Westlock County

Part of the Athabasca and North Saskatchewan River Basins
Parts of Tp 057 to 064, R 23 to 27, W4M and R 01 to 03, W5M
Regional Groundwater Assessment

Prepared for

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
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HYDROGEOLOGICAL CONSULTANTS LTD.

Signature______________________________

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The Association of Professional Engineers, Geologists and Geophysicists of Alberta

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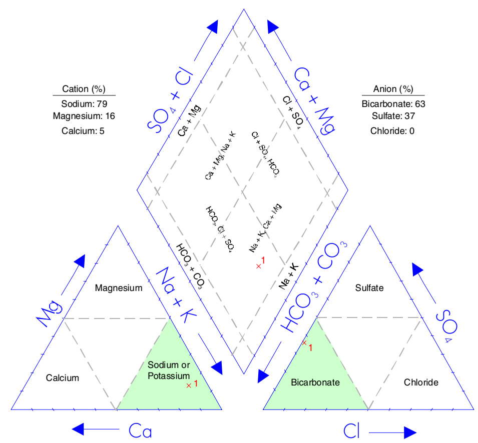
Glossary

Aquifer	a formation, group of formations, or part of a formation that contains saturated permeable rocks capable of transmitting groundwater to water wells or springs in economical quantities
Aquitard	a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer
Available Drawdown	in a confined aquifer, the distance between the non-pumping water level and the top of the aquifer in an unconfined aquifer (water table aquifer), two thirds of the saturated thickness of the aquifer
Borehole	includes all “work types” except springs
Deltaic	a depositional environment in standing water near the mouth of a river
Dewatering	the removal of groundwater from an aquifer for purposes other than use
Evapotranspiration	a combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants (Freeze and Cherry, 1979)
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
Friable	poorly cemented
Hydraulic Conductivity	the rate of flow of water through a unit cross-section under a unit hydraulic gradient; units are length/time
km	kilometre
Kriging	a geo-statistical method for gridding irregularly-spaced data (Cressie, 1990)
Lacustrine	fine-grained sedimentary deposits associated with a lake environment and not including shore-line deposits
Lithology	description of rock material
Lsd	Legal Subdivision
m	metres
mm	millimetres
m^2/day	metres squared per day
m^3	cubic metres
m^3/day	cubic metres per day
mg/L	milligrams per litre
Obs WW	Observation Water Well

Piper tri-linear diagram
: a method that permits the major cation and anion compositions of single or multiple samples to be represented on a single graph. This presentation allows groupings or trends in the data to be identified. From the Piper tri-linear diagram, it can be seen that the groundwater from this sample water well is a sodium-bicarbonate-type. The chemical type has been determined by graphically calculating the dominant cation and anion. For a more detailed explanation, please refer to Freeze and Cherry, 1979



Piper Tri-Linear Diagram

Rock
: earth material below the root zone

Surficial Deposits
: includes all sediments above the bedrock

Thalweg
: the line connecting the lowest points along a stream bed or valley; *longitudinal profile*

Till
: a sediment deposited directly by a glacier that is unsorted and consisting of any grain size ranging from clay to boulders

Transmissivity
: the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient: a measure of the ease with which groundwater can move through the aquifer

Apparent Transmissivity: the value determined from a summary of aquifer test data, usually involving only two water-level readings

Effective Transmissivity: the value determined from late pumping and/or late recovery water-level data from an aquifer test

Aquifer Transmissivity: the value determined by multiplying the hydraulic conductivity of an aquifer by the thickness of the aquifer

Water Well
: a hole in the ground for the purpose of obtaining groundwater; "work type" includes test hole, chemistry, deepened, well inventory, federal well survey, reconditioned, reconstructed, new, old well-test

Yield
: a regional analysis term referring to the rate a properly completed water well could be pumped, if fully penetrating the aquifer

Apparent Yield: based mainly on apparent transmissivity

Long-Term Yield: based on effective transmissivity

AE
: Alberta Environment

AMSL
: above mean sea level

DEM
: Digital Elevation Model

DST
: drill stem test

EUB	Alberta Energy and Utilities Board
GCDWQ	Guidelines for Canadian Drinking Water Quality
NPWL	non-pumping water level
NSR	North Saskatchewan River
PFRA	Prairie Farm Rehabilitation Administration
TDS	Total Dissolved Solids
WSW	Water Source Well or Water Supply Well

I. 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 also creates a solid base for increased economic activity. **Though this report’s scope is regional, it is a first step for Westlock County in managing their groundwater. It is also a guide for future groundwater-related projects.**

A. Purpose

This project is a regional groundwater assessment of Westlock County prepared by Hydrogeological Consultants Ltd. (HCL) with financial assistance from Prairie Farm Rehabilitation Administration (PFRA). 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 will:

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

Under the present program, the groundwater-related data for the 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.

B. The Project

This regional study should only be used 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 - Report
Module 4 - Groundwater Query
Module 5 - Familiarization Session

This report and the accompanying maps represent Modules 2 and 3.

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[1] See glossary
[2] See glossary

C. About This Report

This report provides an overview of (a) the groundwater resources of Westlock 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 to be provided with the final version of 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 as page-size drawings 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[3]
2) a table of contents for the Water (Ministerial) Regulation under the new Water Act
3) a flow chart showing the licensing of a groundwater diversion under the new Water Act
4) additional information.

The Water (Ministerial) 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. The new Water Act was proclaimed 10 Jan 1999.

Appendix E provides a list of water wells recommended for field verification.

[3] See glossary

II. INTRODUCTION

A. Setting

Westlock County is situated in central Alberta. This area is part of the Alberta Plains region. The County is within the Athabasca and North Saskatchewan river basins; a part of the County's northwestern boundary is the Athabasca River. The other County boundaries follow township or section lines. The area includes parts of the area bounded by township 057, range 3, W5M in the southwest and township 064, range 23, W4M in the northeast.

Regionally, the topographic surface varies between 600 and 740 metres above mean sea level (AMSL). The lowest elevations occur in the Pembina River Valley and the highest are in the southern and northeastern parts of the County as shown on Figure 1 and page A-2.

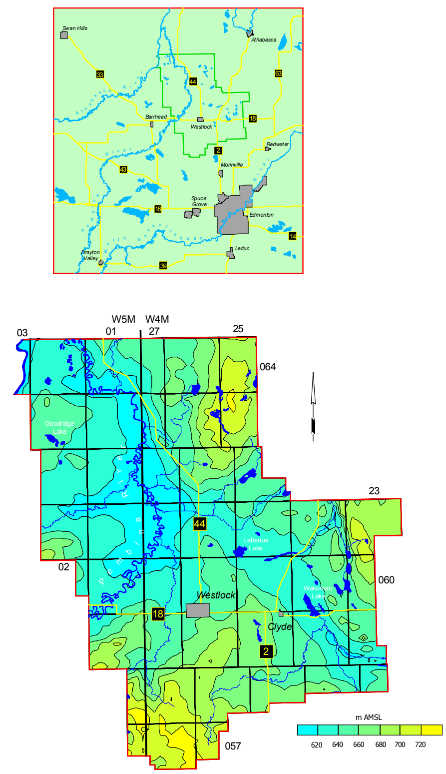

Figure 1. Index Map

B. Climate

Westlock County lies within the Dfb climate boundary. This classification is based on potential evapotranspiration[4] values determined using the Thornthwaite method (Thornthwaite and Mather, 1957), combined with the distribution of natural ecoregions in the area. The ecoregions map (Strong and Leggatt, 1981) shows that the County is located in both the Low Boreal Mixedwood region and the Aspen Parkland region. Increased precipitation and cooler temperatures, resulting in additional moisture availability, influence this vegetation change.

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

The mean annual precipitation averaged from one meteorological station within the County measured 468 millimetres (mm), based on data from 1980 to 1990. The mean annual temperature averaged 1.9° C, with the mean monthly temperature reaching a high of 16.8° C in July, and dropping to a low of -11.4° C in January. The calculated annual potential evapotranspiration is 528 millimetres.

[4] See glossary

C. Background Information

1) Numbers, Types and Depths of Water Wells

There are currently records for 3,677 water wells in the groundwater database for the County. Of the 3,677 water wells, 3,241 are for domestic/stock purposes. The remaining 436 water wells were completed for a variety of uses, including municipal, industrial, irrigation, investigation and observation. Based on a rural population of 6,958 (Phinney, 1999), there are 1.9 domestic/stock water wells per family of four. The domestic or stock water wells vary in depth from 1.2 metres to 365 metres below ground level. Details for lithology[5] are available for 1,924 water wells.

2) Numbers of Water Wells in Surficial and Bedrock Aquifers

There are 1,568 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 top of the bedrock are water wells completed in surficial aquifers. Of the 1,568 water wells for which aquifers could be defined, 451 are completed in surficial aquifers, with 55% having a completion depth of more than 30 metres. The adjacent map shows that the water wells completed in the surficial deposits occur throughout the County, frequently in the vicinity of linear bedrock lows.

The 1,117 water wells that have the top of their completion interval deeper than the top of the bedrock are referred to as bedrock water wells. From Figure 2, it can be seen that water wells completed in bedrock aquifers also occur throughout the County.

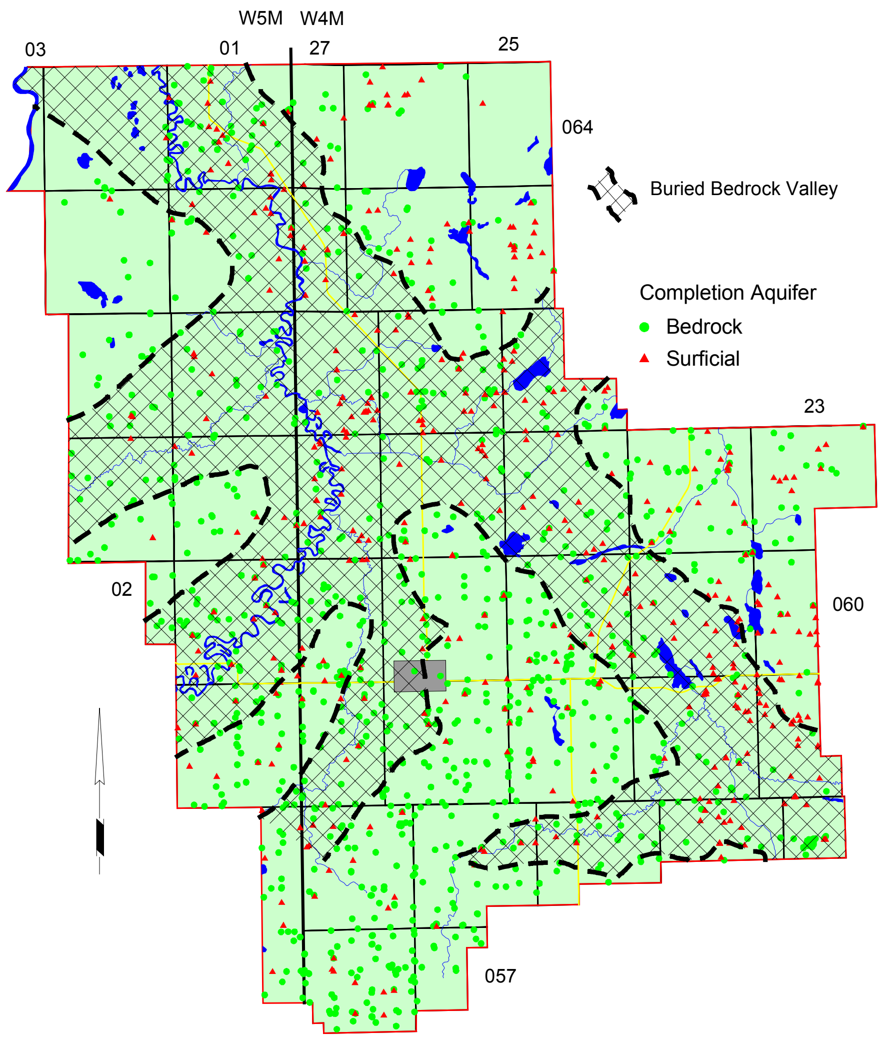

Figure 2. Location of Water Wells

5 See glossary

3) Casing Diameter and Types

Data for casing diameters are available for 1,660 water wells, with 1,497 (90%) indicated as having a diameter of less than 300 mm and 163 having a diameter of more than 300 mm. The casing diameters of greater than 300 mm are mainly bored or dug water wells and those with a surface-casing diameter of less than 300 mm are drilled water wells. Large-diameter water wells are mainly in the areas where significant linear bedrock lows are present.

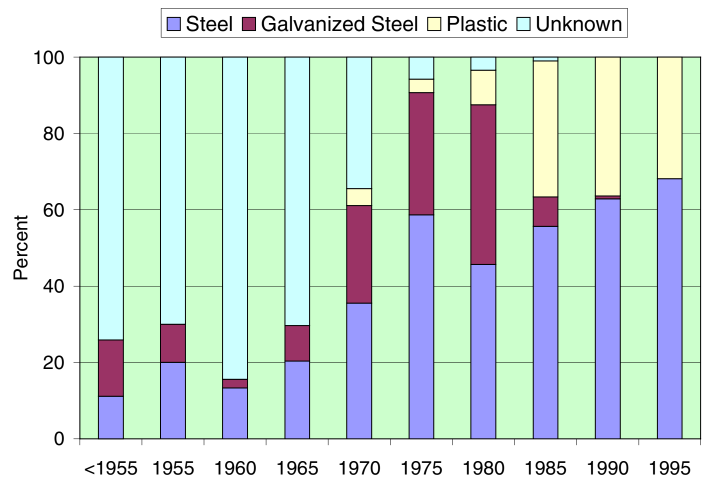

Figure 3. Surface Casing Types used in Drilled Water Wells

In the County, steel, galvanized steel and plastic represent 99% of the materials that have been used for surface casing in drilled water wells over the last 40 years. Until the 1960s, the type of surface casing used in drilled water wells was mainly undocumented. Steel casing was in use in the 1950s and is still used in 70% of the water wells being drilled in the County in the 1990s. Steel and galvanized steel were the main casing types until the start of the 1980s, at which time plastic casing started to replace the use of galvanized steel casing.

Galvanized steel surface casing was used in a maximum of 42% of the new water wells from the 1950s to the early 1990s. Galvanized steel was last used in January 1990.

4) Requirements for Licensing

Water wells used for household needs in excess of 1,250 cubic metres per year and providing groundwater with total dissolved solids (TDS) of less than 4,000 milligrams per litre (mg/L) must be licensed. At the end of 1999, 200 groundwater allocations were licensed in the County. Of the 200 licensed groundwater users, 165 are for agricultural purposes, and the remaining 35 are for power, municipal, dewatering, recreation and commercial purposes. The total maximum authorized diversion from the water wells associated with these licences is 3,098 cubic metres per day (m^3/day), of which 57% is allotted for agricultural use, and 25% is allotted for municipal use. The remaining 18% has been licensed for power, dewatering, recreation and commercial use as shown in Table 1 on the following page.

The largest potable groundwater allocation within the County is for the Village of Clyde, having a diversion of 243 m^3/day. The water supply well, used for municipal purposes, is completed in the Oldman Aquifer.

The following table shows a breakdown of the 200 licensed groundwater allocations by the aquifer in which the water well is completed. The largest total licensed allocations are in the Oldman Aquifer; the majority of the groundwater is used for agricultural and municipal purposes.

	Licensed Groundwater Users* (m³/day)							
Aquifer **	Agricultural	Power	Municipal	Dewatering	Recreation	Commercial	Total	Percentage
Upper Sand and Gravel	247	0	0	176	0	132	555	18
Lower Horseshoe Canyon	90	0	115	0	0	0	205	6
Bearpaw	52	0	0	0	0	0	52	2
Oldman	1,205	45	544	0	0	7	1,801	58
Birch Lake	142	0	108	0	203	2	455	15
Ribstone	24	0	0	0	0	0	24	1
Victoria	7	0	0	0	0	0	7	0
Unknown	0	0	0	0	0	0	0	0
Total	1,767	45	767	176	203	141	3,099	100
Percentage	57	1	25	6	6	5	100	

* - data from AE ** - identification of Aquifer by HCL

Table 1. Licensed Groundwater Diversions

Based on the 1996 Agriculture Census, the water requirement for livestock for the County is in the order of 12,149 m³/day. Of the 12,149 m³/day required for livestock use, groundwater provides 1,767 m³/day (14%) and surface water provides 2,107 m³/day (17%) for a total of 31% licensed by Alberta Environment.

5) Groundwater Chemistry and Base of Groundwater Protection

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 1,500 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. Less than 1% of the chemical analyses indicate a fluoride concentration above 1.0 mg/L.

The minimum, maximum and average concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the upper bedrock in the County have been compared to the Guidelines for Canadian Drinking Water Quality (GCDWQ) in Table 2. Of the five constituents compared to the GCDWQ, only average values of TDS and sodium concentrations exceed the guidelines.

	Range for County in mg/L			Recommended Maximum Concentration
Constituent	Minimum	Maximum	Average	GCDWQ
Total Dissolved Solids	222	4834	1250	500
Sodium	0	1775	454	200
Sulfate	0	1994	109	500
Chloride	<1	4875	195	250
Fluoride	0	13	1.0	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives

GCDWQ - Guidelines for Canadian Drinking Water Quality, Sixth Edition
Minister of Supply and Services Canada, 1996

Table 2. Concentrations of Constituents in Groundwaters from Upper Bedrock Aquifer(s)

Alberta Environment (AE) 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, and the elevation of the Base of Groundwater Protection provided by the Alberta Energy and Utilities Board (EUB), a depth to the Base of Groundwater Protection can be determined. These values are gridded using the Kriging[6] method to prepare a depth to the Base of Groundwater Protection surface. This depth, for the most part, would be the maximum drilling depth for a water well for agricultural purposes or for a potable water supply. If a water well is completed below the Base of Groundwater Protection with the total dissolved solids of the groundwater exceeding 4,000 mg/L, the groundwater use does not require licensing by AE.

Of the 3,535 water wells with completed depth data, 11 are completed below the Base of Groundwater Protection. Most of these water wells are located within a few kilometres of the Pembina River and in other areas where the depth to Base of Groundwater Protection ranges from less than 50 to 200 metres. All 11 water wells are used for industrial purposes; chemistry data are available for one water well, which provides groundwater with TDS of 3,195 mg/L.

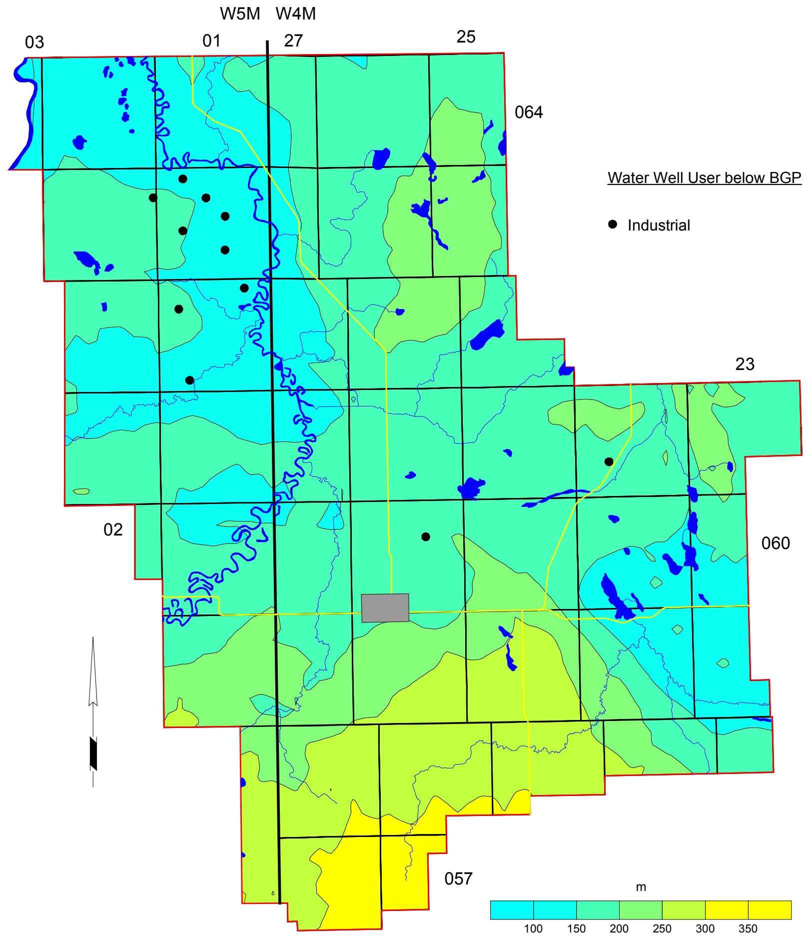

Figure 4. Depth to Base of Groundwater Protection (after EUB, 1995)

Proper management of the groundwater resource requires water-level data. These data are often collected from observation water wells. At the present time, there are no AE-operated observation water wells within the County. Additional data can be obtained from some of the licensed groundwater diversions. In the past, the data for licensed diversions have been difficult to obtain from AE, 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 (see section 6.0). 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.

[6] See glossary

III. TERMS

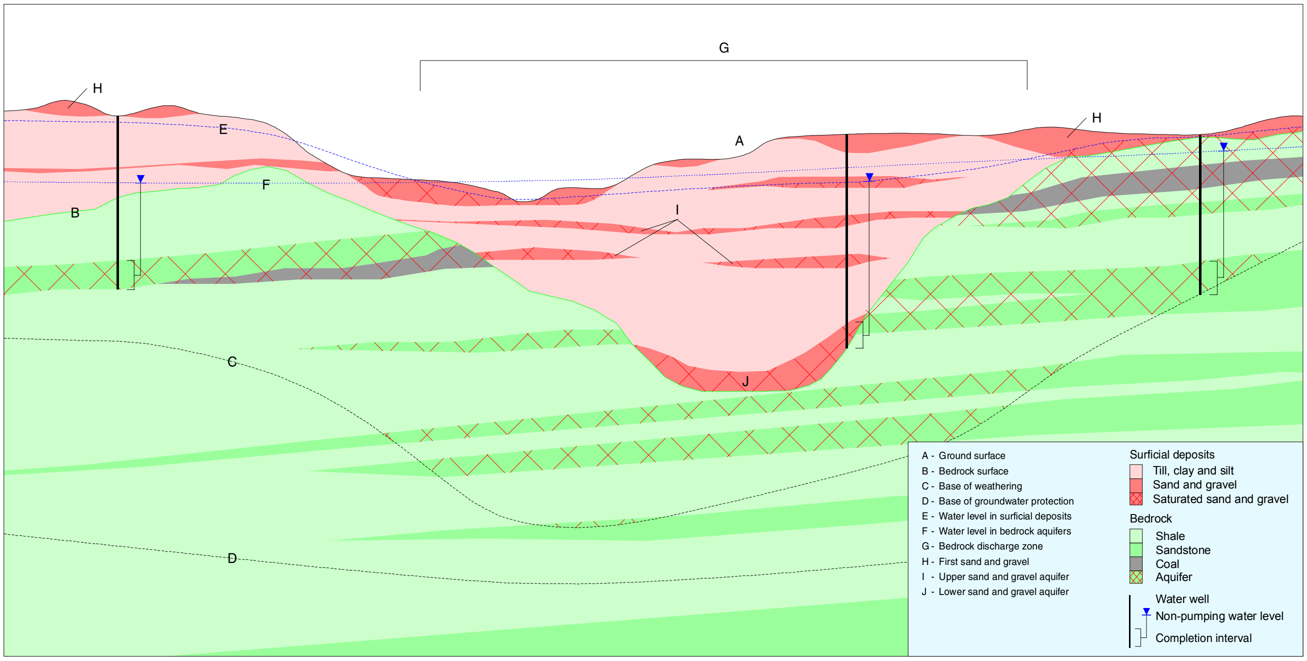

Figure 5. Generalized Cross-Section (for terminology only)

Lithology	Lithologic Description	Group and Formation: Average Thickness (m)	Group	Formation Thickness	Group and Formation: Designation	Member: Average Thickness (m)	Member: Designation	Zone: Average Thickness (m)	Zone: Designation
	sand, gravel, till, clay, silt	<140			Surficial Deposits	<140	Upper	<30	First Sand and Gravel
						<50	Lower		
	shale, sandstone, coal, bentonite, limestone, ironstone	300-380	Edmonton Group		Horseshoe Canyon Formation	~100	Upper		
						~100	Middle		
						~170	Lower		
	shale, sandstone, siltstone	60-120			Bearpaw Formation				
	sandstone, siltstone, shale, coal	<300	Belly River Group	40-130	Oldman Formation		Dinosaur Member	<25	Lethbridge Coal Zone
							Upper Siltstone Member		
							Comrey Member		
	sandstone, shale			<200	Foremost Formation	<70	Birch Lake Member		Taber Coal Zone
						<60	Ribstone Creek Member		
						<70	Victoria Member		McKay Coal Zone
						0-30	Brosseau Member		
	shale, siltstone				Lea Park Formation	100-200			

Figure 6. Geologic Column

IV. METHODOLOGY

A. Data Collection and Synthesis

The AE 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
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. However, unlike other areas in the Province where there are numerous duplicate records, the present database for the County contains less than 40 duplicate water well IDs.

The AE 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 10TM coordinate system. This means that a record for the NW ¼ of section 25, township 058, range 27, W4M, would have a horizontal coordinate with an Easting of 73,077 metres and a Northing of 5,987,106 metres, the centre of the quarter section. If the water well has been repositioned by PFRA using orthorectified aerial photos, the location will be more accurate, possibly within several 10s of metres of the actual location. Once the horizontal coordinates are determined for a record, a ground elevation for that record is obtained from the 1:20,000 Digital Elevation Model (DEM); the DEM is provided by the Resource Data Division of AE.

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 digital surface was prepared representing the minimum depth for water wells and a second digital 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.

After assigning spatial control for the ground location for 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
5) depth to the top and bottom of completion intervals.

Also, where sufficient information is available, values for apparent transmissivity[7] and apparent yield[8] are calculated, based on the aquifer test summary data supplied on the water well drilling reports. Where valid detailed aquifer test results exist, the interpreted data provide values for aquifer transmissivity and effective transmissivity Since the regional hydrogeology map was published in 1977 (Tokarsky, 1977), 143 values for effective transmissivity have been added to the groundwater database.

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
4) drill stem test (DST) summaries.

Values for apparent transmissivity, apparent yield 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 support the geological interpretation of geophysical logs but cannot be distributed because of a licensing agreement.

B. 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
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.

The values for the elevation of the top and bottom of individual geological units at specific locations help to determine the spatial distribution of the individual surfaces. Establishment of a surface distribution digitally requires preparation of a grid. The inconsistent quality of the data 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

7 For definitions of Transmissivity, see glossary
8 For definitions of Yield, see glossary

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 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.

C. 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 these 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. Even when only limited data are available, grids are prepared. However, the data from these grids must be used with extreme caution because the gridding process can be unreliable.

1) Risk Criteria

The main source of groundwater contamination involves activities on or near the land surface. The risk of groundwater contamination is high when the near-surface materials are porous and permeable and low when the materials are less porous and less permeable. The 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 and/or the soil 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 and/or the soil map is categorized based on relative permeability. The information from these sources is combined to form the risk assessment map. The criteria used in the classification of risk are given in the above 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

D. 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 outline and the thickness of the geological unit.

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.

The grids for the geological surfaces are used to prepare a three-dimensional stratigraphic model. The stratigraphic model has been prepared from the USGS 3-D MODFLOW model that was prepared for the County to estimate flow through various aquifers. Cross-sections are prepared by selecting specific rows or columns from the stratigraphic model grid and exporting the data to AutoCAD for finalizing for presentation. If a cross-section is required along a line that is at an angle to the model grid, the grid can be rotated. Once the cross-section has been selected, water wells that are within 400 metres of the line of section are added 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 as poster-size drawings forwarded with this report. The cross-sections also are in Appendix A, and are included on the CD-ROM; page-size maps of the poster-size cross-sections are included in Appendix D of this report.

E. Software

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

- Acrobat 4.0
- ArcView 3.1
- AutoCAD 14.01
- CorelDRAW! 8.0
- Environmental Systems
- Microsoft Professional Office 2000
- Surfer 6.04
- Tecplot 8.0
- USGS 3-D MODFLOW

V. AQUIFERS

A. Background

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

1) Surficial Aquifers

Surficial deposits in the County are mainly less than 50 metres thick, except in areas of linear bedrock lows where the thickness of the surficial deposits can exceed 80 metres. The Buried Dapp Valley is the main linear bedrock low in the County. The Buried Dapp Valley is present in the northwest corner of the County; and extends northwest from the Buried Egremont Valley in township 059, ranges 23 and 24, W4M to township 064, range 02, W5M where the Valley leaves the County. Cross-section A-A' passes across parts of the Buried Dapp Valley, and shows a maximum thickness of surficial deposits of slightly less than 100 metres.

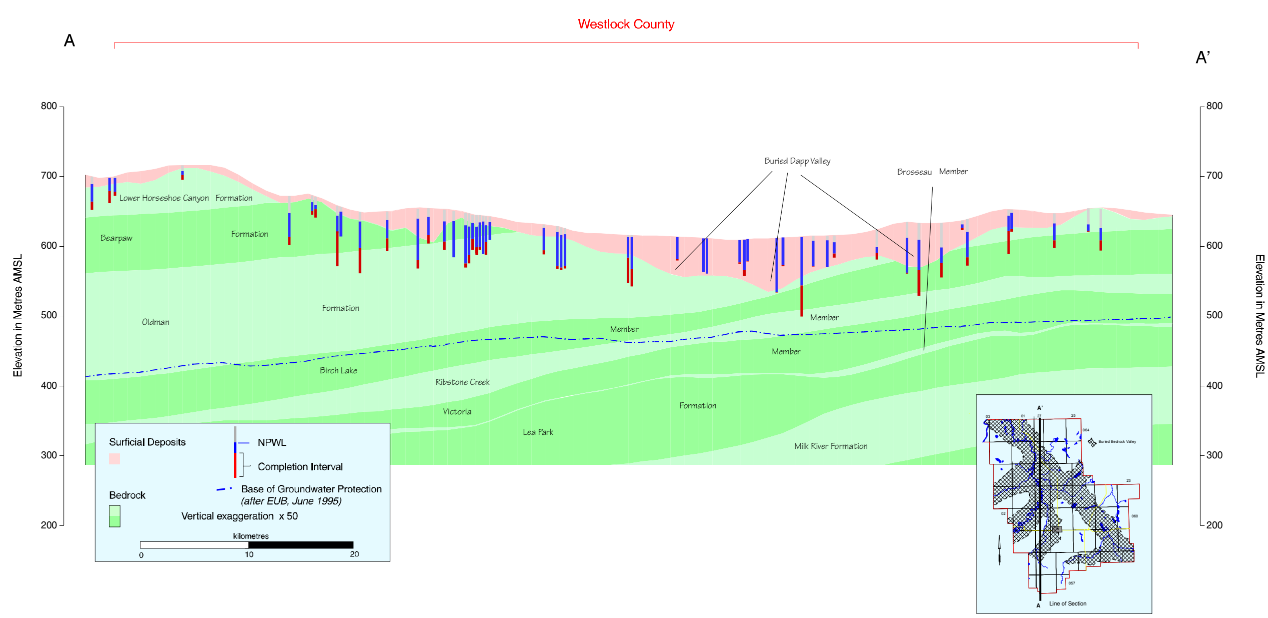

Figure 7. Cross-Section A - A'

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

For a water well with a small-diameter casing to be effective in surficial deposits and to provide sand-free groundwater, the water well must be completed with a water well screen. Some water wells completed in the surficial deposits are completed in low-permeability aquifers and have a large-diameter casing. The large-diameter water wells may have been hand dug or bored and because they are completed in very low permeability aquifers, most of these water wells would not benefit from water well screens. The groundwater from an aquifer in the surficial deposits usually has a chemical hardness of at least a few hundred mg/L and a dissolved iron concentration such that the groundwater must be treated before being used for domestic needs. Within the County, casing-diameter information is available for 367 of the 451 water wells completed in the surficial deposits; 25% of these have a casing diameter of more than 300 millimetres, and are assumed to be bored or dug water wells.

2) Bedrock Aquifers

The upper bedrock includes rocks that are less than 200 metres below the bedrock surface and above the Lea Park Formation. Some of this bedrock contains saturated rocks that are permeable enough to transmit groundwater for a specific need. Water wells completed in bedrock aquifers usually do not require water well screens, although some of the sandstones are friable[9] and water well screens are a necessity. The groundwater from the bedrock aquifers is usually chemically soft.

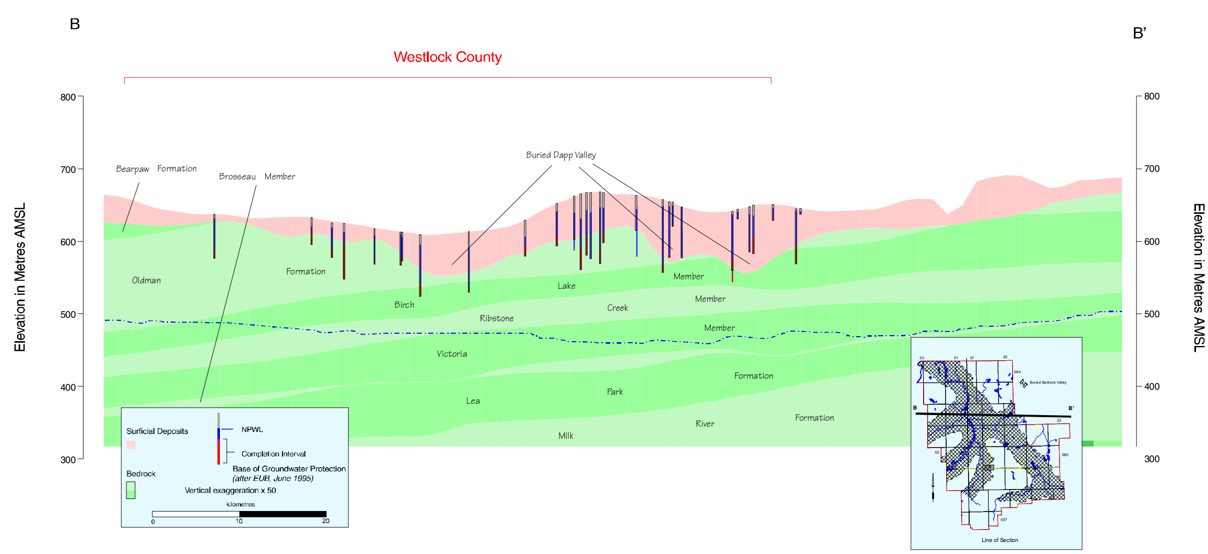

Figure 8. Cross-Section B - B'

The data for 1,117 water wells show 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. Within the County, casing-diameter information is available for 957 of the 1,117 water wells completed below the top of bedrock. Of these 957 water wells, 96% have surface-casing diameters of less than 300 mm and these bedrock water wells have been mainly completed with either a perforated liner (574) or as open hole (231); there are 61 bedrock water wells completed with a water well screen.

The upper bedrock includes a part of the Lower Horseshoe Canyon Formation, the Bearpaw Formation, the Belly River Group and the Lea Park Formation. In the County, the Lea Park Formation is a regional aquitard[10]. The Milk River Formation underlies the Lea Park Formation.

9 See glossary
10 See glossary

B. 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 as a result of glaciation. The *lower surficial deposits* include pre-glacial fluvial[11] and lacustrine[12] deposits. The lacustrine deposits include clay, silt and fine-grained sand. The *upper surficial deposits* include the more traditional glacial deposits of till[13] and meltwater deposits. In the County, no lower surficial deposits have been defined to date and the upper surficial deposits include mainly till.

1) Geological Characteristics of Surficial Deposits

While the surficial deposits are treated as one hydrogeological unit, they are not usually one continuous unit. Sand or gravel deposits in the upper surficial deposits typically occur as pockets, except in linear bedrock lows where a sand or gravel deposit may be several hundred metres wide and continuous over a distance of several 10s of kilometres. The sand and gravel deposits associated with linear bedrock lows are usually saturated, where present. The sand and gravel deposits that occur higher in the stratigraphic section, and tend to occur as pockets, may or may not be saturated. For a graphical depiction of the above description, please refer to Figure 5, Page 8. While the unsaturated deposits are not technically an aquifer, they are significant as 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 the tops of these deposits are present within one metre of the ground surface; these shallow deposits are referred to as the “first sand and gravel”.

The base of the surficial deposits is the bedrock surface, represented by the bedrock topography as shown on the adjacent map. Over the majority of the County, the upper surficial deposits are less than 50 metres thick. The exceptions are mainly in association with areas where linear bedrock lows are present, where the deposits can have a maximum thickness of close to 100 metres. The main linear bedrock low in the County has been designated as the Buried Dapp Valley, as shown on the adjacent figure. This Valley, joined by the Buried Egremont Valley in the southeastern part of the County, trends southeast-northwest. In the northern part of the County, the Buried Dapp Valley is coincidental with the present-day Pembina River Valley. The Buried Dapp Valley may be up to nine kilometres wide, with local relief being up to 80 metres. North of the County, this buried valley becomes the Buried High Prairie Valley.

The Buried Egremont Valley is present in the southeastern part of the County. The relationship between the Buried Dapp Valley and the Buried Egremont Valley is difficult to establish from the present data. There are several connecting buried bedrock valleys to the Buried Dapp Valley, one of which occupies the Pembina River Valley in the west-central part of Westlock County. These lows trend mainly northeast to southwest in the County and may have been tributaries to the Buried Dapp Valley.

