Regional Groundwater Assessment

Part of the South Saskatchewan River Basin
Tp 013 to 022, R 16 to 26, W4M

Prepared for Vulcan County

In conjunction with

Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

Prairie Farm Rehabilitation Administration | Administration du rétablisseme agricole des Prairies

Canada

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HYDROGEOLOGICAL CONSULTANTS LTD.

Signature ______________________

Date ______________________

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The Association of Professional Engineers, Geologists and Geophysicists of Alberta

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Acknowledgements

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Mr. Vic Brown – AAFC-PFRA
Mr. Kelly Malmberg – Vulcan County

For additional copies of the report/CD-ROM, please contact the following:

- 1-800-GEO-WELL
- The Groundwater Centre/Regional Groundwater Assessment

http://www.groundwatercentre.com/m_info_rgwa.asp

1 PROJECT OVERVIEW

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

How a County takes care of one of its most precious resources - groundwater - reflects the future wealth and health of its people. Good environmental practices are not an accident. They must include genuine foresight with knowledgeable planning. Implementation of strong practices not only commits to a better quality of life for future generations, but also creates a solid base for increased economic activity. **Though this report's scope is regional, it can be used as a decision-support tool by Vulcan County in managing their groundwater. It is also a guide for future groundwater-related projects.**

1.1 Purpose

This project is a regional groundwater assessment of Vulcan County prepared by Hydrogeological Consultants Ltd. (HCL) with financial and technical assistance from the Prairie Farm Rehabilitation Administration branch of Agriculture and Agri-Food Canada (AAFC-PFRA) and Vulcan County. The project study area includes the parts of Vulcan County bounded by townships 013 to 022, ranges 16 to 26, W4M (herein referred to as the County). The regional groundwater assessment provides 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 country residential, 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 possible groundwater depletion areas associated with aquifer(s) in the surficial deposits and in the upper bedrock.

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 used in the regional groundwater assessment for Vulcan County.

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[1] See glossary
[2] See glossary

1.2 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 eight parts as follows:

Task 1 - Data Collection and Review
Task 2 - Hydrogeological Maps, Figures, Digital Data Files
Task 3 - Hydrogeological Evaluation and Preparation of Report
Task 4 - Groundwater Information Query Software
Task 5 - Review of Draft Report and GIS Data Files
Task 6 - Report Presentation and Familiarization Session
Task 7 - Provision of Report, Maps, Data Layers and Query
Task 8 - Provision of Compact Disk for Sale to General Public.

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

1.3 About This Report

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

Additional technical details are available from files on the CD-ROM provided with 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, ArcView files and ArcExplorer files. Likewise, all of the illustrations and maps shown in this report, plus additional maps, figures and cross-sections, are available on the CD-ROM. In order to avoid map-edge effects, all maps are based on an analysis of hydrogeological data from those parts of townships 013 to 022, ranges 16 to 26, W4M, that make up the County, plus a buffer area of 5,000 metres. For convenience, some 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. A plastic County map outline is provided to overlay the maps, and contains information such as towns, main rivers, etc.

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 *Water Act*
3) interpretation of chemical analysis of drinking water
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 *Water Act* was proclaimed 10 Jan 1999.

Appendix D includes page-size copies of the poster-size figures provided with this report.

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

This report, and the accompanying support documents, has been prepared in SI Units (metric); for conversions, please refer to Conversion Table on page 64.

[3] See glossary

2 METHODOLOGY

2.1 Data Collection and Synthesis

The Alberta Environment (AENV) 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) locations of some springs
4) locations for some water wells determined during water well surveys
5) chemical analyses for some groundwaters[4]
6) locations of some flowing shot holes
7) locations of some structure test holes
8) a variety of data related to the groundwater resource.

The main disadvantage to the database is the reliability of the information entered into the database. 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. Any duplicate water wells that have been identified within the County have been removed from the database used in this regional groundwater assessment.

The AENV groundwater database uses an area-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 based on the NAD83 datum. This means that a record for the SE ¼ of section 34, township 020, range 25, W4M would have a horizontal coordinate with an Easting of 114,148 metres and a Northing of 5,619,118 metres, the centre of the quarter section. If the water well has been repositioned by AAFC-PFRA using orthorectified aerial photographs, the location will be more accurate, possibly within several tens 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); AltaLIS Ltd. provides the DEM.

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 at a given location.

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 in order to assign water wells to aquifers and to obtain values for the following:

1) depth to bedrock
2) total thickness of sand and gravel below 15 metres
3) total thickness of saturated sand and gravel
4) depth to the top and bottom of completion intervals[5].

[4] Since 1986, Alberta Health and Wellness has restricted access to chemical analysis data, and hence the database includes only limited amounts of chemical data after 1986.

Also, where sufficient information is available, values for apparent transmissivity [6] and apparent yield [7] 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 last regional hydrogeological maps covering the County were published in 1974 (Ozoray and Lytviak), using data collected in 1970, nearly 800 values for apparent transmissivity and nearly 700 values for apparent yield have been added to the groundwater database. With the addition of the apparent yield values, including a 0.1-cubic metres per day (m^3/day) value assigned to "dry" water wells and water test holes, a hydrogeological map has been prepared to help illustrate the general groundwater availability across the County (Figure 1 and page A-13). The map is based on groundwater being obtained from all aquifers and has been prepared to allow direct comparison with the results provided on the Alberta Geological Survey (AGS) hydrogeological maps (Ozoray and Lytviak, 1974). In general, the AGS maps show higher estimated long-term yields. The differences between the two map renderings may be a result of fewer apparent yield values, not applying a 0.1-m^3/day for "dry" water wells, and the gridding method employed by the AGS.

