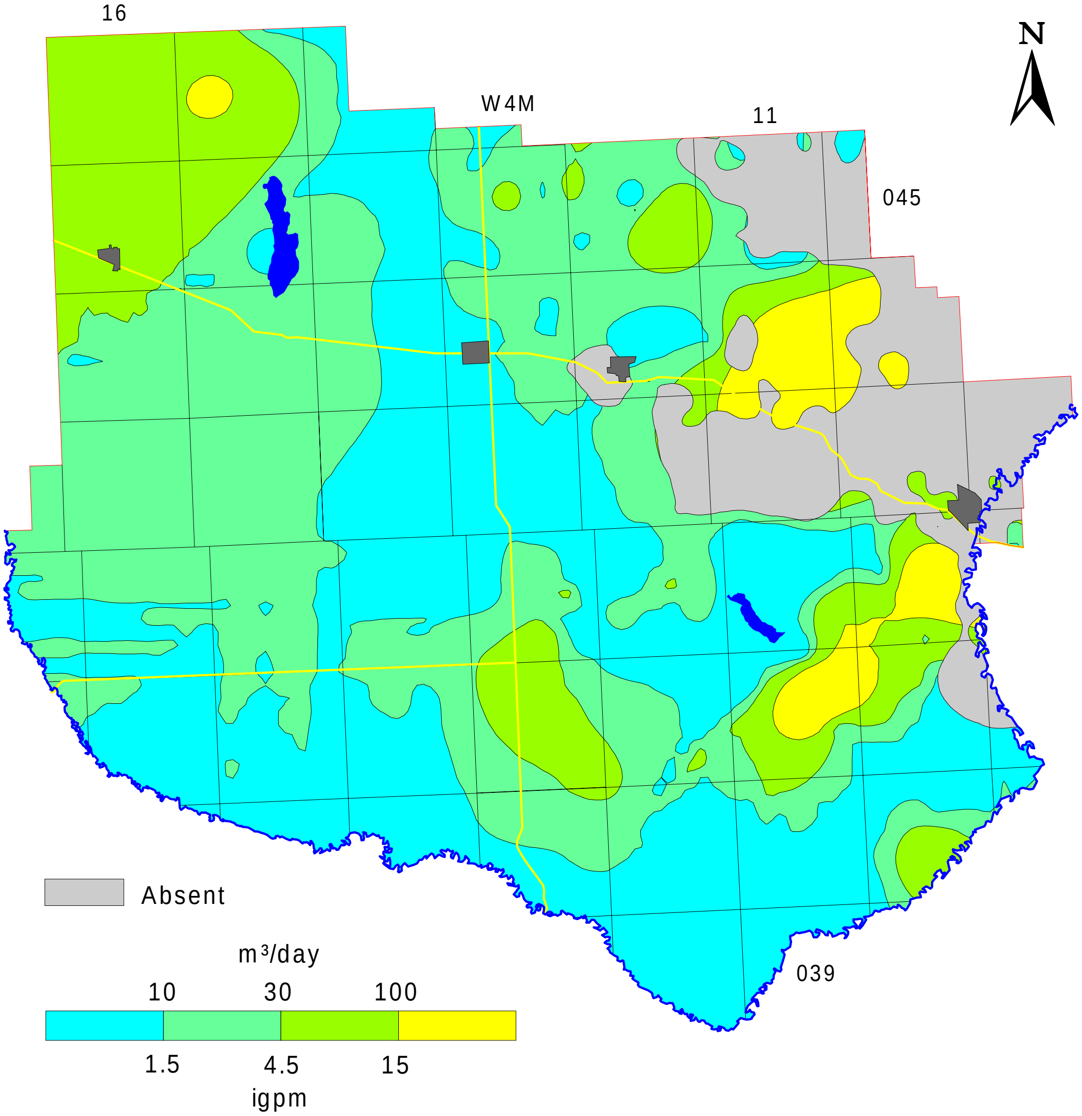
# Apparent Yield for Water Wells Completed through Bearpaw Aquifer



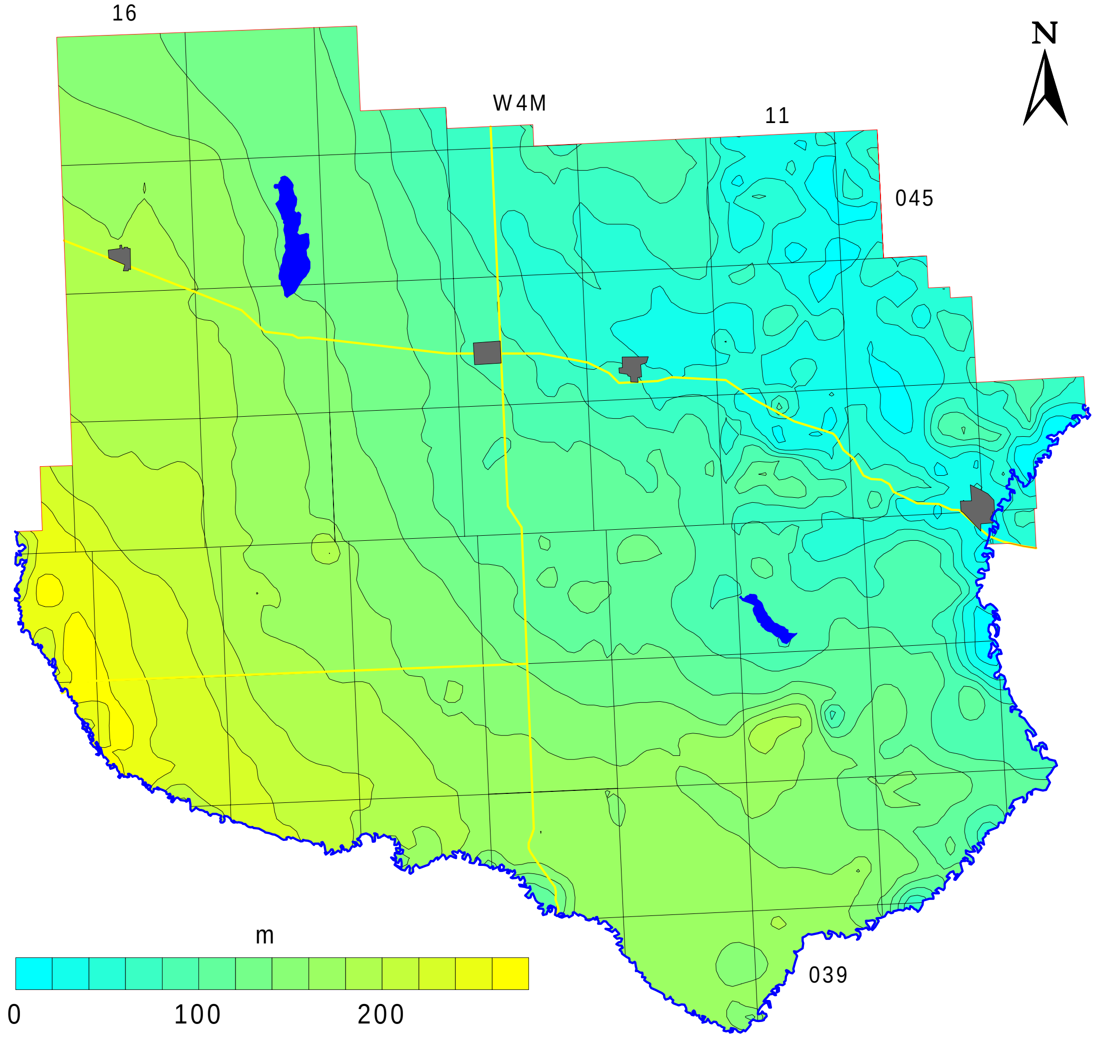
# Depth to Top of Oldman Formation



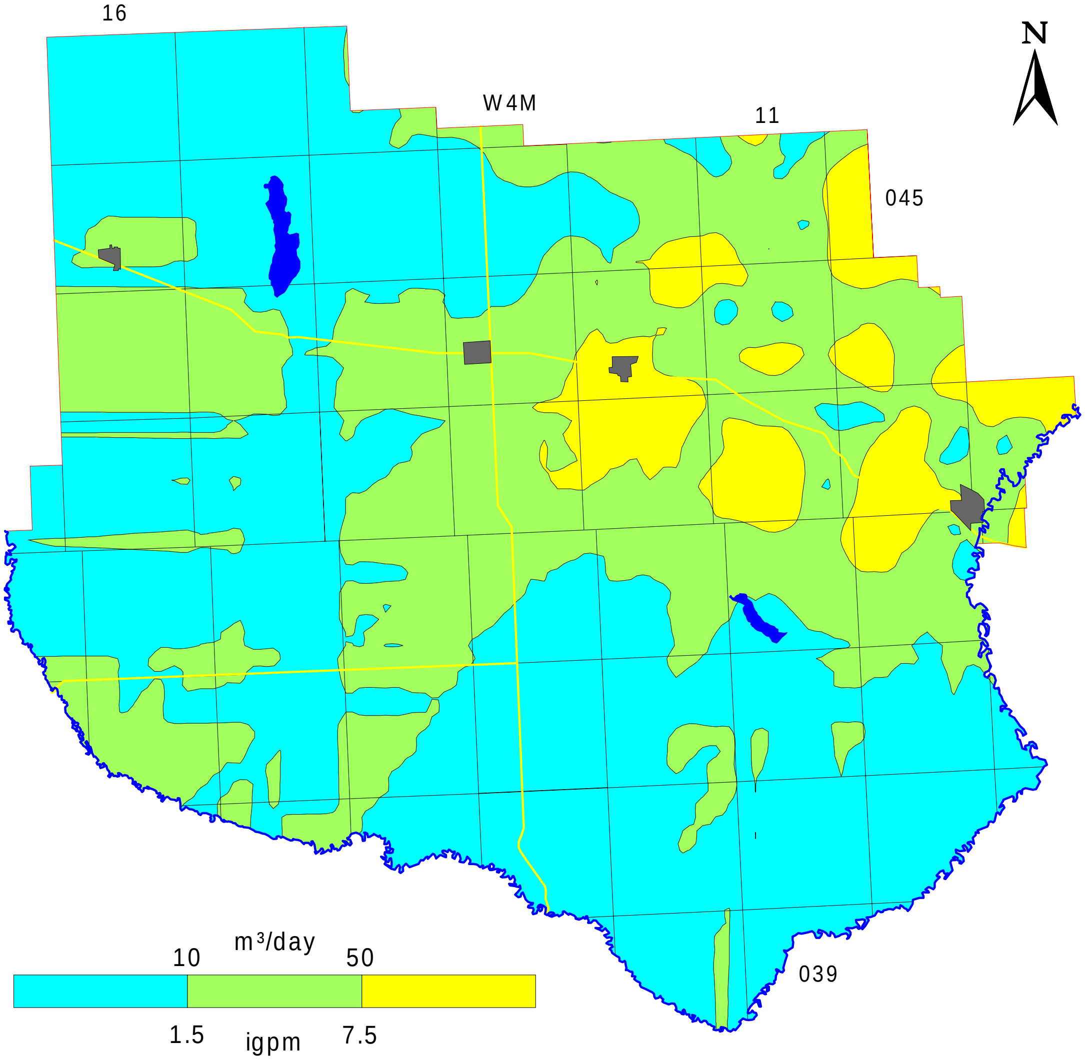
## Apparent Yield for Water Wells Completed through Oldman Aquifer