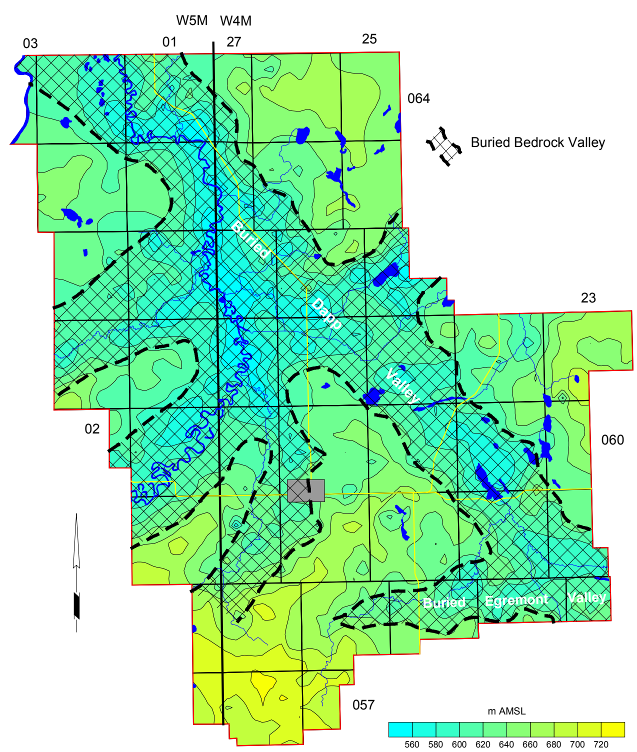

Figure 9. Bedrock Topography

11 See glossary
12 See glossary
13 See glossary

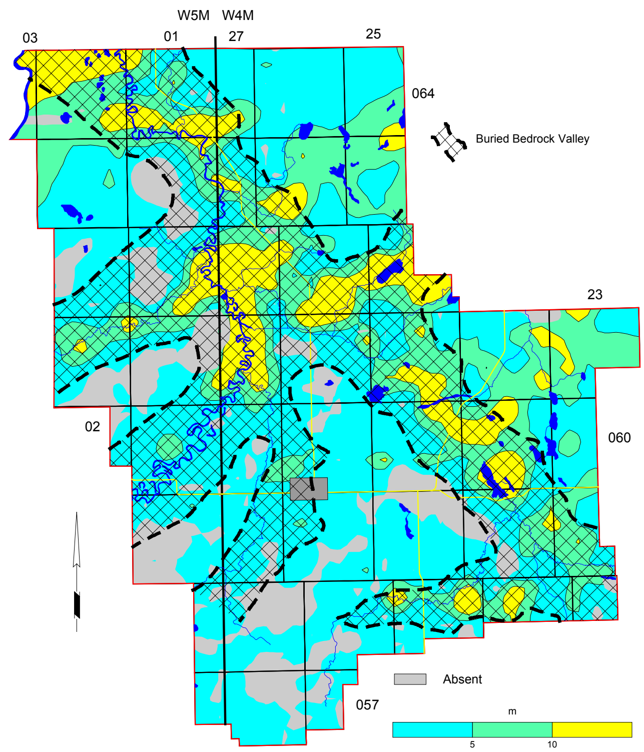

Figure 10. Thickness of Sand and Gravel Deposits

Sand and gravel deposits can occur throughout the surficial deposits. The total thickness of sand and gravel deposits is generally less than ten metres but can be more than 15 metres in the areas of the linear bedrock lows.

The upper surficial deposits are either directly or indirectly a result of glacial activity. The deposits include till, with minor sand and gravel deposits, which are expected to occur mainly as isolated pockets. The greatest thickness of the upper surficial deposits is mainly in association with the linear bedrock lows; there are several small areas where the upper surficial deposits are not present.

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 10% of the County, the sand and gravel deposits are more than 30% of the total thickness of the surficial deposits (page A-13). The areas where sand and gravel deposits constitute more than 30% of the total thickness of the surficial deposits may be in areas of buried bedrock valleys or areas where linear bedrock lows exist but have not been identified due to a shortage of accurate bedrock control points.

2) Sand and Gravel Aquifer(s)

One source of groundwater in the County includes aquifers in the surficial deposits. Since the sand and gravel aquifer(s) are not everywhere, the actual aquifer that is developed at a given location is usually dictated by the aquifer that is present. The thickness of the sand and gravel aquifer(s) is generally less than five metres, but can be more than ten metres in areas of linear bedrock lows.

From the present hydrogeological analysis, 1,068 water wells are completed in aquifers in the upper surficial deposits. This number of water wells is more than twice the number determined to be completed in aquifers in the surficial deposits, based on lithologies given on the water well drilling reports. The larger number is obtained by comparing the elevation of the reported depth of a water well to the elevation of the bedrock surface at the same location. For example, if only the depth of a water well is known, the elevation of the completed depth can be calculated. If the elevation of the completed depth is above the elevation of the bedrock surface determined from the gridded bedrock topography surface at the same location, then the water well is considered to be completed in an aquifer in the surficial deposits.

Water wells completed in the upper surficial deposits occur throughout the project area, but are mainly concentrated in the vicinity of linear bedrock lows (see CD-ROM).

a) Chemical Quality of Groundwater from Surficial Deposits

The chemical analysis results of groundwaters from the sand and gravel aquifers in the surficial deposits indicate the groundwaters are generally chemically hard and high in dissolved iron. In Westlock County, groundwaters from the surficial aquifers mainly have a chemical hardness of less than 400 mg/L.

The groundwaters from the surficial deposits are mainly calcium-magnesium-bicarbonate or sodium-bicarbonate-type waters, with approximately 70% of the groundwaters having a TDS concentration of less than 1,000 mg/L. The groundwaters with a TDS concentration of less than 1,000 mg/L occur mainly in the Buried Dapp Valley on Figure 11. The large expanse showing TDS concentrations to be less than 500 mg/L is a result of gridding a limited amount of data available for that area. Groundwaters from the surficial deposits are expected to have dissolved iron concentrations of less than 1 mg/L.

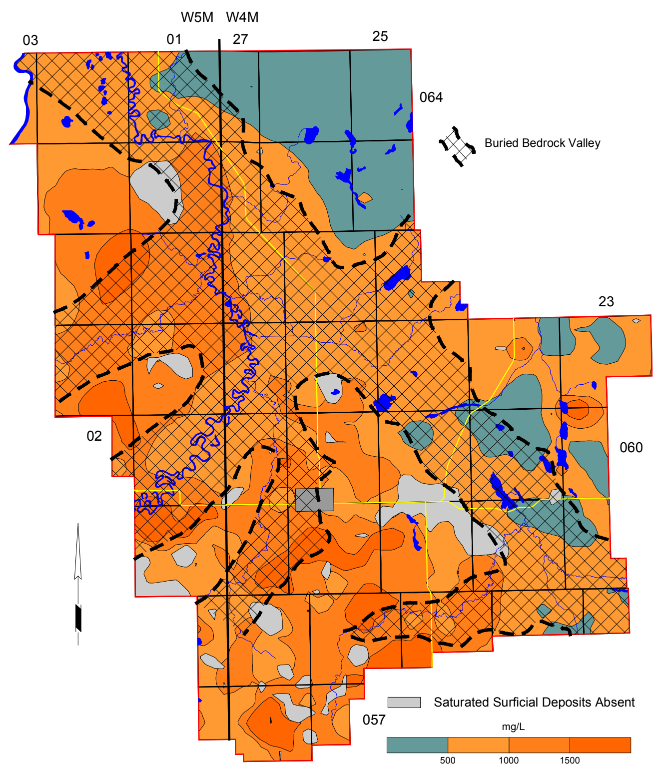

Figure 11. Total Dissolved Solids in Groundwater from Surficial Deposits

Although the majority of the groundwaters are bicarbonate-type waters, there are groundwaters from the surficial deposits with sulfate as the main anion. The groundwaters with elevated levels of sulfate generally occur in areas where there are elevated levels of total dissolved solids. There are very few groundwaters from the surficial deposits with appreciable concentrations of the chloride ion and in most of the County, the chloride ion concentration is mainly less than 100 mg/L.

The nitrate + nitrite (as N) concentrations in the groundwaters from the surficial deposits exceed the maximum acceptable concentrations (MAC) of 10 mg/L mainly in the southern half of the County and in the vicinity of the Hamlet of Fawcett.

	Range for County in mg/L			Recommended Maximum Concentration
Constituent	Minimum	Maximum	Average	GCDWQ
Total Dissolved Solids	42	5131	961	500
Sodium	0	1380	194	200
Sulfate	0	3480	162	500
Chloride	<1	1815	54	250
Nitrate + Nitrite (as N)	<0.05	122	2.9	10

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives

GCDWQ - Guidelines for Canadian Drinking Water Quality, Sixth Edition
Minister of Supply and Services Canada, 1996

Table 4. Concentrations of Constituents in Groundwaters from Surficial Aquifers

The minimum, maximum and average concentrations of TDS, sodium, sulfate, chloride and nitrate + nitrite (as N) in the groundwaters from water wells completed in the surficial deposits in the County have been compared to the Guidelines for Canadian Drinking Water Quality (GCDWQ) in the adjacent table. Of the five constituents that have been compared to the GCDWQ, only the average values of TDS concentrations exceed the guidelines.

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 can directly overlie or be close to the bedrock surface. Saturated sand and gravel deposits are not continuous but are expected over approximately 85% of the County.

a) Aquifer Thickness

The thickness of the Upper Sand and Gravel Aquifer is a function of two parameters: (1) the elevation of the non-pumping water-level surface associated with the upper surficial deposits; and (2) the depth to the bedrock surface. Since the non-pumping water-level surface in the surficial deposits tends to be a subdued replica of the bedrock surface, the thickness of the Upper Sand and Gravel Aquifer tends to be directly proportional to the thickness of the surficial deposits.

While the sand and gravel deposits in the upper surficial deposits are not continuous, the Upper Sand and Gravel Aquifer includes all of the aquifers present in the upper surficial deposits. The Upper Sand and Gravel Aquifer is more than ten metres thick in a few areas, but over the majority of the County where the Upper Sand and Gravel Aquifer is present, is less than ten metres thick; in about 15% 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.

b) 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 apparent yields of the water wells are limited. The apparent yields for water wells completed in this Aquifer are expected to be mainly between ten and 300 m³/day. Yields of more than 300 m³/day are expected in the areas of linear bedrock lows. The higher yields present in the northeastern part of the County may be in an area of a linear bedrock low, that has not been identified due to a shortage of accurate bedrock control points. 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. From this Aquifer, construction of a water supply well into the underlying bedrock may be the only alternative, provided yields and quality of groundwater from the bedrock aquifers are suitable.

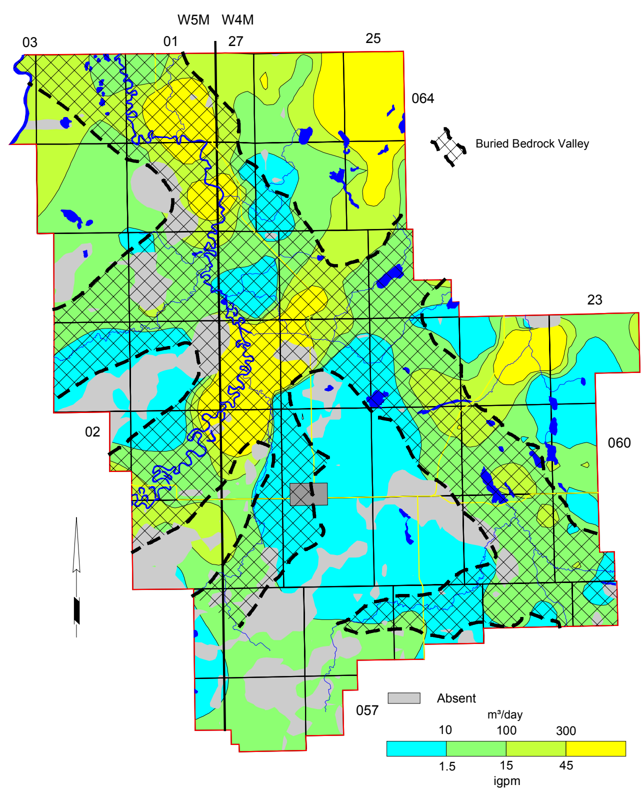

Figure 12. Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer

C. Bedrock

1) Geological Characteristics

The upper bedrock in the County includes the Edmonton Group, the Bearpaw Formation and the Belly River Group. The Edmonton Group in the County includes only the Lower Horseshoe Canyon Formation. The Belly River Group subcrop in the County includes the Oldman Formation and the Birch Lake Member. The adjacent bedrock geology map, showing the subcrop of different geological units, has been prepared in part from the interpretation of geophysical logs related to oil and gas activity.

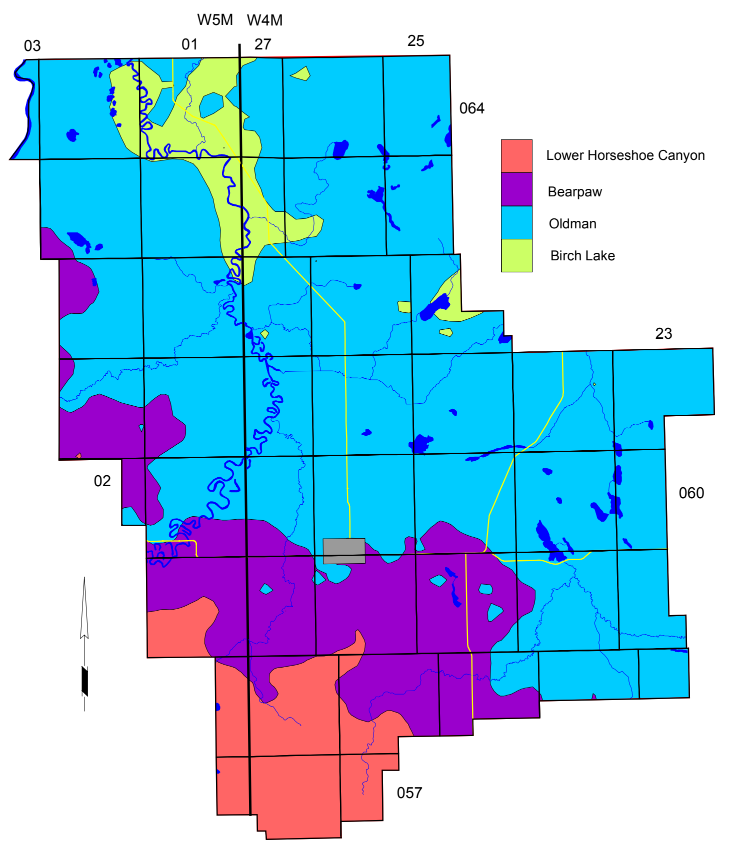

Figure 13. Bedrock Geology

The Horseshoe Canyon Formation is the lower part of the Edmonton Group. The Horseshoe Canyon Formation has a maximum thickness of 350 metres and has three separate units: Upper, Middle and Lower. The Lower Horseshoe Canyon, which can be up to 170 metres thick, is less than 80 metres thick within the County and is the upper bedrock in the extreme southern part of the County.

The Horseshoe Canyon Formation consists of deltaic[14] and fluvial sandstone, siltstone and shale with interbedded coal seams, bentonite and thin nodular beds of limestone and ironstone. Because of the low-energy environment in which deposition occurred, the sandstone, when present, tends to be finer grained. The lower 60 to 70 metres and the upper 30 to 50 metres of the Horseshoe Canyon Formation can include coarser grained sandstone deposits.

The Bearpaw Formation underlies the Horseshoe Canyon Formation, is in the order of 80 metres thick and is the upper bedrock in the western and southern parts of the County. The Bearpaw Formation includes transgressive, shallow marine (shoreface) and open marine facies[15] deposits.

The Belly River Group includes the Oldman Formation and the Birch Lake, Ribstone Creek, Victoria and Brosseau members of the Foremost Formation. The Belly River Group in the County has a maximum thickness of 200 metres. In the County, only the Oldman Formation and the Birch Lake Member are present as the upper bedrock. The Oldman Formation is present as the upper bedrock in most of the northern two-thirds of the County and has a maximum thickness of 80 metres. The Foremost Formation includes the continental facies within the County.

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14 See glossary
15 See glossary

The *continental* Foremost Formation is less than 160 metres thick and is between the overlying Oldman Formation and the underlying Lea Park Formation. In the *continental* Formation, individual members have been identified. The members include both sandstone and shale units. For the present project, the individual members are identified by the designation given to the sandstone members associated with the marine facies, with the underlying shale member being considered as the shale facies of the member. For example, in this report the Birch Lake Member includes the Birch Lake Member (a sandstone deposit) and the underlying shale deposit. Eastward, the sandstone layers of individual members grade into marine deposits.

The present breakdown of the Foremost Formation would not be possible without identifying a continuous top for the Lea Park Formation. The top of the Lea Park Formation represents a geologic time border between the marine environment of the Lea Park Formation and the mostly continental environment of the Foremost Formation.

The top of the Lea Park Formation is the bottom of the higher resistivity layer that occurs within a few metres below a regionally identifiable bentonite marker, as shown in the adjacent e-log. This marker occurs approximately 100 metres above the Milk River Shoulder.

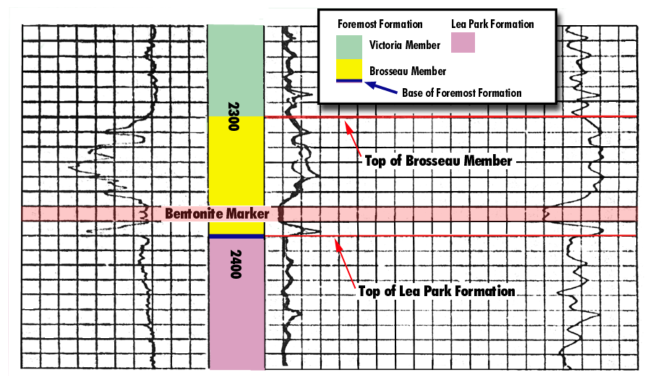

Figure 14. E-Log showing Base of Foremost Formation

The Lea Park Formation is mostly composed of shale, with only minor amounts of bentonitic siltstone present in some areas. Regionally, the Lea Park Formation is an aquitard. A structure-contour map associated with the Lea Park Formation is included in Appendix A and on the CD-ROM. In most of the area, the top of the Lea Park coincides with the Base of Groundwater Protection. In some areas, the Base of Groundwater Protection extends below the Colorado Group. A map showing the depth to the Base of Groundwater Protection is given on page 7 of this report, in Appendix A, and on the CD-ROM.

2) Aquifers

Of the 3,677 water wells in the database, 1,117 were defined as being completed below the top of bedrock. However, at least a reported completion depth is available for the majority of boreholes[16] and assigning the borehole to specific geologic units is possible only if the completion interval is identified. In order to make use of additional information within the groundwater database, it was assumed that if the total drilled depth of a borehole was more than ten metres below the top of a particular geological unit, the borehole was assigned to the particular geological unit. With this assumption, it has been possible to designate the aquifer of completion for 1,769 additional boreholes. There are 469 water wells that have been identified as being completed in bedrock aquitards/aquifers below the Birch Lake Member, or in more than one bedrock aquifer.

Geological Unit	No. of Boreholes
Lower Horseshoe Canyon	277
Bearpaw	382
Oldman	1,550
Birch Lake	208
Other	197
Multiple Completions	272
Total	2,886

Table 5. Completion Aquifer

The bedrock boreholes are mainly completed in the Oldman and Bearpaw aquifers, as shown in the above table. Nearly 10% of the bedrock boreholes are likely to have multiple completions, of which 98% have the top of the first completion interval less than 100 metres below ground level.

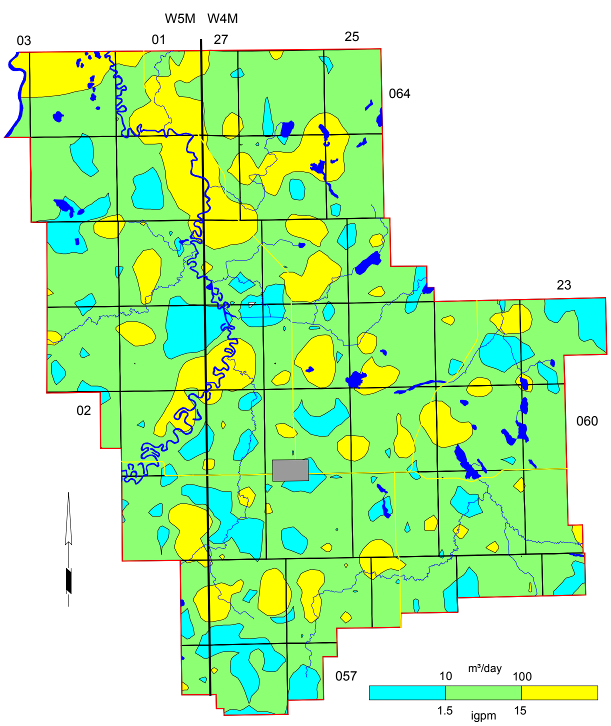

Figure 15. Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)

There are 1,112 records for bedrock water wells that have apparent yield values, or 38% of all bedrock boreholes. In the County, yields for water wells completed in the upper bedrock aquifer(s) are mainly between ten and 100 m³/day. The areas with yields of more than 100 m³/day indicated on the adjacent figure are mainly in the vicinity of linear bedrock lows. These higher yield areas may identify areas of increased permeability resulting from the weathering process.

Aquifer	No. of Water Wells with Values for Apparent Yield	Number of Water Wells with Apparent Yields <10 m³/day	10 to 100 m³/day	>100 m³/day
Lower Horseshoe Canyon	104	48	52	4
Bearpaw	139	41	75	23
Oldman	690	173	419	98
Birch Lake	96	8	57	31
Totals	1,029	270	603	156

Table 6. Apparent Yields of Bedrock Aquifers

Of the 1,112 water well records with apparent yield values, 1,029 have been assigned to aquifers associated with specific geologic units that are being discussed. Fifty-nine percent or 603 of the water wells completed in the bedrock aquifers have apparent yields that range from ten to 100 m³/day, and 26% or 270 have apparent yields that are less than ten m³/day, as shown in the table above.

3) Chemical Quality of Groundwater

16 See glossary

The TDS concentrations in the groundwaters from the upper bedrock aquifer(s) range from less than 500 to more than 1,500 mg/L, with most of the elevated TDS concentrations occurring in the southwestern part of the County.

The relationship between TDS and sulfate concentrations shows that when TDS values in the groundwaters from the upper bedrock aquifer(s) exceed 1,200 mg/L, the sulfate concentrations exceed 400 mg/L. The chloride concentrations in the groundwaters from the upper bedrock aquifer(s) are less than 100 mg/L in more than 75% of the County. The higher values can be expected in the southern part of the County, mainly in townships 059 and 060, W4M.

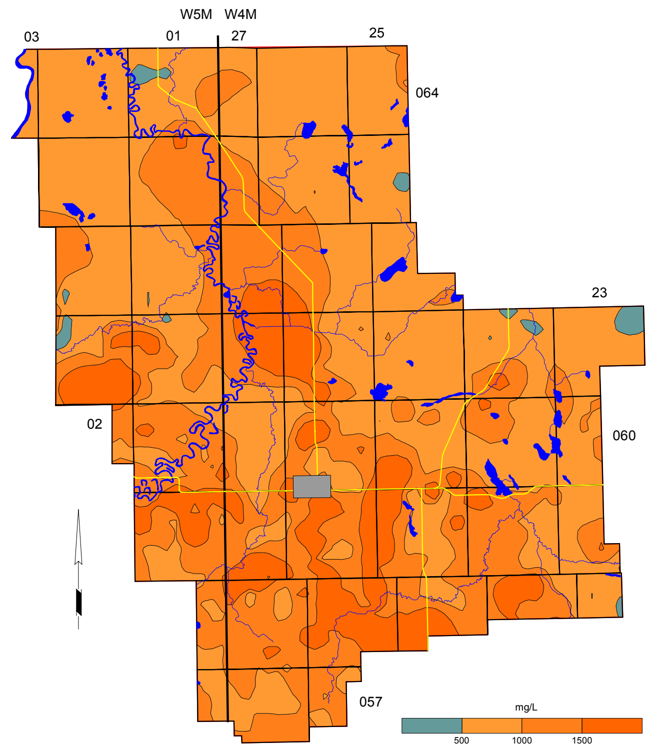

Figure 16. Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)

Thirty-one percent of the groundwater samples from upper bedrock aquifer(s) had fluoride concentrations that were too low (less than 0.5 mg/L) to meet the recommended daily needs of people. Approximately 42% of the groundwater samples were between 0.5 and 1.5 mg/L and 24% exceeded the maximum acceptable concentration for fluoride of 1.5 mg/L.

The Piper tri-linear diagrams [17] (see Appendix A) show that all chemical types of groundwater occur in the bedrock aquifers. However, the majority of the groundwaters are sodium-bicarbonate or sodium-sulfate types.

[17] See glossary

4) Lower Horseshoe Canyon Aquifer

The Lower Horseshoe Canyon Aquifer comprises the permeable parts of the Lower Horseshoe Canyon Formation, as defined for the present program. Structure contours have been prepared for the top and bottom of the Formation, which underlies the southwestern part of the County. The structure contours show the Lower Horseshoe Canyon unit has a thickness that is less than 60 metres.

a) Depth to Top

The depth to the top of the Lower Horseshoe Canyon Formation is mainly less than 15 metres below ground level. Because the Lower Horseshoe Canyon unit occurs as a subcrop, the depth is a reflection of the thickness of the surficial deposits.

b) Apparent Yield

The apparent yields for individual water wells completed through the Lower Horseshoe Canyon Aquifer are mainly in the range of ten to 100 m³/day. The areas where water wells with higher yields are expected are mainly associated with the edge of the Aquifer.

c) Quality

The groundwaters from the Lower Horseshoe Canyon Aquifer are mainly a sodium-bicarbonate type (see CD-ROM), with TDS concentrations ranging mainly from 500 to 1,500 mg/L. The lower values of TDS concentrations occur in range 01, W5M. When TDS values in the groundwaters from the Lower Horseshoe Canyon Aquifer exceed 1,200 mg/L, the sulfate concentrations exceed 400 mg/L.

The chloride concentrations of the groundwaters from the Lower Horseshoe Canyon Aquifer can be expected to be mainly less than 100 mg/L.

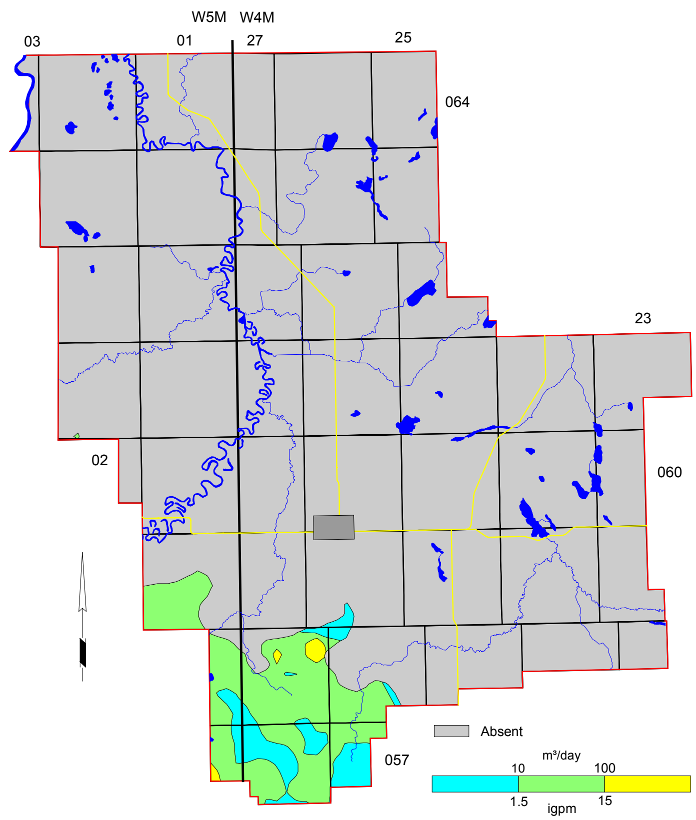

Figure 17. Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer

5) Bearpaw Aquifer

The Bearpaw Aquifer comprises the permeable parts of the Bearpaw Formation. Structure contours have been prepared for the top and bottom of the Formation, which underlies most of the southwestern one-third of the County. The structure contours show the Formation having a maximum thickness of 80 metres.

a) Depth to Top

The depth to the top of the Bearpaw Formation is mainly less than 50 metres below ground level but can be more than 70 metres where the Lower Horseshoe Canyon Formation is the upper bedrock.

b) Apparent Yield

The apparent yields for individual water wells completed through the Bearpaw Aquifer are mainly in the range of ten to 100 m³/day, with 16% of the values being more than 100 m³/day. The areas where water wells with higher yields are expected are mainly south of township 059 and west of the fifth Meridian, where the Aquifer is present. Water wells with yields of less than ten m³/day occur throughout the area where the Bearpaw Aquifer is present. The low yields may be variations in the permeability of the aquifer or the techniques used by the water well drillers to drill and complete the water wells.

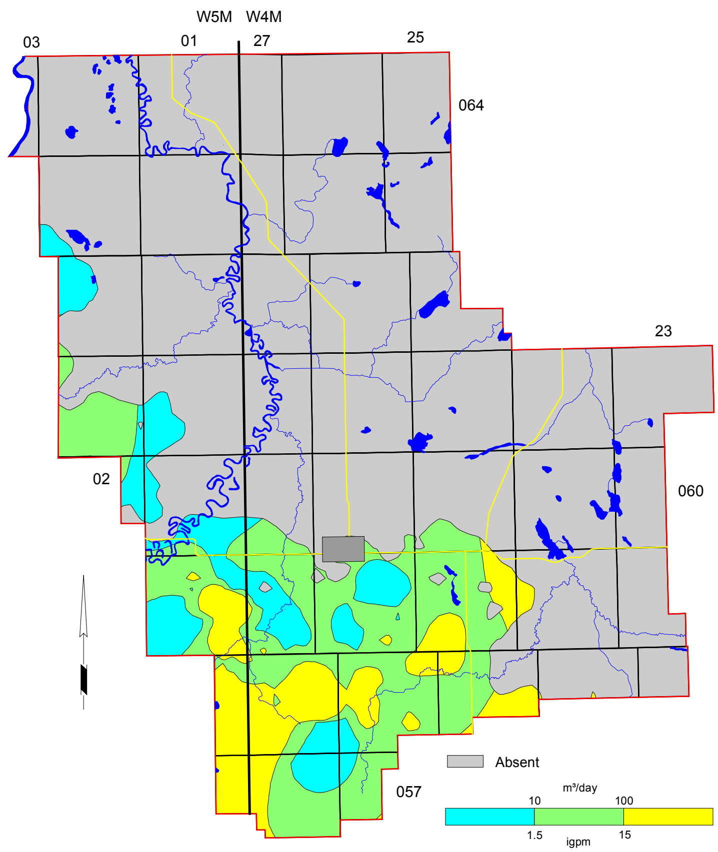

Figure 18. Apparent Yield for Water Wells Completed through Bearpaw Aquifer

c) Quality

The groundwaters from the Bearpaw Aquifer are mainly sodium-bicarbonate or sodium-sulfate types (see Piper diagram on CD-ROM). The TDS concentrations range from less than 750 to more than 1,500 mg/L. The sulfate concentrations are mainly less than 500 mg/L. Chloride concentrations in the groundwaters from the Bearpaw Aquifer are mainly less than 100 mg/L, with concentrations increasing as the thickness of the Formation increases.

6) Oldman Aquifer

The Oldman Aquifer comprises the porous and permeable parts of the Oldman Formation. Structure contours have been prepared for the top of the Formation, which underlies most of the County. The structure contours show the Oldman Formation having a maximum thickness of in the order of 150 metres.

i) Depth to Top

The depth to the top of the Oldman Formation is mainly less than 80 metres below ground level but can be more than 140 metres in the southwestern part of the County, where the Lower Horseshoe Canyon Formation is the upper bedrock.

ii) Apparent Yield

The apparent yields for individual water wells completed through the Oldman Aquifer range mainly from ten to 100 m³/day. The adjacent map indicates that water wells with apparent yields of more than 100 m³/day are expected mainly in association with areas where linear bedrock lows are present. In these areas, weathering processes may be increasing the local permeability.

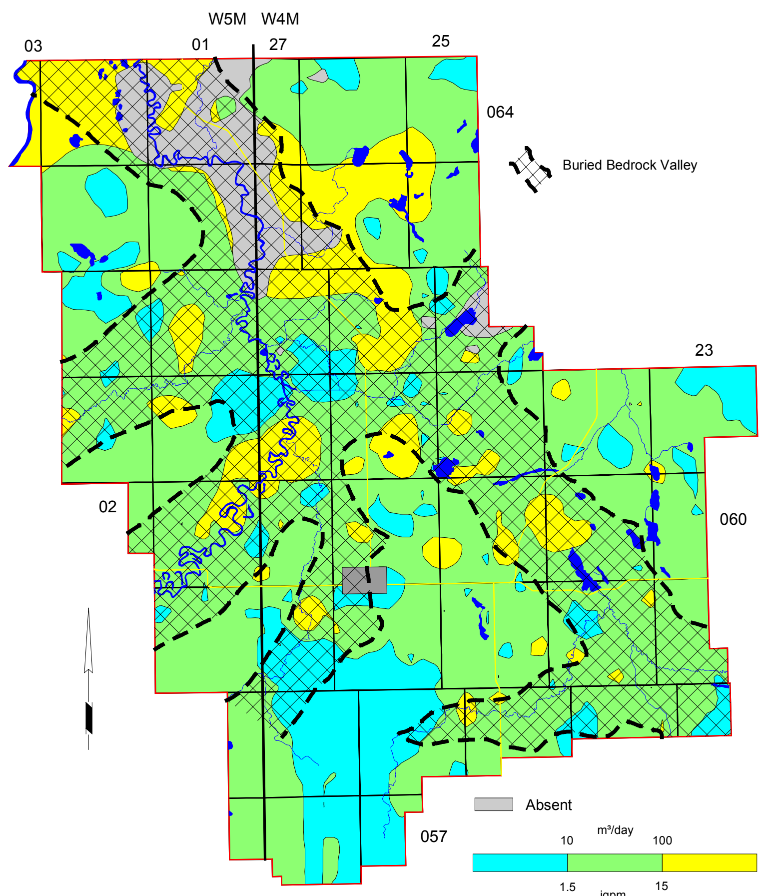

Figure 19. Apparent Yield for Water Wells Completed through Oldman Aquifer

iii) Quality

The groundwaters from the Oldman Aquifer are mainly sodium-bicarbonate or sodium-chloride types (see Piper diagram on CD-ROM). Total dissolved solids concentrations are expected to range mainly from 1,000 to 2,000 mg/L, with higher TDS concentrations occurring where the depth of burial is greater than 80 metres. However, since most of the Oldman Formation is above the Base of Groundwater Protection, the TDS concentrations would still be expected to be less than 4,000 mg/L.

When TDS values in the groundwaters from the Oldman Aquifer exceed 1,500 mg/L, the sulfate concentrations exceed 400 mg/L. The indications are that chloride concentrations are expected to be less than 100 mg/L in the northern half of the County and greater than 250 mg/L in the southern half of the County.

7) Foremost Aquifers

a) Birch Lake Aquifer

The Birch Lake Aquifer comprises the permeable parts of the Birch Lake Member. Structure contours have been prepared for the top of the Member, which underlies the entire County; in the north-central part of the County, the Birch Lake Aquifer subcrops and thickness of the Birch Lake Member is less than 60 metres.

i) Depth to Top

The depth to the top of the Birch Lake Member is variable, ranging from less than 20 metres near the Pembina River in township 064, range 01, W5M where the Member subcrops to more than 320 metres in the southern part of the County.

ii) Apparent Yield

The apparent yields for individual water wells completed through the Birch Lake Aquifer range mainly from ten to 100 m³/day. However, the control points are limited to where the top of the Member is less than 100 metres below ground level. This includes the northern part of the County east of range 02, W5M. The adjacent map indicates that water wells with apparent yields of more than 300 m³/day are expected mainly in townships 063 and 064, ranges 26 and 27, W4M and range 01, W5M. There are little or no data for the Aquifer in the southern half of the County. In this area, the top of the Birch Lake Aquifer would be at a depth of more than 140 metres.

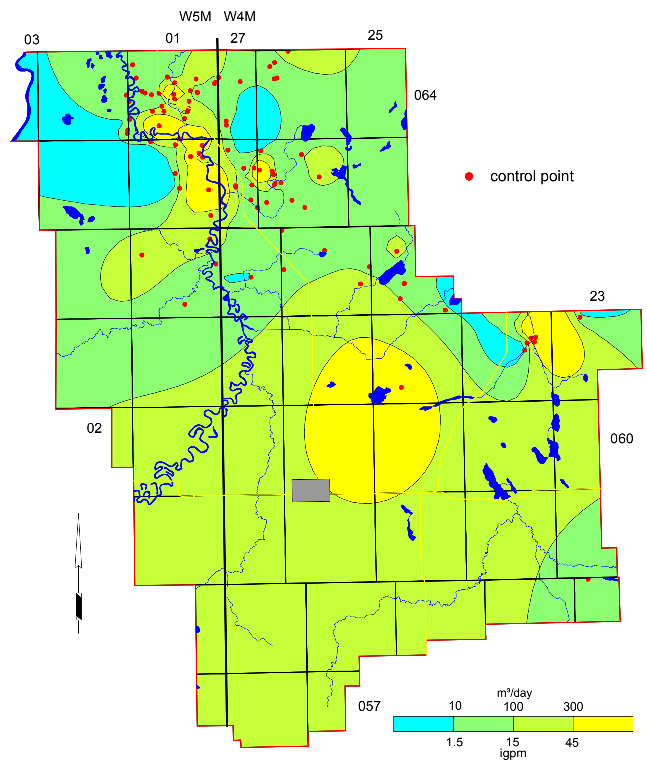

Figure 20. Apparent Yield for Water Wells Completed through Birch Lake Aquifer

iii) Quality

There are 18 water well records in the groundwater database with sufficient information to determine the chemical type of groundwaters from the Birch Lake Aquifer in Westlock County. The groundwaters are sodium-bicarbonate-type waters.