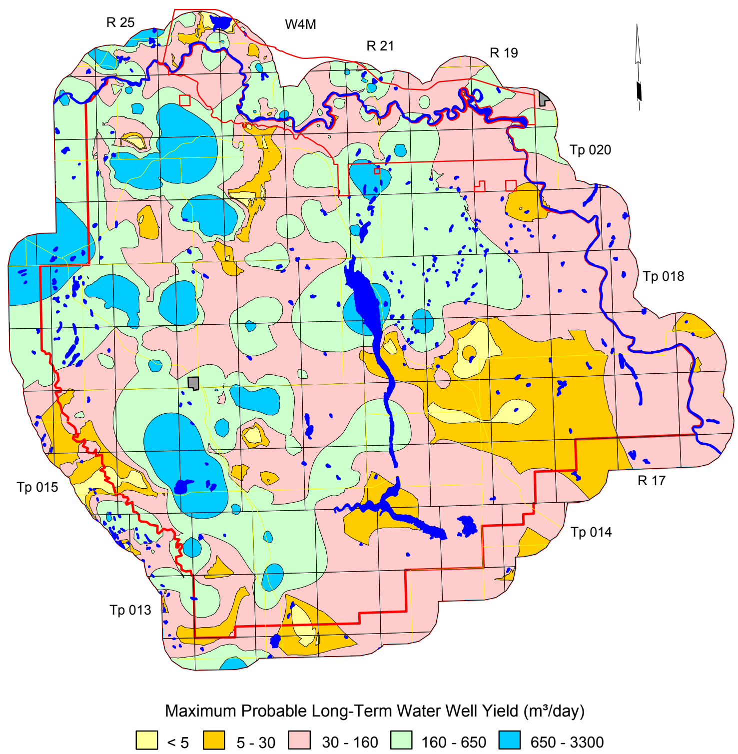


Figure 1. Hydrogeological Map

The EUB well database includes records for wells drilled for 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 geologic units
3) type and intervals for various down-hole geophysical logs
4) drill stem test (DST) summaries.

Values for apparent transmissivity and apparent yield 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.

[5] See glossary
[6] For definitions of Transmissivity, see glossary
[7] For definitions of Yield, see glossary

2.2 Spatial Distribution of Geologic Units

Determination of the spatial distribution of the geologic units is based on:

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

The geologic units are defined by mapping the tops and bottoms of individual geologic units. The values for the elevation of the top and bottom of individual geologic 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 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[8] 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.

2.3 Hydrogeological Parameters

Water well records that indicate the depths to the top and bottom of their completion interval are compared digitally to the spatial distribution of the various geological surfaces. This procedure allows for the determination of the aquifer in which individual water wells are completed. When the completion depth of a water well cannot be established, 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 geologic unit, the parameters from the water well records are assigned to the individual geologic units. The parameters include non-pumping (static) water level (NPWL), apparent transmissivity, and apparent water well yield. The parameters are provided and calculated from data included on the water well drilling reports. The NPWL given on the water well record is usually the water level recorded when the water well was drilled, measured prior to the initial aquifer test. In areas where groundwater levels have since declined, the NPWL may now be lower and, accordingly, the potential apparent yield would be reduced. The total dissolved solids (TDS), sulfate, chloride, Nitrate + Nitrite (as N), fluoride and total hardness concentrations from the chemical analyses of the groundwaters are also assigned to applicable geologic units. Nitrate + Nitrite (as N) concentrations can often be attributed to physical conditions at or near the water well, and may not indicate general aquifer conditions.

Constituent	Recommended Maximum Concentration SGCDWQ (mg/L)	Colour Blends Used on Maps to Indicate Areas that are Below SGCDWQ	Colour Blends Used on Maps to Indicate Areas that Exceed SGCDWQ
Total Dissolved Solids	500		
Nitrate + Nitrite (as N)	10		
Sulfate	500		
Chloride	250		
Fluoride	1.5		

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives (AOs) except for Fluoride and Nitrate + Nitrite (as N), which are for Maximum Acceptable Concentrations (MACs)
SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality
Federal-Provincial-Territorial Committee on Drinking Water, March 2006

Blue hues have been chosen to represent map areas where the chemical parameters are below the Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ) and orange hues have been chosen to represent map areas where the chemical parameters are above the SGCDWQ.

[8] See glossary

After 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. The representative data set included using the available data from townships 013 to 022, ranges 16 to 26, W4M, plus a buffer area of at least 5,000 metres. Even when only limited data are available, grids are prepared. However, the grids prepared from the limited data must be used with extreme caution because the gridding process can be unreliable; for the maps, the areas with little or no data are identified.

On some maps, values are posted as a way of showing anomalies to the underlying grid or as a means of emphasizing either the lack of sufficient data or areas where there is concentrated hydrogeological data control.

2.4 Maps and Cross-Sections

After grids for geological surfaces have been prepared, various grids need to be combined to establish the extent and thickness of individual geologic 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 geologic unit.

After the appropriate grids are available, the maps are prepared by contouring the grids. For the Upper Bedrock Aquifer(s) where areas of sufficient data are not available from the groundwater database, prepared maps have been masked with a solid faded pink colour to indicate these areas. These masks have been added to the hydrogeological maps for the Lacombe and Haynes members of the Paskapoo Formation, the Scollard, the Horseshoe Canyon, the Bearpaw, and the Oldman formations. 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.

Water well records to be used on cross-sections are chosen from the groundwater database, and where possible have the following criteria: geo-referenced lithology; completion interval; and NPWL. Data from these water well control points are then placed in the AutoCAD drawing with an appropriate vertical exaggeration. Tops from individual geologic units are then transferred to the cross-section from the digitally prepared surfaces.