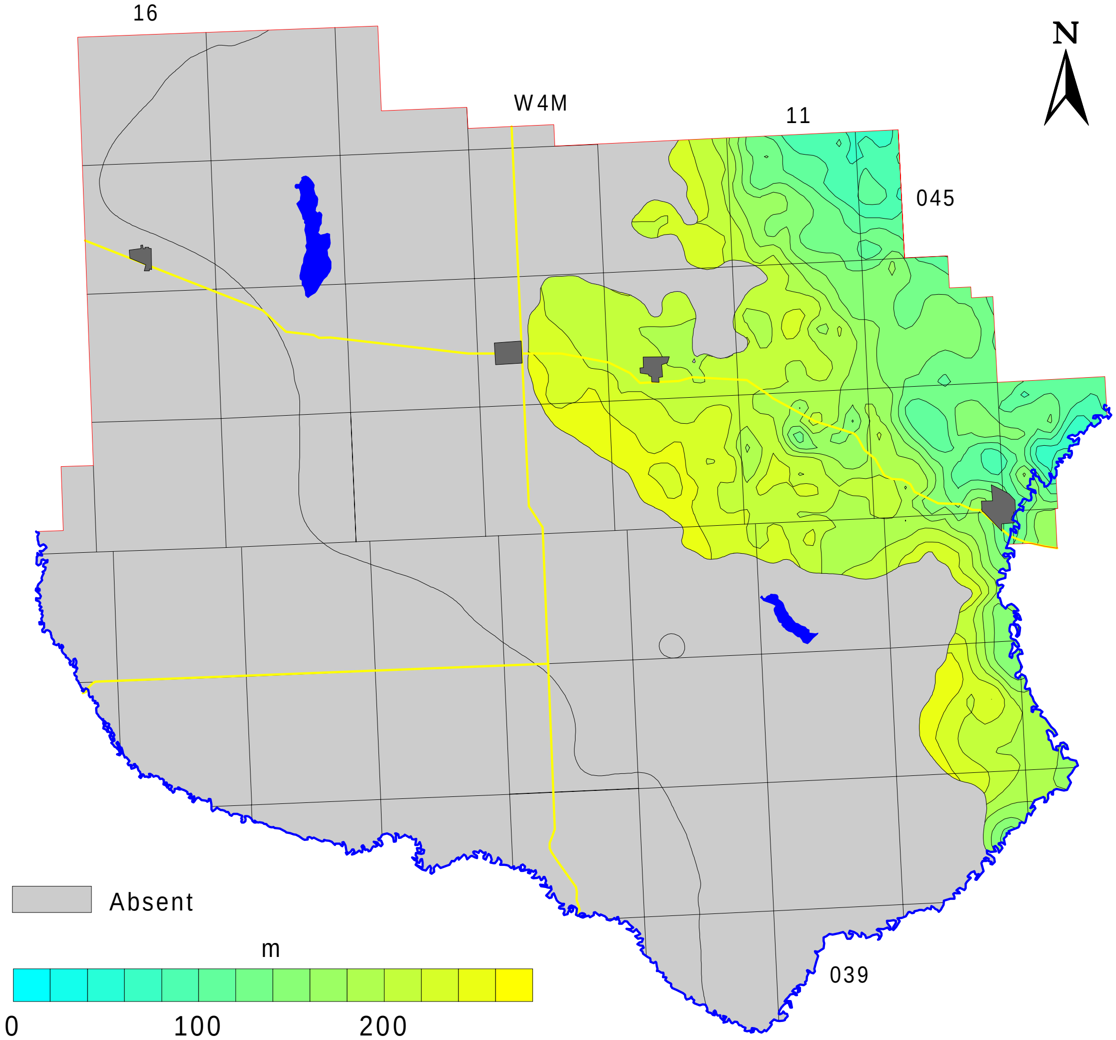
# Depth to Top of continental Foremost Formation



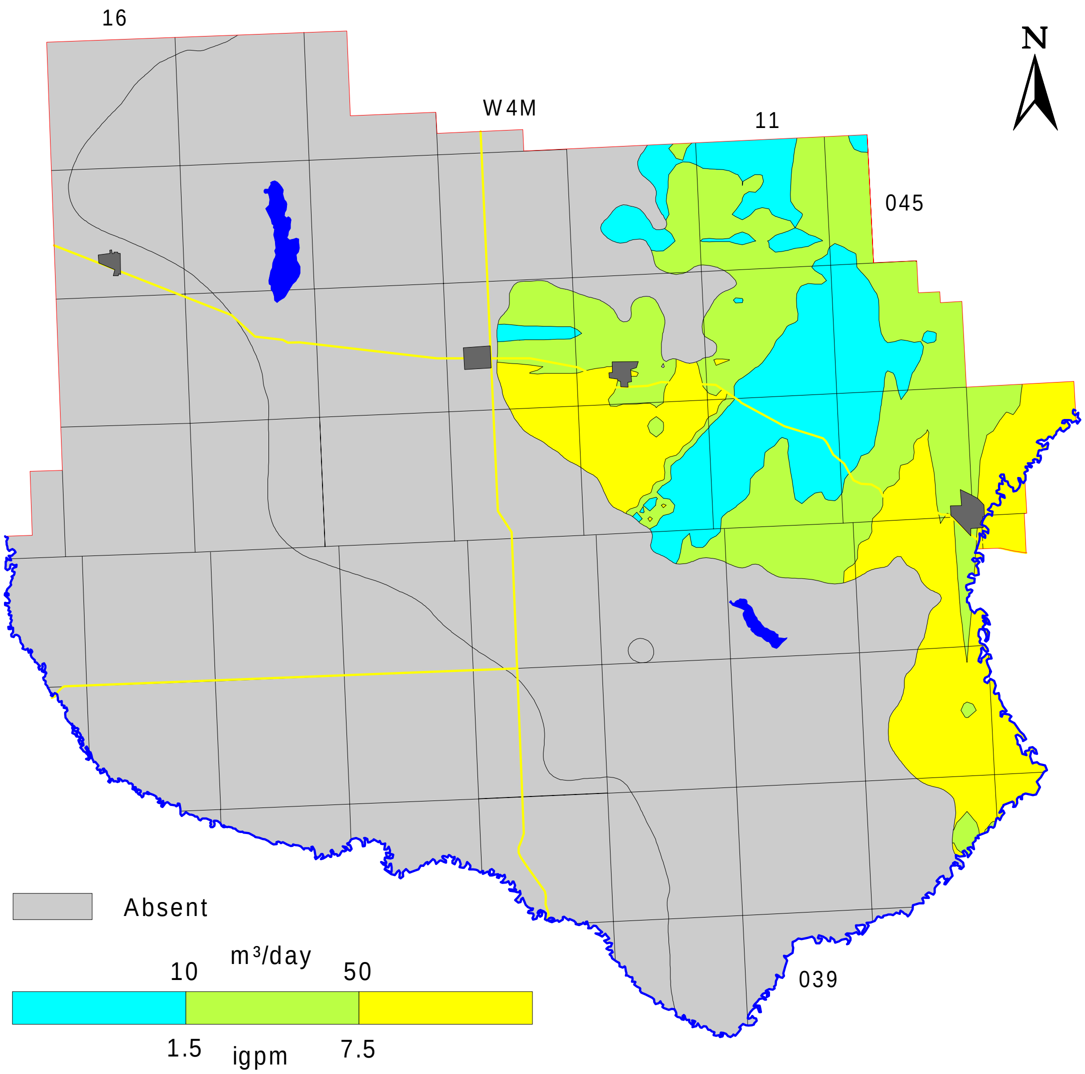
# *Apparent Yield for Water Wells Completed through continental Foremost Aquifer*