The TDS values for the groundwater from the Birch Lake Aquifer are mainly between 500 and 1,000 mg/L. However, most of the control points are limited to township 064, range 01, W5M, where the Member subcrops. The sulfate values are mainly less than 100 mg/L, and the chloride values are mainly less than 10 mg/L.

b) Other Foremost Aquifers

There are 19 water wells that are completed in the Ribstone Creek Aquifer, with 16 of the 19 located in township 063 or 064, range 01, W5M. There are apparent long-term yields for two water wells and both are less than 50 m³/day. There are results of nine chemical analyses available and all have TDS concentrations less than 2,000 mg/L. A detailed discussion of this Aquifer has not been completed because of the limited amount of data and the depth to the top of the Aquifer in most of the County.

There is even less information available for the Victoria and Brosseau Aquifers than for the Ribstone Creek Aquifer.

VI. GROUNDWATER BUDGET

A. 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 laterally 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.

1) Quantity of Groundwater

The adjacent water-level map has been prepared from water levels associated with water wells completed in aquifers in the surficial deposits. These water levels were used for the calculation of the saturated thickness of the surficial deposits. In areas where the elevation of the water-level surface is below the bedrock surface, the surficial deposits are not saturated. The water-level map for the surficial deposits shows a general flow direction toward the Pembina River.

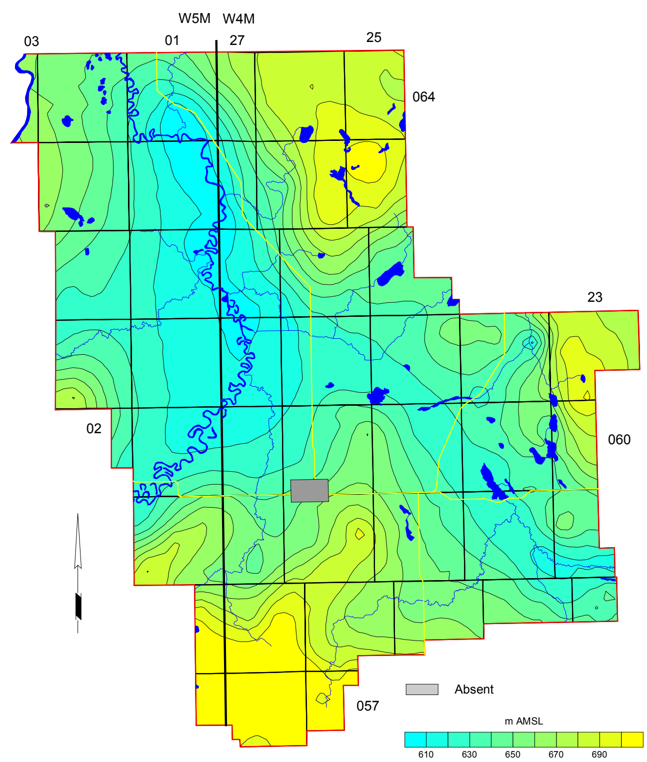

Figure 21. Non-Pumping Water-Level Surface in Surficial Deposits Based on Water Wells Less than 20 Metres Deep

2) Recharge/Discharge

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

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

a) Surficial Deposits/Bedrock Aquifers

The hydraulic gradient between the surficial deposits and the upper bedrock aquifer(s) has been determined by subtracting the non-pumping water-level surface associated with all water wells completed in the upper bedrock aquifer(s) from the non-pumping water-level surface determined for all water wells in the surficial deposits. The recharge classification is used 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, that is, no recharge and no discharge.

The adjacent map shows that, in more than 75% of the County, there is a downward hydraulic gradient (i.e. recharge) from the surficial deposits toward the upper bedrock aquifer(s). Areas where there is an upward hydraulic gradient from the bedrock to the surficial deposits are mainly in the vicinity of linear bedrock lows. The remaining parts of the County are areas where there is a transition condition.

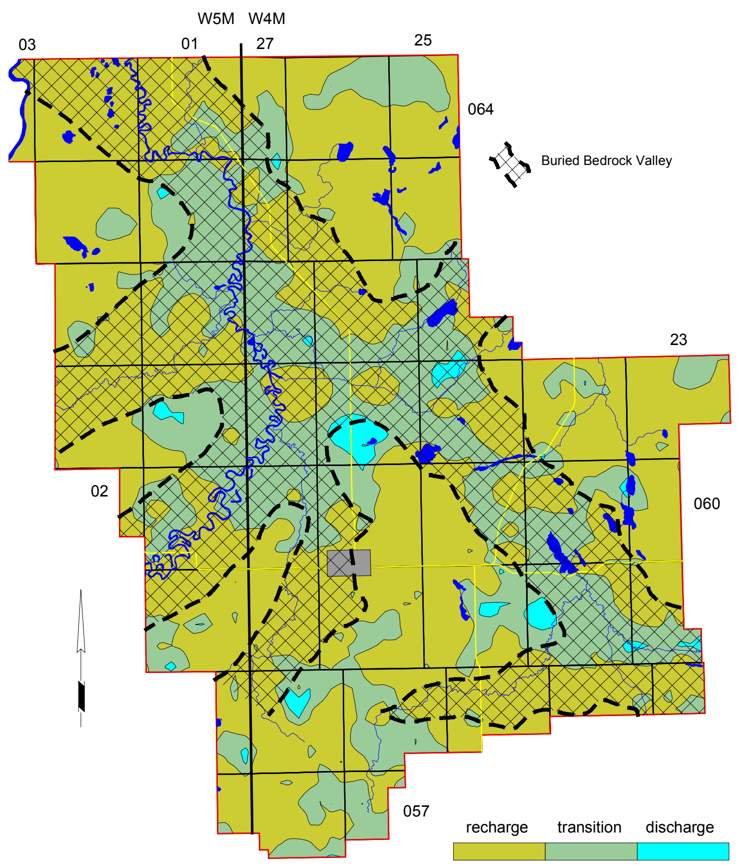

Figure 22. Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)

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

b) Bedrock Aquifers

Recharge to the bedrock aquifers within the County takes place from the overlying surficial deposits and from flow in the aquifer from outside the County. The recharge/discharge maps show that generally for most of the County, there is a downward hydraulic gradient from the surficial deposits to the bedrock, i.e. recharge to the bedrock aquifers. 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 more than 75% of the County where the Oldman Aquifer is present, there is a downward hydraulic gradient (i.e. recharge). Discharge areas for the Oldman Aquifer are mainly associated with the edge of the Aquifer or in areas of buried bedrock valleys. The main exception is in the northeastern part of the County in township 064, range 25, W4M. The discharge area at this location may be a result of gridding procedures and not necessarily a discharge area.

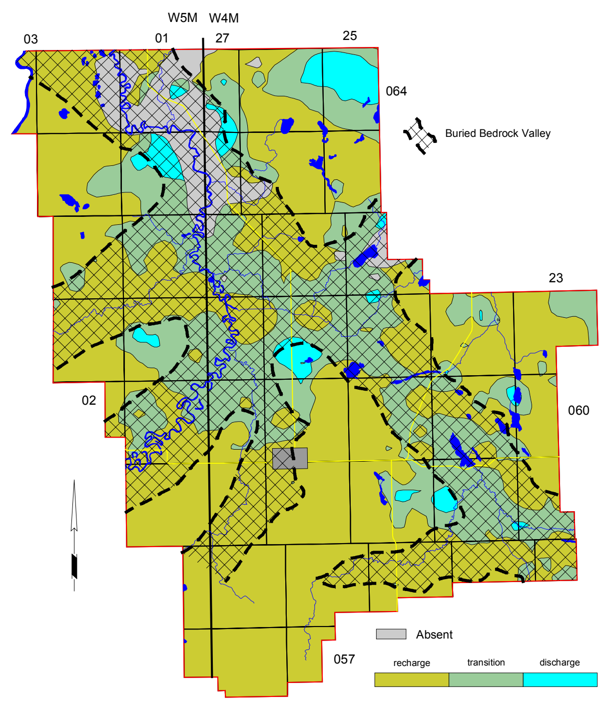

Figure 23. Recharge/Discharge Areas between Surficial Deposits and Oldman Aquifer

The hydraulic relationship between the surficial deposits and the remainder of the bedrock aquifers indicates there is also mainly a downward hydraulic gradient.

B. Groundwater Flow Model

A USGS 3-D MODFLOW groundwater model was prepared for the County. A simulation was completed using the model. The model has five layers, one layer for each geological unit. The values for the transmissivity distribution for each geological unit were determined using an automated calibration method. The main criterion for the calibration is the water level in the surficial deposits. The initial values for transmissivity distribution were the values determined from the present study. The model results are considered very approximate and are meant to support the regional study. The model needs considerably more data before it could be used for management of the groundwater resource in the County.

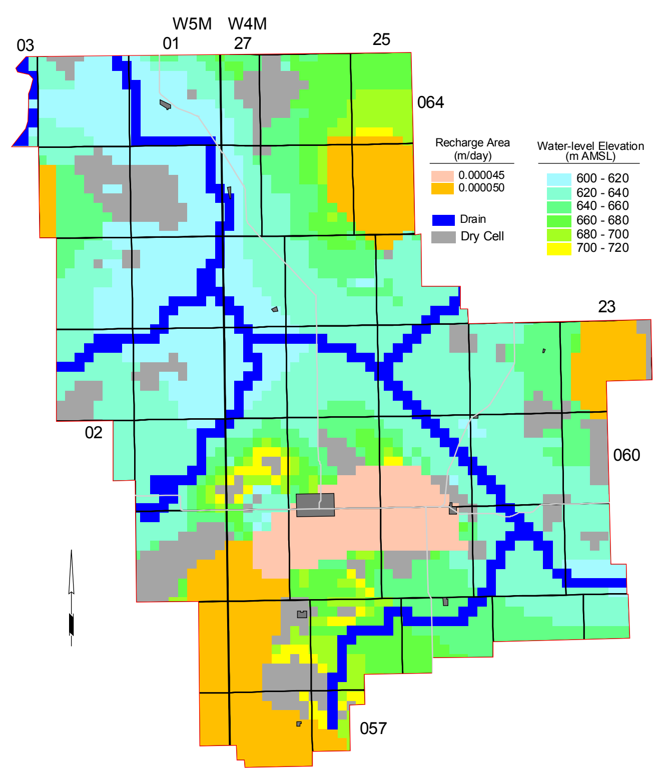

Figure 24. Modelled Non-Pumping Water-Level Surface in Surficial Deposits

The adjacent figure shows the water-level surface for the surficial deposits for the model. There are four main groundwater recharge areas; the main drain areas are outlined in blue.

The results of the model were used to prepare the following table:

Aquifer/Area	Horizontal Volume (m^3/day)	Vertical Volume (m^3/day)	General Horizontal Direction of Flow	Volume (m^3/day)	Aquifer Volume (m^3/day)	Authorized Diversion (m^3/day)
Upper Surficial					7,700	555
Southern area	750	1200	north	1950		
Northern area	850	753	south	1603		
Eastern area	1300	924	west	2224		
Western area	483	1400	east	1883		
Lower Horseshoe Canyon					800	205
Southern area	470	310	north	780		
Bearpaw					2,400	52
Southern area	674	780	northwest	1454		
Western area	480	427	northeast	907		
Oldman					5,900	1,801
Southern area	600	970	north	1570		
Northern area	450	539	south	989		
Eastern area	958	720	west	1678		
Western area	513	1117	east	1630		
Birch Lake					3,500	455
Southern area	747	250	north	997		
Northern area	407	137	south	544		
Eastern area	238	470	west	708		
Western area	613	588	east	1201		

Table 7. Groundwater Budget

The data provided in the adjacent table indicate there is more groundwater flowing through the individual bedrock aquifers than has been authorized to be diverted from each aquifer. The calculations of flow through individual aquifers as presented in the above table are very approximate and are intended as a guide for future investigations.

VII. 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. Additional agricultural activities that generate contaminants include the improper spreading of fertilizers, pesticides, herbicides and manure. The spreading of highway salt can also degrade groundwater quality.

When activities occur that can or do produce a liquid that 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. In areas of groundwater recharge, 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 Agricultural Region of Alberta Soil Inventory Database (AGRASID) (CAESA, 1998) 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
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 2,167 records with lithological descriptions in the area of the County, 275 have the top of a sand and gravel deposit present within one metre of ground level. In the remaining 1,892 records, the first sand and gravel deposit is deeper than one metre 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.

1) Risk of Groundwater Contamination Map

The information from the reclassification of the soil 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 8. Risk of Groundwater Contamination Criteria

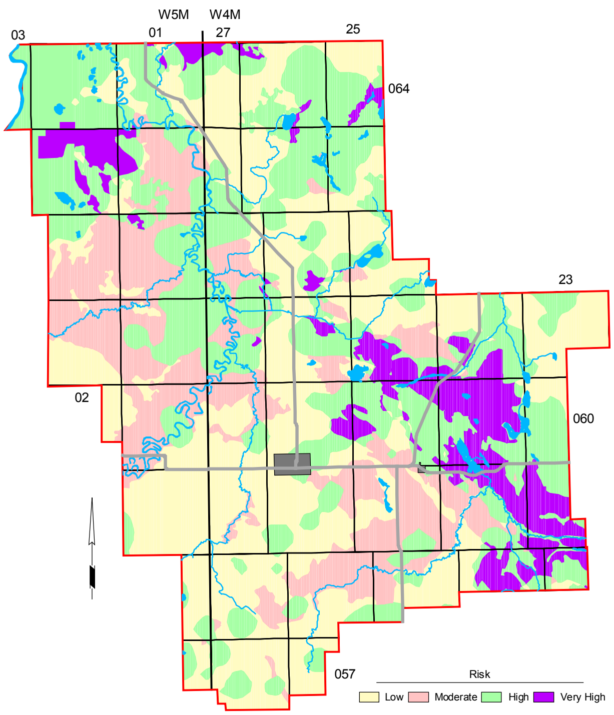

Figure 25. Risk of Groundwater Contamination

The Risk of Groundwater Contamination map shows that, in 45% of the County, there is a high or very high risk for the groundwater to be 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 contaminants will not affect groundwater quality.

VIII. 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
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 first step would be to field-verify the 125 existing water wells listed in Appendix E. These water well records indicate that a complete water well drilling report is available along with at least a partial chemical analysis. 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. Even though the water wells for which the County has responsibility do not satisfy the above criteria, it is recommended that they be field-verified, water levels be measured, a water sample be collected for analysis, and a short aquifer test be conducted. There is one County-operated water well that is also included in Appendix E. An attempt to update the quality of the entire database is not recommended.

While there are a few areas where water-level data are available, on the overall, there are an insufficient number of water levels to set up a 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 and in Flagstaff County, 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.

A second approach to obtain water-level data would be to conduct a field survey to identify water wells not in use that could be used as part of an observation water well network. County personnel and/or local residents could measure the water levels in the water wells regularly.

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 provide a major upgrade to 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 (see pages C-2 to C-3):

1) The horizontal location of the water well should be determined within ten 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 two 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 five and 115 minutes of pumping, and analyzed for major and minor ions.

A list of 125 water wells that could be considered for the above program is given in Appendix E.

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. One method of obtaining uniformity would be to have the water well drilling reports submitted to the AE Resource Data Division in an electronic form. The money presently being spent by AE and 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.

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X. CONVERSIONS

Multiply	by	To Obtain
Length/Area		
feet	0.304 785	metres
metres	3.281 000	feet
hectares	2.471 054	acres
centimetre	0.032 808	feet
centimetre	0.393 701	inches
acres	0.404 686	hectares
inchs	25.400 000	millimetres
miles	1.609 344	kilometres
kilometer	0.621 370	miles (statute)
square feet (ft^2)	0.092 903	square metres (m^2)
square metres (m^2)	10.763 910	square feet (ft^2)
square metres (m^2)	0.000 001	square kilometres (km^2)
Concentration		
grains/gallon (UK)	14.270 050	parts per million (ppm)
ppm	0.998 859	mg/L
mg/L	1.001 142	ppm
Volume (capacity)		
acre feet	1233.481 838	cubic metres
cubic feet	0.028 317	cubic metres
cubic metres	35.314 667	cubic feet
cubic metres	219.969 248	gallons (UK)
cubic metres	264.172 050	gallons (US liquid)
cubic metres	1000.000 000	litres
gallons (UK)	0.004 546	cubic metres
imperial gallons	4.546 000	litres
Rate		
litres per minute (lpm)	0.219 974	UK gallons per minute (igpm)
litres per minute	1.440 000	cubic metres/day (m^3/day)
igpm	6.546 300	cubic metres/day (m^3/day)
cubic metres/day	0.152 759	igpm

WESTLOCK COUNTY
Appendix A

Hydrogeological Maps and Figures

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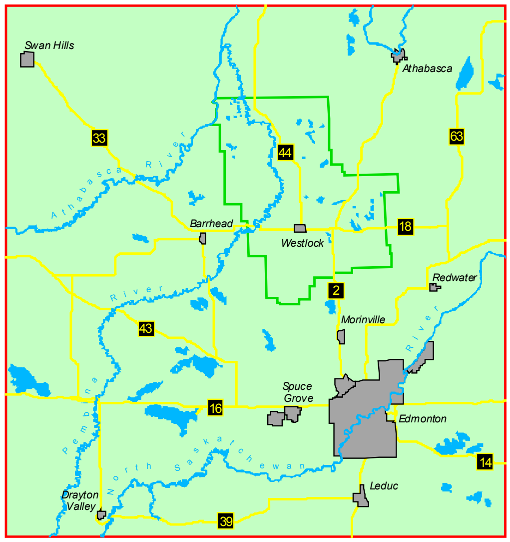
Index Map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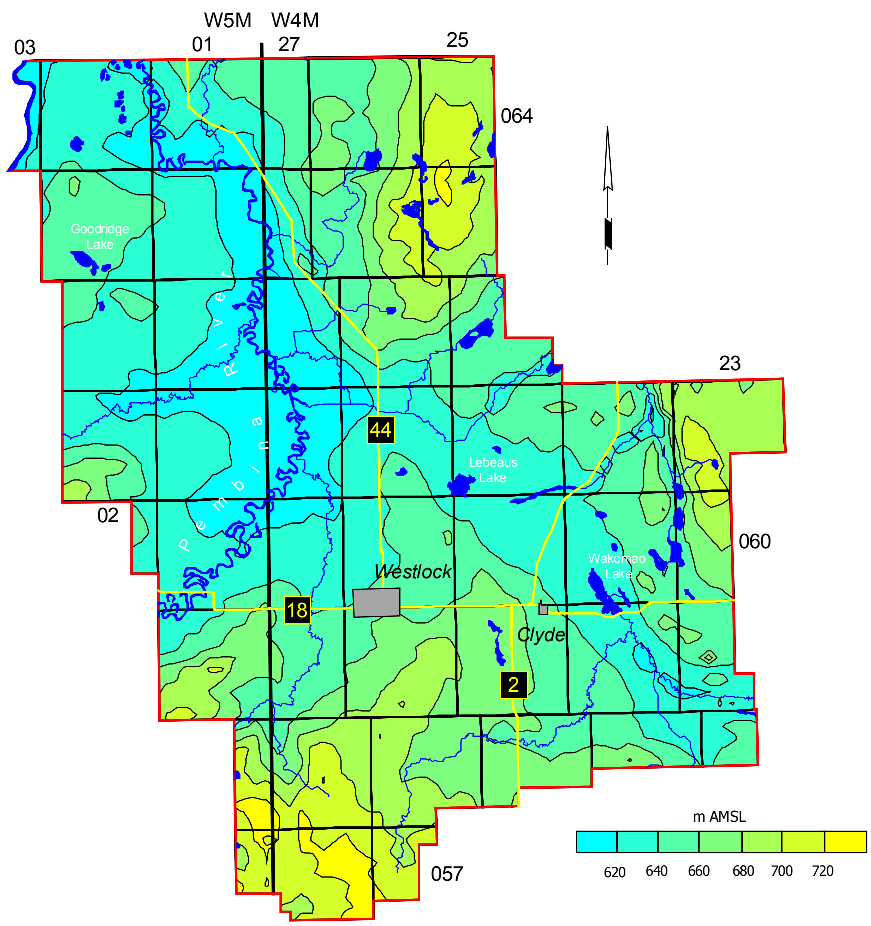
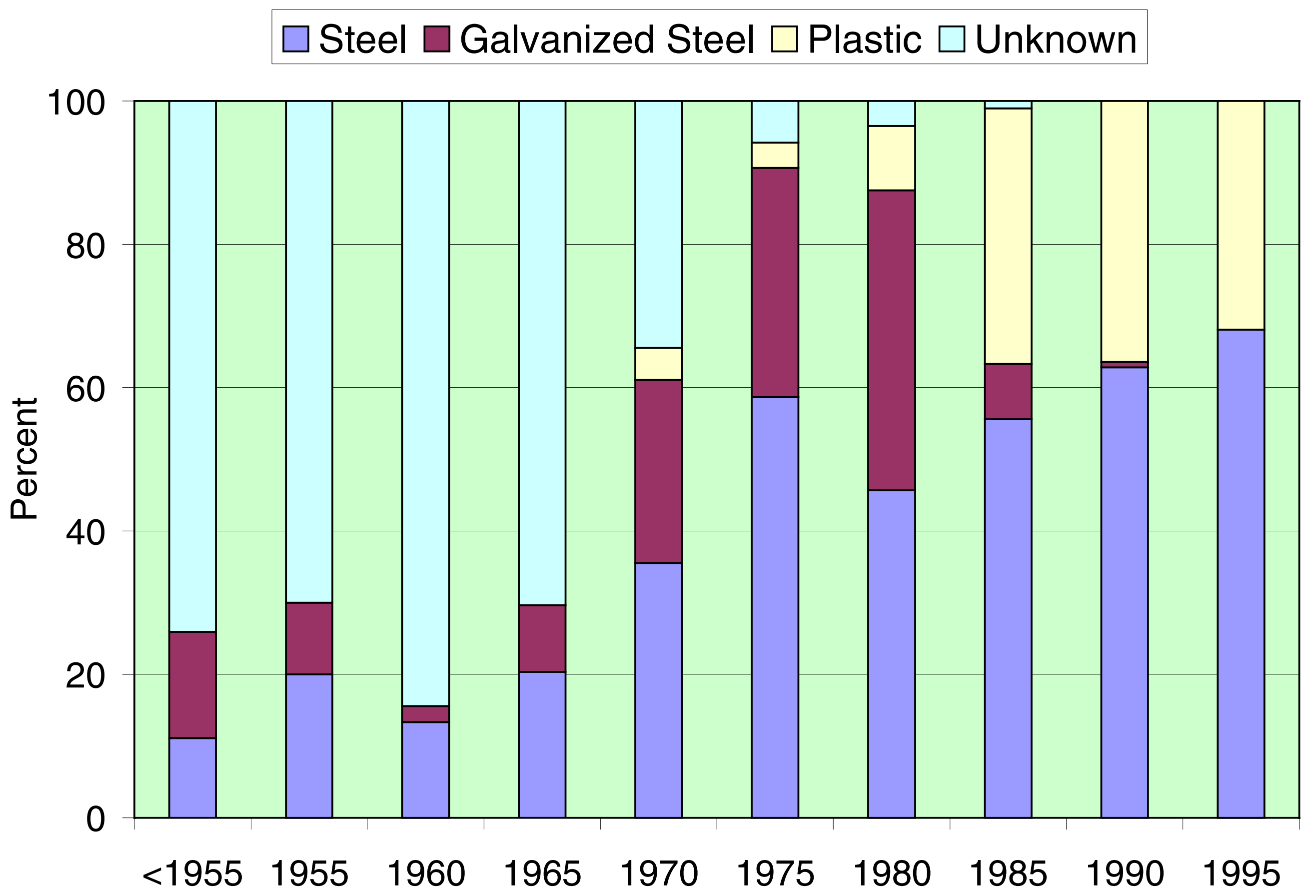
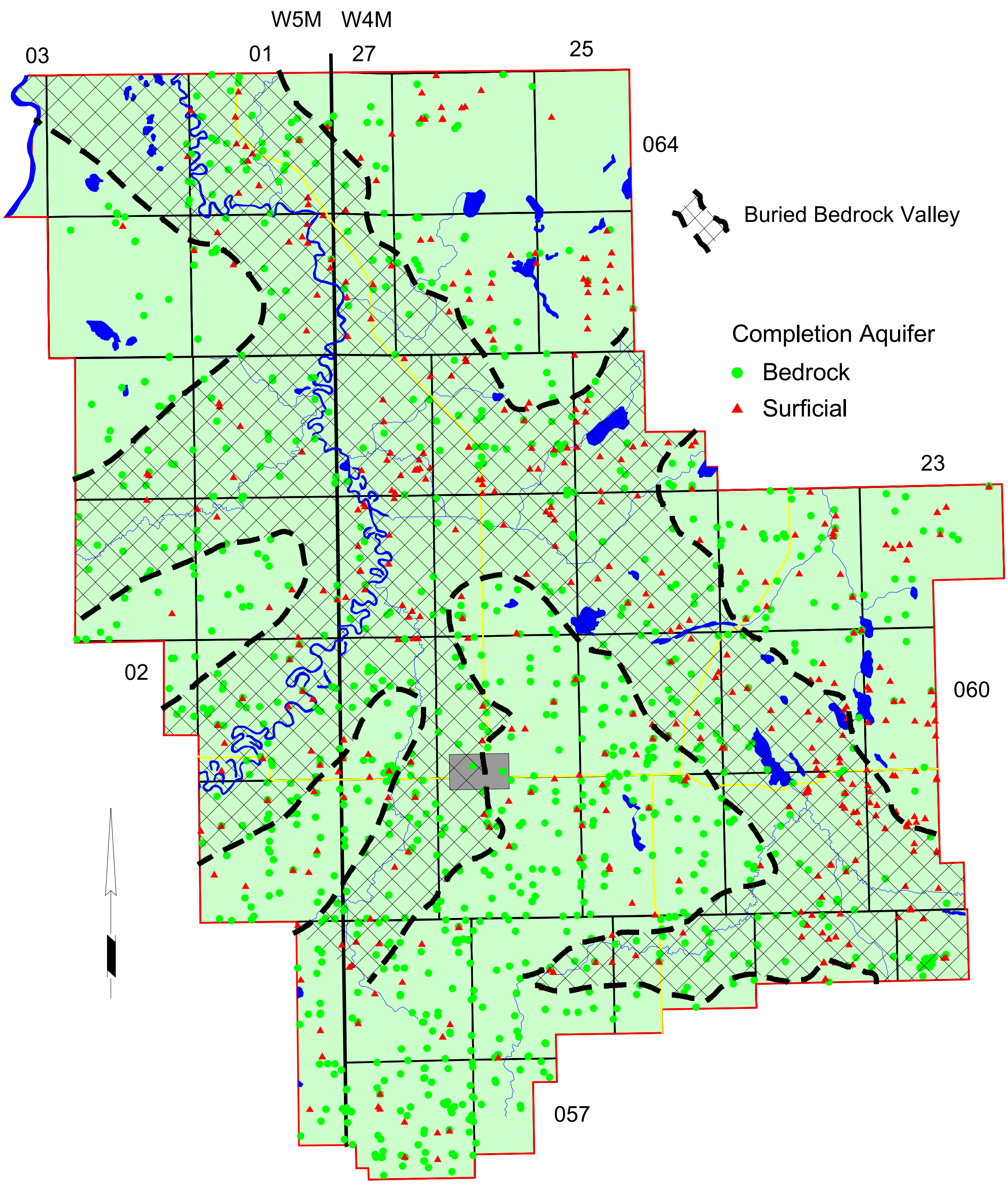
44
63
Athabasca River
Barrhead
Westlock
18
2
Redwater
River
Morinville
43
River
16
Spuce
Grove
Edmonton
Pembina
North Saskatchewan
14
Leduc
Drayton
Valley
39


W5M
W4M
03
01
27
25
064
23
Goodridge
Lake
Pembina River
44
Lebeaus
Lake
02
060
Wakomao
Lake
Westlock
18
Clyde
2
057
m AMSL
620
640
660
680
700
720

Surface Casing Types used in Drilled Water Wells

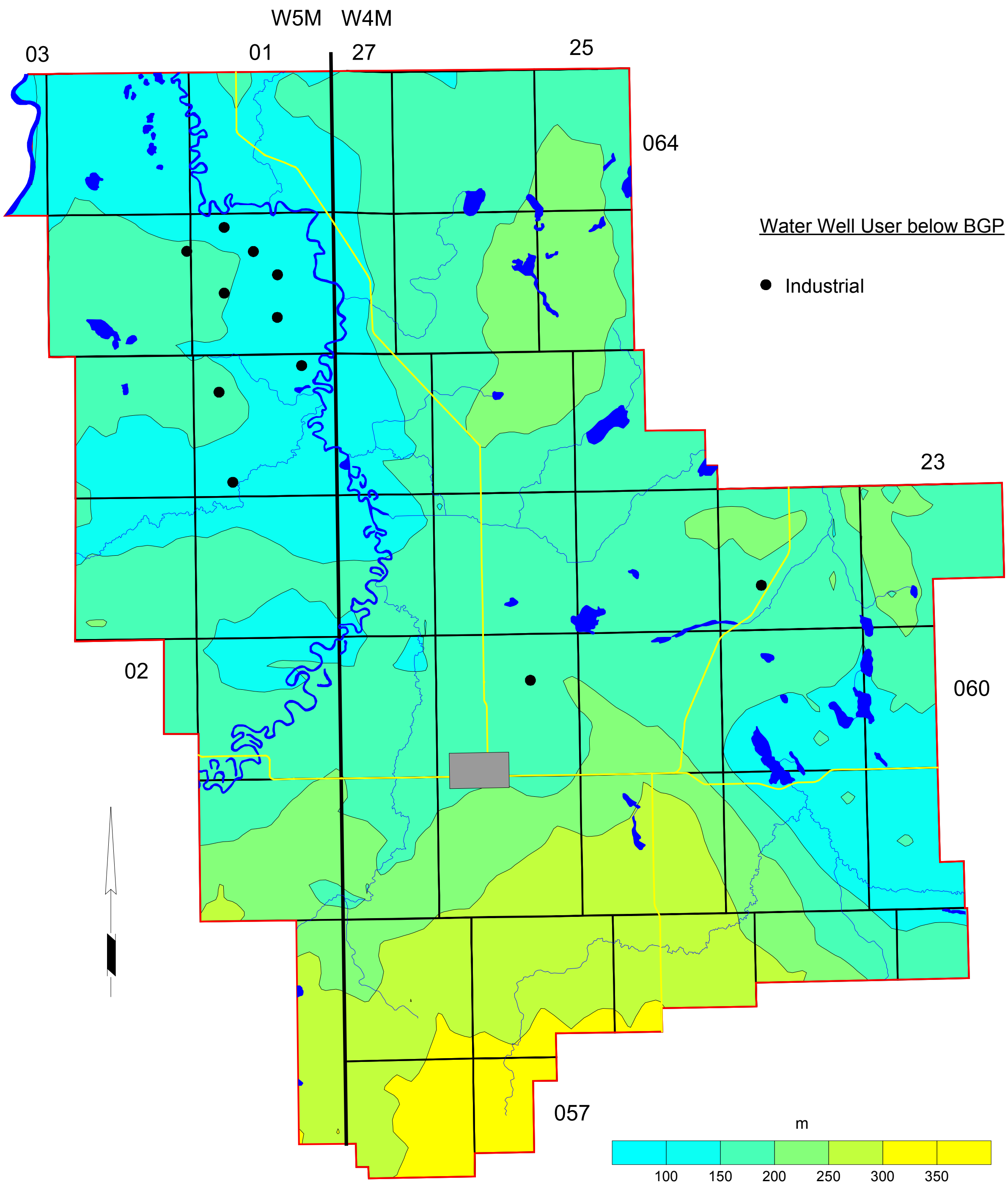


Location of Water Wells

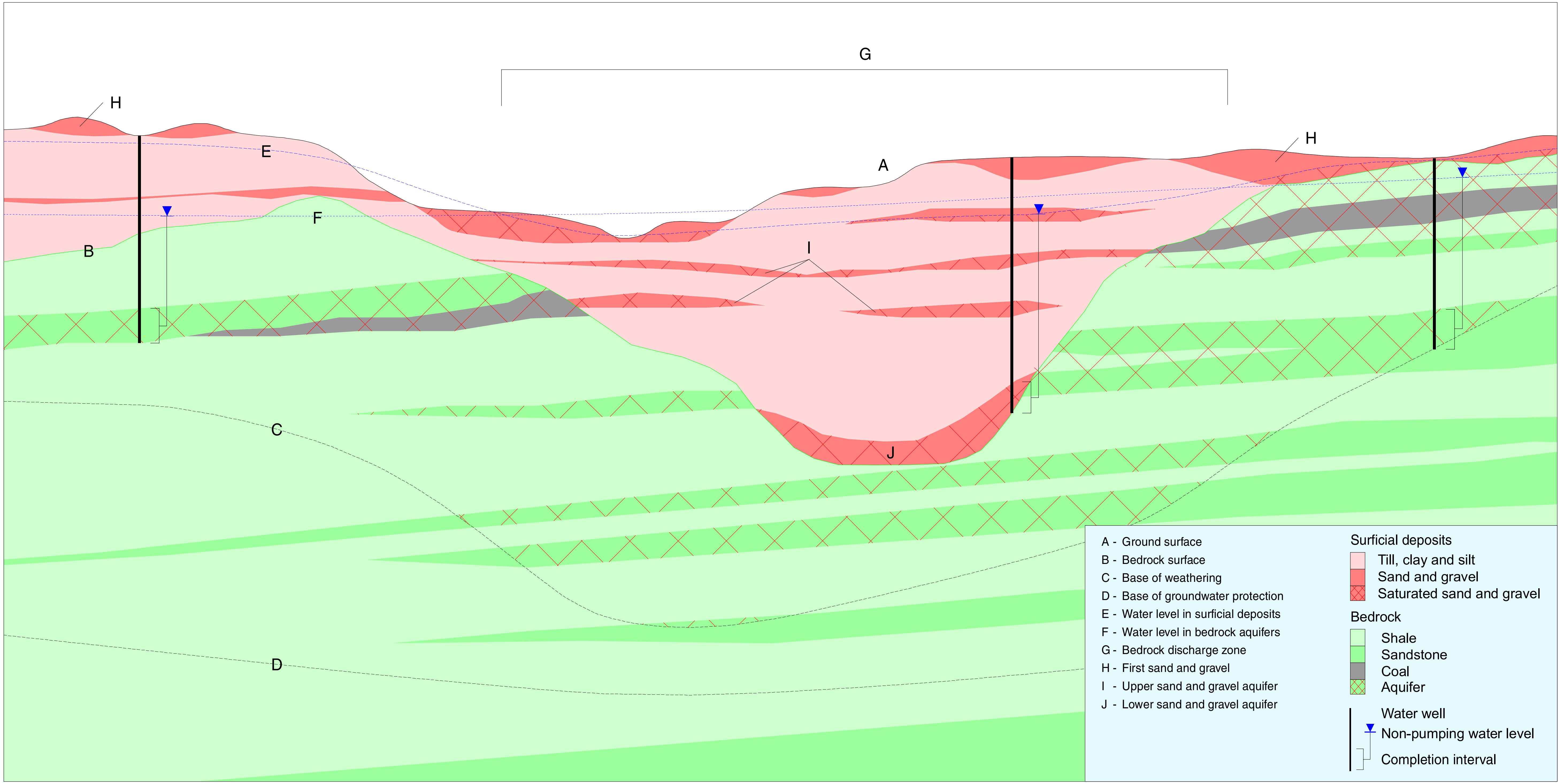


Depth to Base of Groundwater Protection

(modified after EUB, 1995)



Generalized Cross-Section
(for terminology only)



Generalized Cross-Section
(for terminology only)