After the technical details of a cross-section have been finalized, the drawing file is moved to the software package CorelDraw! for simplification and presentation in a hard-copy form. Eight cross-sections are presented in Appendix A of this report and as poster-size drawings forwarded with this report; two (G-G' and B-B') are included in the text of this report. The cross-sections are also included on the CD-ROM; page-size maps of the poster-size cross-sections are included in Appendix D of this report.

2.5 Software

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

- Acrobat 7.0
- AquaChem 3.7
- ArcView 3.2
- AutoCAD 2004
- CorelDraw! 12.0
- Grapher 3
- Microsoft Office 2003
- Surfer 8

3 INTRODUCTION

3.1 Setting

Vulcan County is situated in southern Alberta. The western half of the County is within the Western Alberta Plains physiographic region, and the eastern half of the County is mainly within the Eastern Plains physiographic region (Vulcan County, Jan 2005). The County is within the Bow River and Oldman River sub-basins of the South Saskatchewan River basin (see page A-4). The Bow River forms the northern and northeastern boundaries, and the Little Bow River forms the southwestern border. The Siksika First Nation lands form part of the County's northern border with Wheatland County, and the other Vulcan County boundaries are as shown on the adjacent topography map.

Regionally, the topographic surface varies between 734 and 1,174 metres above mean sea level (AMSL). The highest elevations occur mainly in the westesrn part of the County, and the lowest elevations occur mainly in the eastern part of the County, as shown on Figure 2 and page A-5.

The area is well drained by the Bow River, McGregor Lake and Travers Reservoir.

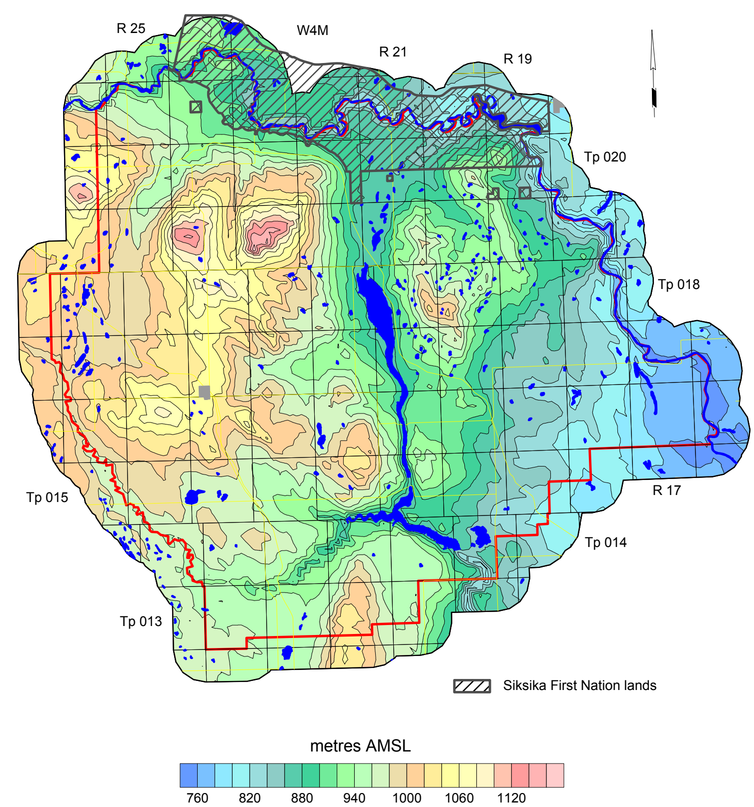


Figure 2. Surface Topography

3.2 Climate

Vulcan County lies mainly within the semiarid Bsk climate. This classification is based on potential evapotranspiration[9] 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 Leggat, 1981) shows that the County is located mainly in the Moist Mixed Grassland region.

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

The mean annual precipitation averaged from two meteorological stations within the County measured 416 millimetres (mm), based on data from 1971 to 2000. The annual temperature averaged 4.6° C, with the mean monthly temperature reaching a high of 18.3° C in July, and dropping to a low of -9.4° C in December and January. The calculated annual potential evapotranspiration is 547.4 millimetres.

[9] See glossary

4 BACKGROUND INFORMATION

4.1 Number, Type and Depth of Water Wells

There are currently 3,951 records in the groundwater database for the County, of which 2,799 are water wells. Of the 2,799 water wells, there is a proposed use for 2,559 water wells, as shown in the adjacent table. Of the 2,559 water wells, there are records for domestic (1,619), domestic/stock (497) or stock (330) purposes. The remaining 353 water wells were completed for municipal (47), observation (7), industrial (19), and other numerous categories (40); 240 water well designations are classified as "unknown". Forty percent the water wells were completed between 1975 and 1989.

Date Completed	Domestic	Domestic/Stock	Stock	Municipal	Observation	Industrial	Other	Unknown	Total
No Date	687	109	28	27	0	0	11	111	851
pre-1955	17	7	0	0	1	0	2	6	24
1955	52	5	10	4	0	1	0	12	71
1960	86	14	16	8	0	6	3	25	124
1965	91	15	20	1	0	2	1	32	127
1970	108	44	45	0	0	2	1	10	197
1975	130	93	42	1	0	2	5	7	266
1980	141	89	29	0	2	2	5	31	259
1985	80	91	87	0	0	1	4	6	258
1990	55	20	27	5	0	2	2	0	107
1995	97	3	10	0	4	1	2	0	110
2000	75	7	16	1	0	0	4	0	99
Total	1619	497	330	47	7	19	40	240	2799

Table 1. Proposed Use for Water Wells

The highest percentages of domestic (46%), domestic/stock (53%), stock (51%), and municipal (38%) water wells are completed in the depth interval between 30 and 60 metres below ground surface, and the highest percentage of industrial water wells (87%) are completed in the depth interval between 60 and 100 metres below ground surface, as shown in Figure 4.