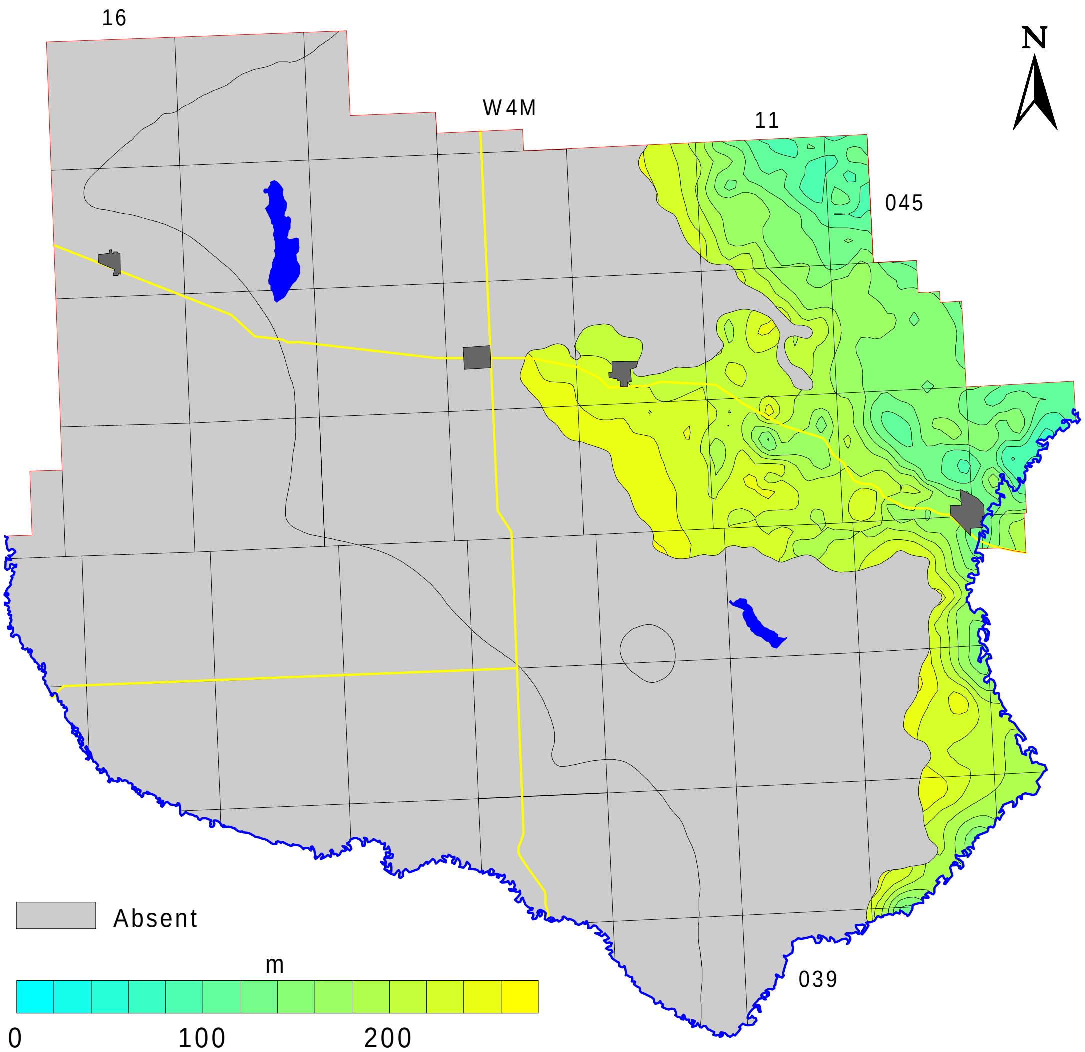
# Depth to Top of Milan Formation



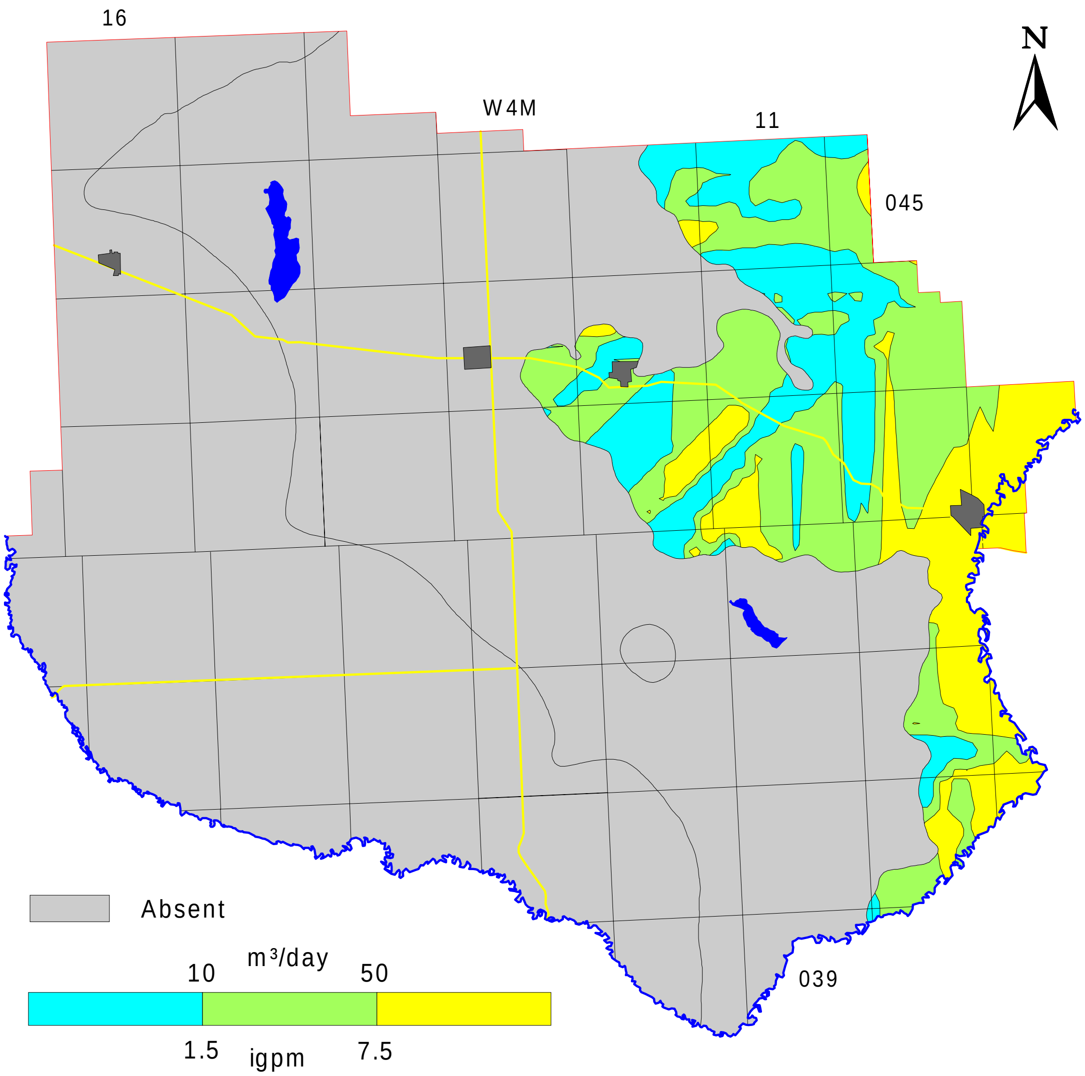
## Apparent Yield for Water Wells Completed through Milan Aquifer



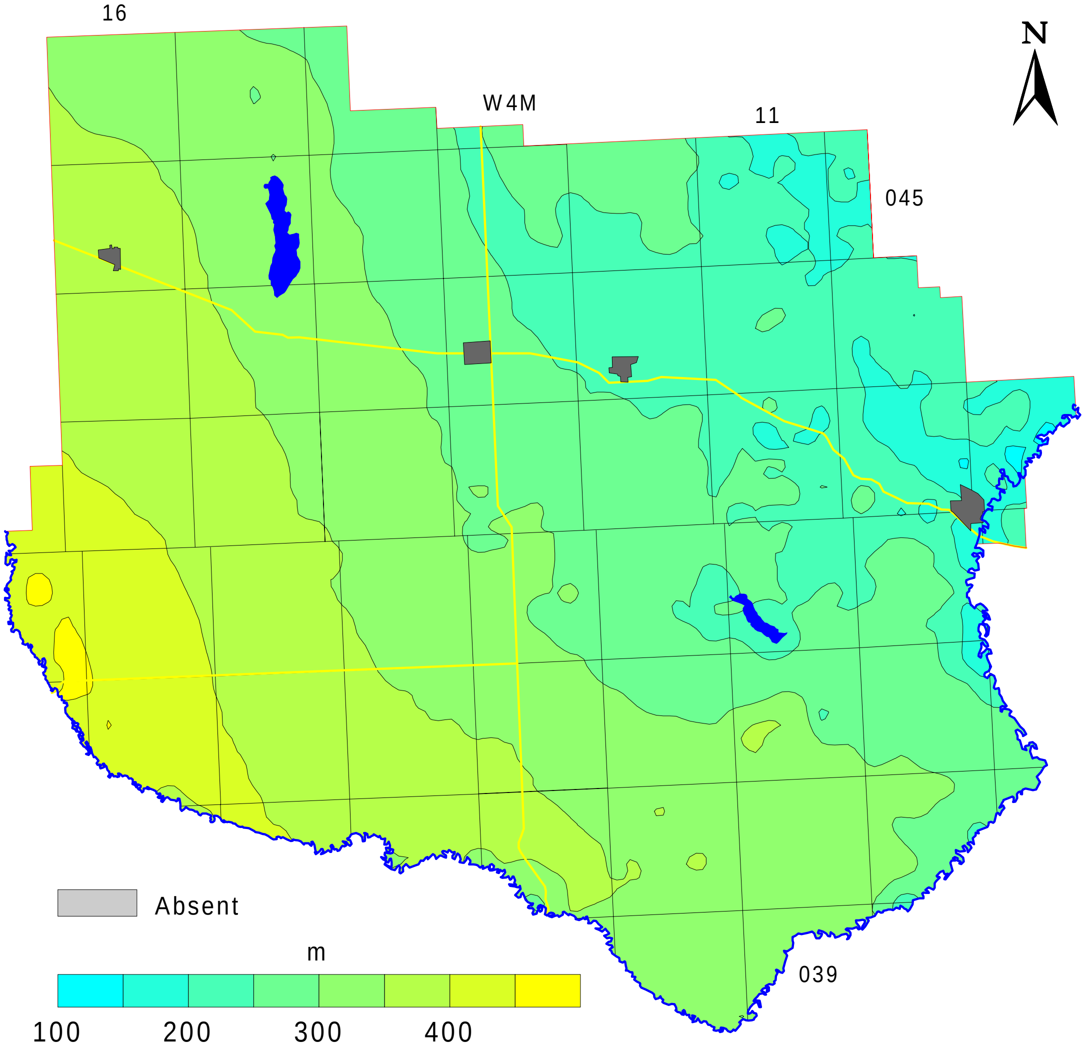
## Depth to Top of marine Foremost Formation