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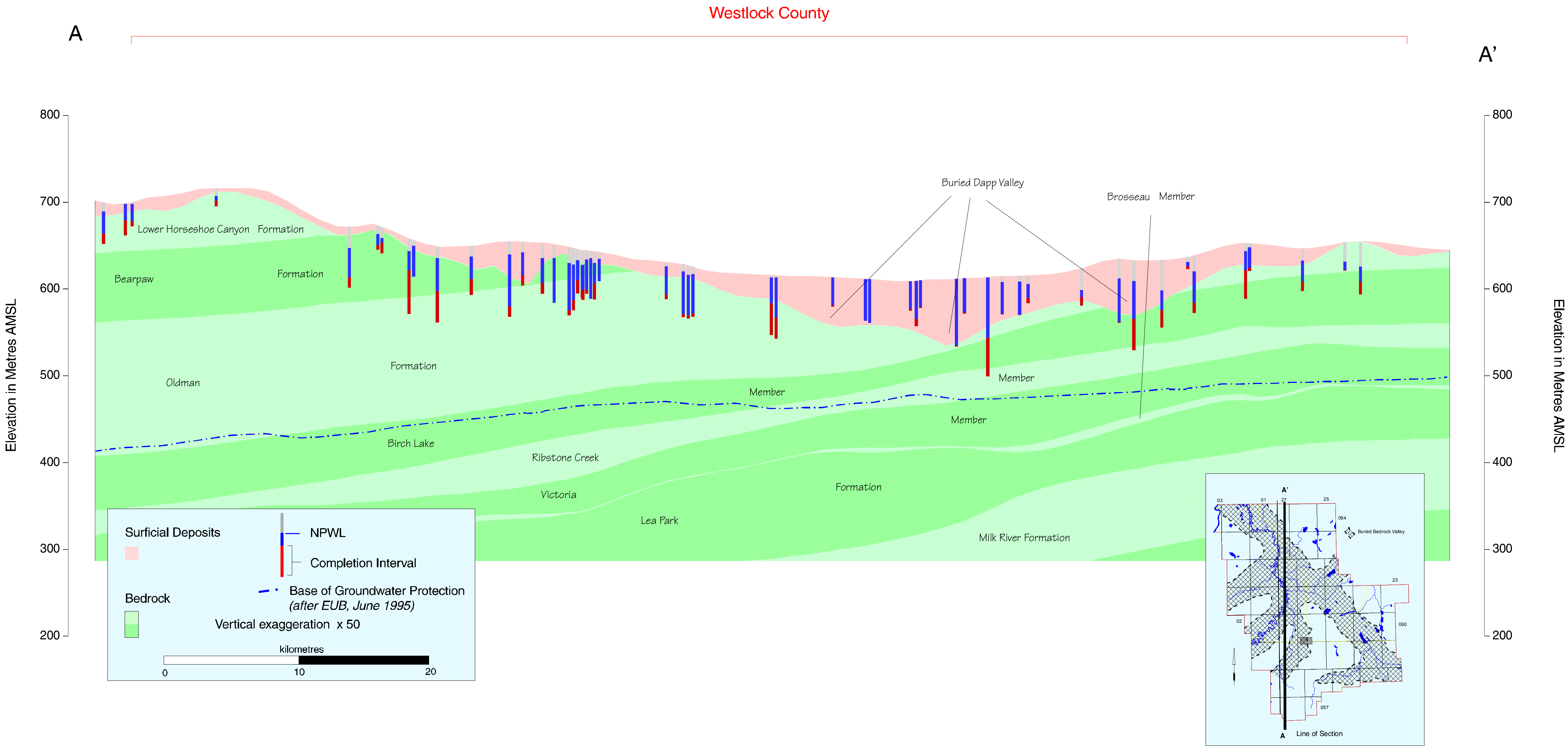
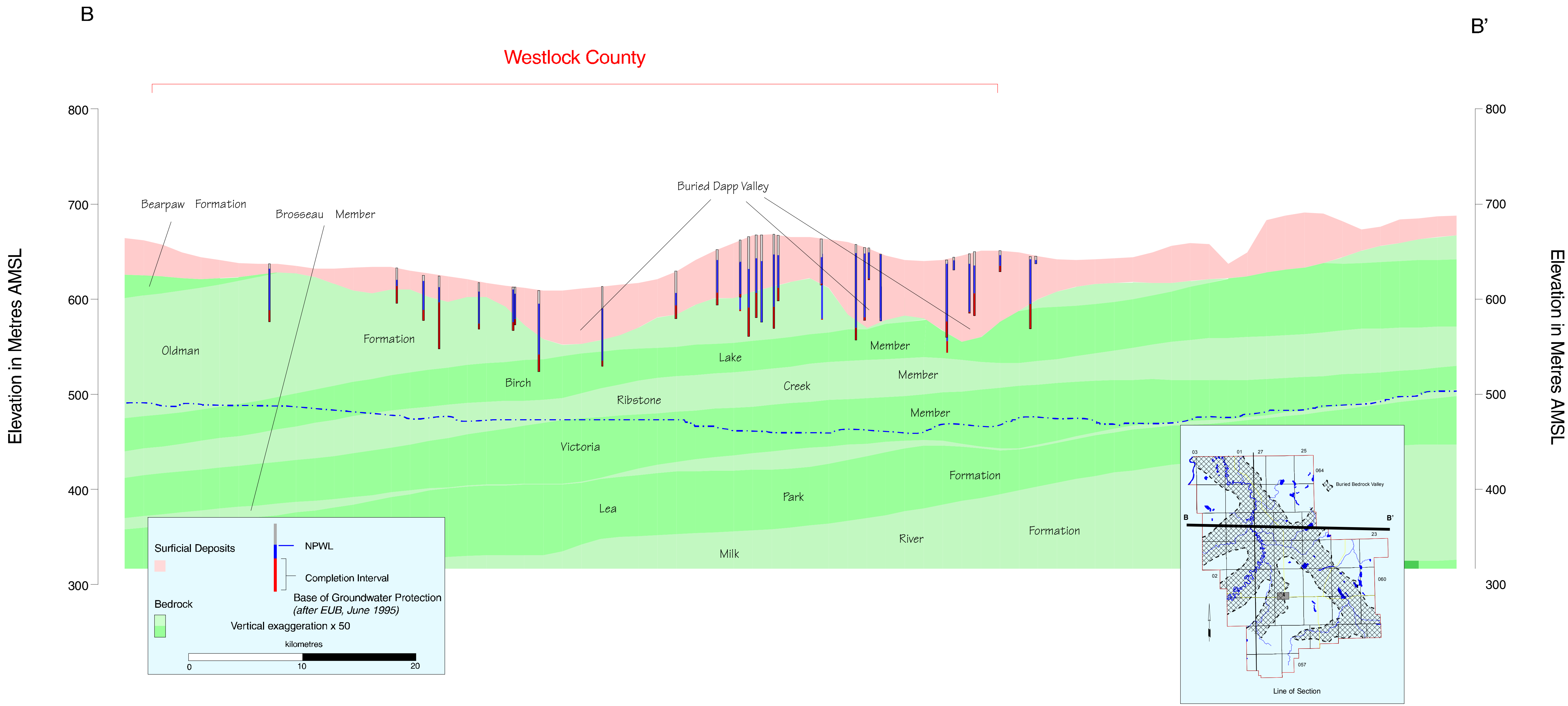
Geologic Column

Lithology	Lithologic Description	Group and Formation: Average Thickness (m)	Group and Formation: Designation (Group)	Group and Formation: Formation Thickness (m)	Group and Formation: Designation (Formation)	Member: Average Thickness (m)	Member: Designation	Zone: Average Thickness (m)	Zone: Designation
	sand, gravel, till, clay, silt	<140			Surficial Deposits	<140	Upper	<30	First Sand and Gravel
						<50	Lower		
	shale, sandstone, coal, bentonite, limestone, ironstone	300-380	Edmonton Group		Horseshoe Canyon Formation	~100	Upper		
						~100	Middle		
						~170	Lower		
	shale, sandstone, siltstone	60-120			Bearpaw Formation				
	sandstone, siltstone, shale, coal	<300	Belly River Group	40-130	Oldman Formation		Dinosaur Member	<25	Lethbridge Coal Zone
							Upper Siltstone Member		
							Comrey Member		
	sandstone, shale			<200	Foremost Formation	<70	Birch Lake Member		Taber Coal Zone
						<60	Ribstone Creek Member		
						<70	Victoria Member		McKay Coal Zone
						0-30	Brosseau Member		
	shale, siltstone				Lea Park Formation	100-200			

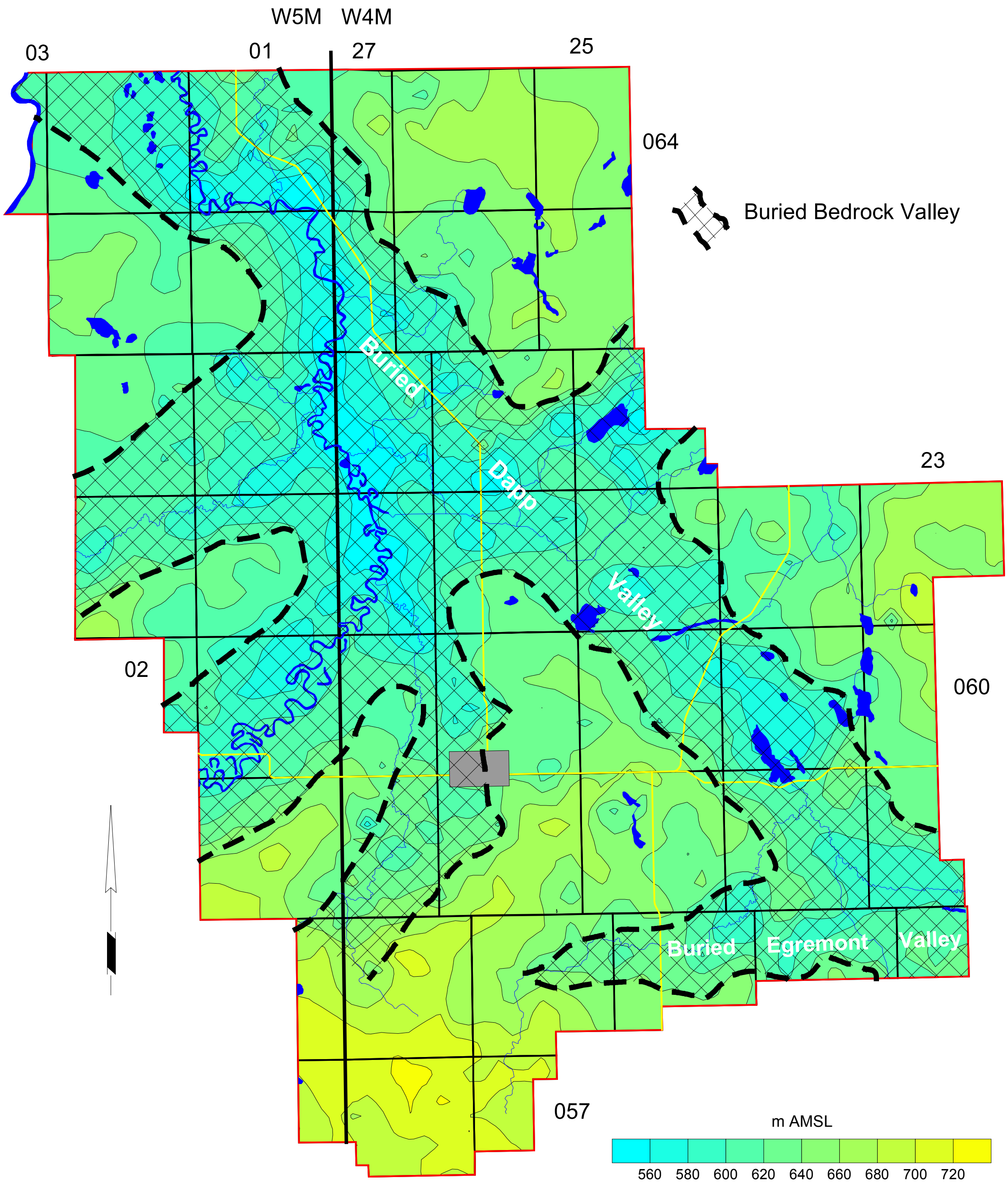
Cross-Section A - A'



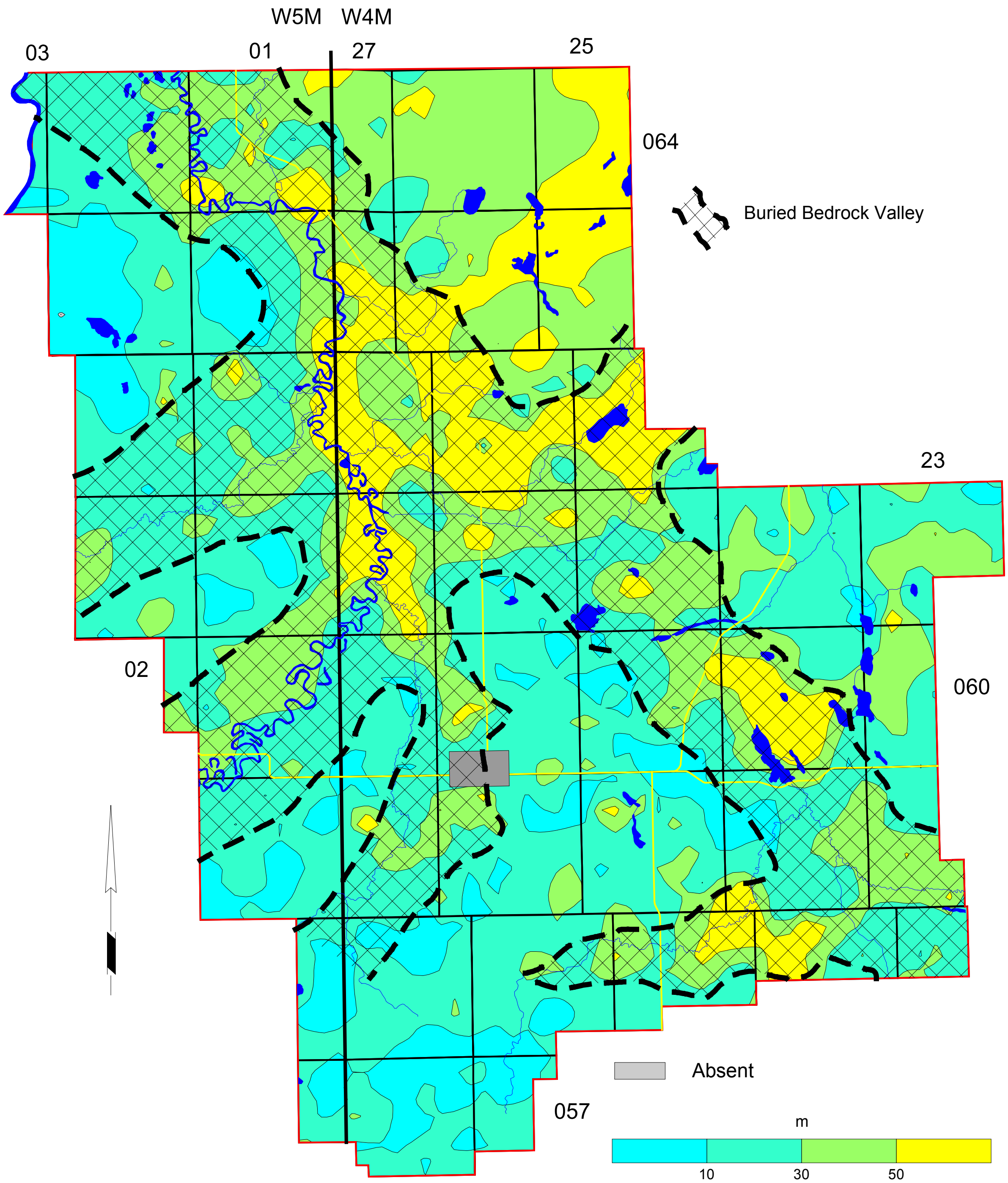
Cross-Section B - B'



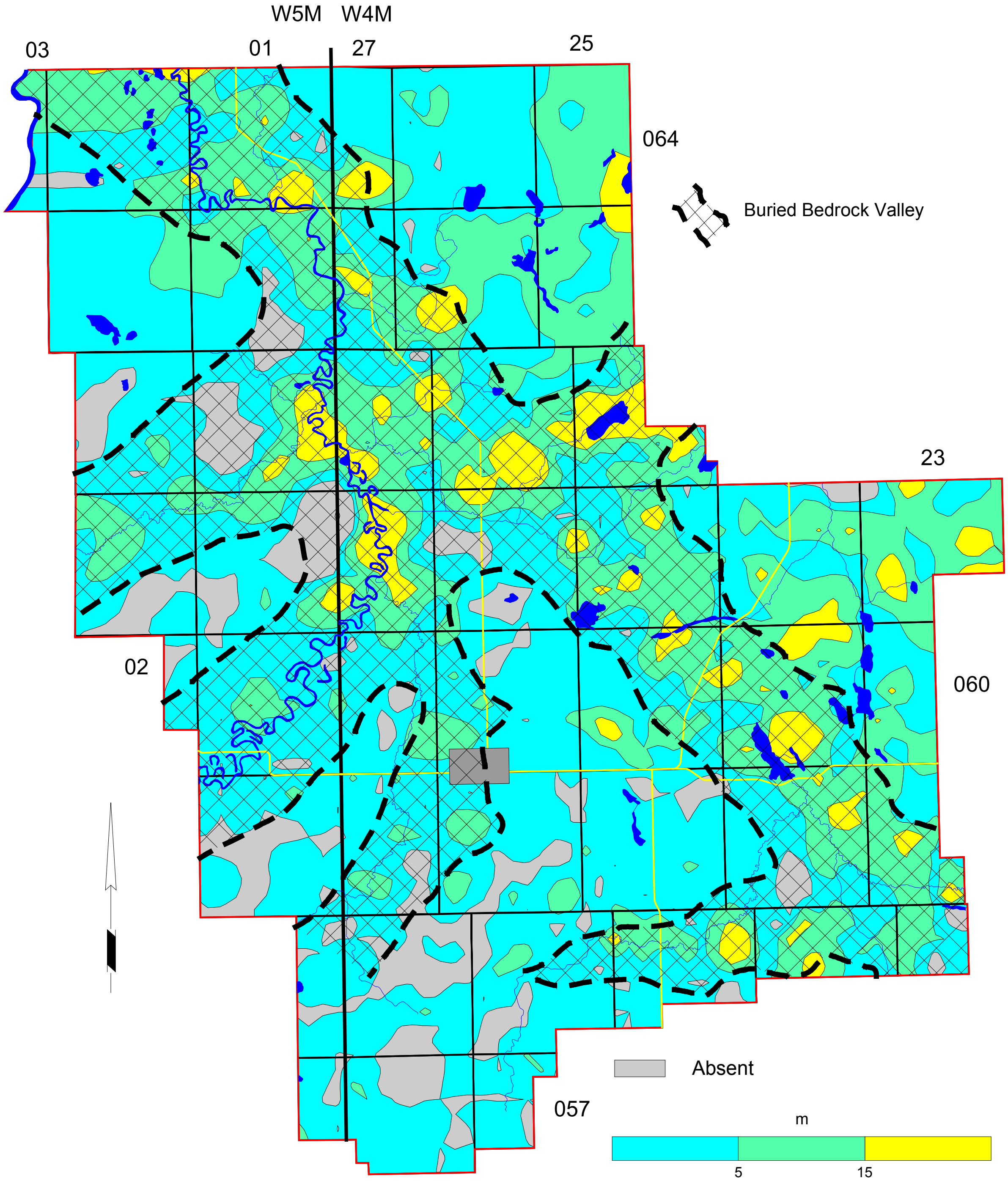
Bedrock Topography



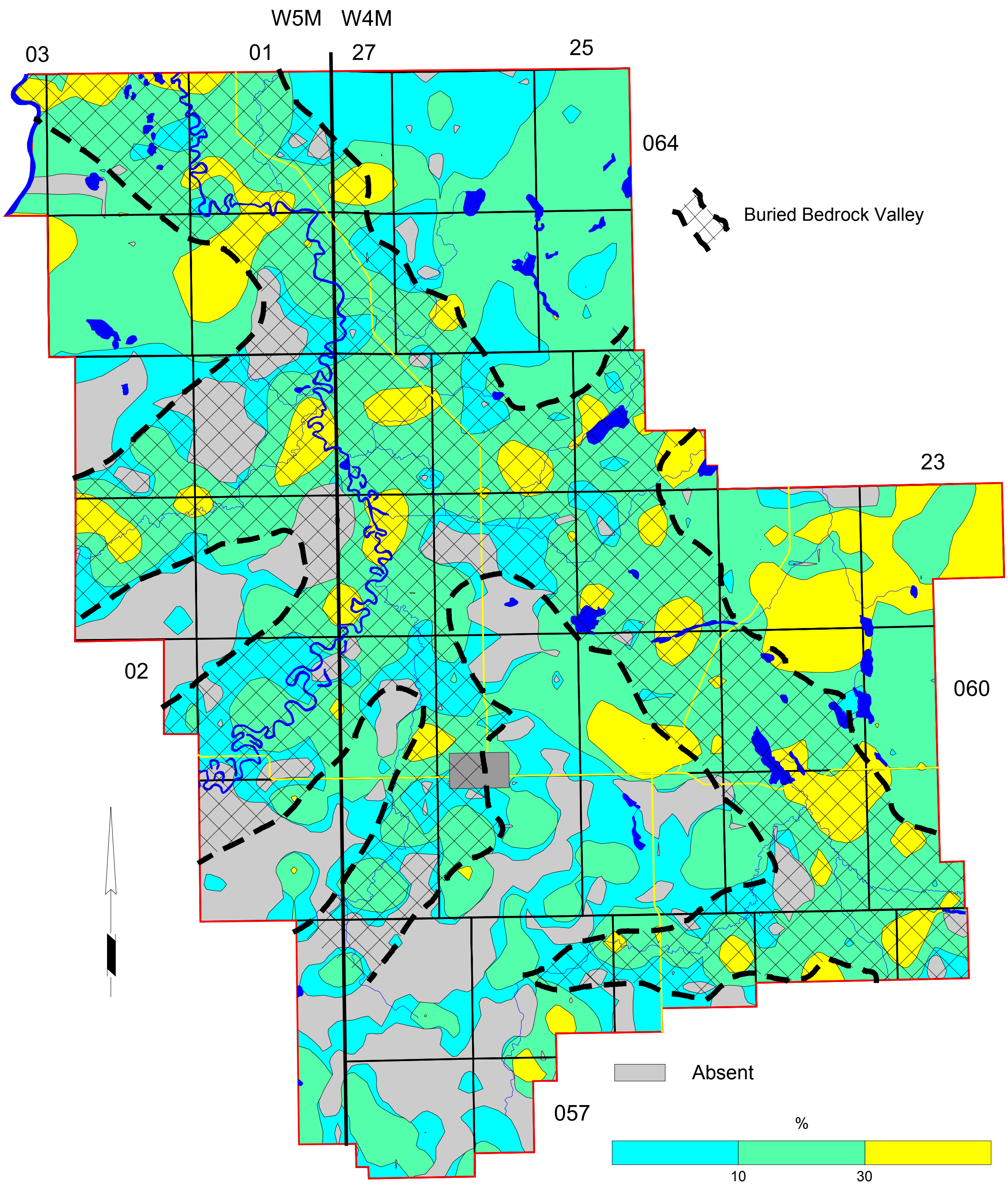
Thickness of Surficial Deposits



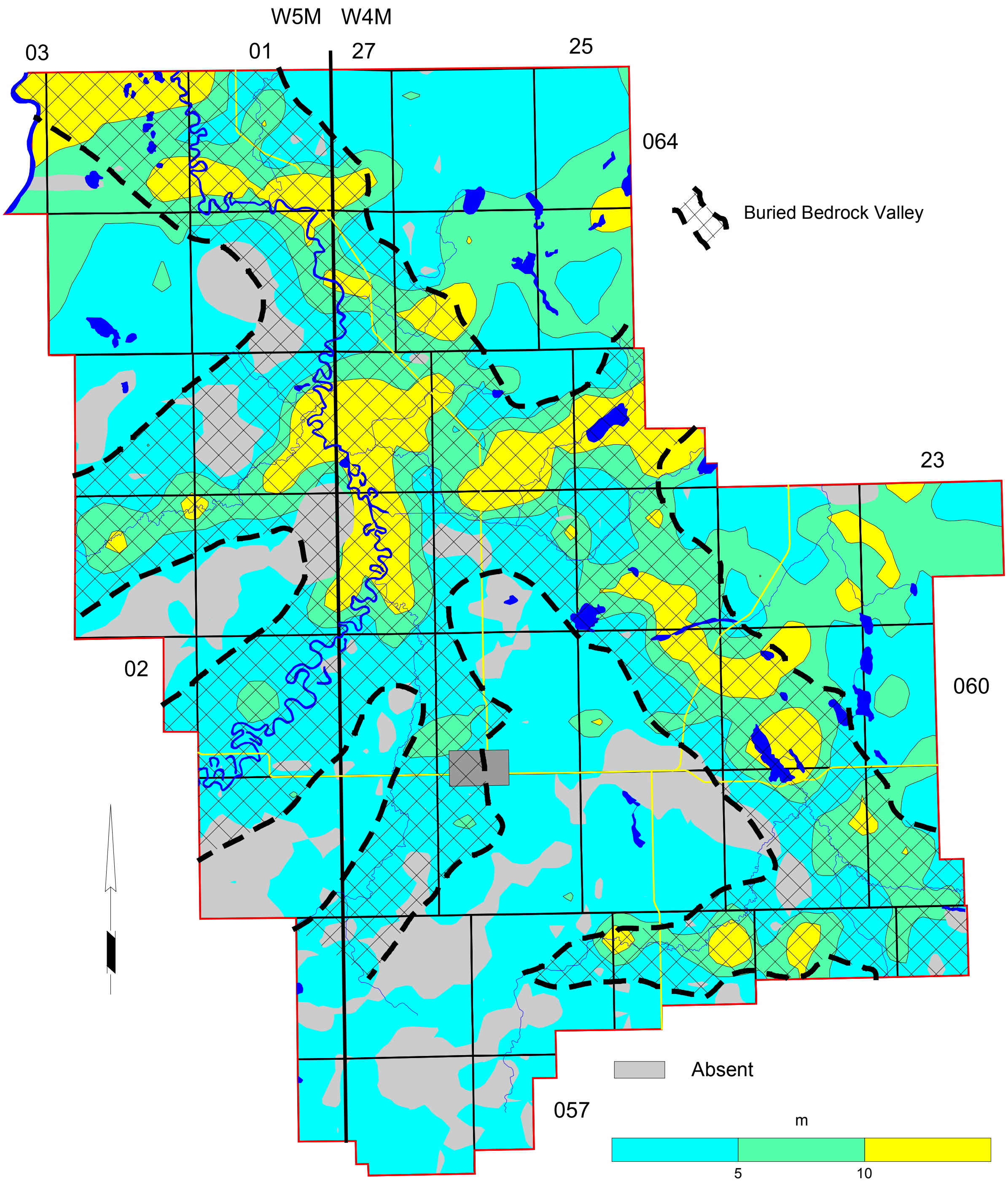
Thickness of Sand and Gravel Deposits



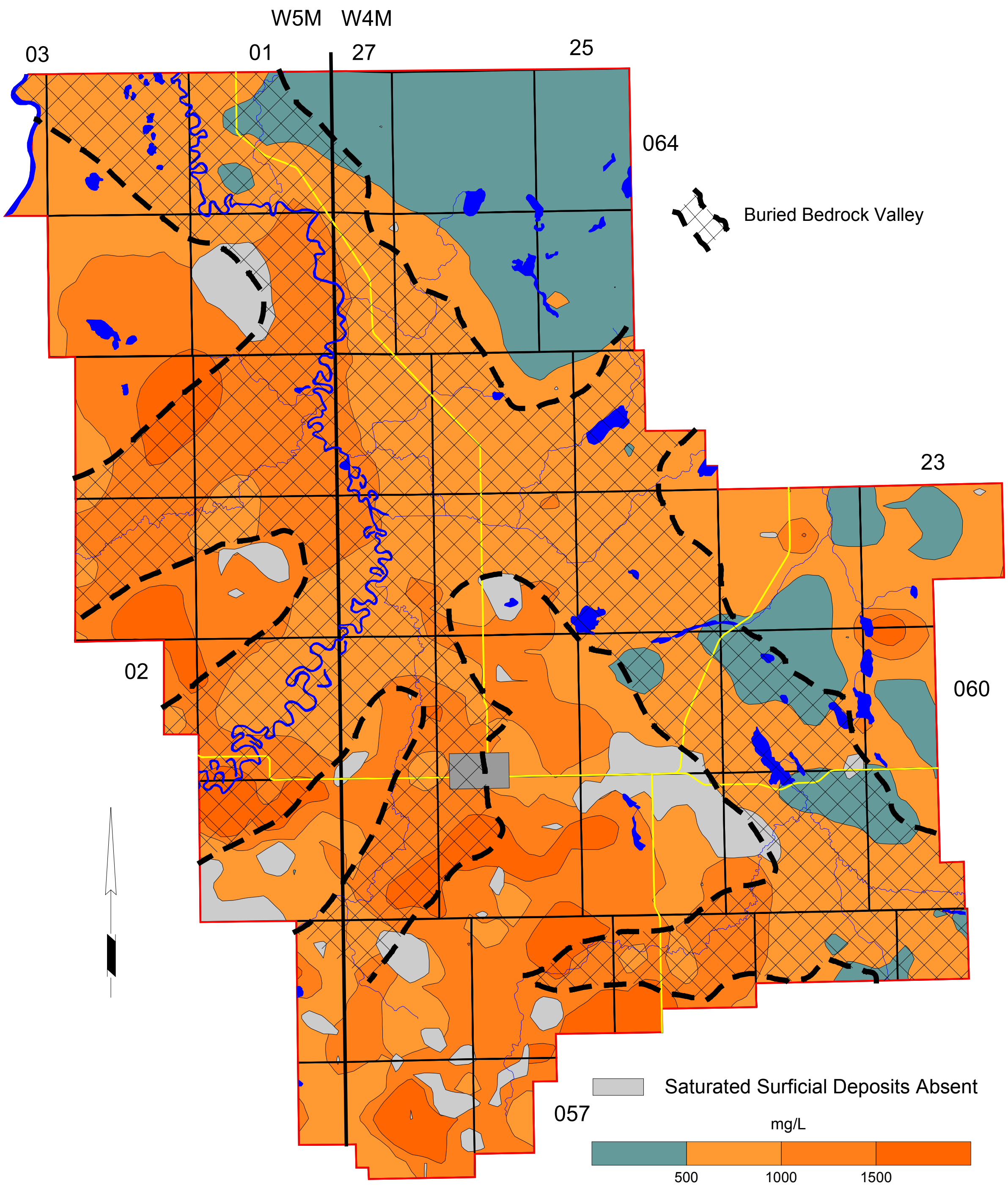
Amount of Sand and Gravel in Surficial Deposits



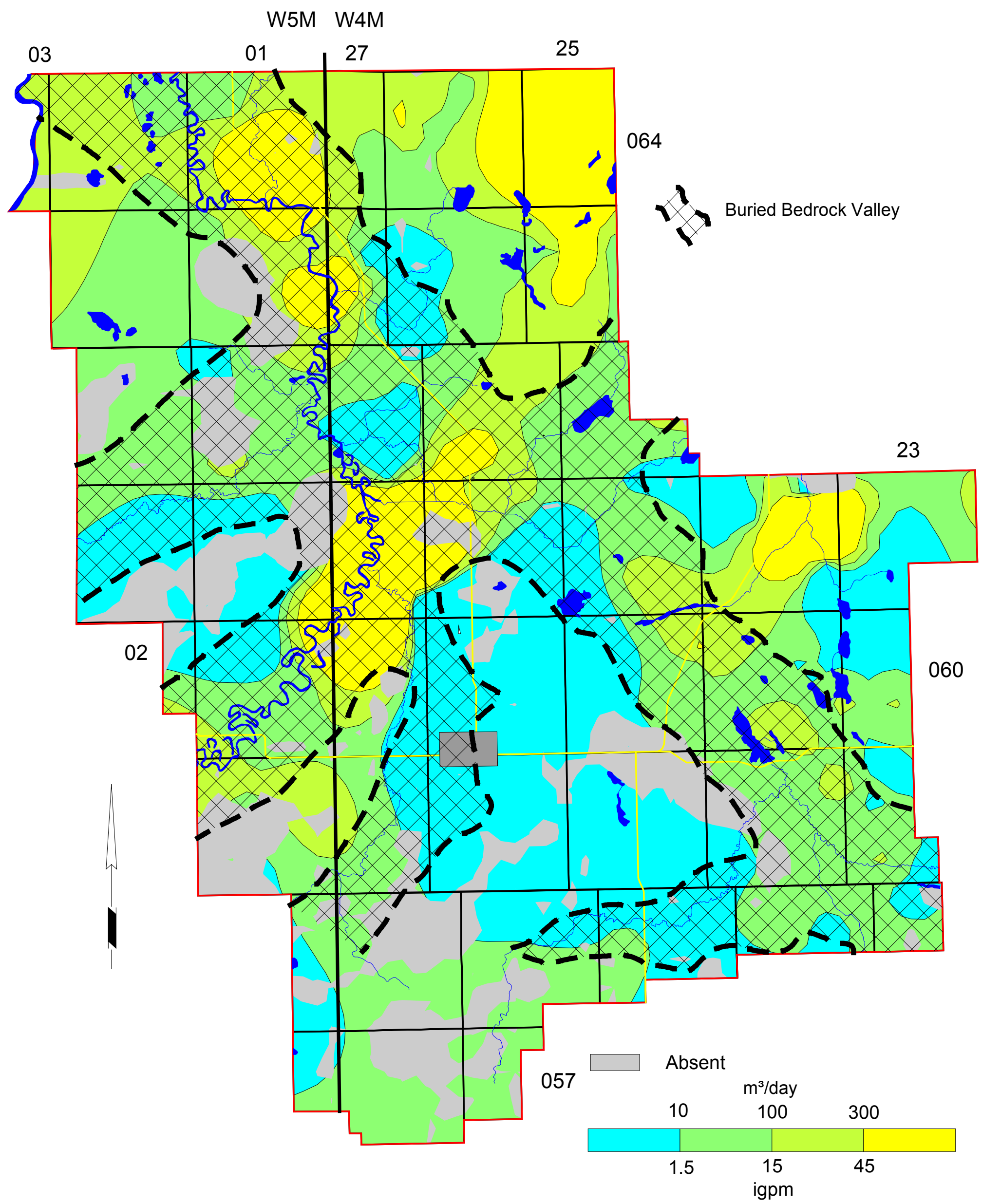
Thickness of Sand and Gravel Aquifer(s)



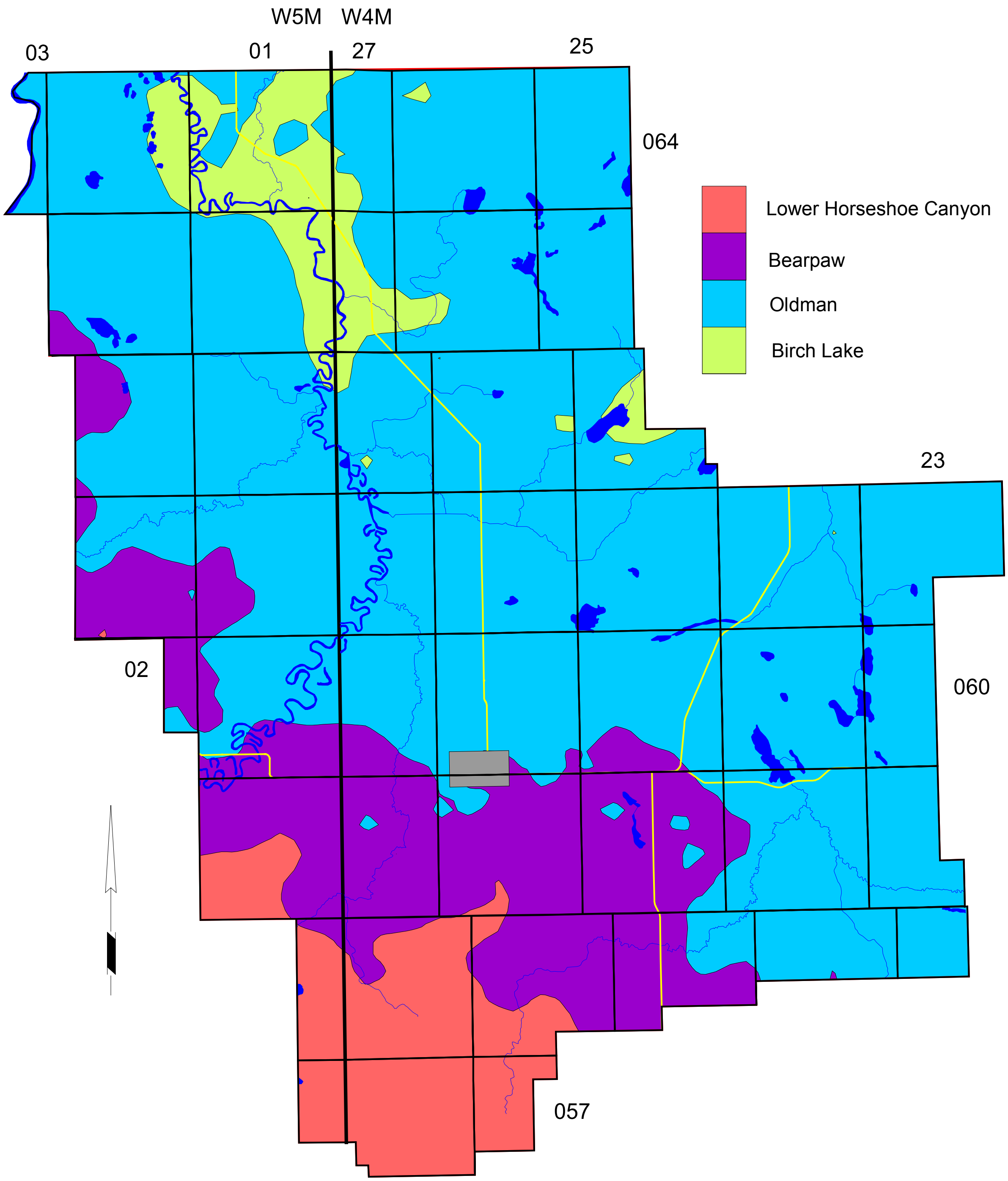
Total Dissolved Solids in Groundwater from Surficial Deposits