Details for lithology[10] are available for 2,969 water wells.

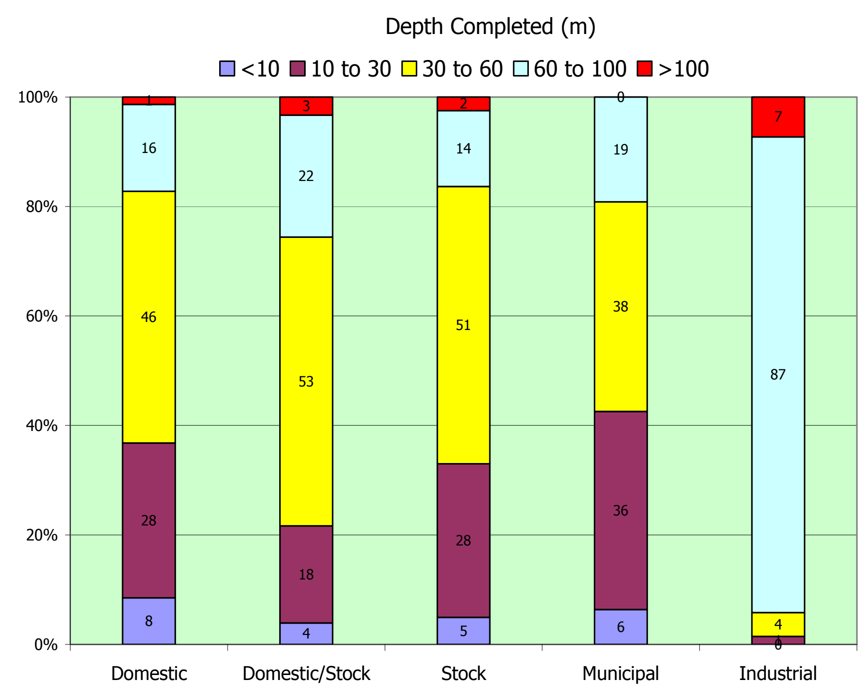


Figure 3. Proposed Use vs Completed Depth

10 See glossary

4.2 Number of Water Wells in Surficial and Bedrock Aquifers

There are 1,138 water wells with completion interval and lithologic information, such that the aquifer in which the water wells are completed can be identified. 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 1,138 water wells for which aquifers could be defined, 243 are completed in surficial aquifers, with 184 (76%) having a completion depth of less than 40 metres below ground surface. The adjacent map shows that the surficial water wells are completed mainly in association with the lower elevations of the bedrock surface (see Figure 9 on page 16).

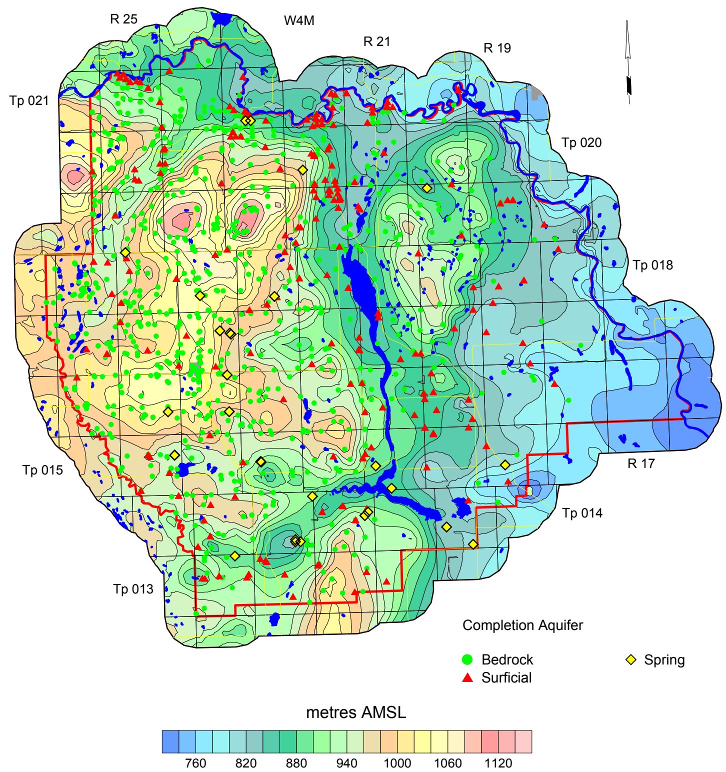


Figure 4. Locations of Water Wells and Springs Relative to Bedrock Topography

The data for 895 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. From Figure 4 (also see page A-8), it can be seen that water wells completed in bedrock aquifers occur throughout the County, where water wells are present.

Within Vulcan County, there are currently records for 31 springs in the groundwater database, including seven springs that were documented by Borneuf (1983). There are 27 springs having at least one TDS value, with 23 springs having a TDS of more than 500 milligrams per litre (mg/L). No flow rates for the 31 springs are available in the groundwater database.

4.3 Casing Diameter and Type

Data for casing diameters are available for 1,480 water wells, with 1,455 (98%) indicated as having a diameter of less than 275 mm and 25 (2%) having a diameter of more than 275 mm. The casing diameters of greater than 275 mm are mainly bored, hand dug, or dug by backhoe water wells and those with a surface-casing diameter of less than 275 mm are mainly drilled water wells. The entire water well database for the County suggests that 77 of the water wells in the County were bored, hand dug or dug by backhoe and 1,844 are drilled water wells.