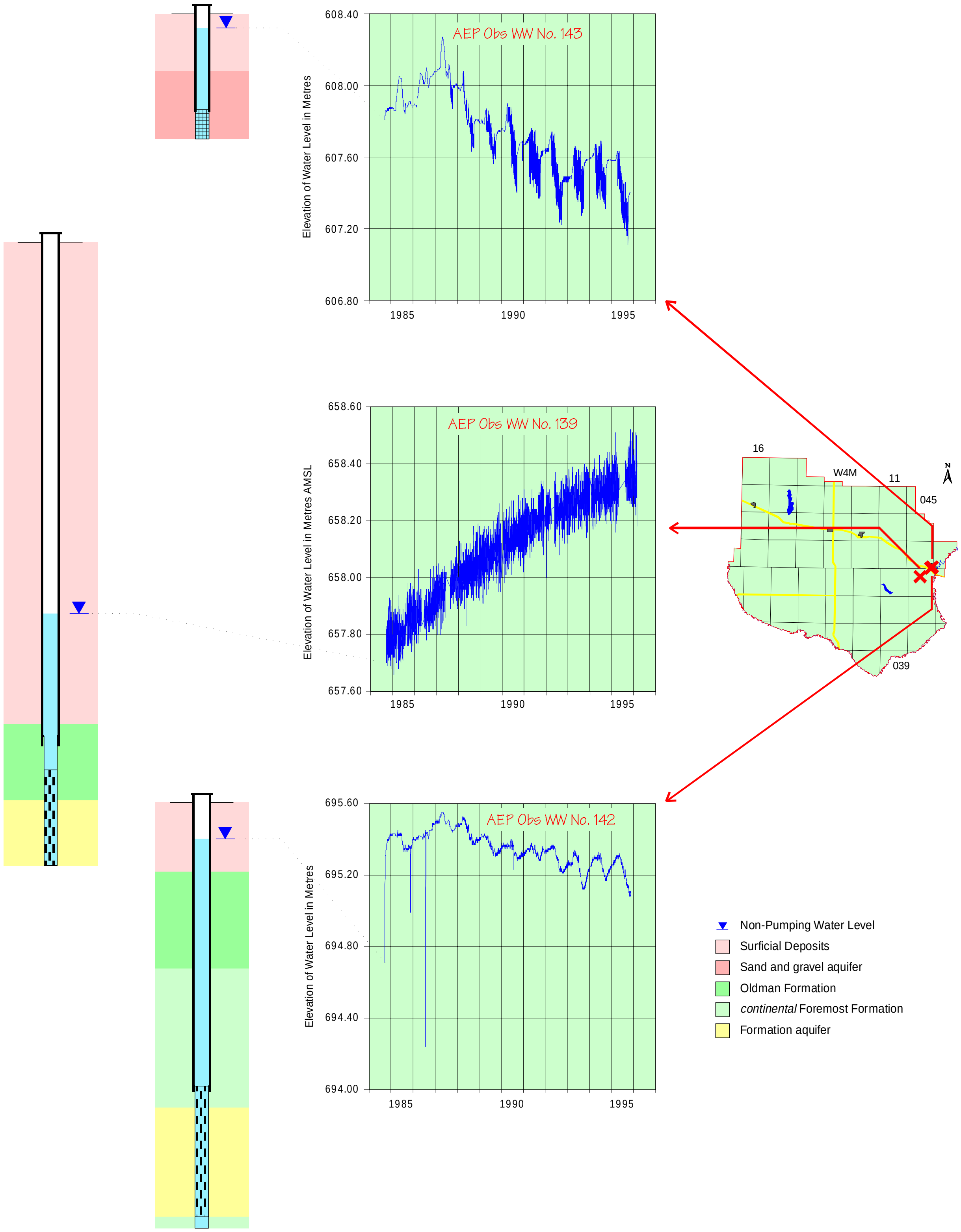
## Apparent Yield for Water Wells Completed through marine Foremost Aquifer