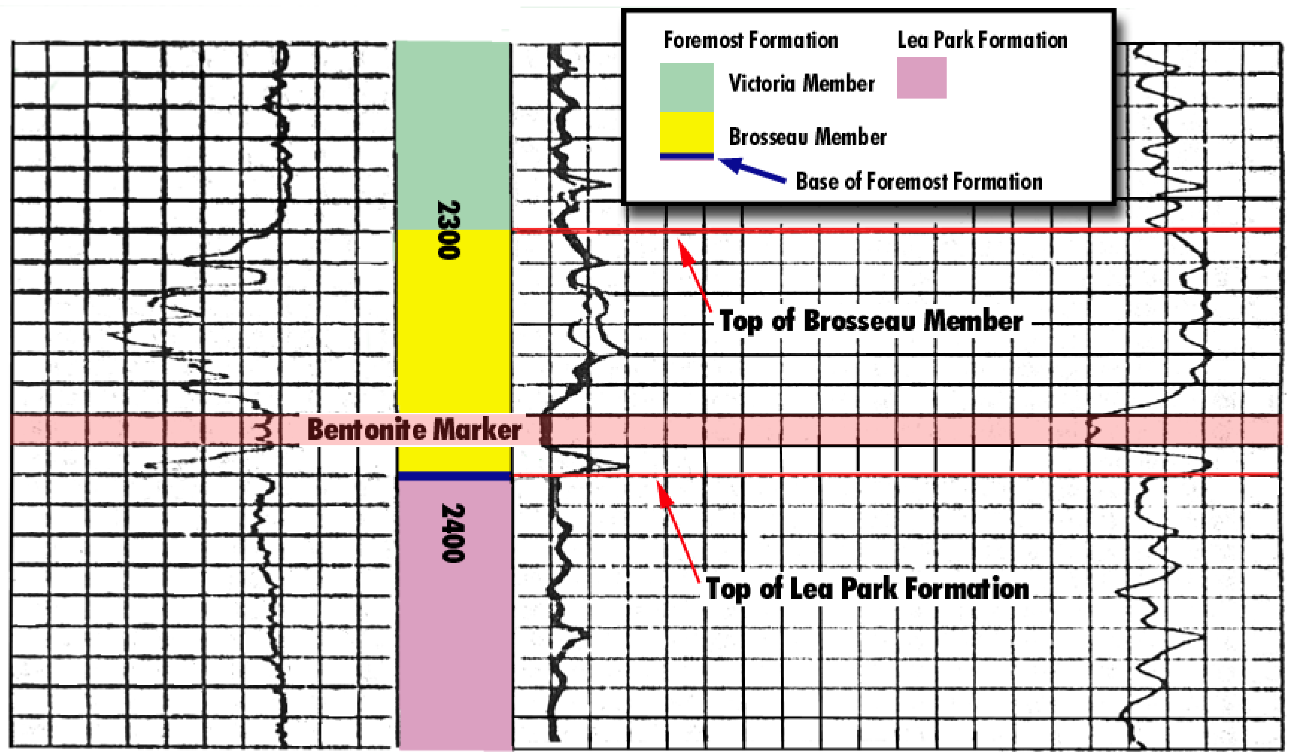
Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer(s)



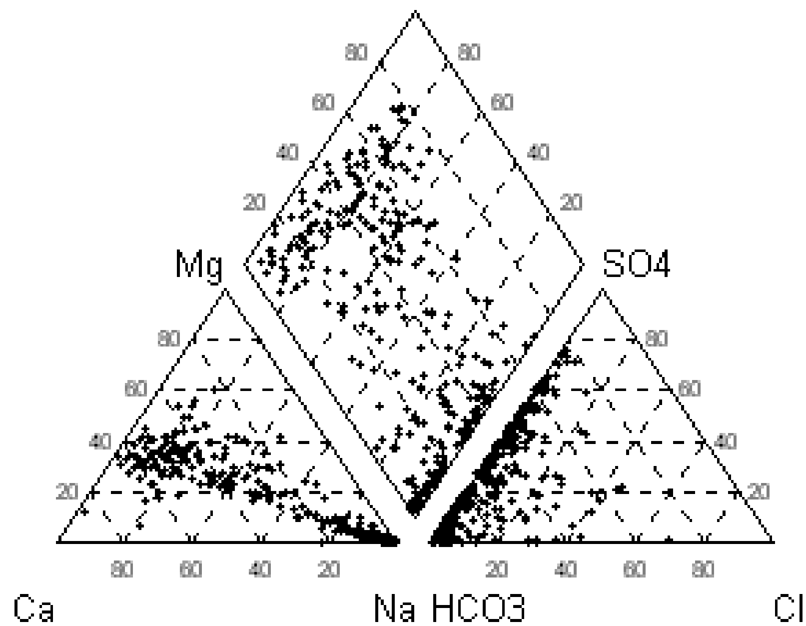
Bedrock Geology



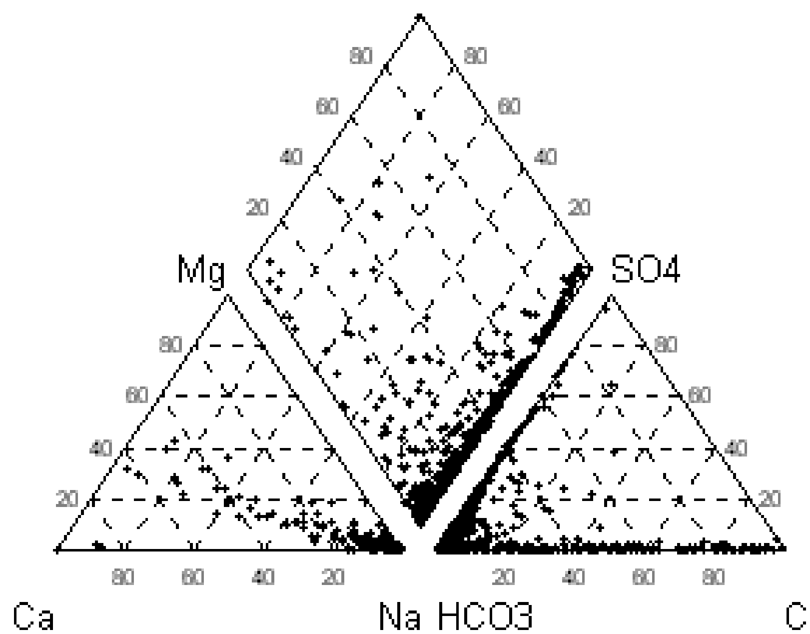
E-Log Showing Base of Foremost Formation



Piper Diagrams

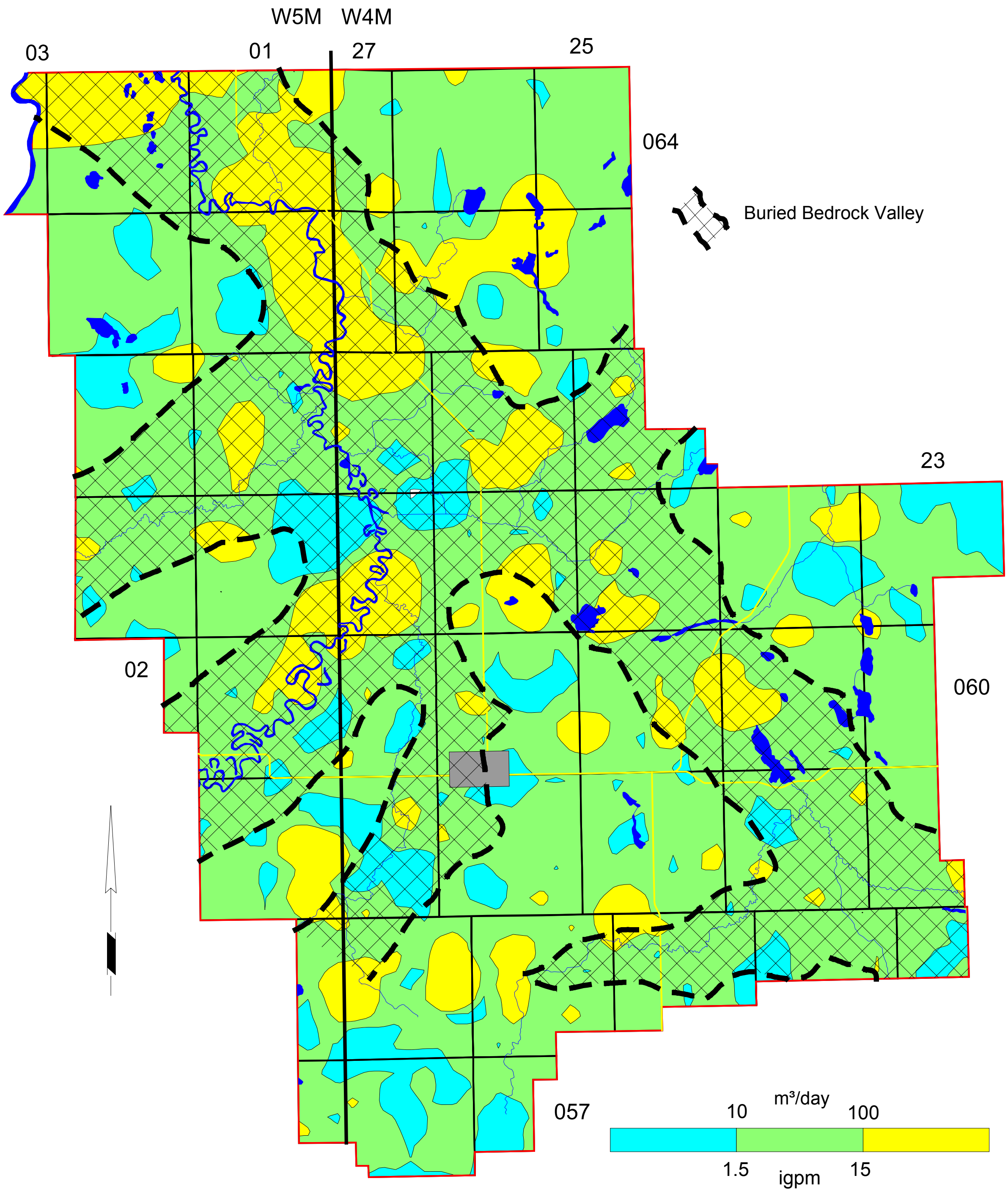


Surficial Deposits

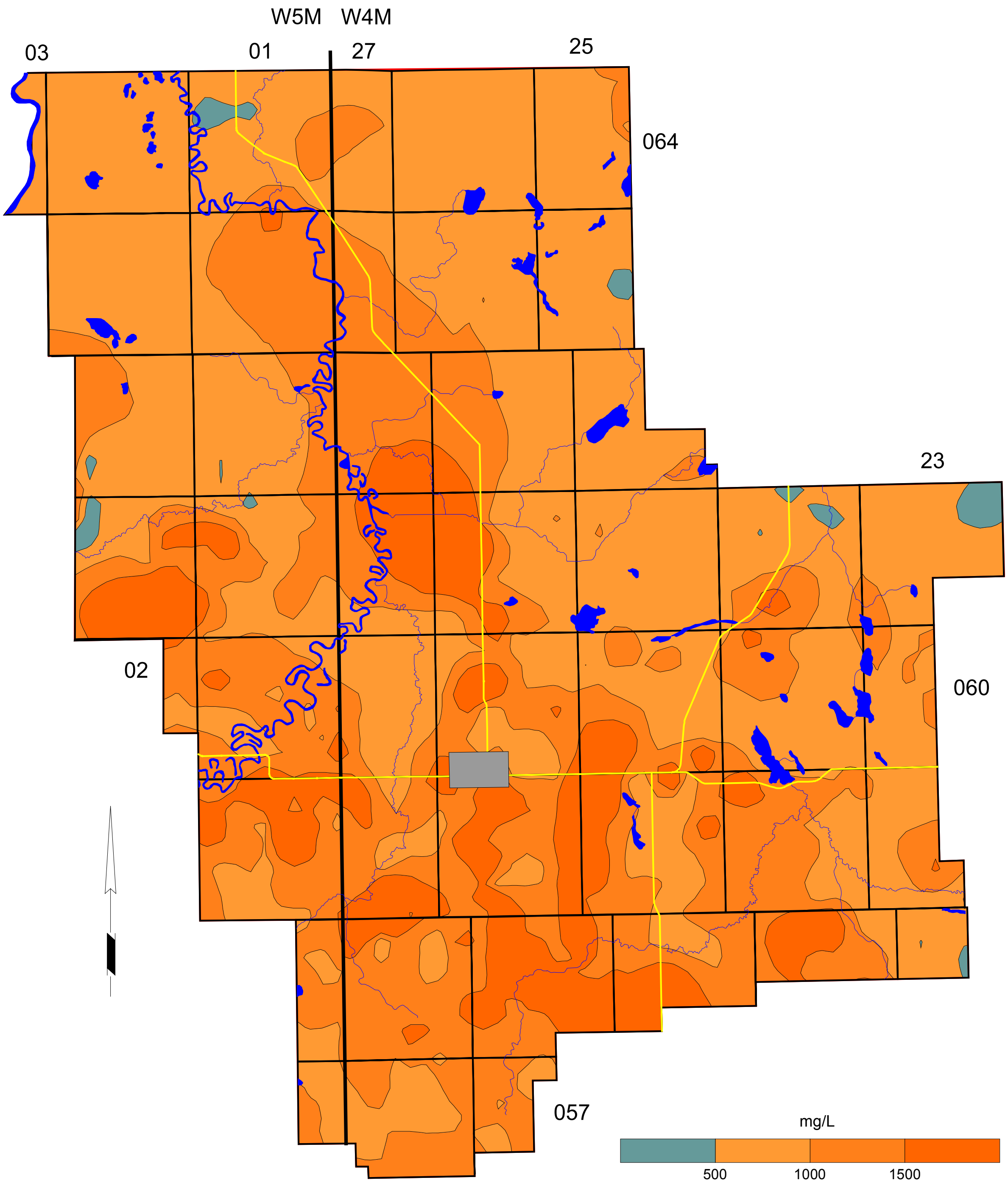


Bedrock Aquifers

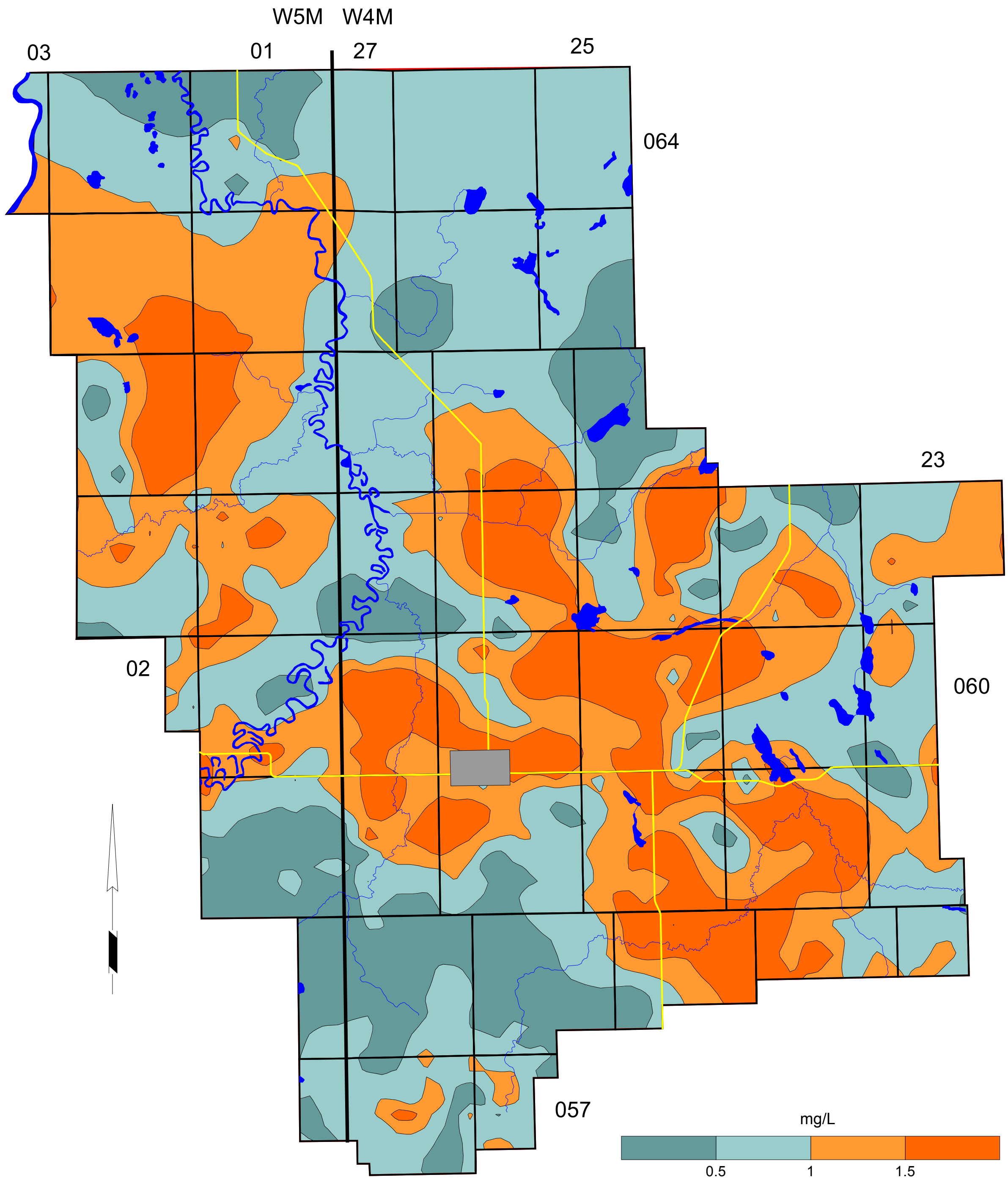
Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)



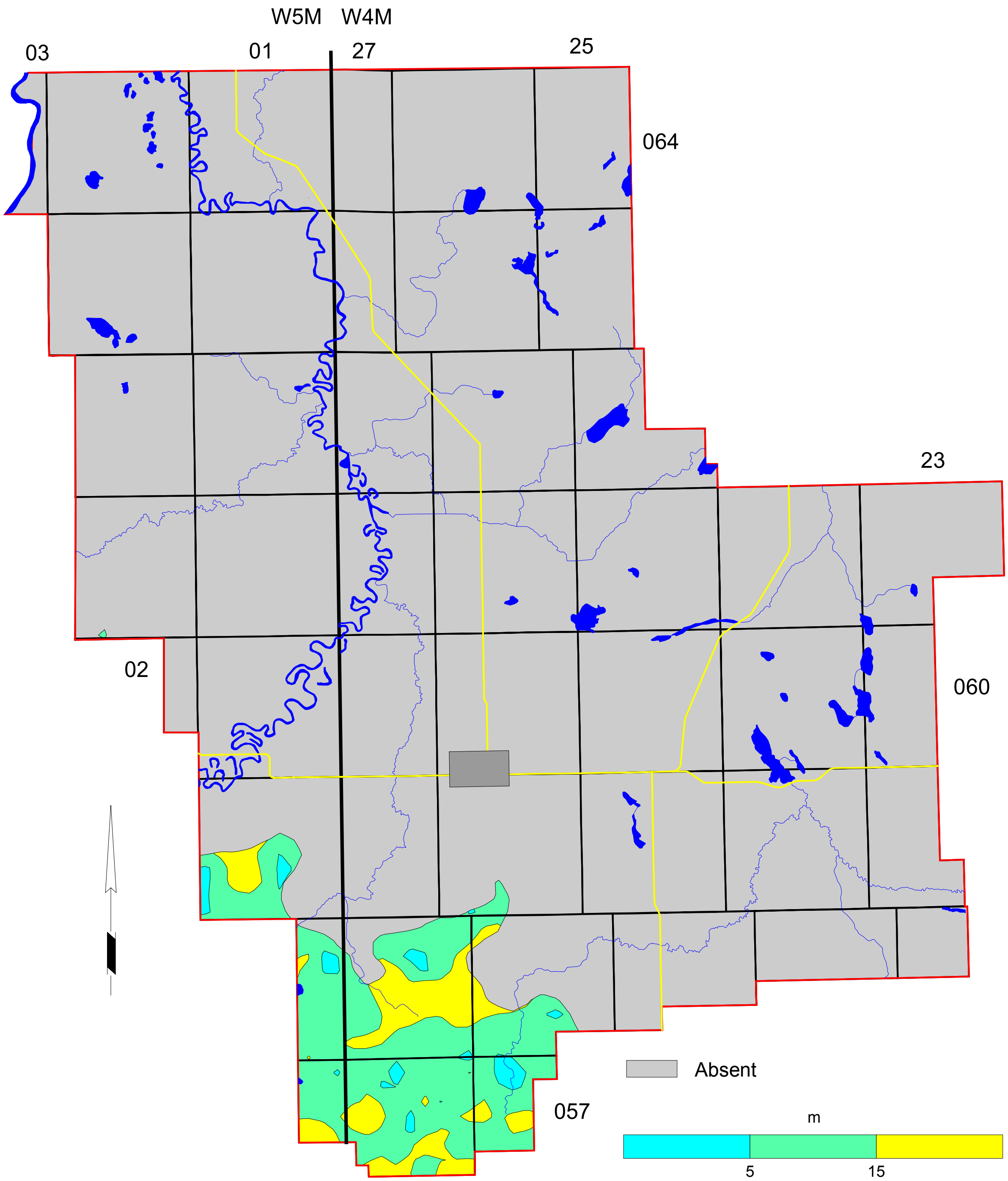
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)



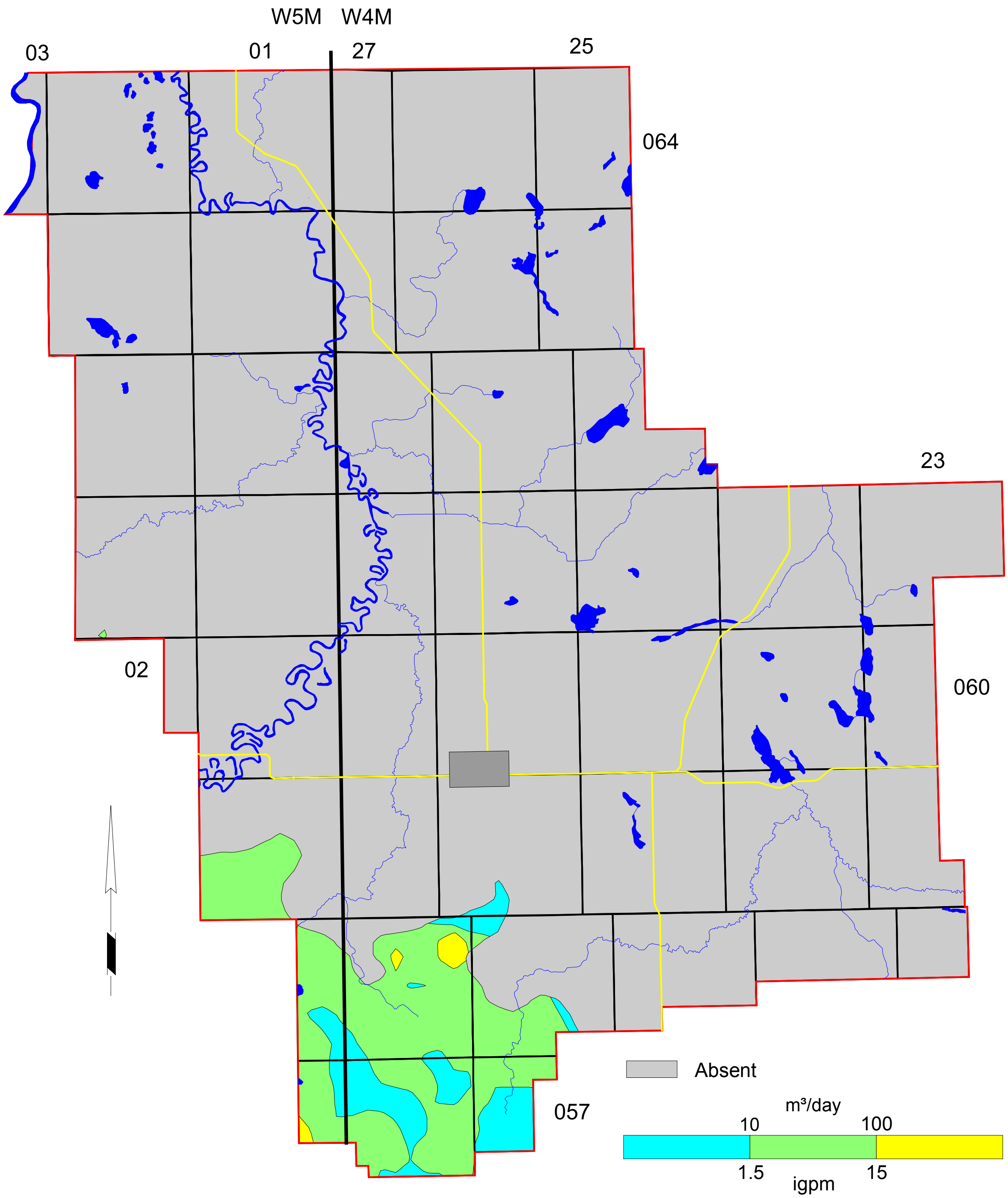
Fluoride in Groundwater from Upper Bedrock Aquifer(s)



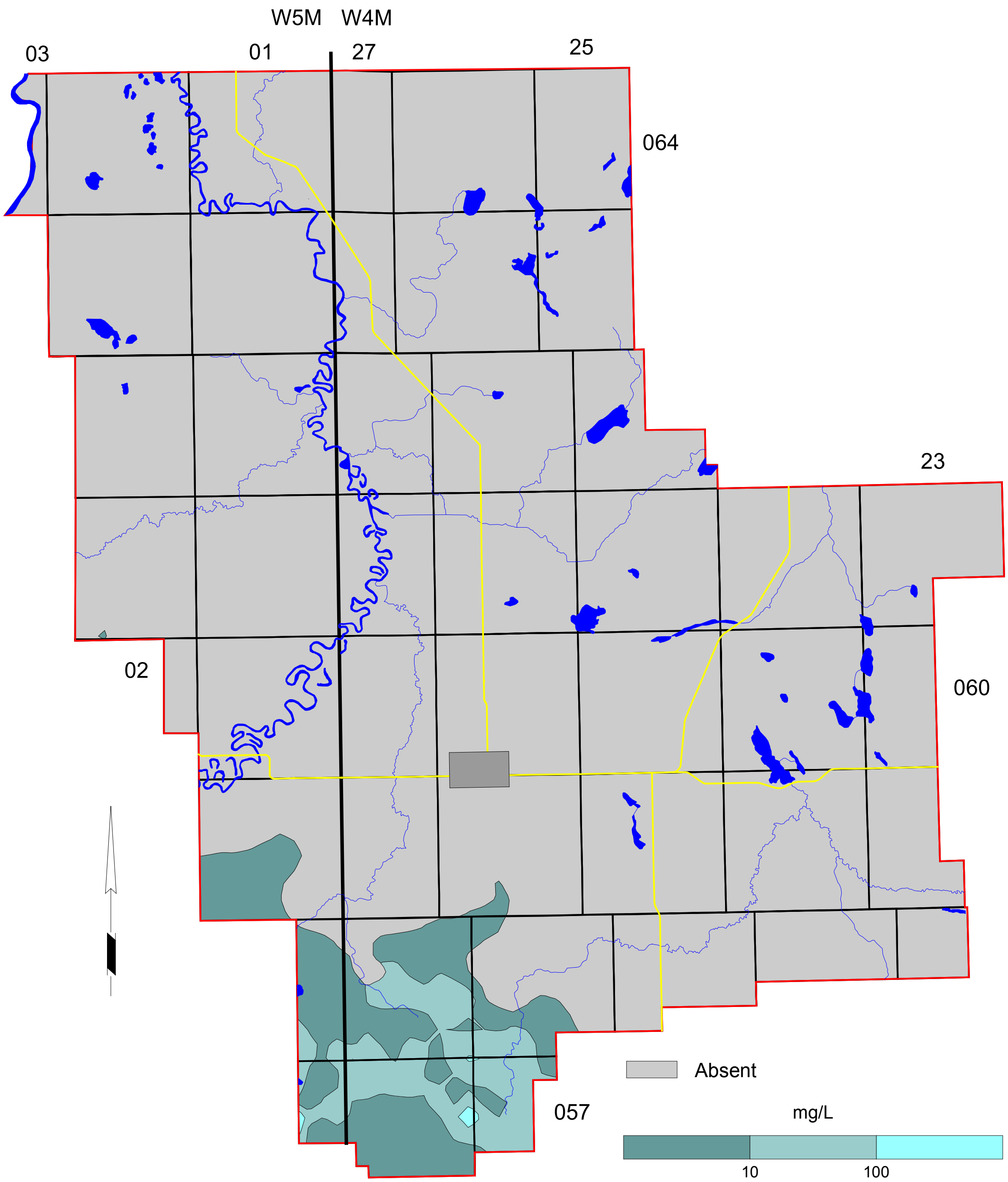
Depth to Top of Lower Horseshoe Canyon Formation



Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer



Chloride in Groundwater from Lower Horseshoe Canyon Aquifer



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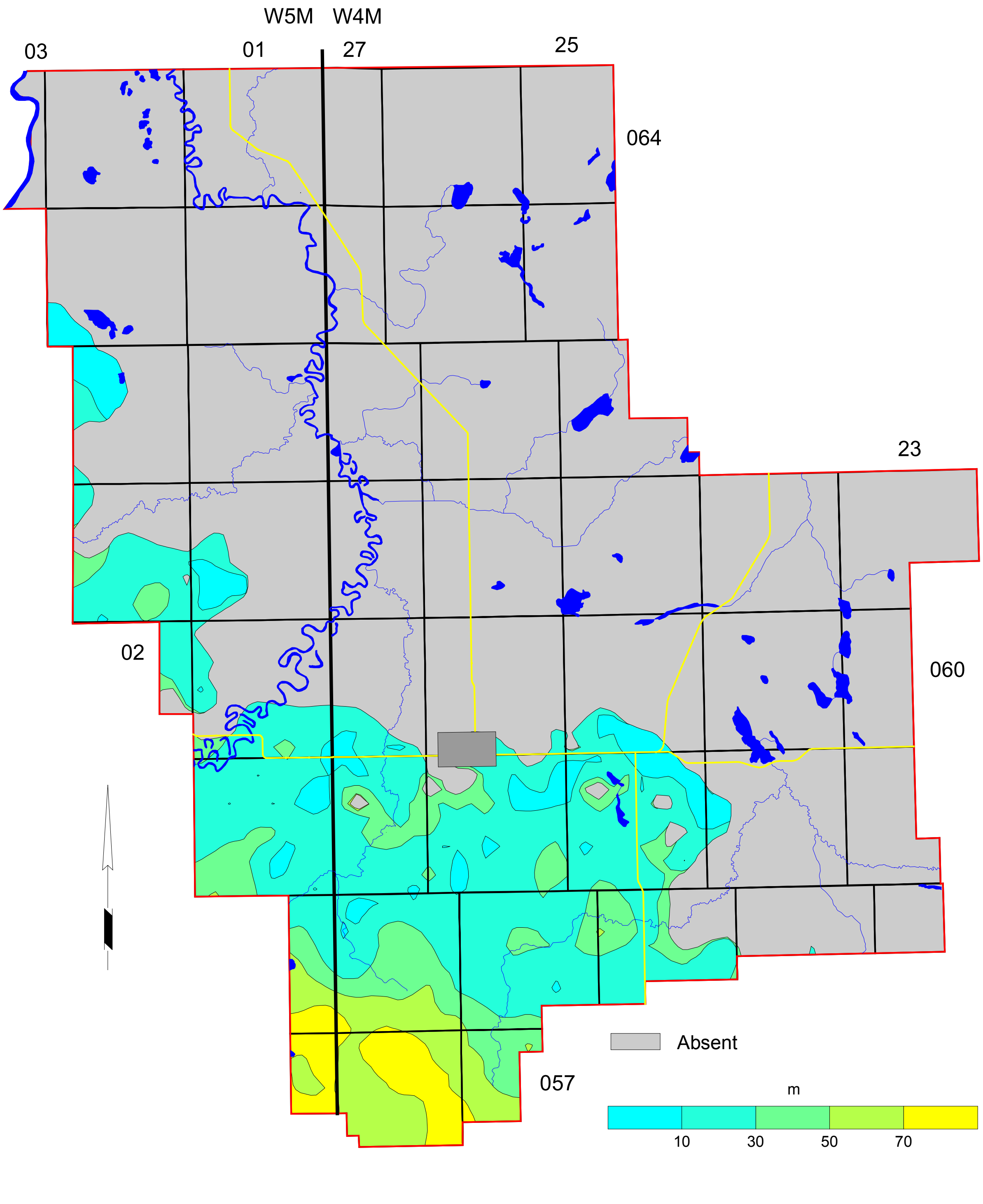
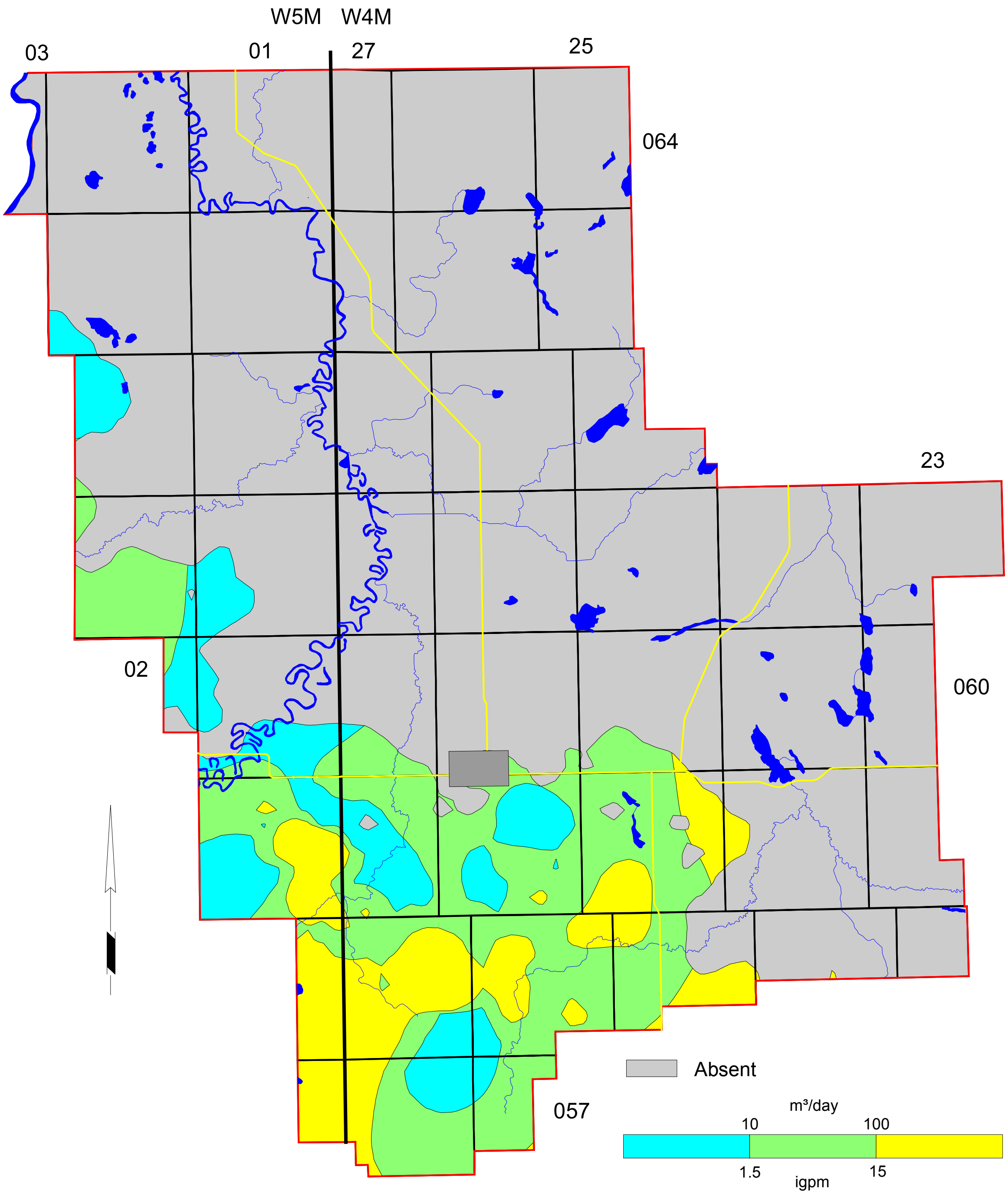
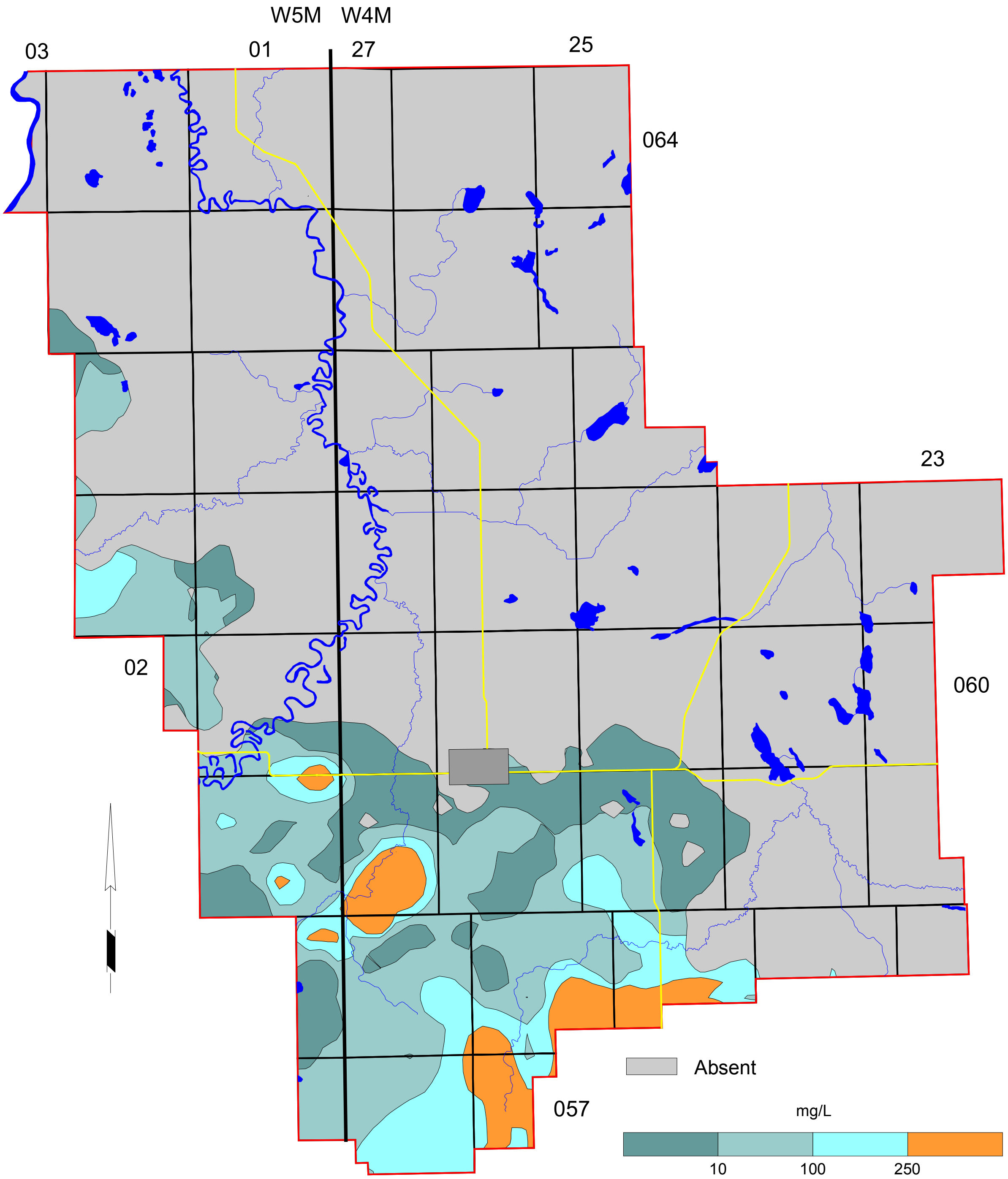
Depth to Top of Bearpaw Formation