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. Within the County, casing-diameter information is available for 236 of the 243 water wells completed in the surficial deposits, of which 224 surficial water wells have a casing diameter of less than 275 mm and are assumed to be drilled water wells. Within the County, casing-diameter information is available for 878 of the 895 water wells completed below the top of bedrock, of which 875 have a surface-casing diameter of less than 275 mm and have been mainly completed with either a perforated liner or as open hole. Water wells completed in bedrock aquifers usually do not require water well screens, although some of the sandstones may be friable[11] and water well screens are a necessity. In the County, 16 bedrock water wells are completed with a water well screen.

Where the casing material is known, steel surface casing materials have been used in 90% of the drilled water wells over the last 50 years. For the remaining drilled water wells with known surface casing material, nine percent were completed with plastic casing, and the remaining one percent were completed with galvanized steel, stainless steel, and concrete. The main years where the type of surface casing was undocumented were prior to 1955 to the mid-1960s. Plastic casing was first used in July 1983, and is currently being used in 40% of the water wells drilled in the County.

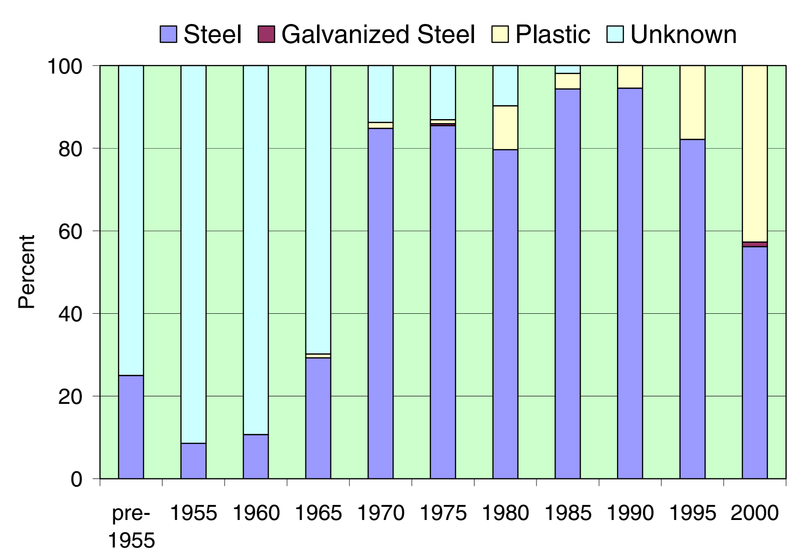


Figure 5. Surface Casing Types Used in Drilled Water Wells

4.4 Dry Water Test Holes

In the County, there are 3,951 records in the groundwater database. Of these 3,951 records, 95 (2%) are indicated as being “dry” or “abandoned” with “insufficient water”[12]. Of the 95 “dry” water test holes, 22 are completed in surficial deposits and 73 are completed in bedrock; the aquifer for the remaining one “dry” water test hole is unknown. Fifteen percent of all water wells with apparent yield estimates were judged to yield less than 6.5 m³/day (1 igpm).

11 See glossary
12 “dry” can be due to a variety of reasons: skill of driller, type of drilling rig/method used, the geology encountered

4.5 Requirements for Licensing

With some exemptions, a diversion of groundwater starting after 01 Jan 1999 must have a licence. Exemptions include (1) the diversion for household use of up to 3.4 cubic metres per day (1,250 m³/year [750 imperial gallons per day[13]]), (2) the diversion of groundwaters with total dissolved solids in excess of 4,000 mg/L, (3) the diversion from a manually pumped water well, or (4) a diversion of groundwater that was eligible for registration as "Traditional Agriculture Use" but was not registered can continue to be used for Traditional Agriculture Use but without the protection of the *Water Act*.

In the last update from the AENV groundwater database, 517 groundwater licences and/or registrations were shown to be within the County, with the most recent groundwater user being licensed in March 2005. Of the 517 licensed and registered groundwater users, 401 (78%) are registrations of Traditional Agriculture Use under the *Water Act*. These 401 registered users will continue to divert groundwater for stock watering and/or crop spraying. Typically, the groundwater diversion for crop spraying averages less than one m³/day so most registered groundwater diversion is for stock watering. Of the remaining 116 groundwater users, 92 are for agricultural purposes (mainly stock watering), 17 are for municipal purposes (mainly urban), three are for recreation purposes, two are for irrigational purposes, one is for industrial purposes, and the remaining one is for commercial purposes. Of the 401 registrations, 161 (40%) could be linked to the AENV groundwater database. Of the 116 licensed groundwater diversions in the County, 68 (59%) could be linked to the AENV groundwater database. The maximum amount of groundwater that can be diverted each year from the water wells associated with these licences and/or registrations is 6,418 m³/day, although actual use could be less. Of the 6,418 m³/day, 845 m³/day (13%) is registered for Traditional Agriculture Use, 4,153 m³/day (65%) licensed for agricultural purposes, 713 m³/day (11%) is licensed for municipal purposes, 683 m³/day (11%) is licensed for irrigation, and 23 m³/day (<1%) is licensed for industrial, recreation and commercial purposes, as shown below in Table 2. A figure showing the locations of the groundwater users with either a licence or a registration is in Appendix A (page A-9) and on the CD-ROM. Table 2 also shows a breakdown of the 517 groundwater licences and/or registrations by the aquifer in which the water well is completed. Forty-four percent of the total quantity of licensed and registered groundwater use is from the Dalehurst and Scollard aquifers. The water wells associated with the 78 licensed and registered use where a specific aquifer cannot be determined is because insufficient completion information is available.