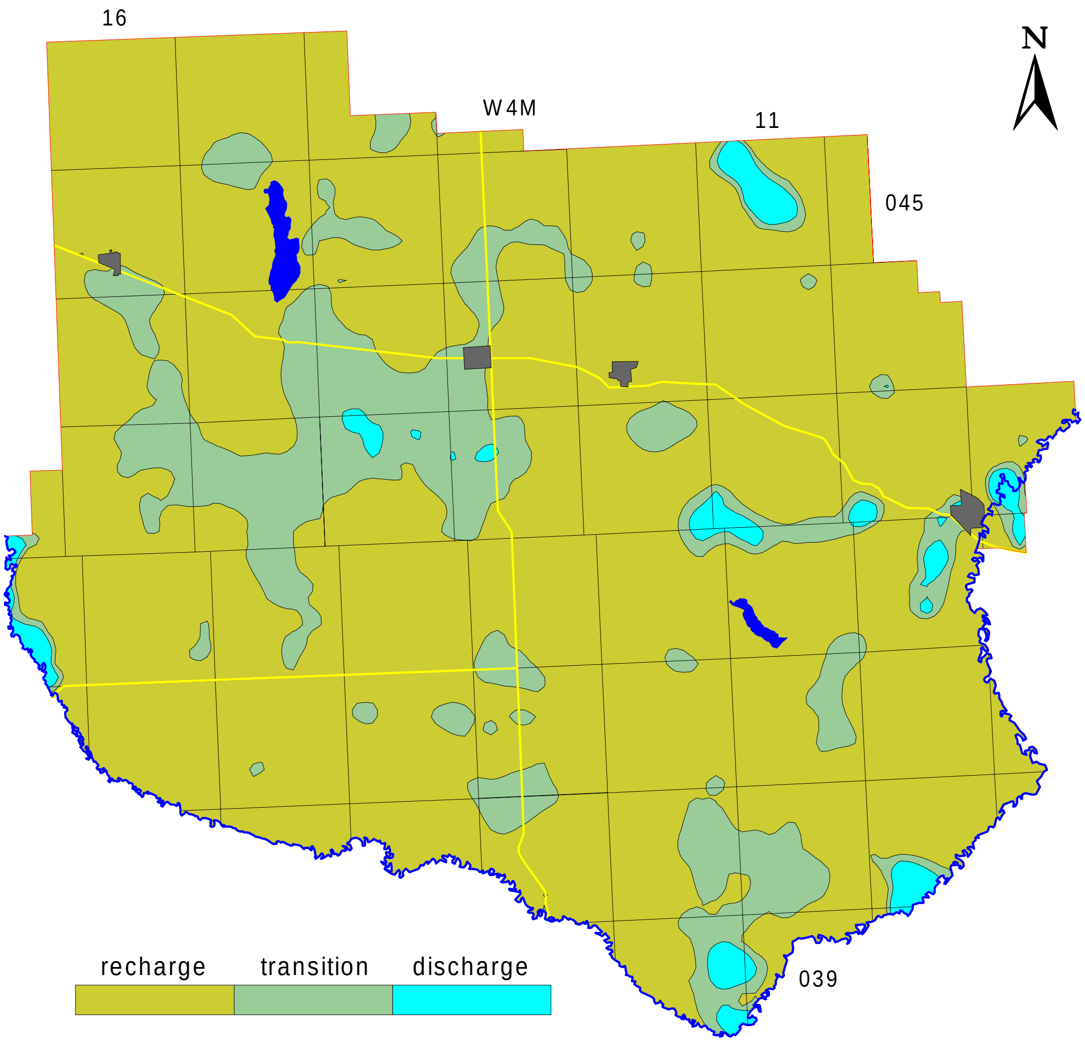
## *Depth to Top of Lea Park Aquitard*



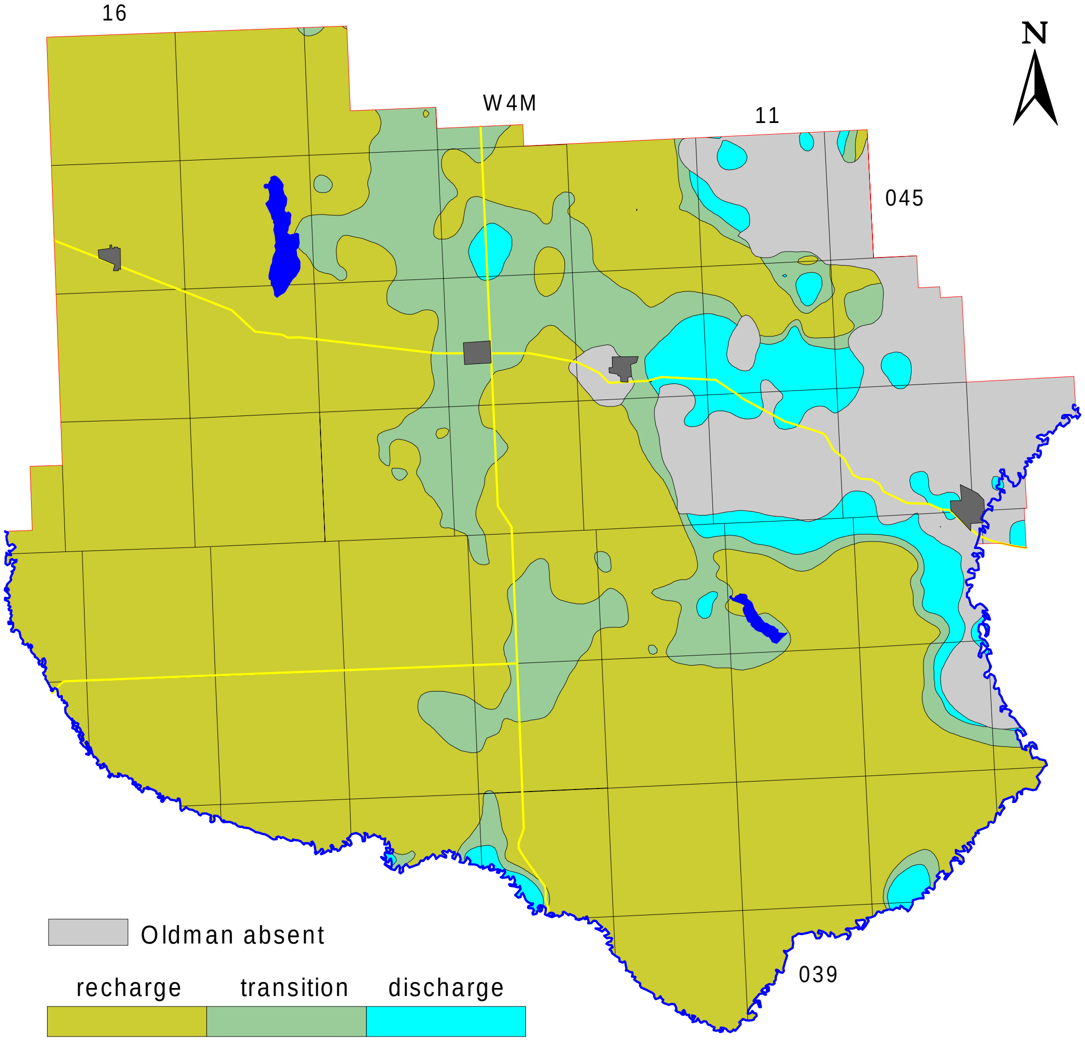
# Hydrographs - AEP Observation Water Wells



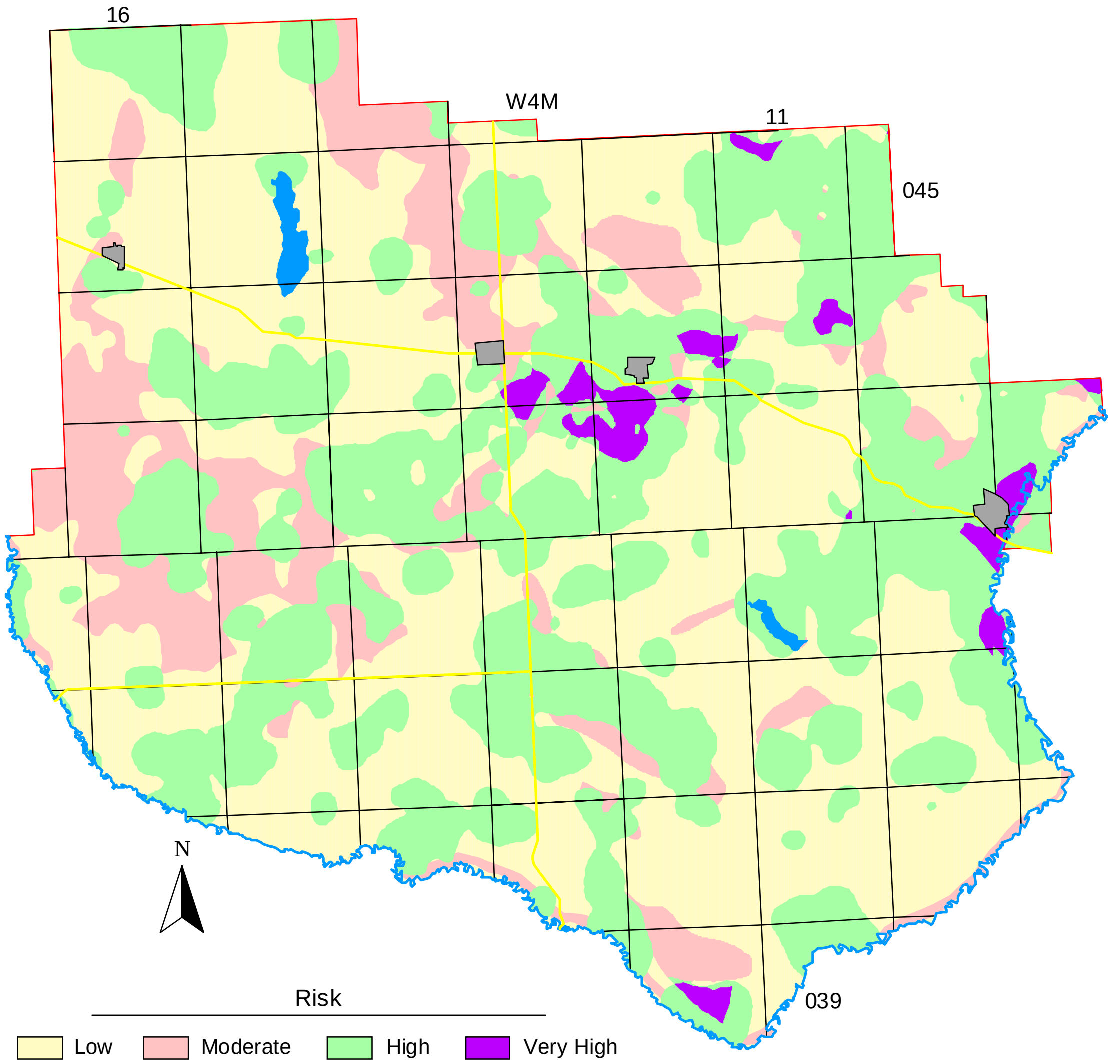
## Recharge/Discharge between Surficial Deposits and Upper Bedrock Aquifer(s)



## Recharge/Discharge between Surficial Deposits and Oldman Aquifer



## Risk of Groundwater Contamination



# FLAGSTAFF 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
- Location of Water Wells
- Depth of Existing Water Wells
- Depth to Base of Groundwater Protection
- Bedrock Topography
- Bedrock Geology
- Cross-Section A - A'
- Cross-Section B - B'
- Geologic Column
- Generalized Cross-Section (for terminology only)
- 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 Shallower than 15 metres
- 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
- Total Hardness of 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 Aquifer (not all drill holes fully penetrate surficial deposits)
- 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 (not all drill holes fully penetrate surficial deposits)
- 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)
- Total Hardness of Groundwater from Upper Bedrock Aquifer(s)
- Piper Diagram - Bedrock Aquifer(s)
- Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)
- Non-Pumping Water-Level Surface in Upper Bedrock Aquifer(s)

**b) 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

**c) Bearpaw Aquifer**

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

**d) Oldman Aquifer**

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

**e) *continental* Foremost Aquifer**

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

**f) Milan Aquifer**

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

**g) *marine* Foremost Aquifer**

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

**h) Lea Park Aquitard**

Depth to Top of Lea Park Aquitard
Structure-Contour Map - Top of Lea Park Aquitard

# FLAGSTAFF COUNTY
## Appendix C

## GENERAL WATER WELL INFORMATION


Domestic Water Well Testing ........................................ C - 2

Site Diagrams ........................................ C - 3

Surface Details. ........................................ C - 3

Groundwater Discharge Point ........................................ C - 3

Water-Level Measurements ........................................ C - 3

Discharge Measurements ........................................ C - 4

Water Samples ........................................ C - 4

Environmental Protection and Enhancement Act Water Well Regulation ........................................ C - 5

Additional Information ........................................ C - 6

# 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**

EXTRACT FROM THE ALBERTA GAZETTE

Published by the Queen's Printer for Alberta

*Distributed by:*

Publication Services
11510 Kingsway
Edmonton, T5G 2Y5
427-4952
FAX 452-0668

*and*

Publication Services
Main Floor, McDougall Centre
455 - 6th Street S.W.
Calgary, T2P 4E8
297-6251

**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)-(n) of the Environmental Protection and Enhancement Act.

*Table of Contents*

| | |
|---|---|
| Definitions | 1 |
| Approvals required | 2 |
| Duty to comply with Regulation | 3 |
| Application for approval | 4 |
| Requirements for Class A approval | 5 |
| Refusal of approval | 6 |
| Notification of change in information | 7 |
| Plates for approval holder | 8 |
| Problem well | 9 |
| Driller's report | 10 |
| Records during drilling | 11 |
| Certificate of variance | 12 |
| Reporting mineralized water or gas | 13 |
| Well site specifications | 14 |
| Pumphouse | 15 |
| Distance from sources of contamination | 16 |
| Construction requirements | 17 |
| Covering of well | 18 |
| Specifications for materials | 19 |
| Fluids and substances | 20 |