Apparent Yield for Water Wells Completed through Bearpaw Aquifer



Chloride in Groundwater from Bearpaw Aquifer



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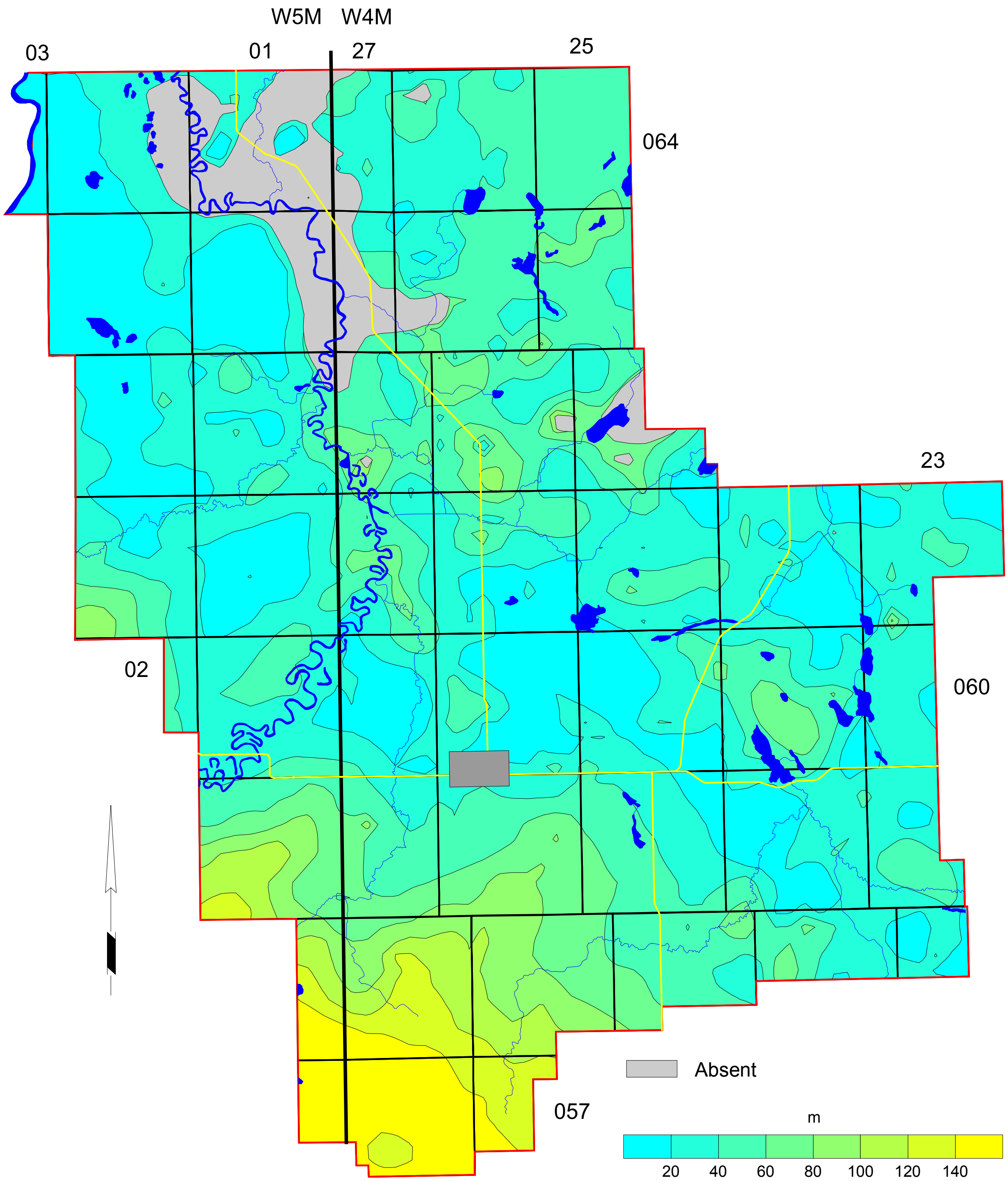
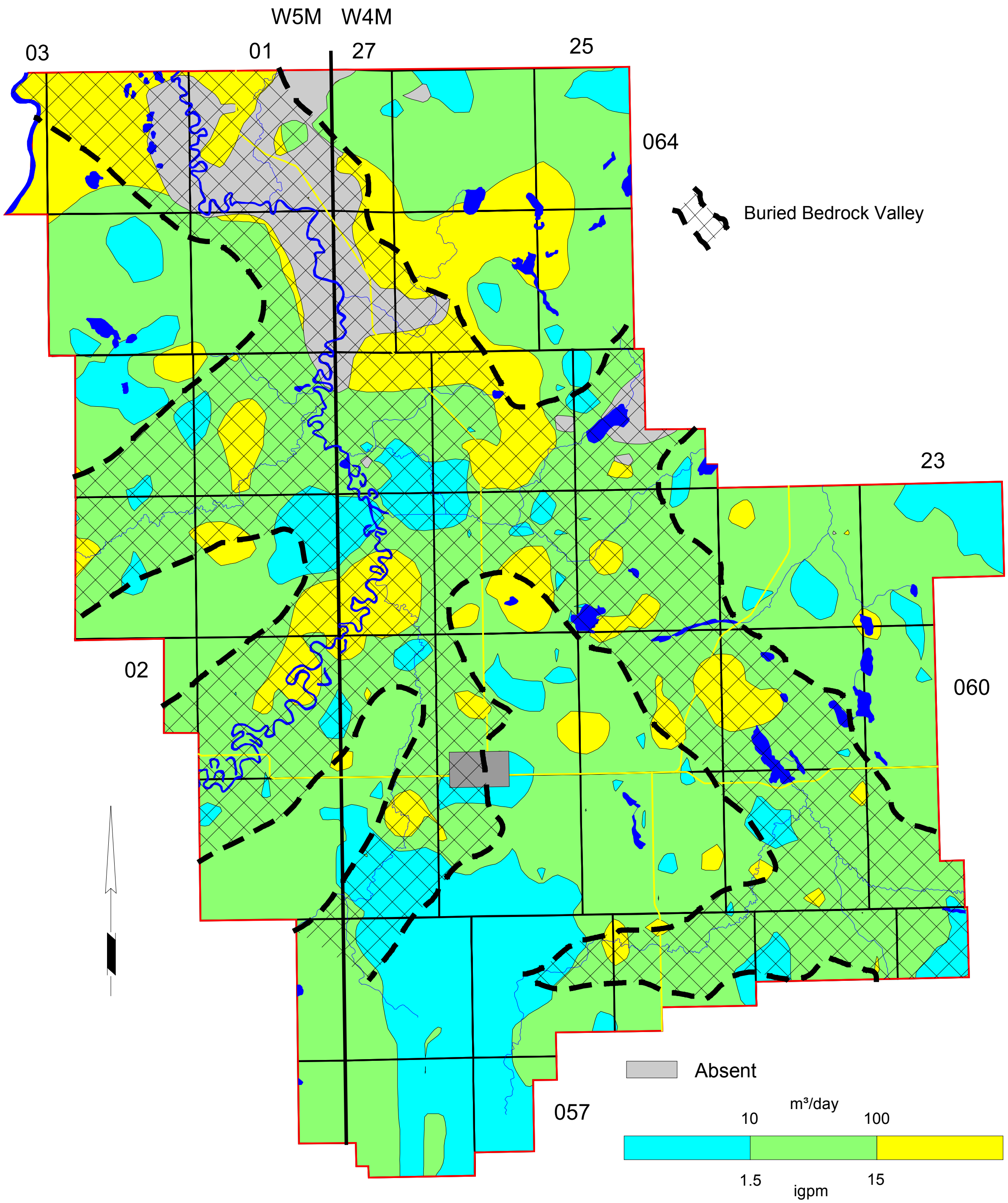
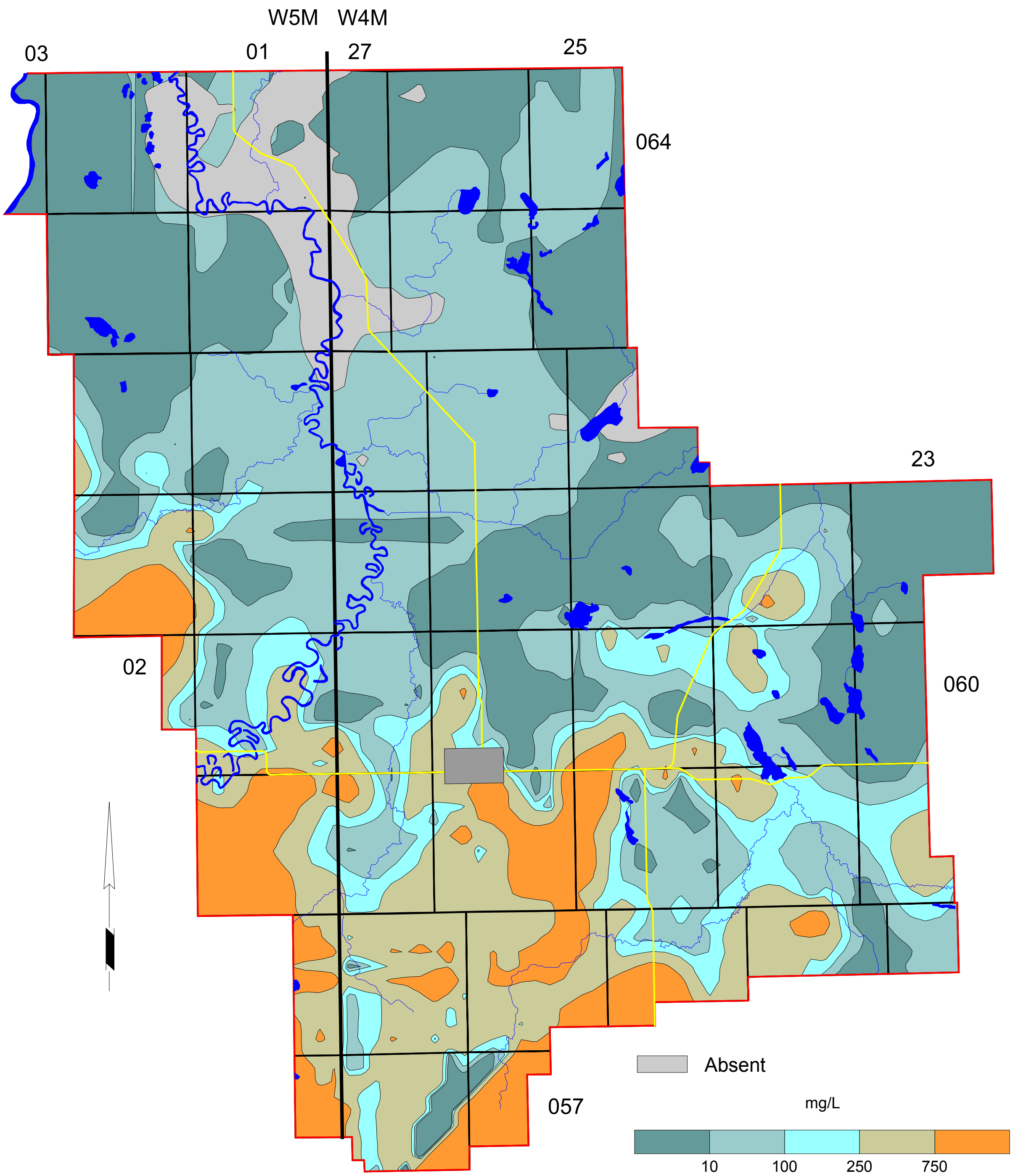


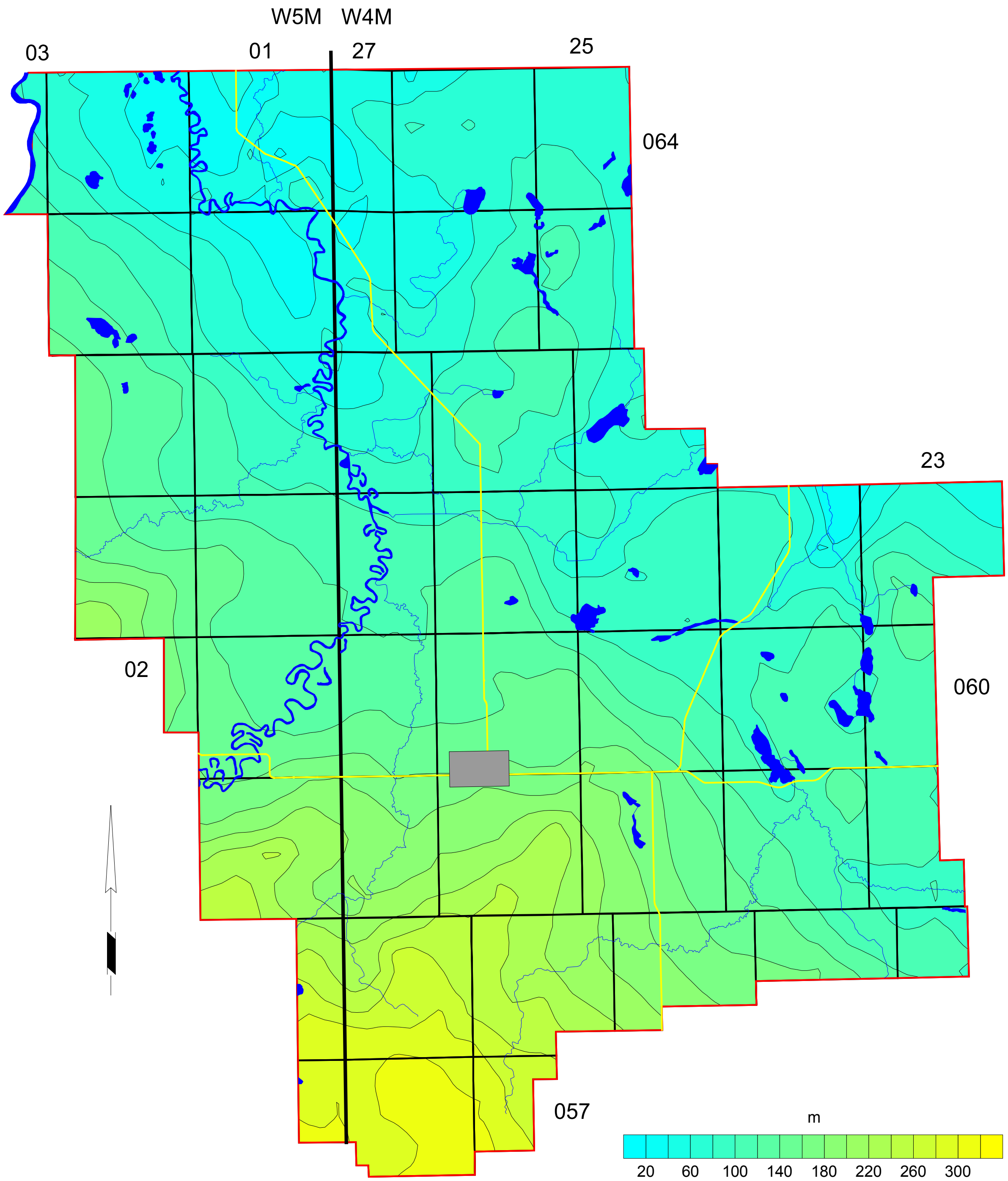
Apparent Yield for Water Wells Completed through Oldman Aquifer



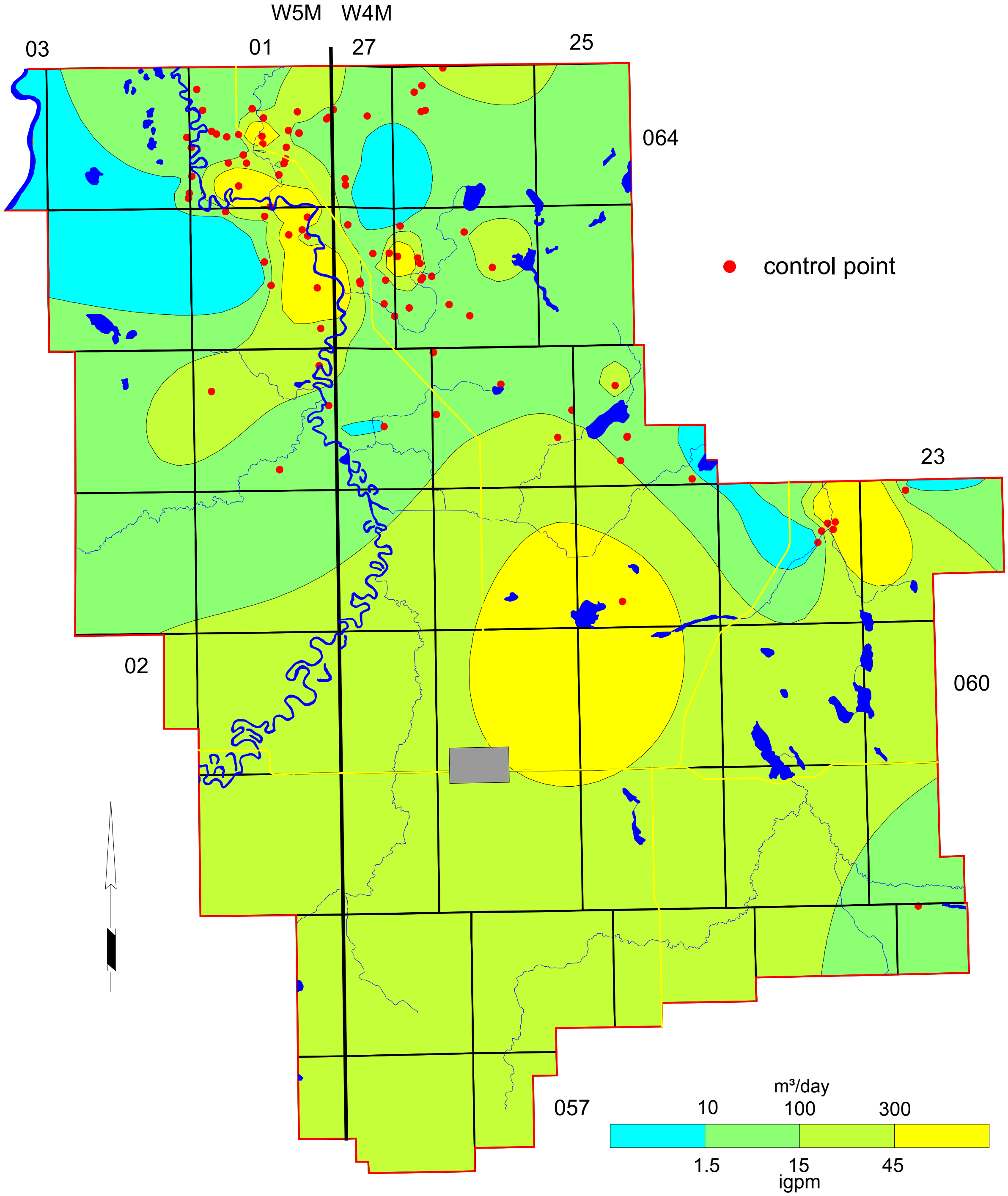
Chloride in Groundwater from Oldman Aquifer



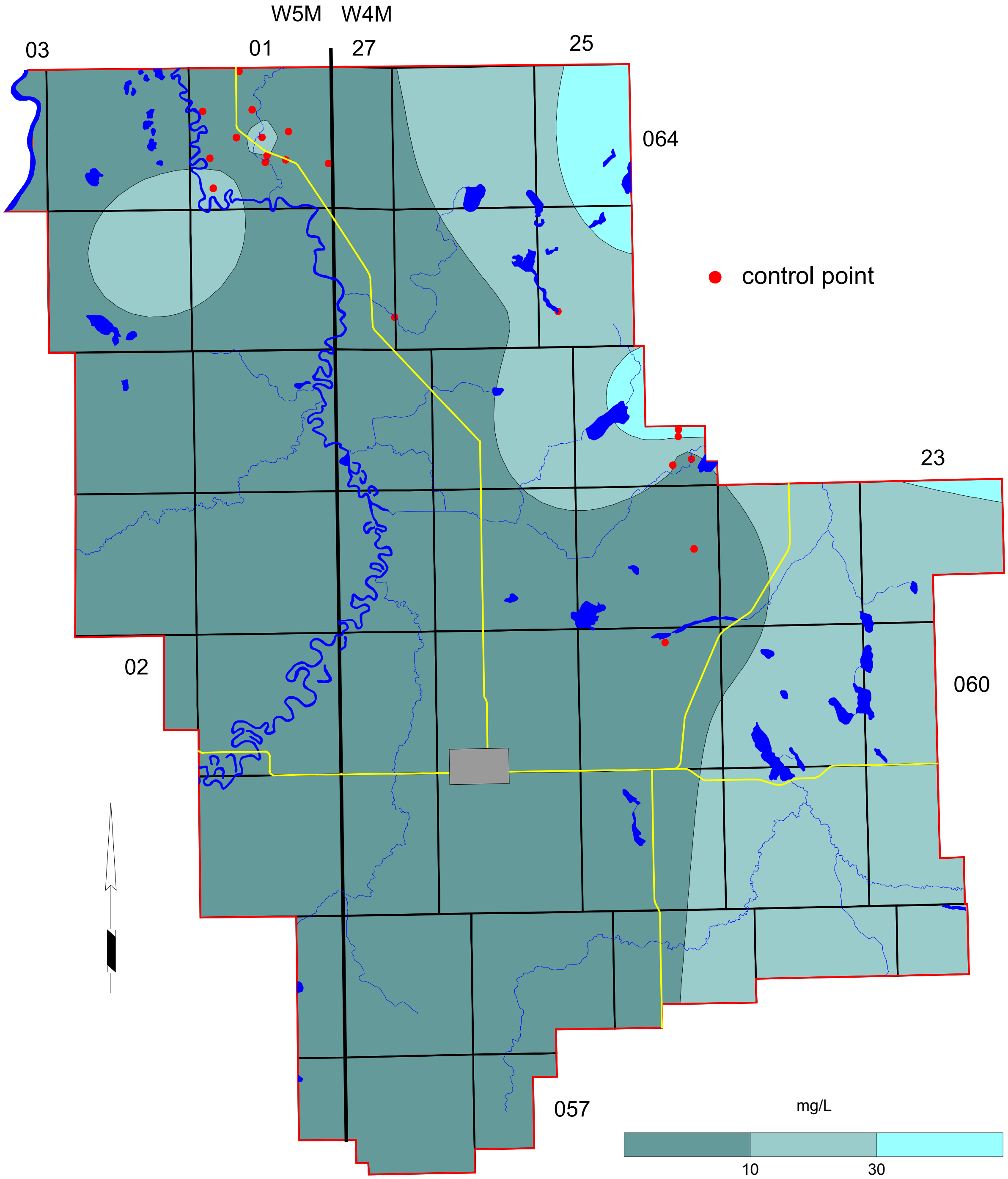
Depth to Top of Birch Lake Member



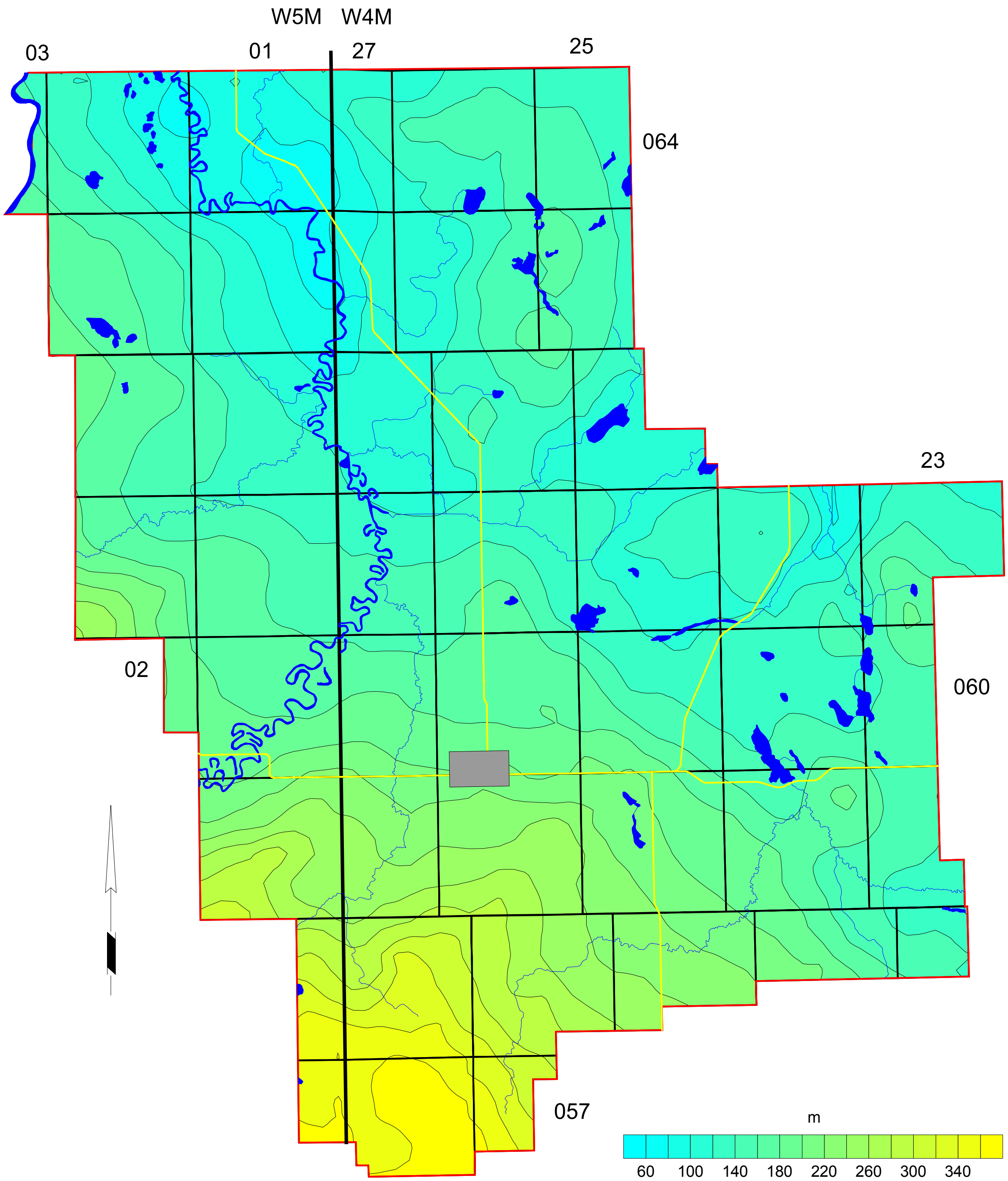
Apparent Yield for Water Wells Completed through Birch Lake Aquifer



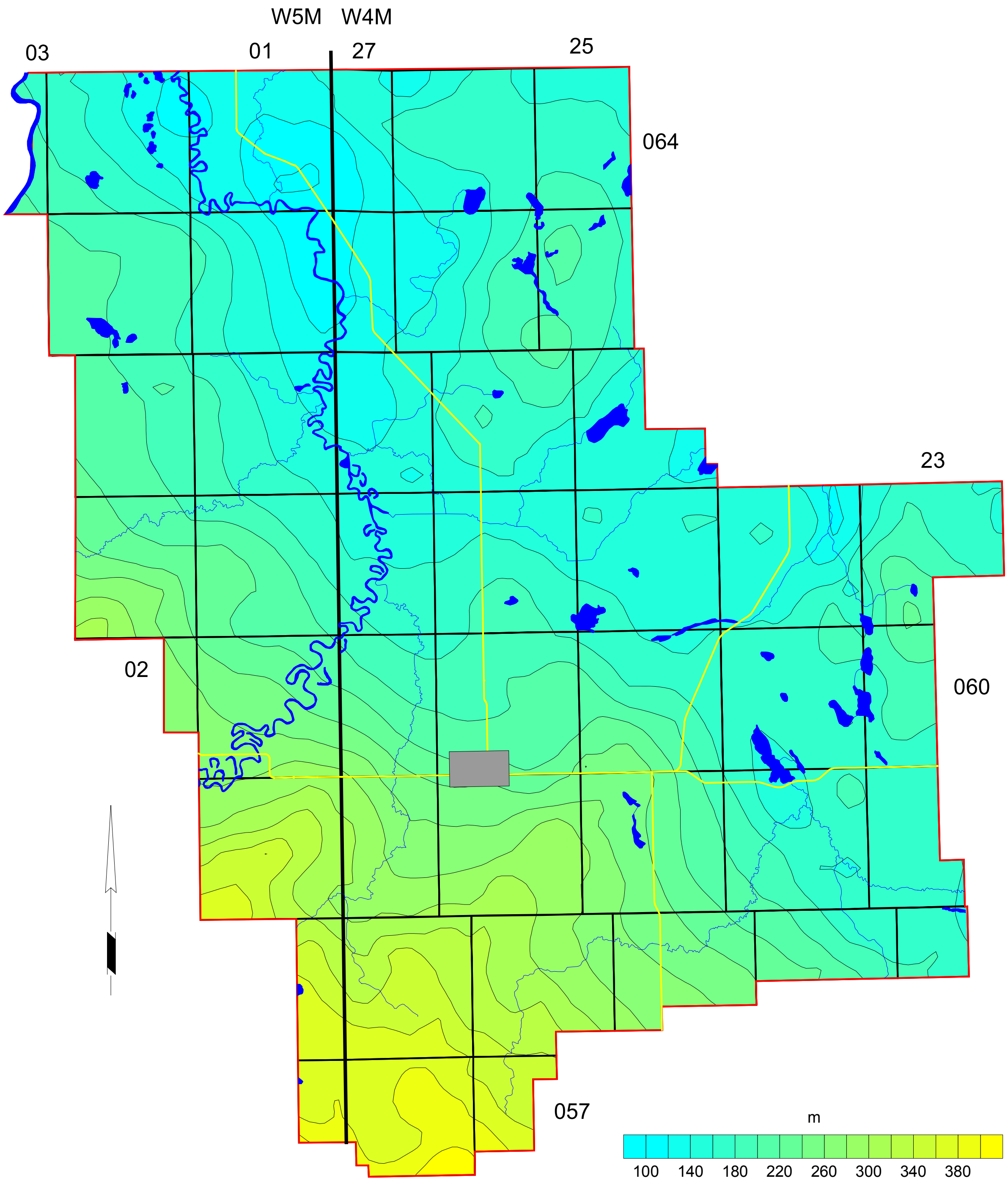
Chloride in Groundwater from Birch Lake Aquifer