Aquifer **	No. of Licences and/or Registrations	Registrations (m³/day)	Licensed Groundwater Users* (m³/day) Agricultural	Municipal	Irrigation	Industrial	Recreation	Commericial	Total Quantity of Licensed and/or Registered Groundwater Diversion (m³/day)	Percentage
Multiple Surficial Completions	10	1	34	0	0	3	0	0	38	0.6
Upper Sand and Gravel	61	106	6	14	341	0	14	0	481	7.5
Lower Sand and Gravel	53	87	83	561	341	0	0	0	1,072	16.7
Mulitple Bedrock Completion	29	59	1,052	0	0	0	0	2	1,113	17.3
Dalehurst	165	279	1,026	81	0	0	0	0	1,386	21.6
Upper Lacombe	7	18	0	0	0	0	0	0	18	0.3
Lower Lacombe	5	9	2	0	0	0	0	0	11	0.2
Haynes	16	41	147	0	0	0	0	0	188	2.9
Upper Scollard	31	31	1,324	24	0	0	0	0	1,379	21.5
Lower Scollard	18	22	24	34	0	0	3	0	83	1.3
Battle/Whitemud	0	0	0	0	0	0	0	0	0	0.0
Upper Horseshoe Canyon	21	34	4	0	0	0	0	0	38	0.6
Middle Horseshoe Canyon	12	25	17	0	0	0	0	0	42	0.7
Lower Horseshoe Canyon	7	5	6	0	0	0	0	0	11	0.2
Bearpaw	2	5	0	0	0	0	0	0	5	0.1
Oldman	2	4	0	0	0	0	0	0	4	0.1
Unknown	78	118	428	0	0	0	0	0	546	8.5
Total(1)	517	845	4,153	713	683	3	18	2	6,417	100.0
Percentage		13.2	64.7	11.1	10.6	0.0	0.3	0.0	100	

* - data from AENV ** - Aquifer identified by HCL

(1) The values given in the table have been rounded and, therefore, the columns and rows may not add up equally

Table 2. Licensed and/or Registered Groundwater Diversions

13 see conversion table on page 64

Based on the 2001 Agriculture Census[14] (Statistics Canada), the calculated water requirement for 208,977 livestock for the County is in the order of 4,952 m³/day. This number includes intensive livestock use but not domestic animals and is based on an estimate of water use per livestock type. Of the 4,952 m³/day calculated livestock use, AENV has authorized a groundwater diversion of 4,999 m³/day (agricultural and registration) (101%) and licensed a surface-water diversion (stock and registration) based on consumptive use of 2,374 m³/day (48%) for a total diversion of 7,373 m³/day. Agriculture purpose includes water diverted and used for stockwatering and feedlot use. This assumes the majority of the groundwater and surface water authorized for diversion for Traditional Agriculture Use is used for watering livestock. Using this assumption, AENV may have authorized 1.5 times the amount that is required for calculated livestock use.

Livestock Type	Number	Estimated Water Requirement (m³/day)
Total hens and chickens	88,032	18
Turkeys	0	0
Other poultry	6,784	2
Total cattle and calves	78,751	4,296
Total pigs	26,665	485
Total sheep and lambs	5,612	51
Horses and ponies	1,633	74
Goats	936	9
Rabbits	84	0
Mink	0	0
Fox	0	0
Bison	355	16
Deer and elk	0	0
Llamas and alpacas	125	1
Totals	208,977	4,952

Table 3. Estimated Water Requirement for Livestock in Vulcan County

The discrepancy may be partially accounted for in that, at the time of application for the licence, the applicant may have had more livestock than the current 2001 Agriculture Census numbers, or the applicant applied for the amount of water needed for a planned expansion that did not take place.

4.6 Base of Groundwater Protection

In general, AENV defines the Base of Groundwater Protection (BGP) as the elevation below which the groundwater will have more than 4,000 mg/L of total dissolved solids. By using the ground elevation, formation elevations, and Alberta Energy and Utilities Board (EUB) information indicating the formations containing the deepest useable water for agricultural needs, a value for the depth to the BGP can be determined. These values are gridded using the Kriging method to prepare a depth to the BGP 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 has a TDS concentration that exceeds 4,000 mg/L, the groundwater use does not require licensing by AENV. The depth to the BGP is mainly less than 200 metres below ground surface in the southeastern parts of the County but can be more than 800 metres below ground surface in the western parts of the County, as shown on Figure 6 on the following page, on the cross-sections presented with this report, in Appendix A, and on the CD-ROM.

14 The 2006 Agricultural Census has not yet been published. Phone conversation (08 Jan 07) with AAFC-PFRA Ag-Water Technician Vic Brown indicated that livestock census numbers for Vulcan County in 2006 would be similar to the 2001 livestock census numbers.

There are 2,652 water wells with completed depth data, of which two appear to be completed below the BGP. The two water wells are completed nearly 1,200 metres below the BGP, and are used for industrial purposes. Chemistry details are available for all 2,652 water wells; 64 of the 2,652 water wells had TDS concentrations that were greater than 4,000 mg/L, as shown on the adjacent figure. In the County, the BGP corresponds to, or is below, the top of the Oldman Formation (see pages A-14 to A-21).