# 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)

ALBERTA ENVIRONMENTAL PROTECTION

WATER WELL INSPECTORS

Jennifer McPherson (Edmonton: 403-427-6429)
Colin Samis (Lac La Biche: 403-623-5235

GEOPHYSICAL INSPECTION SERVICE

Edmonton: 403-427-3932

COMPLAINT INVESTIGATIONS

Blair Stone (Red Deer: 340-5310)

UNIVERSITY OF ALBERTA – Department of Earth and Atmospheric Sciences - Hydrogeology

Carl Mendosa (Edmonton: 403-492-2664)

UNIVERSITY OF CALGARY – Department of Geology and Geophysics - Hydrogeology

Larry Bentley (Calgary: 403-220-4512)

FARMERS ADVOCATE

Paul Vasseur (Edmonton: 403-427-2433)

PRAIRIE FARM REHABILITATION ADMINISTRATION

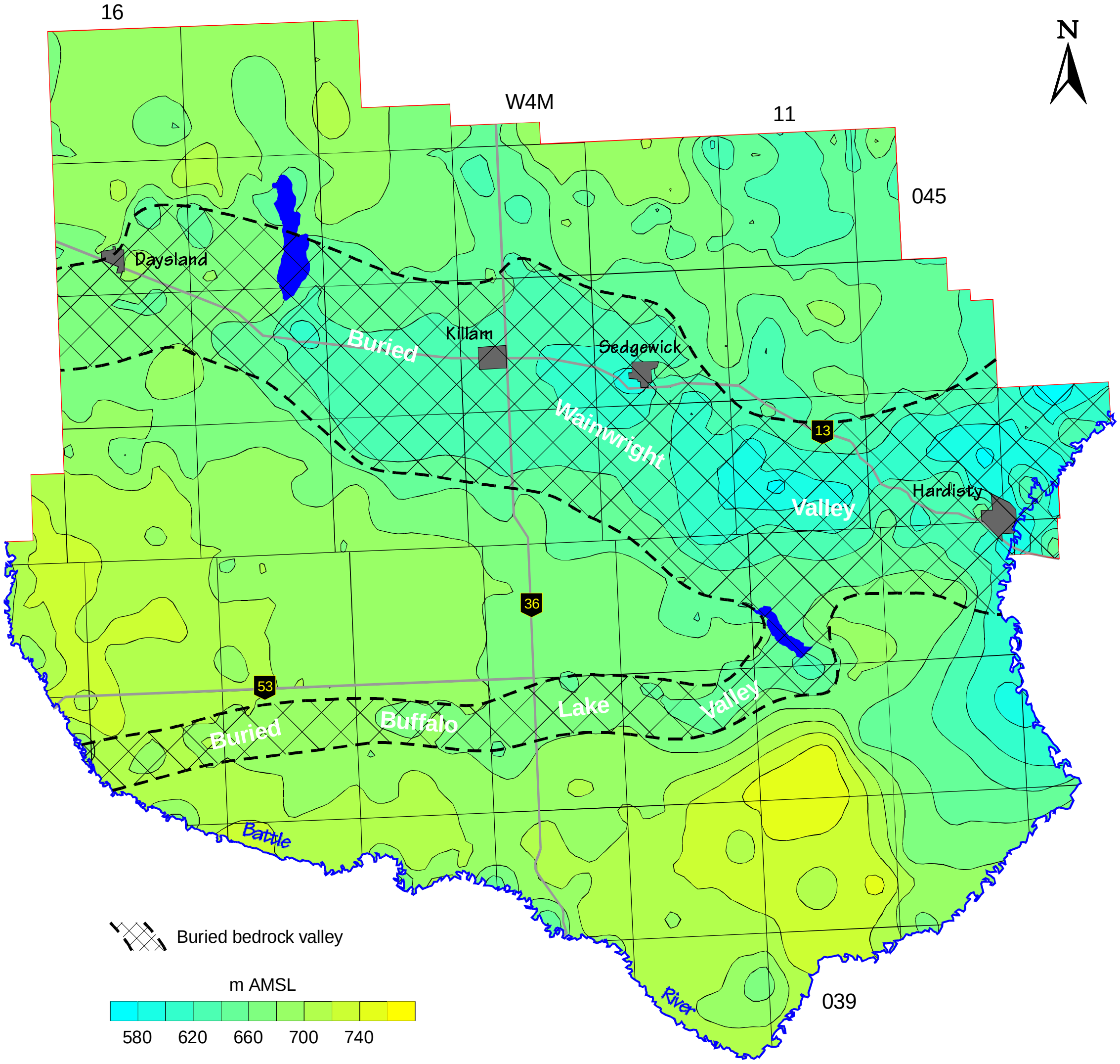
Dave Seitz (Hanna: (403) 854-4448)

LOCAL HEALTH DEPARTMENTS

# FLAGSTAFF COUNTY
## Appendix D

## MAPS AND FIGURES INCLUDED AS LARGE PLOTS

# Flagstaff County
# Bedrock Topography



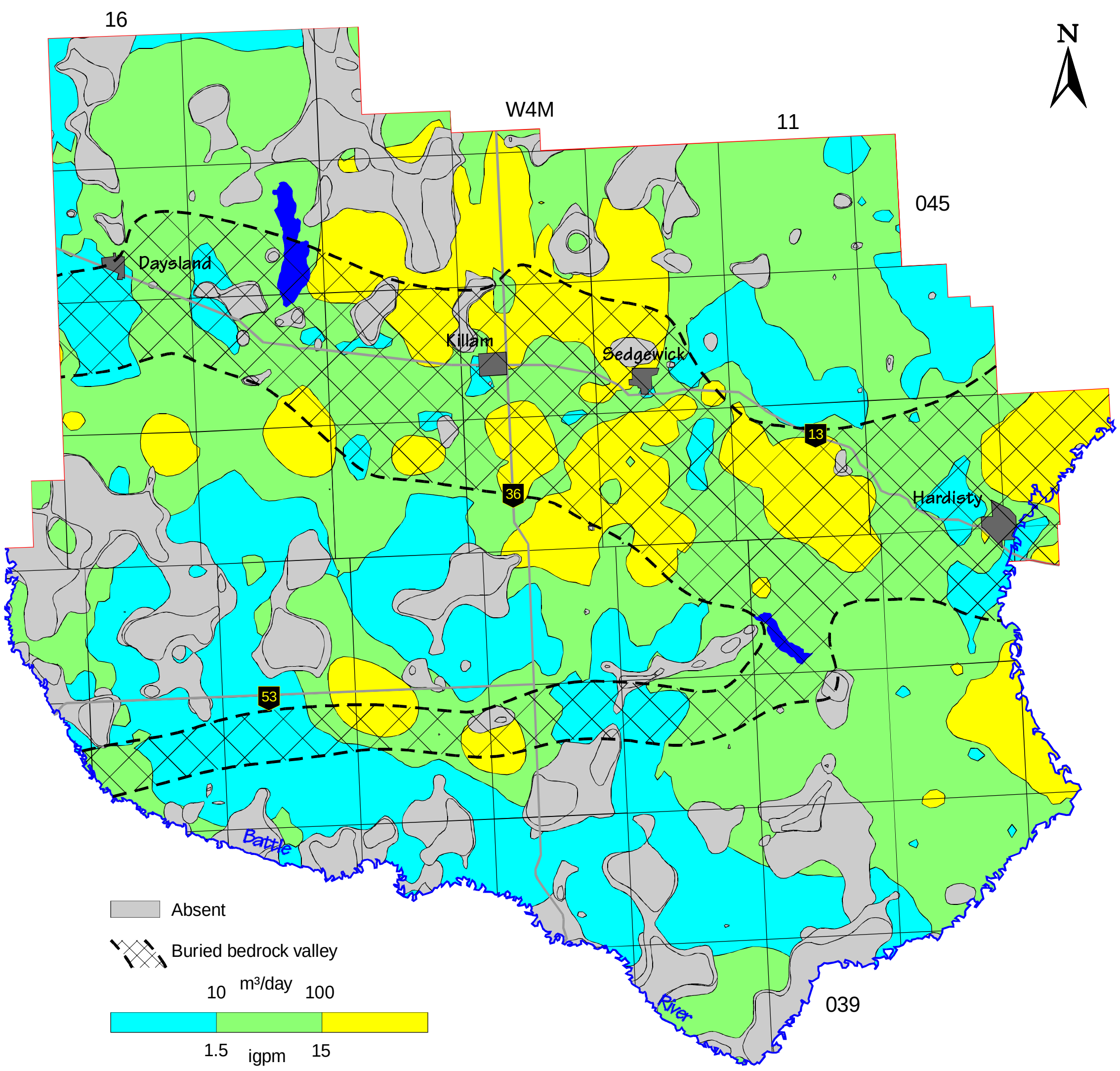

Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada

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.

hydrogeological consultants ltd.