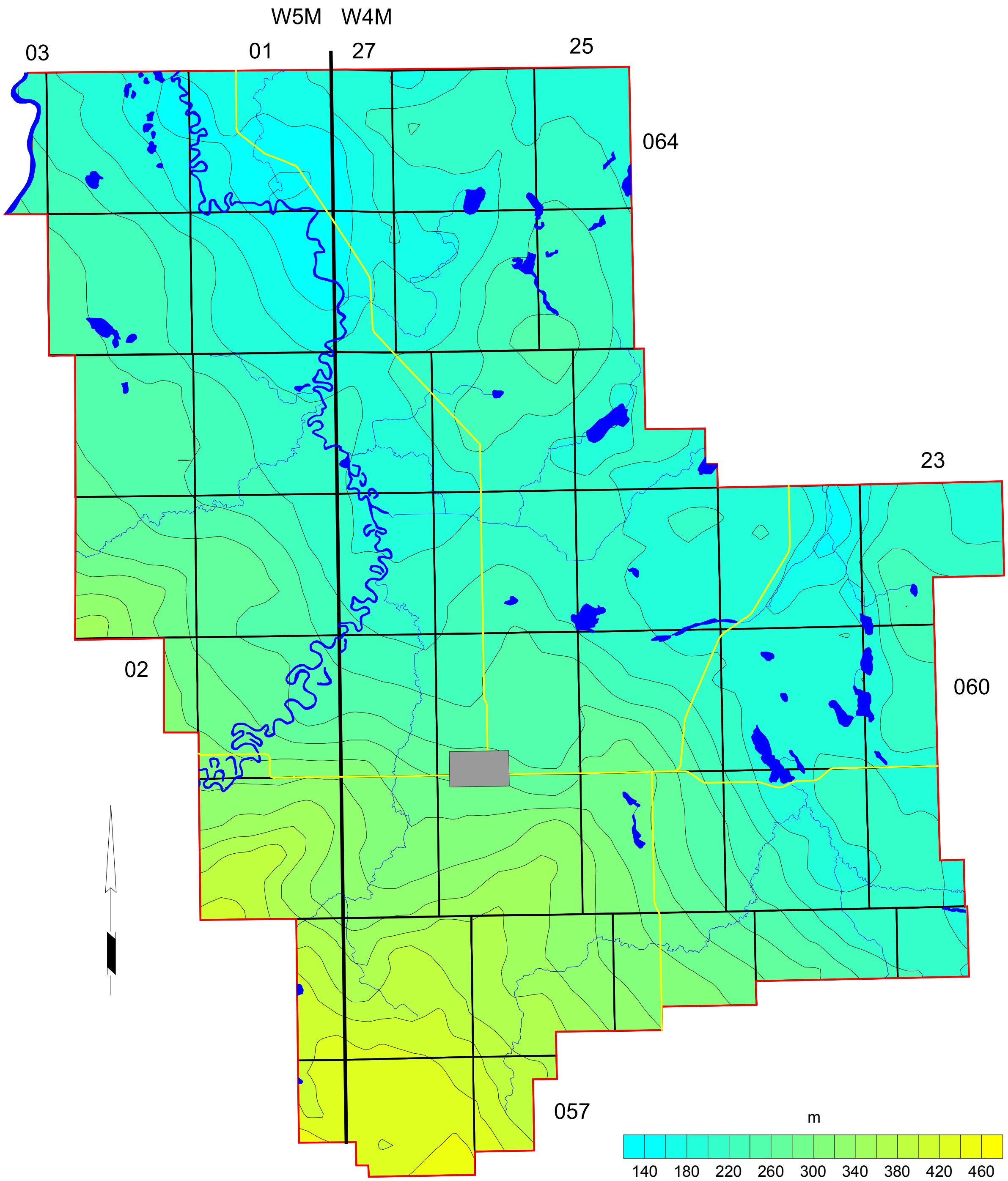
Depth to Top of Ribstone Creek Member



Depth to Top of Victoria Member



Depth to Top of Brosseau Member



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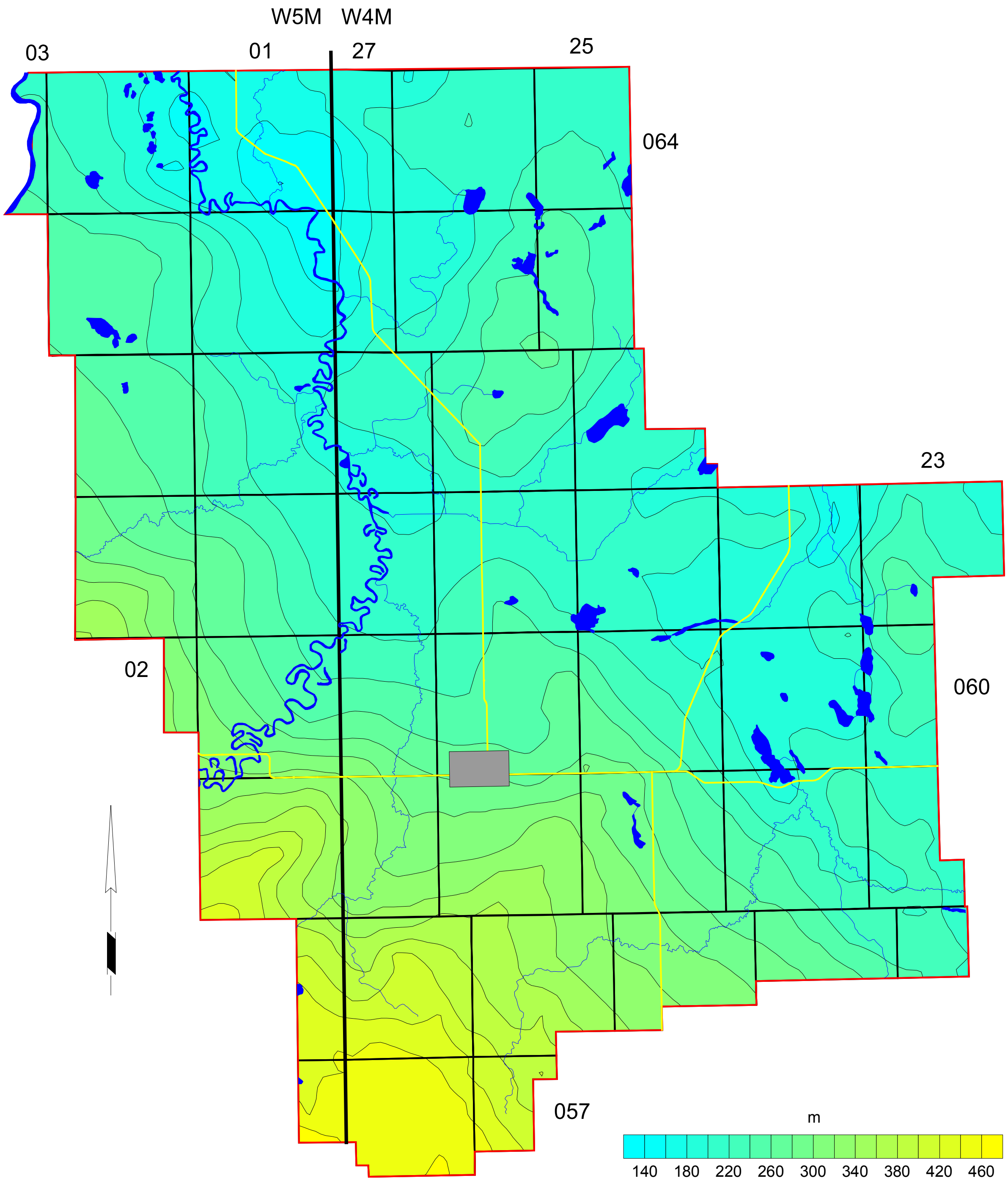
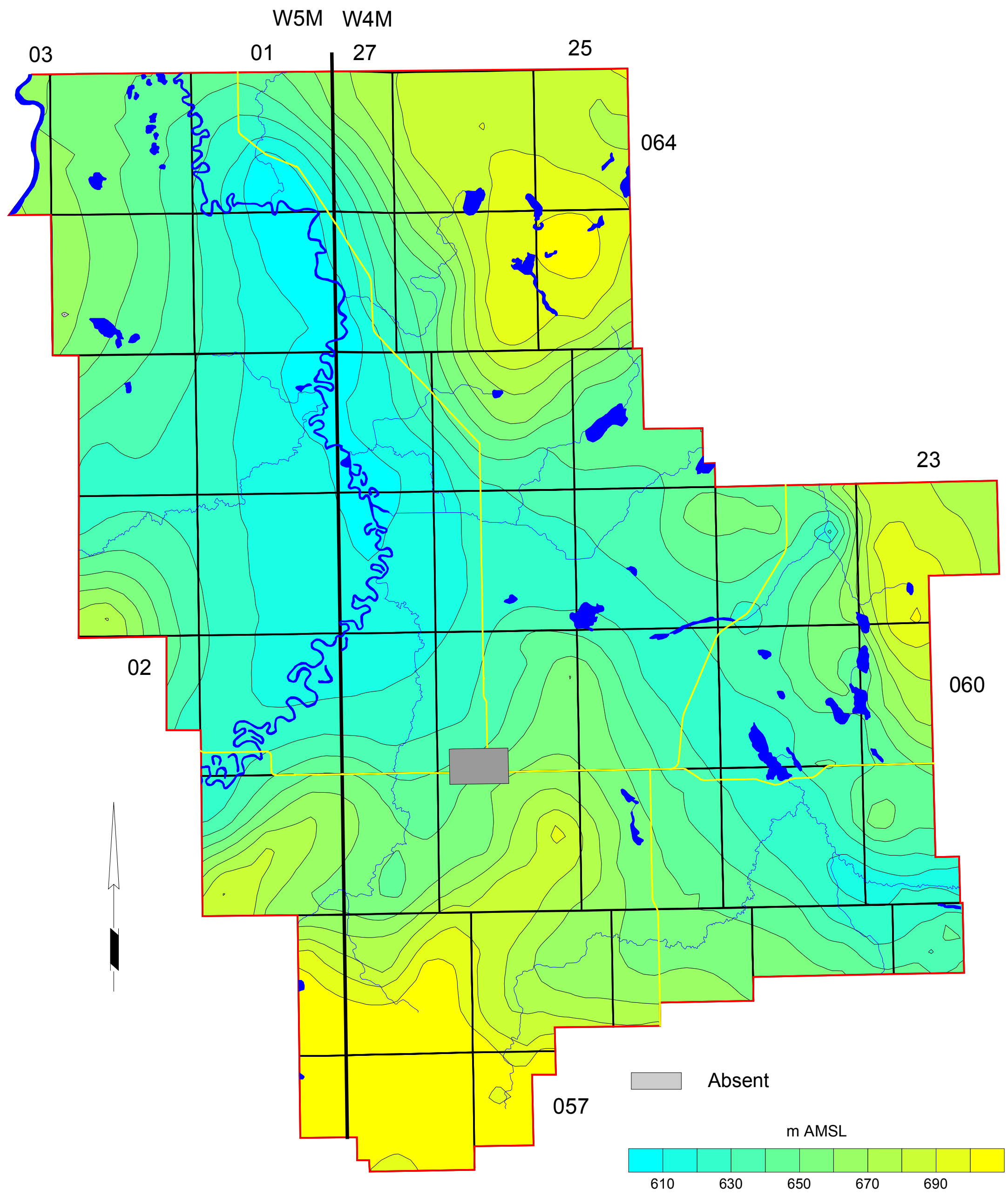
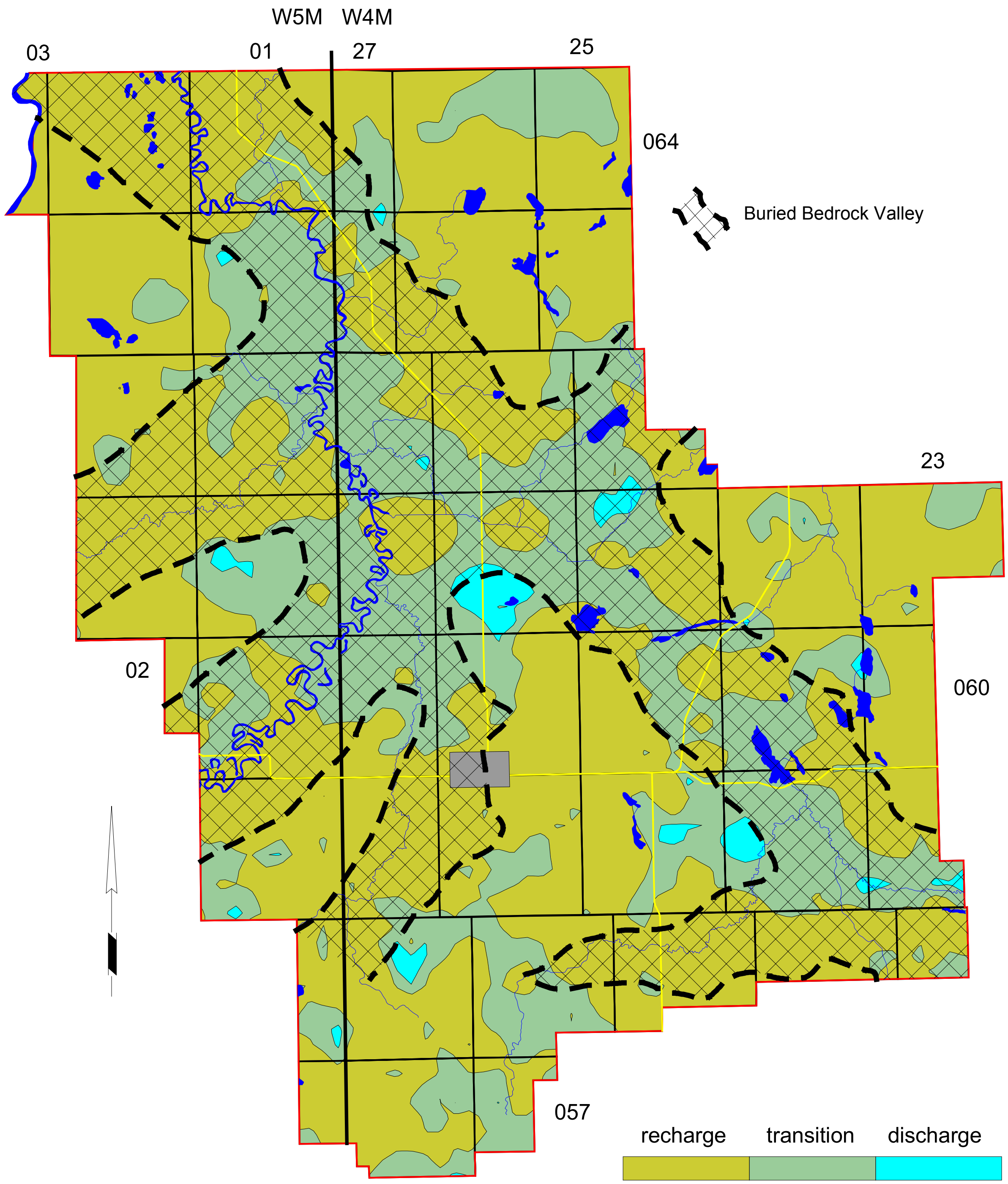


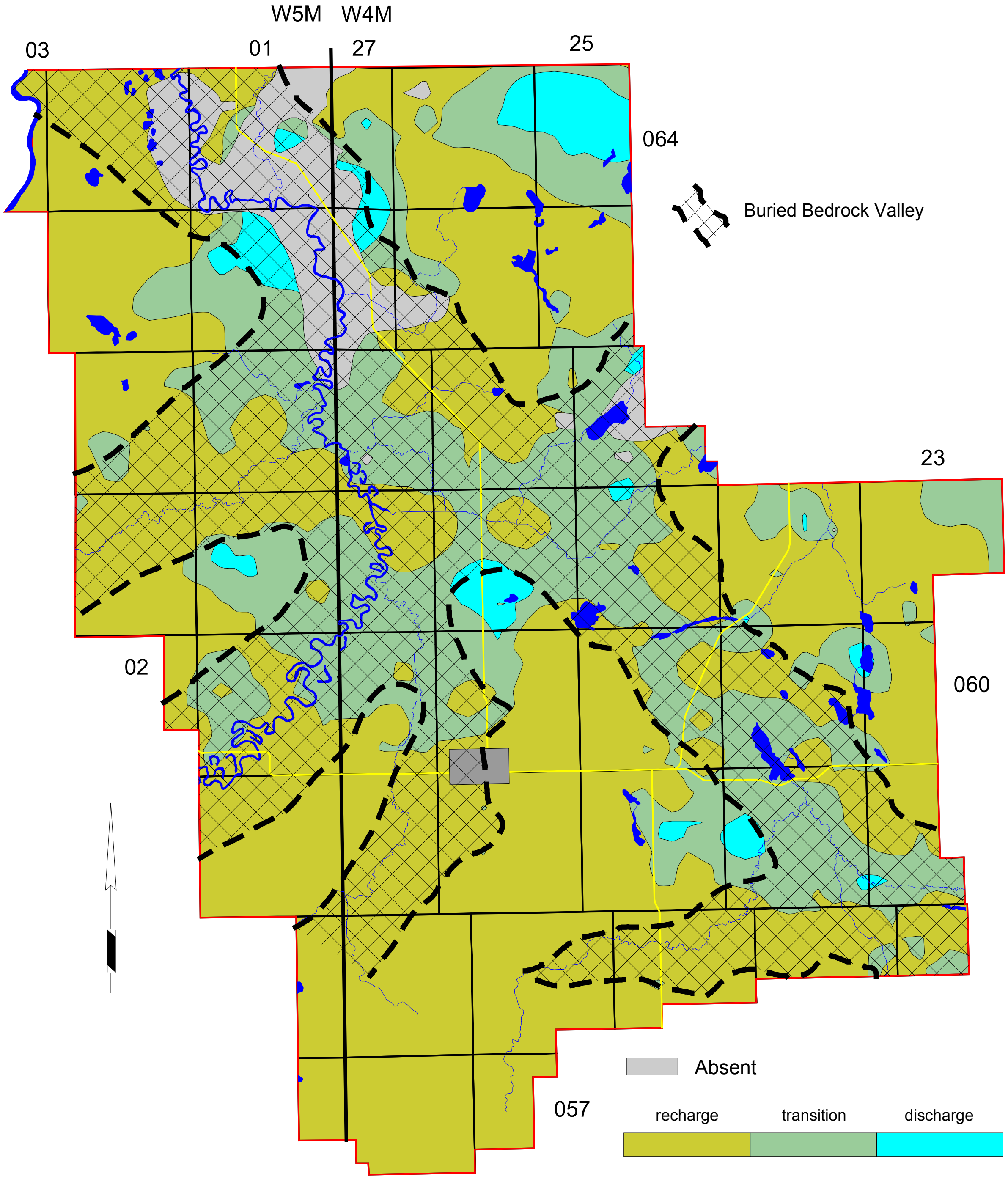
Non-Pumping Water-Level Surface in Surficial Deposits Based on Water Wells Less than 20 Metres Deep



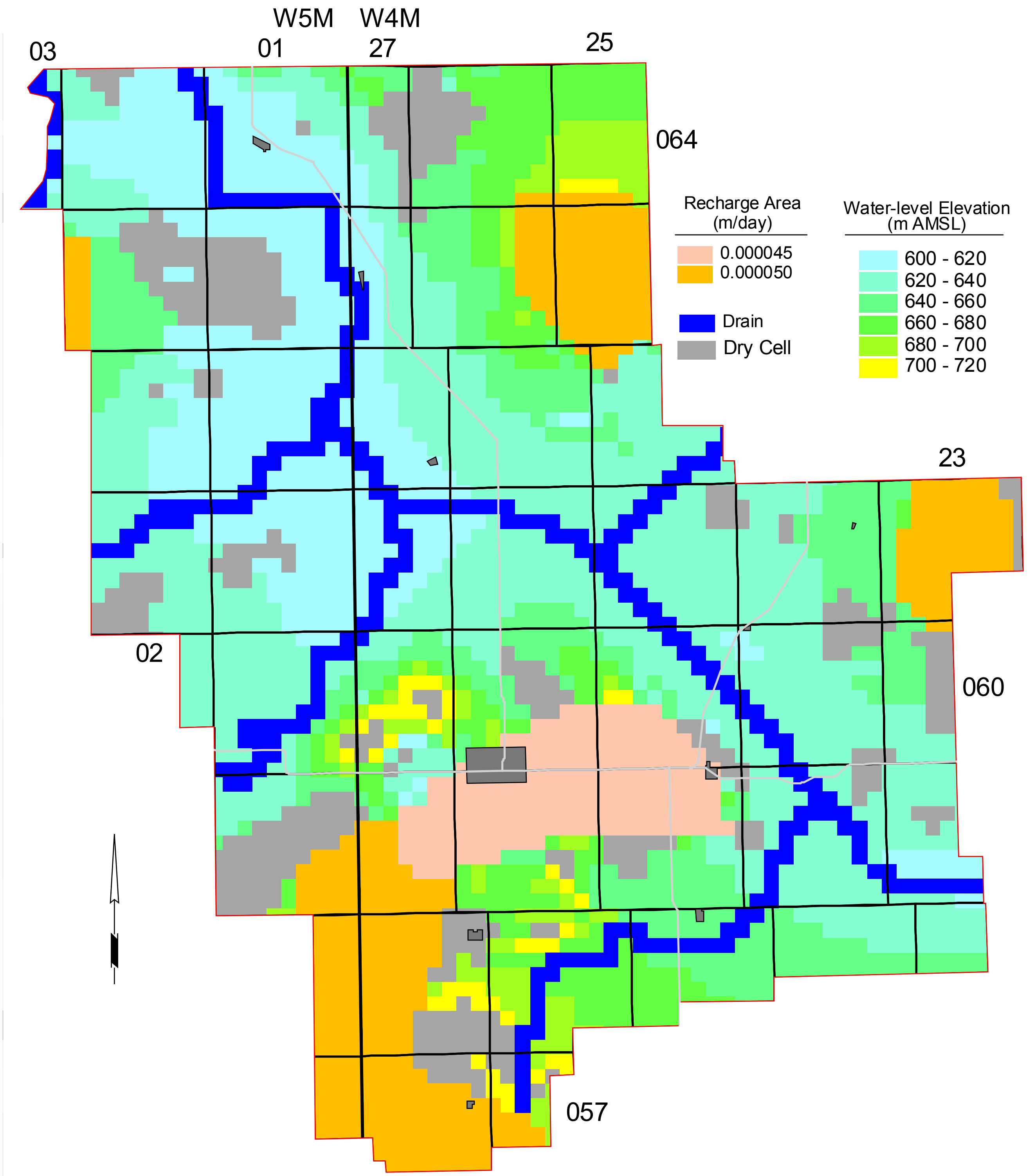
Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)



Recharge/Discharge Areas between Surficial Deposits and Oldman Aquifer



Modelled Non-Pumping Water-Level Surface in Surficial Deposits



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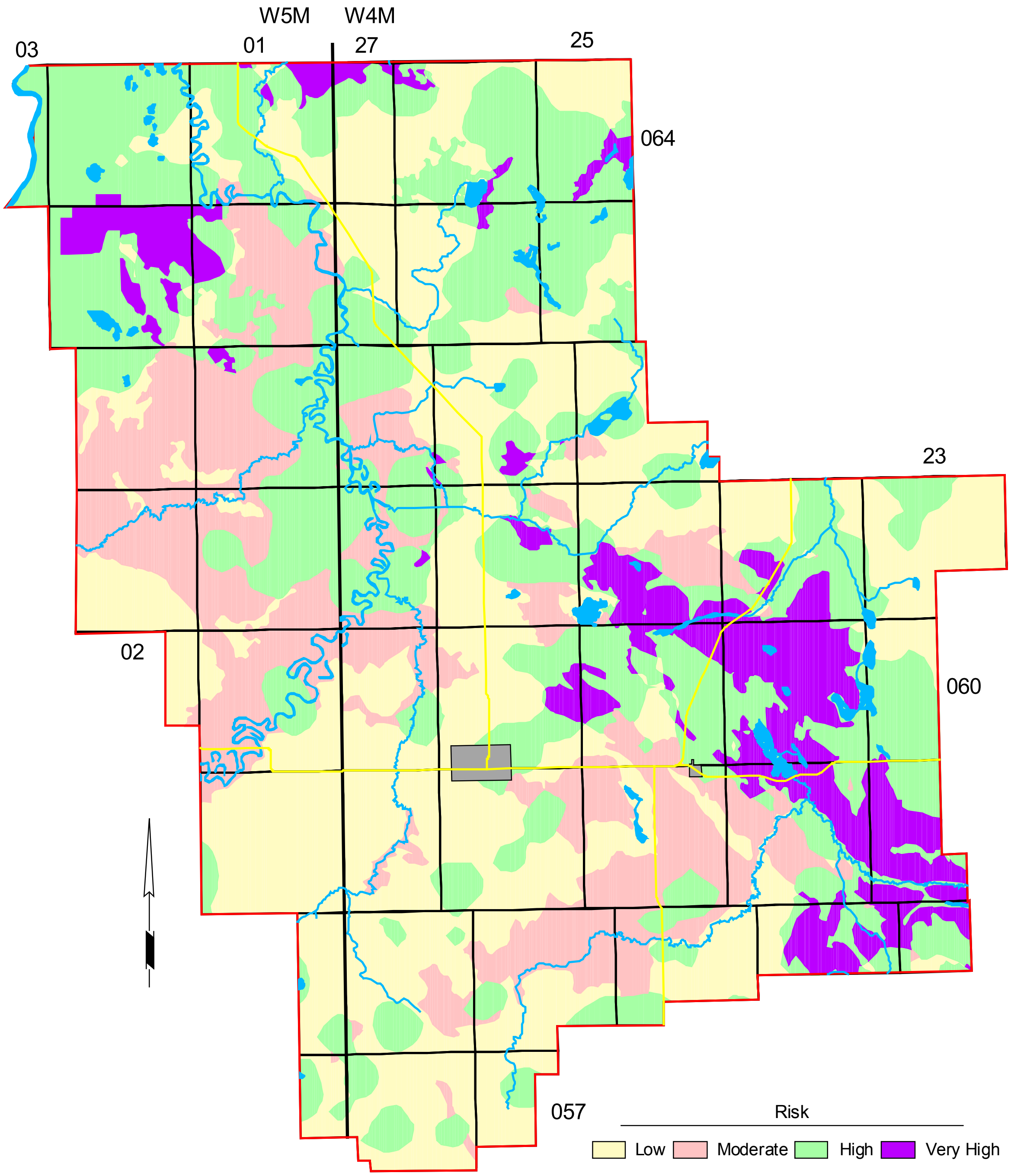
Risk of Groundwater Contamination



WESTLOCK COUNTY

Appendix B

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WESTLOCK COUNTY
Appendix C

General Water Well Information

Domestic Water Well Testing

Purpose and Requirements

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

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

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

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

During the pumping and recovery intervals, the water level is to be measured at the appropriate times. An example of the time schedule for a four-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.

Water Act - Water (Ministerial) Regulation

PROVINCE OF ALBERTA

WATER ACT

WATER (MINISTERIAL) REGULATION

Alberta Regulation 205/98

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Water Act

WATER (MINISTERIAL) REGULATION

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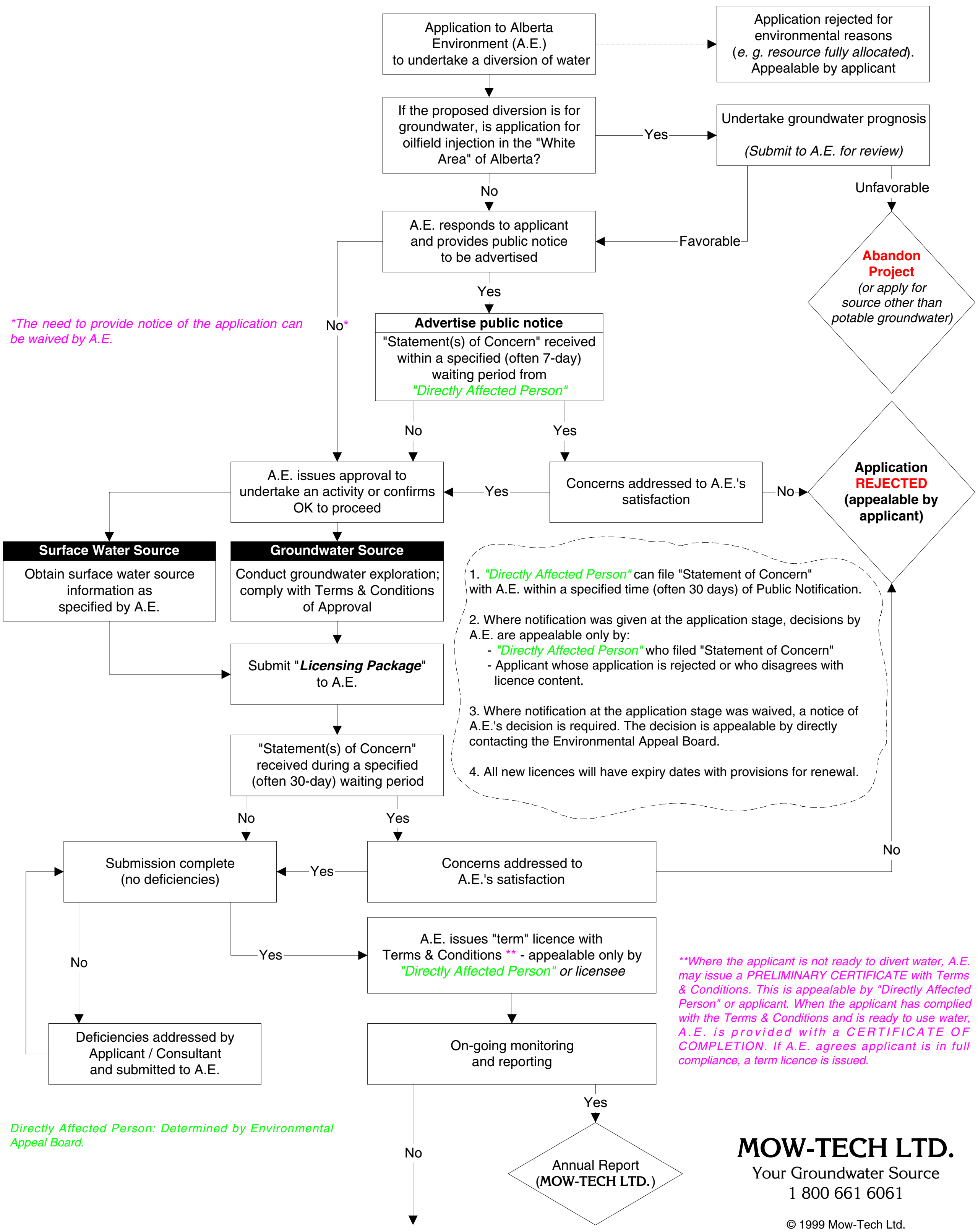

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*This flow chart was developed by Mow-Tech Ltd. and is provided as a guide **only** to Alberta's new **Water Act**. Mow-Tech Ltd. accepts no responsibility for the information provided.*

Additional Information

VIDEOS

Will the Well Go Dry Tomorrow? (Mow-Tech Ltd.: 1-800 GEO WELL)
Water Wells that Last (PFRA – Edmonton Office: 780-495-3307)
Ground Water and the Rural Community (Ontario Ground Water Association)

BOOKLET

Water Wells that Last (PFRA – Edmonton Office: 780-495-3307)

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Colin Samis (Lac La Biche: 780-623-5235)

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Edmonton: 780-427-3932

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Carl Mendosa (Edmonton: 780-492-2664)

UNIVERSITY OF CALGARY – Department of Geology and Geophysics - Hydrogeology

Larry Bentley (Calgary: 780-220-4512)

FARMERS ADVOCATE

Paul Vasseur (Edmonton: 780-427-2433)

PRAIRIE FARM REHABILITATION ADMINISTRATION

Curtis Snell (Westlock: 780-349-3963)

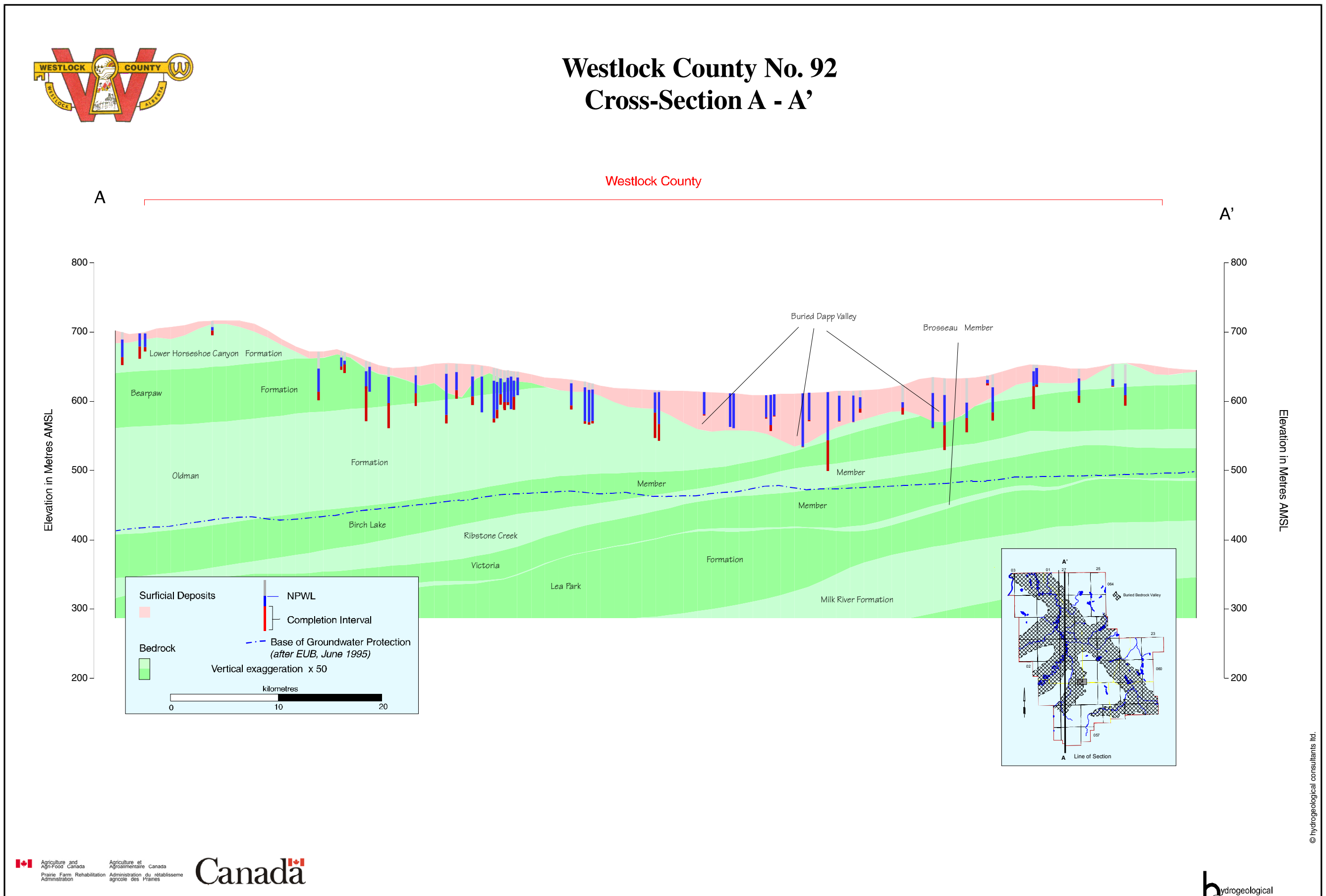
LOCAL HEALTH DEPARTMENTS

WESTLOCK COUNTY

Appendix D

Maps and Figures Included as Large Plots

Cross-Section A - A'



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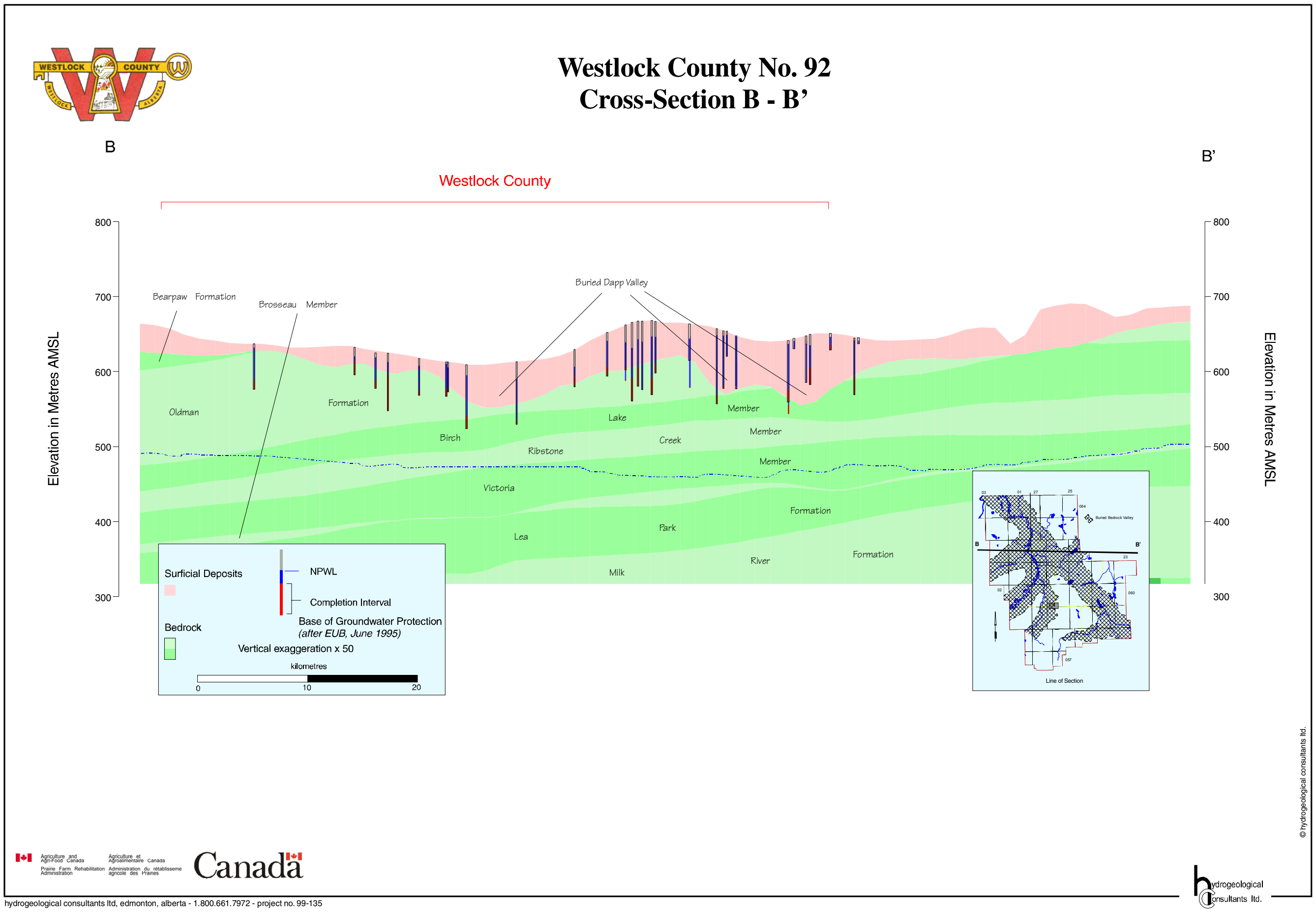
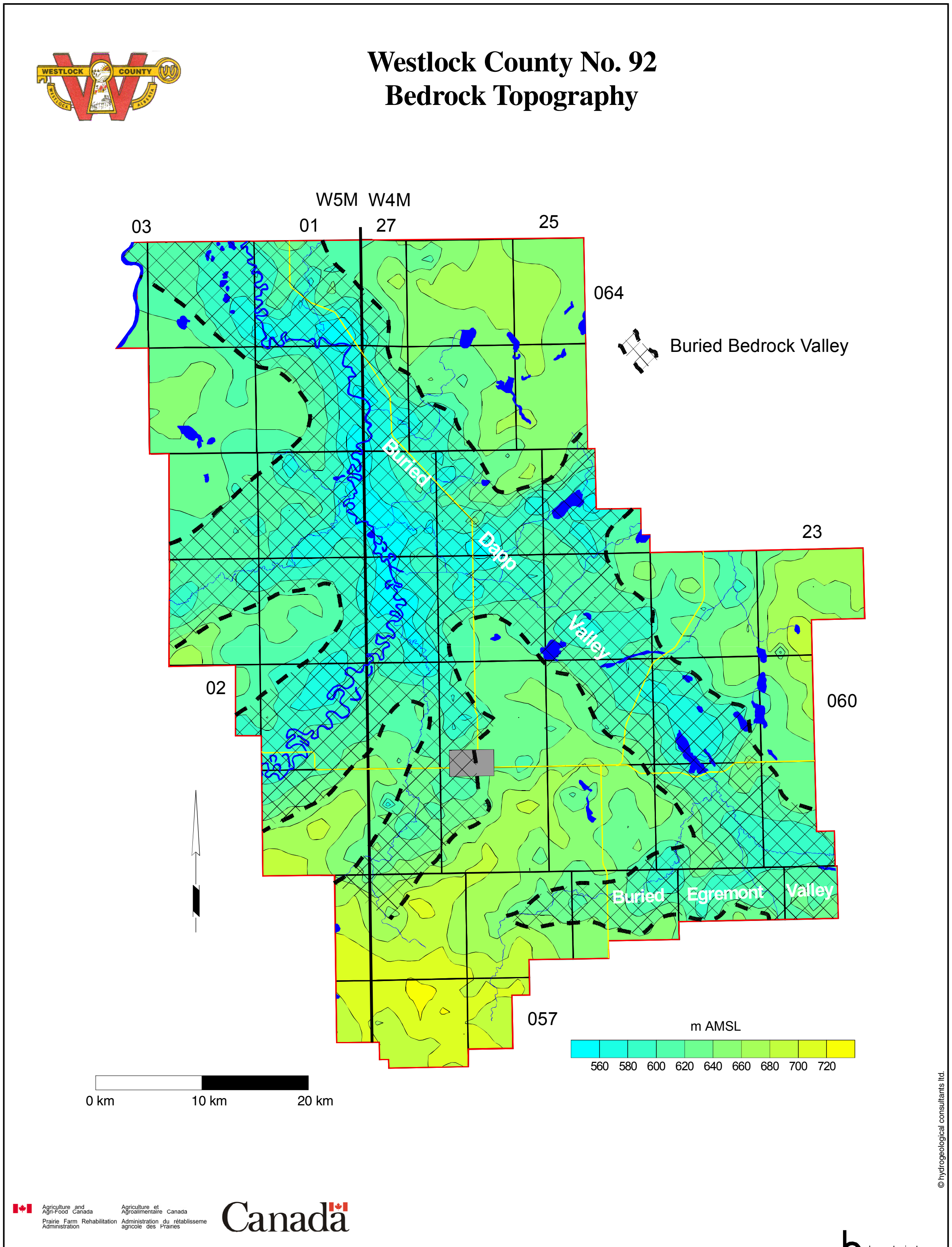
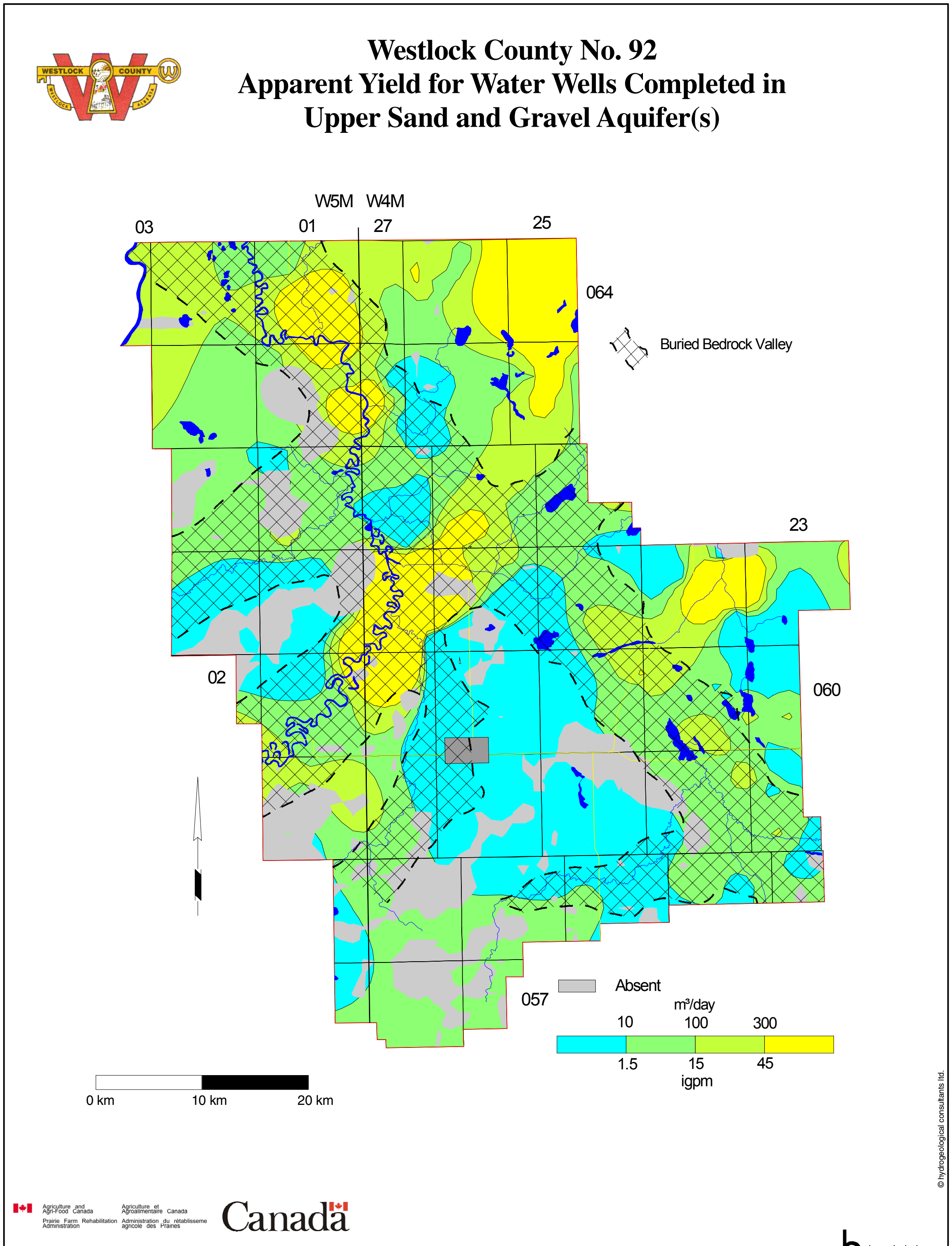
Cross-Section B - B'