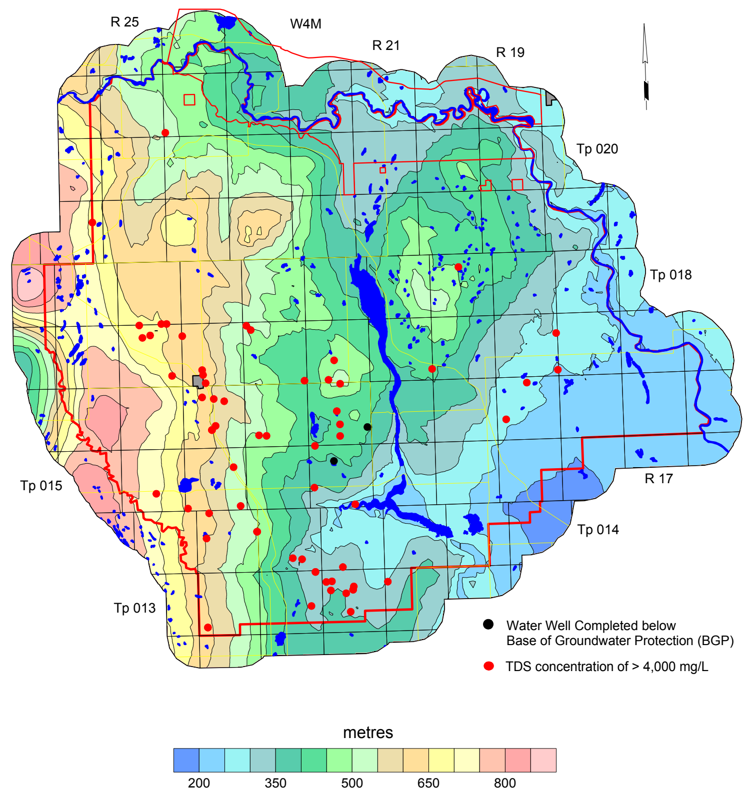


Figure 6. Depth to Base of Groundwater Protection (after EUB, 1995 and Tokarsky, 1986)

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 AENV-operated observation water wells within the County. The nearest AENV-operated observation well with water-level data is AENV Obs No. 220 in 13-06-022-25 W4M, located in Wheatland County. In the past, the data for authorized diversions have been difficult to obtain from AENV, in part because of the failure of the applicant to provide the data. 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 of this report). 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, as has been the case in the Wildrose Country Ground Water Monitoring Association and the M.D. of Flagstaff.

The County of Grande Prairie was involved in a Regional Groundwater Assessment in 2002 and, from the study, it was identified that there is a shortage of information related to changes in the water levels in the various aquifers in the region. In an attempt to supplement the existing data, a groundwater monitoring program is being set up to measure the water levels in 50 selected water wells each month over the next five years. Also, groundwater samples are to be collected to determine if changes in the groundwater quality are taking place.

5 TERMS

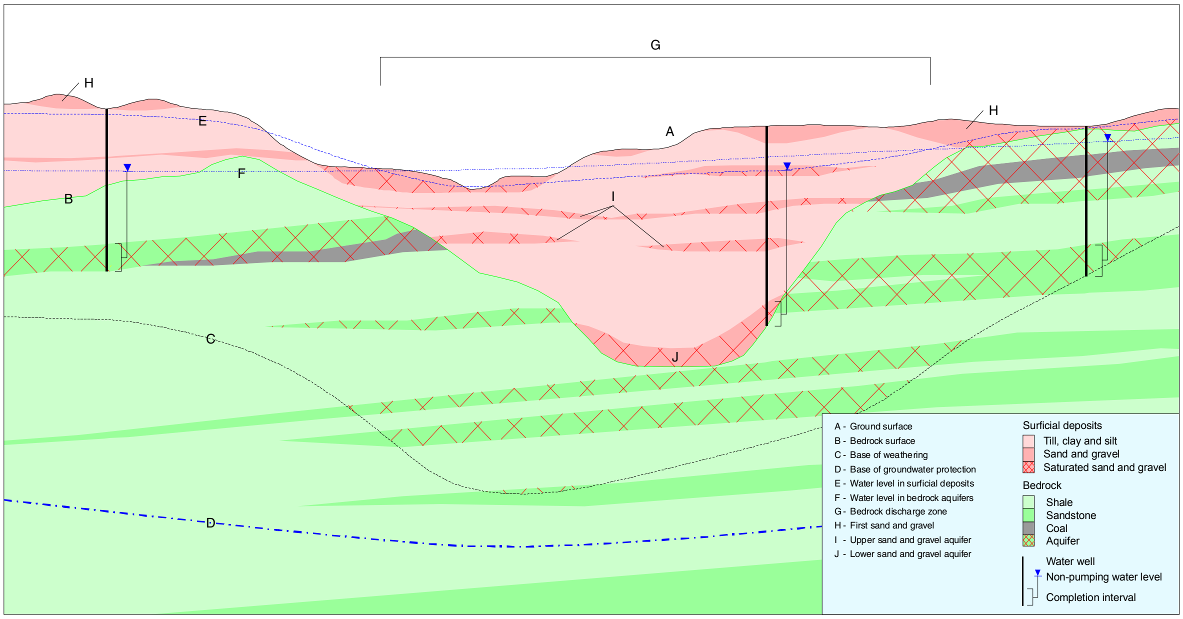


Figure 7. Generalized Cross-Section (for terminology only)

(for larger version, see page A-11)