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




Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada

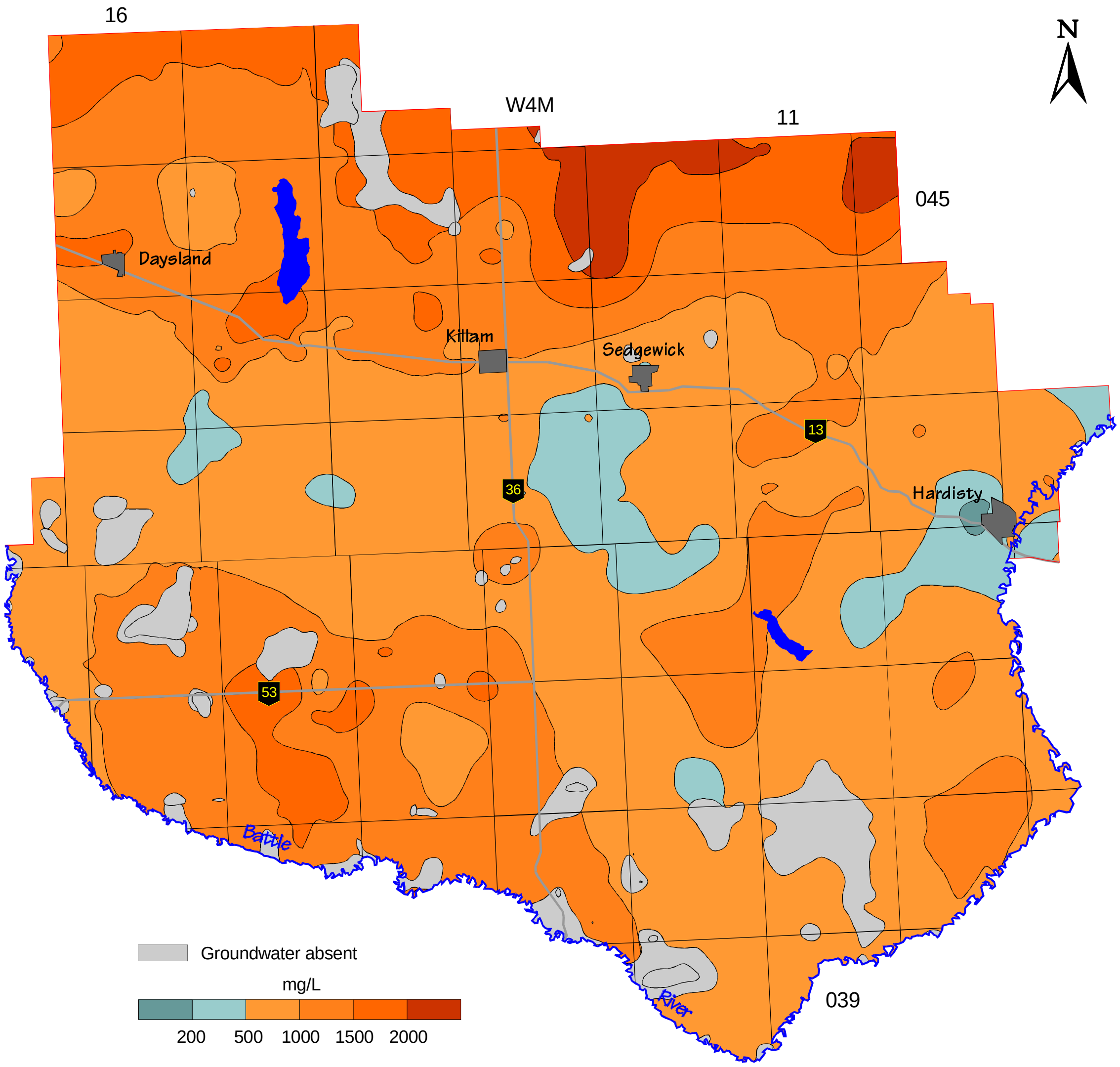
PFRA Prairie Farm Rehabilitation Administration

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.

hydrogeological consultants ltd.

hydrogeological consultants ltd, edmonton, alberta - 1-800-661-7972 - project no. 96-193 - sgqf.cdr - 25 Aug 98

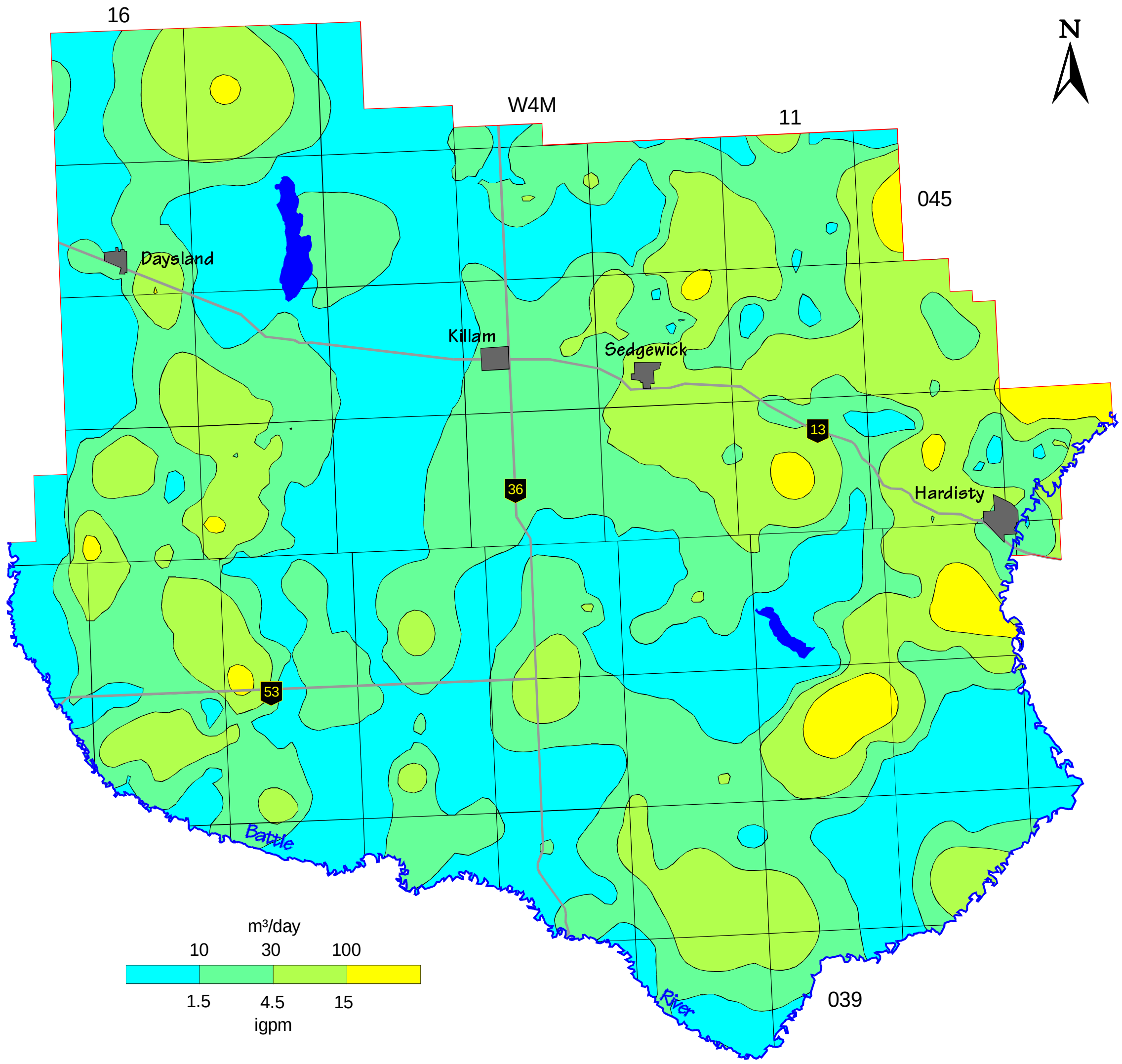
# Flagstaff County
# Total Dissolved Solids in Groundwater from Surficial Deposits




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.

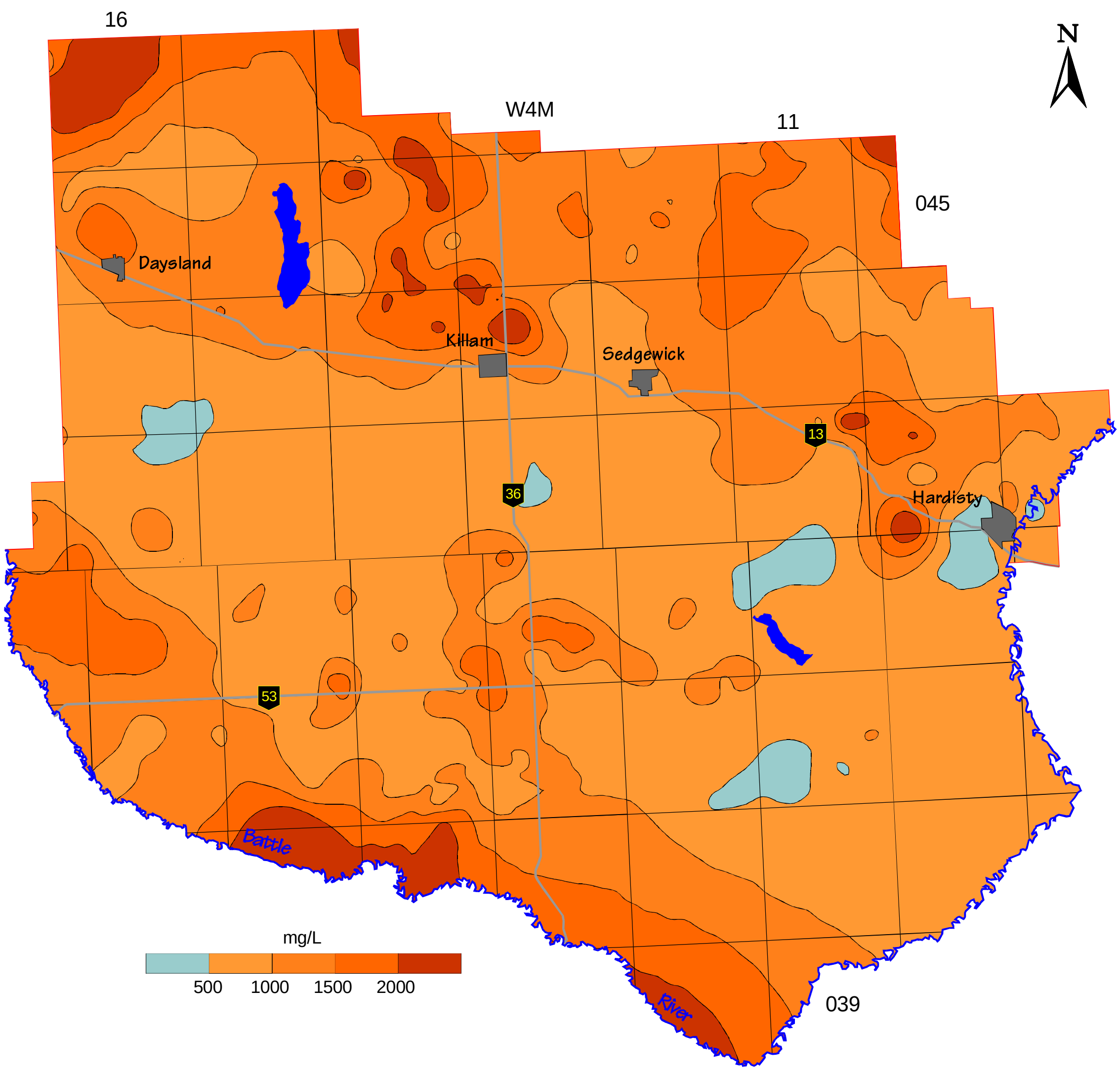
# Flagstaff County
# Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)