Bedrock Topography



Apparent Yield for Water Wells Completed in Surficial Aquifer(s)



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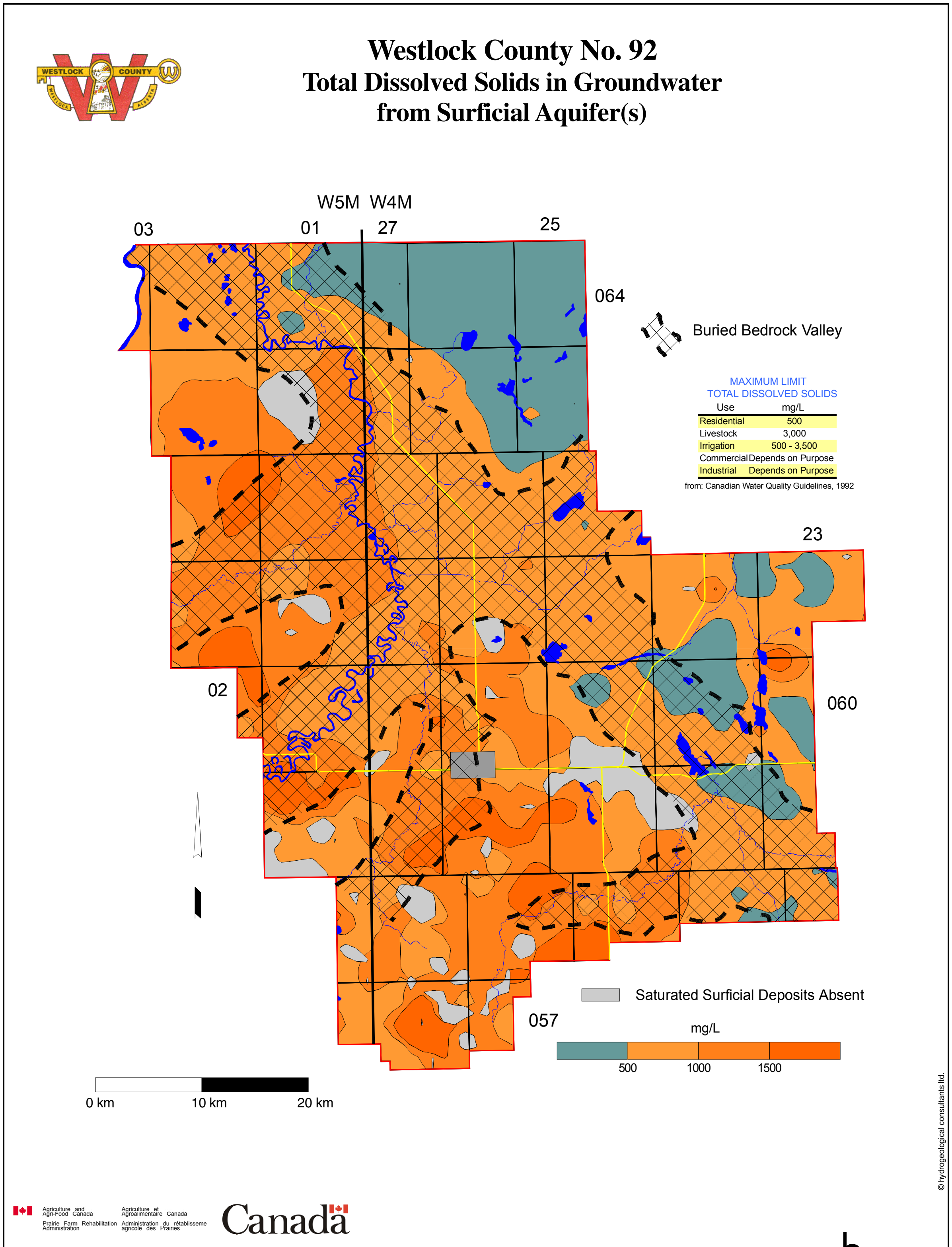
Total Dissolved Solids in Groundwater from Surficial Aquifer(s)



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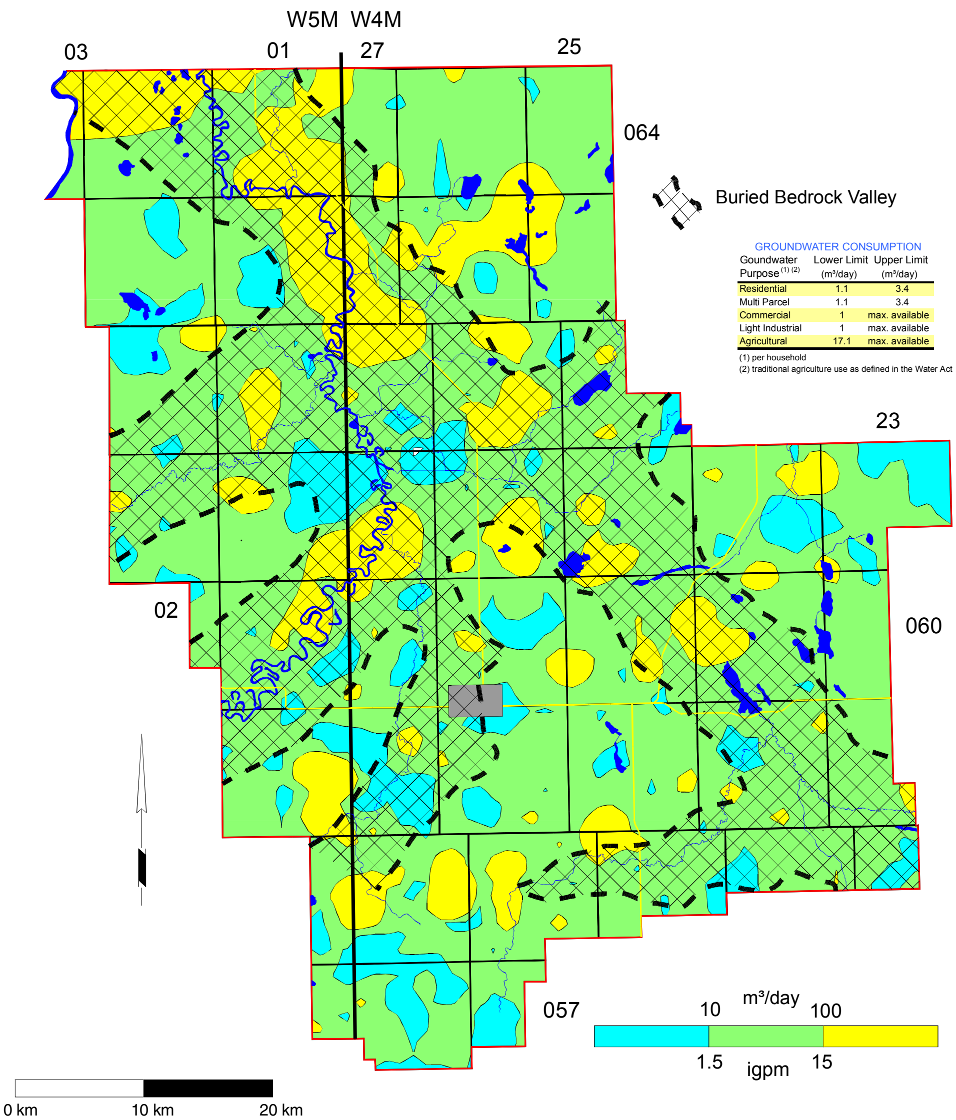
Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)

Westlock County No. 92

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



GROUNDWATER CONSUMPTION

Goundwater Purpose (1) (2)	Lower Limit (m^3/day)	Upper Limit (m^3/day)
Residential	1.1	3.4
Multi Parcel	1.1	3.4
Commercial	1	max. available
Light Industrial	1	max. available
Agricultural	17.1	max. available

(1) per household
(2) traditional agriculture use as defined in the Water Act

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

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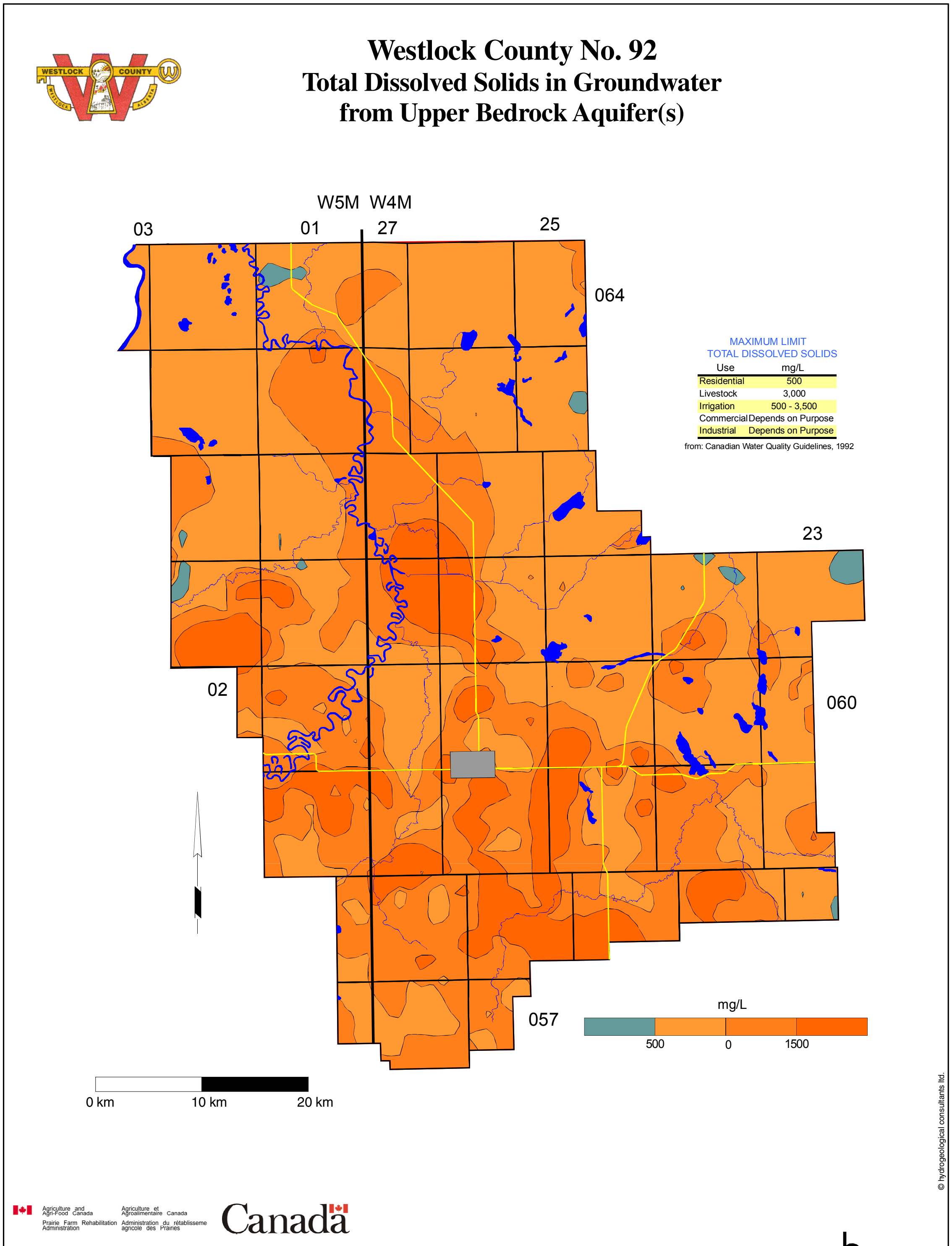
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)



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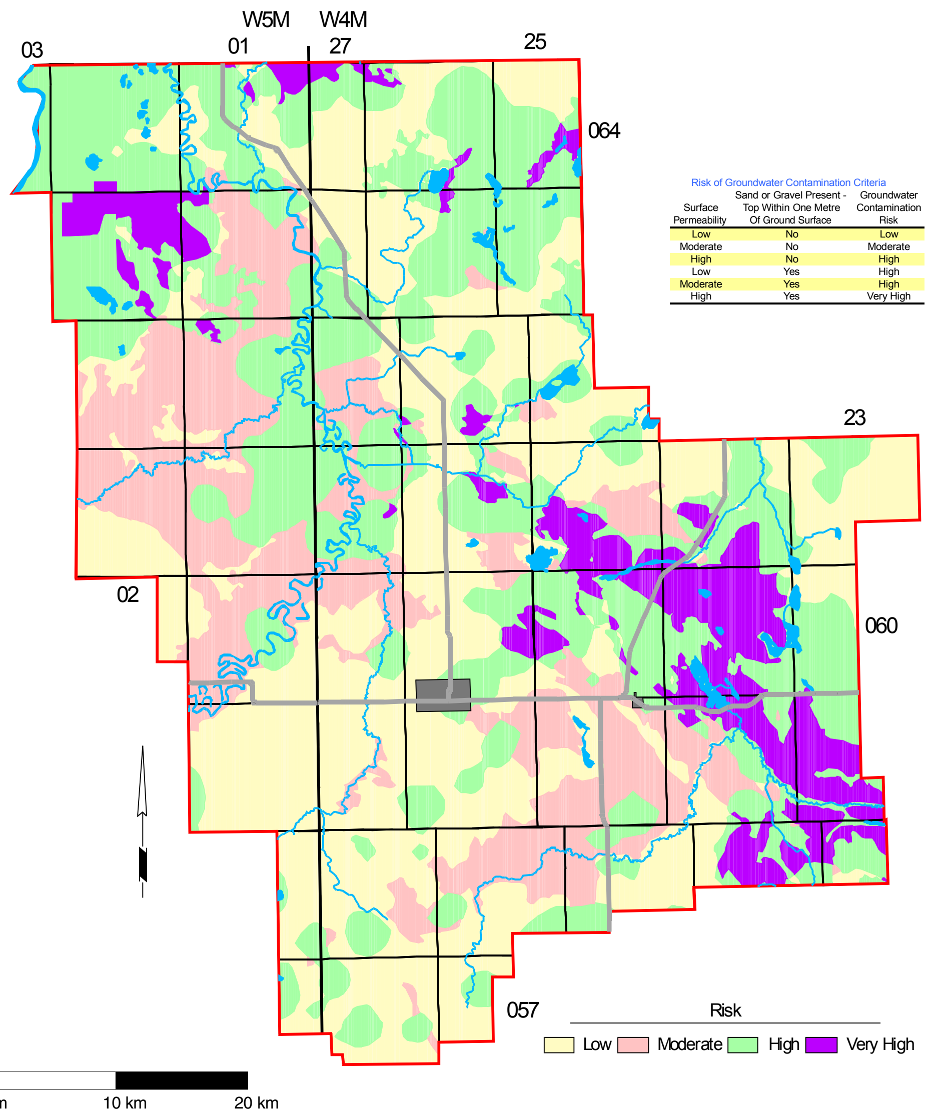
Risk of Groundwater Contamination

Westlock County No. 92
Risk of Groundwater Contamination



Risk of Groundwater Contamination 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

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

WESTLOCK COUNTY

Appendix E

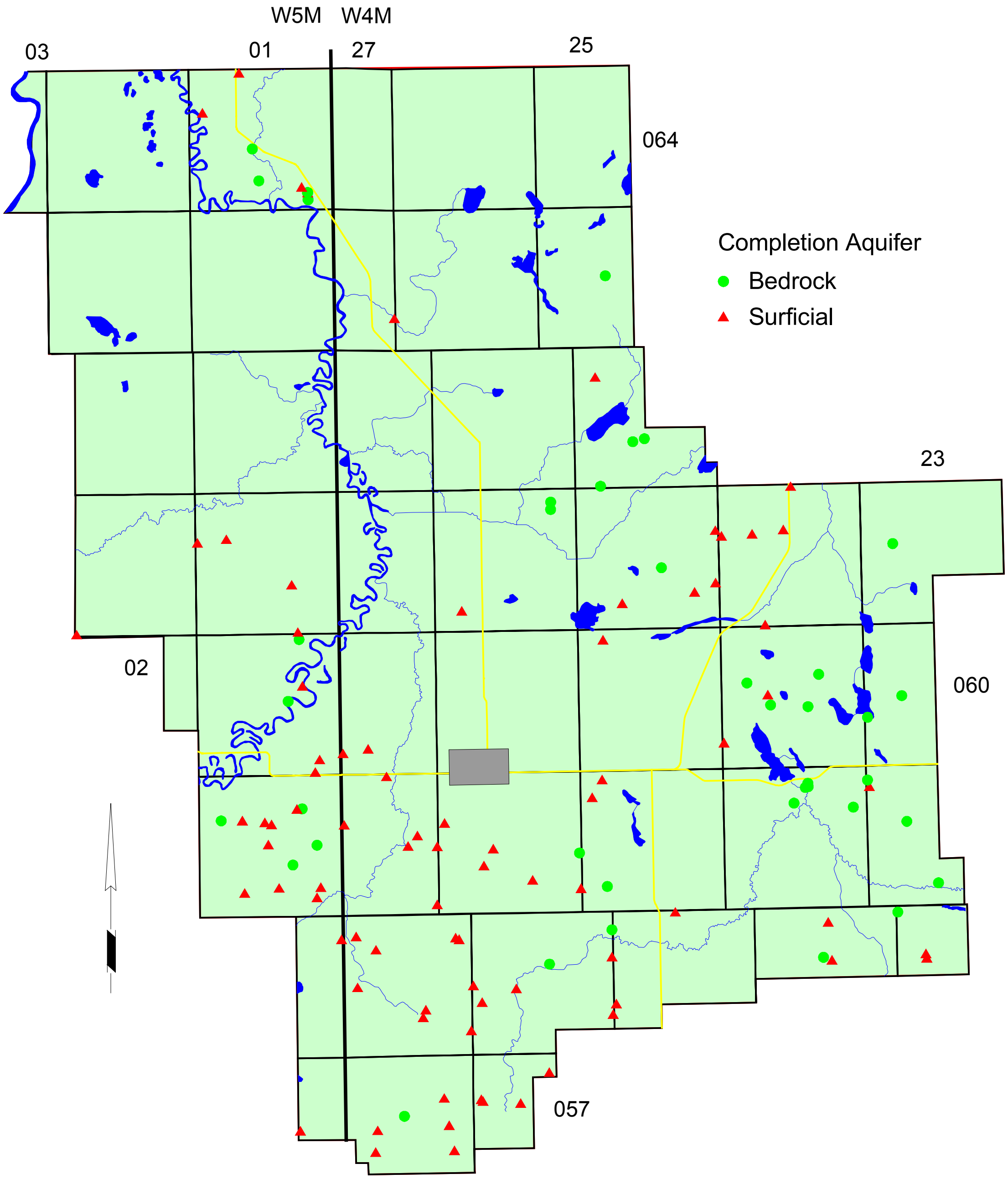
Water Wells Recommended for Field Verification

and

County – Operated Water Wells

Water Wells Recommended for Field Verification

(details on following pages)



WATER WELLS RECOMMENDED FOR FIELD VERIFICATION

Owner	Location	Aquifer Name	Date Water Well Drilled	Completed Depth Metres	Completed Depth Feet	NPWL Metres	NPWL Feet
Advanchura Holdings	13-22-059-01 W5M	Bearpaw	Nov-83	22.9	75.0	6.1	20.0
Allers, Gordon	SE-17-059-26 W4M	Bearpaw	Jan-78	30.5	100.0	15.2	50.0
Anderson, O.	01-16-062-25 W4M	Upper Surficial	Jun-85	62.5	205.0	10.7	35.0
Baker, David	SE-23-059-01 W5M	Upper Surficial	May-83	18.9	62.0	7.3	24.0
Balascak, Steve	SE-28-061-24 W4M	Oldman	Oct-78	25.9	85.0	35.7	117.0
Berry, Ken	SW-34-059-24 W4M	Upper Surficial	Sep-86	10.4	34.0	1.2	4.0
Breault, R.	NW-16-059-26 W4M	Bearpaw	May-76	43.3	142.0	9.5	31.0
Brown, Earl	SW-18-058-25 W4M	Bearpaw	Sep-86	61.0	200.0	24.4	80.0
Brown, Gordon	NE-34-059-27 W4M	Oldman	Sep-84	67.1	220.0	11.6	38.0
Burns, B.	NE-17-058-26 W4M	Bearpaw	Jun-82	28.0	92.0	14.6	48.0
Byvank, Ken	SE-28-059-01 W5M	Bearpaw	Jan-78	21.3	70.0	12.2	40.0
Callaghan, Geo	SE-30-064-01 W5M	Birch Lake	Oct-79	36.6	120.0	12.2	40.0
Cameron, Dorothy	NW-21-059-27 W4M	Bearpaw	Jan-83	30.5	100.0	10.7	35.0
Chiovelli, A.	NE-15-060-24 W4M	Upper Surficial	Aug-81	8.5	28.0	20.7	68.0
Clark, Zane	SW-24-059-27 W4M	Oldman	Jan-75	77.7	255.0	16.8	55.0
Clausen, Eric	SE-02-060-01 W5M	Oldman	Nov-86	85.3	280.0	30.5	100.0
County of Westlock	15-33-058-25 W4M	Oldman	Jun-84	79.2	260.0	22.9	75.0
County of Westlock	13-05-061-26 W4M	Oldman	Nov-80	68.3	224.0	8.8	28.9
Dobson, Brian	NW-31-058-23 W4M	Upper Surficial	Aug-73	9.8	32.0	4.9	16.0
Dul, Ted	08-02-064-01 W5M	Upper Surficial	Apr-83	35.7	117.0	9.5	31.2
Dundas, Wayne	12-14-057-01 W5M	Lower Horseshoe Canyon	Jun-85	41.2	135.0	16.8	55.0
Dusseault, George	SE-36-058-26 W4M	Upper Surficial	Mar-84	30.5	100.0	4.6	15.0
Dzivinski, Dave	16-12-061-25 W4M	Oldman	Feb-84	47.2	155.0	4.9	16.0
Empson, Robert	13-04-060-27 W4M	Oldman	Apr-81	77.7	255.0	22.9	75.0
Erdmann, Ron	16-04-059-23 W4M	Upper Surficial	Aug-85	19.5	64.0	9.5	31.0
Famco Holdings Ltd.	NW-20-058-23 W4M	Oldman	Mar-79	38.4	126.0	7.9	26.0
Fauque, Jim	SE-09-064-01 W5M	Upper Surficial	Nov-80	19.2	63.0	14.3	47.0
Fedorvich, George	SW-22-057-27 W4M	Upper Surficial	Nov-79	7.3	24.0	1.5	5.0
Fesyk, John	NE-17-057-27 W4M	Lower Horseshoe Canyon	Aug-73	36.6	120.0	4.6	15.0
Fesyk, John	NE-08-057-27 W4M	Lower Horseshoe Canyon	Jun-82	39.0	128.0	2.4	8.0
French, J./Louis/Davis, Darrel	04-32-058-27 W4M	Bearpaw	Aug-58	24.4	80.0	3.1	10.0
Gerun, Nick	01-25-061-25 W4M	Oldman	Apr-81	27.4	90.0	9.1	30.0
Goydar, Dave	NW-01-060-01 W5M	Oldman	Nov-81	54.9	180.0	12.8	42.0
Guest, George	SE-02-060-01 W5M	Oldman	Jul-55	95.1	312.0	13.7	45.0
Hadley, Allan	SE-08-059-01 W5M	Lower Horseshoe Canyon	Sep-78	13.7	45.0	3.7	12.0
Hansen, Jim	14-20-061-24 W4M	Oldman	Oct-69	45.7	150.0	15.2	50.0
Hess, Bill	04-31-059-23 W4M	Oldman	Jun-83	39.6	130.0	15.2	50.0
Hess, Joseph	SE-28-059-24 W4M	Upper Surficial	Aug-77	9.1	30.0	3.1	10.0
Hill, Roland	12-32-060-25 W4M	Oldman	Aug-81	22.9	75.0	3.1	10.0
Hillgardner, Stanley	SE-08-061-25 W4M	Oldman	Sep-80	57.9	190.0	3.7	12.0
Holmes, Ron	SE-34-059-24 W4M	Upper Surficial	Nov-81	19.8	65.0	6.1	20.0
Hunt, Ernie	NE-02-059-01 W5M	Bearpaw	Oct-77	24.4	80.0	1.8	6.0
James, Don	01-30-059-01 W5M	Upper Surficial	Jul-80	11.3	37.0	4.0	13.0
Jensen, Ham	SW-34-057-26 W4M	Lower Horseshoe Canyon	Sep-73	16.5	54.0	6.7	22.0

WATER WELLS RECOMMENDED FOR FIELD VERIFICATION

Owner	Location	Aquifer Name	Date Water Well Drilled	Completed Depth Metres	Completed Depth Feet	NPWL Metres	NPWL Feet
Kallal, Dave	10-20-059-23 W4M	Upper Surficial	Jun-78	6.7	22.0	4.3	14.0
Kallal, Terry	09-30-062-25 W4M	Oldman	Jun-81	59.4	195.0	21.3	70.0
Keyser, Ron	04-14-061-01 W5M	Oldman	Apr-82	32.0	105.0	6.1	20.0
Kinsella, Lyle	SE-29-059-01 W5M	Bearpaw	Aug-83	14.0	46.0	3.4	11.0
Kinsella, Lyle	SE-29-059-01 W5M	Bearpaw	Aug-83	18.0	59.0	3.4	11.0
Klimosko, Barry/Holland, Elain	NE-10-058-27 W4M	Lower Horseshoe Canyon	Aug-79	20.7	68.0	0.6	2.0
Kohlruss, Wm	12-16-060-24 W4M	Upper Surficial	Jun-78	62.5	205.0	9.1	30.0
Kosky, Martin	05-34-058-24 W4M	Oldman	Jun-79	94.5	310.0	13.4	44.0
Kushnieryk, Bill	04-05-062-25 W4M	Upper Surficial	Aug-69	34.8	114.0	5.5	18.0
Lambert, Emile	NE-13-059-26 W4M	Upper Surficial	May-75	30.5	100.0	12.2	40.0
Lanctot, R.	09-12-058-26 W4M	Bearpaw	Jun-82	31.1	102.0	5.5	18.0
Larsen, John	11-26-059-01 W5M	Upper Surficial	Aug-82	12.2	40.0	5.5	18.0
Laughy, James	09-02-064-01 W5M	Upper Surficial	Apr-83	33.2	109.0	11.5	37.7
Laughy, Jim	NE-02-064-01 W5M	Upper Surficial	Sep-78	7.3	24.0	3.7	12.0
Laughy, Jim	NE-02-064-01 W5M	Ribstone Creek	Feb-84	79.2	260.0	3.1	10.0
Lewicki, Morris	SE-21-063-25 W4M	Upper Surficial	Sep-86	18.3	60.0	8.7	28.5
Linaria Ag Society	13-19-061-01 W5M	Oldman	Nov-79	48.8	160.0	12.8	42.0
Logan, Tom	NE-20-057-26 W4M	Lower Horseshoe Canyon	Aug-67	35.1	115.0	2.4	8.0
Look, Gorden	01-06-061-02 W5M	Bearpaw	Aug-83	32.0	105.0	5.8	19.0
Luchka, Victor	SE-25-058-26 W4M	Bearpaw	Jun-86	58.8	193.0	6.1	20.0
Lynes, Daryl	09-11-061-25 W4M	Oldman	Aug-82	59.4	195.0	4.0	13.0
Lyons, Albert	04-10-060-27 W4M	Oldman	Sep-75	61.0	200.0	24.4	80.0
M.D. Westlock	10-16-064-01 W5M	Upper Surficial	Oct-86	64.9	213.0	12.5	41.0
Macintyre, David	15-14-059-27 W4M	Oldman	Aug-78	64.0	210.0	14.6	48.0
Macleod, Brian	01-35-061-26 W4M	Upper Surficial	Jul-81	16.8	55.0	0.6	2.0
Majeau, Paul	SE-21-059-01 W5M	Lower Horseshoe Canyon	Aug-75	25.9	85.0	19.8	65.0
Mandryk, William	NE-15-061-25 W4M	Upper Surficial	Jan-83	36.6	120.0	3.7	12.0
Marko, Mike	NE-31-059-25 W4M	Oldman	Oct-75	64.0	210.0	27.4	90.0
Mccoy, Alfred	13-23-060-24 W4M	Upper Surficial	Jul-81	5.8	19.0	4.0	13.0
Mcdonald, W.	NW-18-058-26 W4M	Lower Horseshoe Canyon	Aug-70	22.9	75.0	10.7	35.0
Mcnelly, Stewart	SW-25-059-24 W4M	Upper Surficial	May-83	51.5	169.0	36.6	120.0
Message, Alymer	SW-12-059-01 W5M	Bearpaw		28.0	92.0	3.1	10.0
Mirus, Carl	SE-23-057-27 W4M	Lower Horseshoe Canyon	May-80	19.2	63.0	1.8	6.0
Mowbray, Ralph	14-30-059-25 W4M	Oldman	Jul-86	85.3	280.0	27.4	90.0
Mt. Sinai Hermitage	01-05-061-24 W4M	Oldman	Aug-79	45.7	150.0	12.2	40.0
Myziuk, Michael	SE-10-059-26 W4M	Bearpaw	Feb-83	51.8	170.0	11.6	38.0
Nixon, William R.	16-13-059-27 W4M	Oldman	Feb-82	67.1	220.0	12.2	40.0
Norell, Glen/Verheul, Michael	01-12-058-27 W4M	Lower Horseshoe Canyon	Oct-81	24.4	80.0	7.9	26.0
Page, Raymond	NW-22-058-26 W4M	Upper Surficial	May-76	36.0	118.0	10.7	35.0
Paquette, Bob	SE-15-059-01 W5M	Upper Surficial	Oct-83	13.7	45.0	2.1	7.0
Passey, Irene/Groundwater Cons	NW-22-058-24 W4M	Oldman	May-80	61.0	200.0	24.4	80.0
Pax Natura Ranch For The Deaf	NE-17-060-23 W4M	Upper Surficial	Jun-76	9.8	32.0	25.4	83.3
Pinchuk, L.	SW-07-060-24 W4M	Oldman	Aug-82	80.8	265.0	26.4	86.6
Pointer Realty Ltd	NW-20-058-23 W4M	Oldman	Oct-82	36.6	120.0	27.4	89.8
Pointer Realty Ltd	NW-20-058-23 W4M	Oldman	May-83	77.7	255.0	28.4	93.1

WATER WELLS RECOMMENDED FOR FIELD VERIFICATION

Owner	Location	Aquifer Name	Date Water Well Drilled	Completed Depth Metres	Completed Depth Feet	NPWL Metres	NPWL Feet
Primrose, Mel	01-22-060-01 W5M	Upper Surficial	Jun-70	37.8	124.0	2.7	9.0
Pudlowski, Wm.	NW-23-060-01 W5M	Oldman	May-60	54.3	178.0	1.8	6.0
Riopel, Rene	SE-26-057-27 W4M	Lower Horseshoe Canyon	May-85	48.8	160.0	24.1	79.0
Rosendale, G.	03-18-058-26 W4M	Bearpaw	Jul-85	42.7	140.0	4.6	15.0
Rude, Allan	01-36-058-01 W5M	Bearpaw	Jul-76	39.6	130.0	3.1	10.0
Sabourin, Richard	SW-08-059-25 W4M	Upper Surficial	Apr-73	13.4	44.0	3.7	12.0
Schnirer	SW-30-057-26 W4M	Lower Horseshoe Canyon	Sep-57	29.0	95.0	13.7	45.0
Schnirer, Arvin	SW-30-057-26 W4M	Lower Horseshoe Canyon	Aug-82	26.5	87.0	13.7	45.0
Schuster, Ken	08-01-059-27 W4M	Bearpaw	Jun-78	21.3	70.0	9.1	30.0
Semeniuk, Delmer	13-19-061-24 W4M	Oldman	Apr-82	46.6	153.0	5.2	17.0
Sheehan, Leo	NW-35-060-01 W5M	Upper Surficial	Aug-62	27.4	90.0	0.6	2.0
Sheehan, Terry	SW-02-061-01 W5M	Oldman	Aug-85	50.0	164.0	0.3	1.0
Shelton, John	14-09-062-25 W4M	Upper Surficial	Sep-80	13.7	45.0	3.7	12.0
Shewchuck, Pete	NW-11-058-27 W4M	Lower Horseshoe Canyon	Jul-74	19.8	65.0	2.4	8.0
Sjostrom, Berner	NW-17-058-27 W4M	Bearpaw	May-85	24.4	80.0	3.7	12.0
Smith, A.	SW-18-060-23 W4M	Upper Surficial	Jun-83	10.4	34.0	0.9	3.0
Smith, Kevin	08-35-061-26 W4M	Upper Surficial	Mar-84	27.4	90.0	6.4	21.0
Spence, Brian	13-34-061-24 W4M	Oldman	Mar-76	42.7	140.0	9.1	30.0
Sportsmans Service	13-33-064-01 W5M	Birch Lake	Sep-80	64.0	210.0	27.4	90.0
St. Louis, Edward	NE-29-058-27 W4M	Bearpaw	May-67	21.3	70.0	15.9	52.0
Sterling, Brent & Jean	01-12-059-26 W4M	Bearpaw	Nov-82	39.0	128.0	3.7	12.0
Sterling, Church	NW-20-060-24 W4M	Upper Surficial	Sep-80	7.3	24.0	2.4	8.0
Sterling, Jim	NW-26-059-01 W5M	Bearpaw	Oct-81	26.2	86.0	18.3	60.0
Stowe, D.	SW-10-059-01 W5M	Bearpaw	Jun-75	57.9	190.0	24.4	80.0
Terhorst, Hardy	08-12-063-27 W4M	Birch Lake	Aug-84	73.8	242.0	22.9	75.0
Vachon, G. & C.	NE-02-064-01 W5M	Ribstone Creek	Aug-84	70.1	230.0	9.1	30.0
Village of Pickardville	NW-25-058-27 W4M	Lower Horseshoe Canyon	Mar-81	18.9	62.0	7.3	24.0
Village of Pickardville	NW-25-058-27 W4M	Lower Horseshoe Canyon	Jun-77	18.3	60.0	8.0	26.1
Wajtowich, Frank	05-31-059-23 W4M	Upper Surficial	Mar-84	28.0	92.0	10.7	35.0
Walker, Dick	SW-29-061-01 W5M	Oldman	Jun-79	42.7	140.0	13.7	45.0
Welsh, James	NW-19-059-26 W4M	Oldman	Jul-75	57.9	190.0	12.2	40.0
Whitson/Andersen, Allan	NW-12-057-27 W4M	Lower Horseshoe Canyon	Jul-66	36.6	120.0	4.6	15.0
Yaremko, Mike	01-20-060-24 W4M	Oldman	Jul-83	76.2	250.0	11.0	36.0
Young, Henry	SE-34-059-24 W4M	Upper Surficial	May-85	9.1	30.0	3.1	10.0
Zabelski, Zane/Staffen, Don	16-21-058-24 W4M	Upper Surficial	Jul-78	36.6	120.0	18.3	60.0

WESTLOCK COUNTY-OPERATED WATER WELLS

Owner	Location	Date Water Well Drilled	Aquifer Name	Completed Depth Metres	Completed Depth Feet	NPWL Metres	NPWL Feet
County of Westlock	13-05-061-26 W4M	Nov-80	Oldman	68.3	224.0	8.8	28.9
County of Westlock	15-33-058-25 W4M	Jun-84	Oldman	79.2	260.0	22.9	75.0