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.

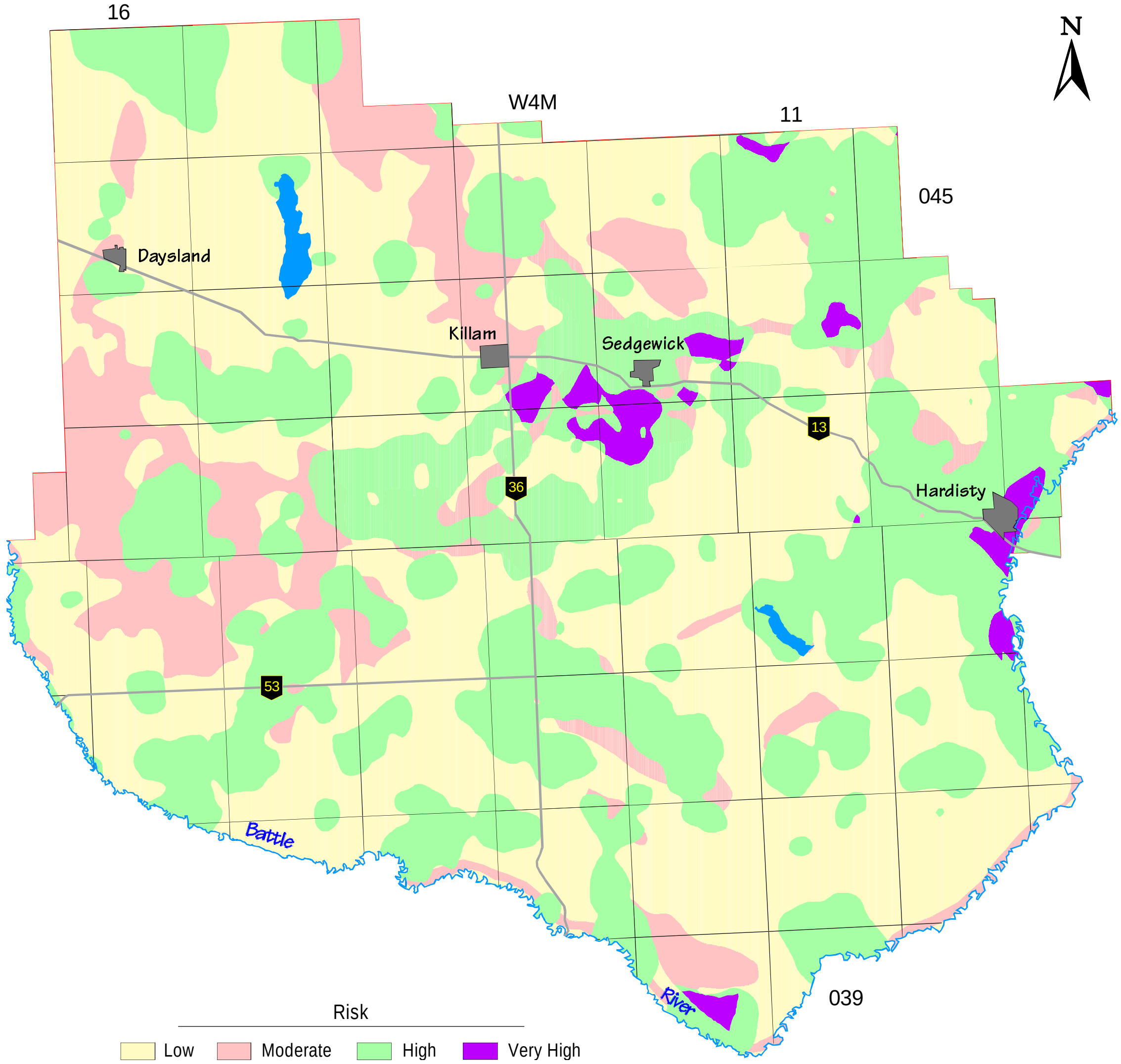
# Flagstaff County
# Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)




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.


hydrogeological consultants ltd.

# Flagstaff County
# Risk of Groundwater Contamination



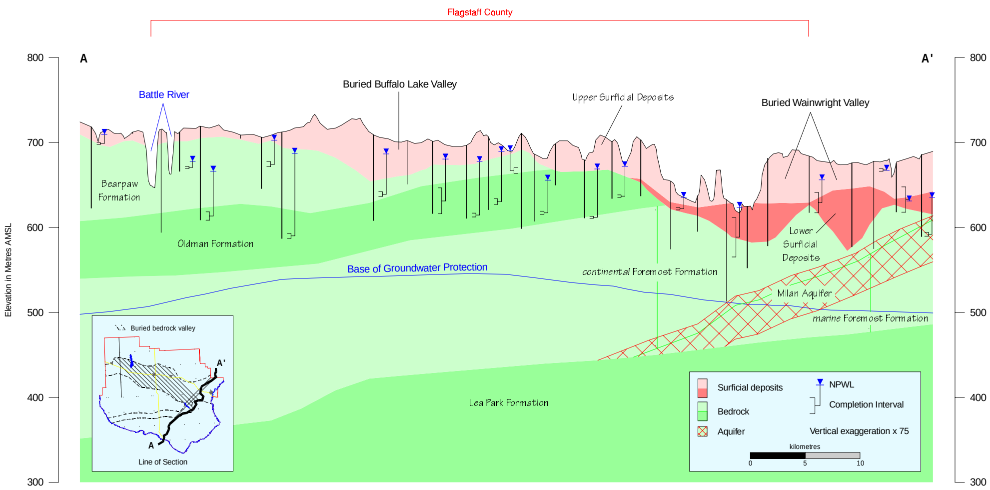

Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada
PFRA
Prairie Farm Rehabilitation Administration

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.



hydrogeological consultants ltd.

# Flagstaff County
# Cross-Section A - A'



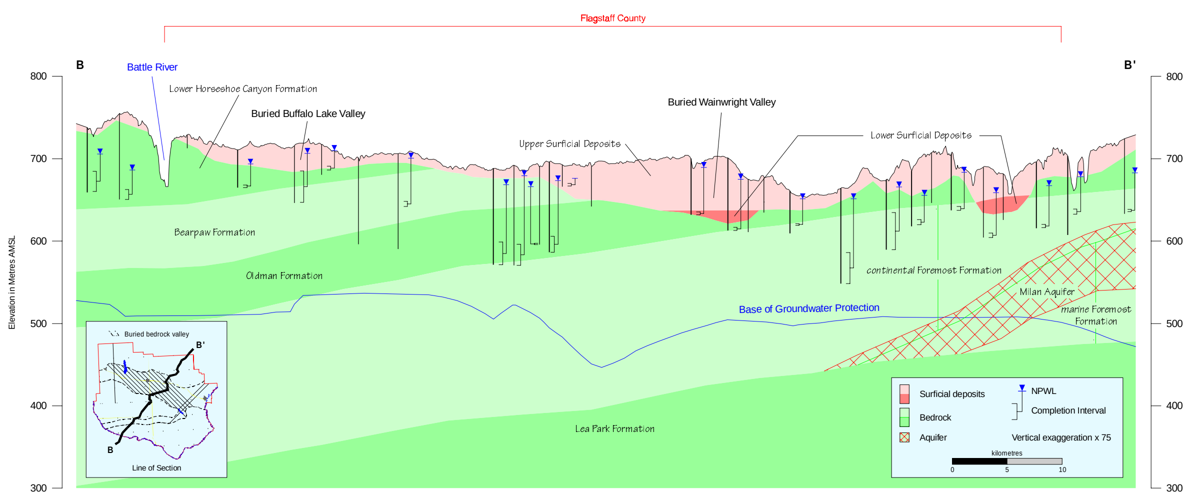

Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada

PFRA Prairie Farm Rehabilitation Administration

hydrogeological consultants ltd, edmonton, alberta - 1-800-661-7972 - project no. 97-102 - csAA-e.cdr - 09 Sep 98

hydrogeological consultants ltd.

# Flagstaff County
# Cross-Section B - B'




Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada
PFRA
Prairie Farm Rehabilitation Administration