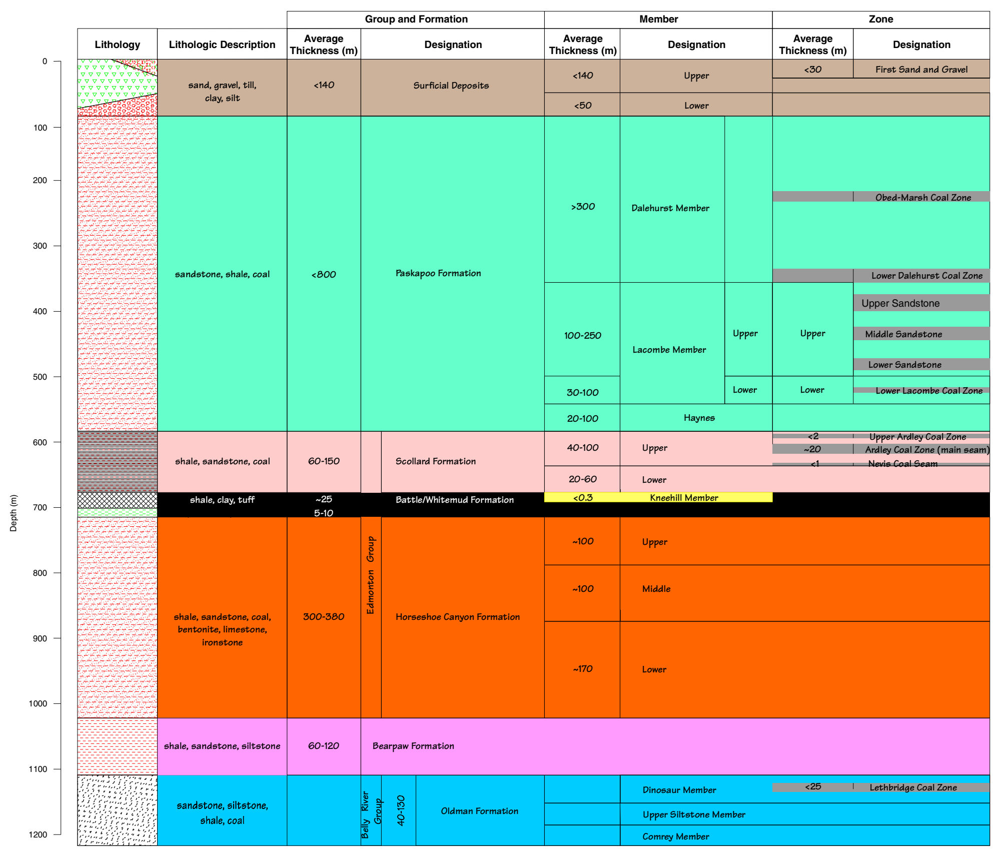


Figure 8. Geologic Column

(for larger version, see page A-12)

6 AQUIFERS

6.1 Background

An aquifer is a permeable geologic unit[15] that is saturated. In this context, “geologic unit” refers to subsurface materials, such as sand, gravel, sandstone and coal. 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 sediments are referred to as the surficial deposits. The second geological setting includes aquifers in the upper bedrock. If the NPWL is above the top of the geologic unit, this type of aquifer is a confined or artesian aquifer. If the rock unit is not entirely saturated and the water level is below the top of the geologic unit, this type of aquifer is a water-table aquifer. 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 geologic units, and the general chemical quality of the groundwater associated with each setting are reviewed separately.

6.2 Surficial Deposits – Geological Characteristics

The surficial deposits are the sediments above the bedrock surface. These include pre-glacial materials, which were deposited before glaciation, and materials deposited directly or indirectly as a result of glaciation. For the present study, the surficial deposits have been assigned to two different groupings in the County: (a) Lower Surficial, (b) Upper Surficial. The Lower Surficial deposits include pre-glacial fluvial[16] deposits. The Upper Surficial deposits include the traditional glacial sediments of till[17] and ice-contact deposits. Pre-glacial materials are expected to be present in association with linear bedrock lows.

While the surficial deposits are treated as one hydrogeologic unit[18], they consist of three hydraulic units[19]. The first unit is the preglacial sand and gravel deposits of the Lower Surficial deposits that directly overlie the bedrock surface, when present. These deposits are mainly saturated. The second and third hydraulic units are associated with the sand and gravel deposits in the Upper Surficial deposits. The sand and gravel deposits in the Upper Surficial deposits occur mainly as pockets. The second hydraulic unit is the saturated part of these sand and gravel deposits; the third hydraulic unit is the unsaturated part of these deposits that occurs close to ground surface. For a graphical depiction of the above description, please refer to Figure 7, page 14 and to page A-11. While the unsaturated deposits are not technically an aquifer, they are significant as they provide a pathway for soluble contaminants to move downward into the groundwater.

The base of the surficial deposits is the bedrock surface, represented by the bedrock topography as shown on the following page on Figure 9 and on page A-22. Regionally, the bedrock surface varies between 720 and 1,140 metres AMSL. The lowest elevations occur in the buried bedrock valleys.

Over the majority of the County, the surficial deposits are less than 50 metres thick (see CD-ROM). The exceptions are mainly in association with areas where buried bedrock valleys are present, where the deposits can have a thickness ranging from 50 to 100 metres.

15 See glossary
16 See glossary
17 See glossary
18 See glossary
19 See glossary

6.2.1 Buried Valleys

The main buried bedrock valleys in the County that have west-east features have been designated as the Calgary Buried Valley and the Tee Pee Buried Valley.

The main buried bedrock valleys in the County that have southwest-northeast features have been designated as the Silver Buried Valley and the McGregor Buried Valley.

Both the Silver Buried Valley and the McGregor Buried Valley are tributaries to the Calgary Buried Valley, and the Tee Pee Buried Valley is a tributary to the Lethbridge Buried Valley, present to the east of the Vulcan County study area.

The Vulcan Buried Valley is a tributary to the Silver Buried Valley. The Kirkcaldy, Champion, Carmangay, Armada and Bow City buried valleys are tributaries to the Tee Pee Buried Valley.

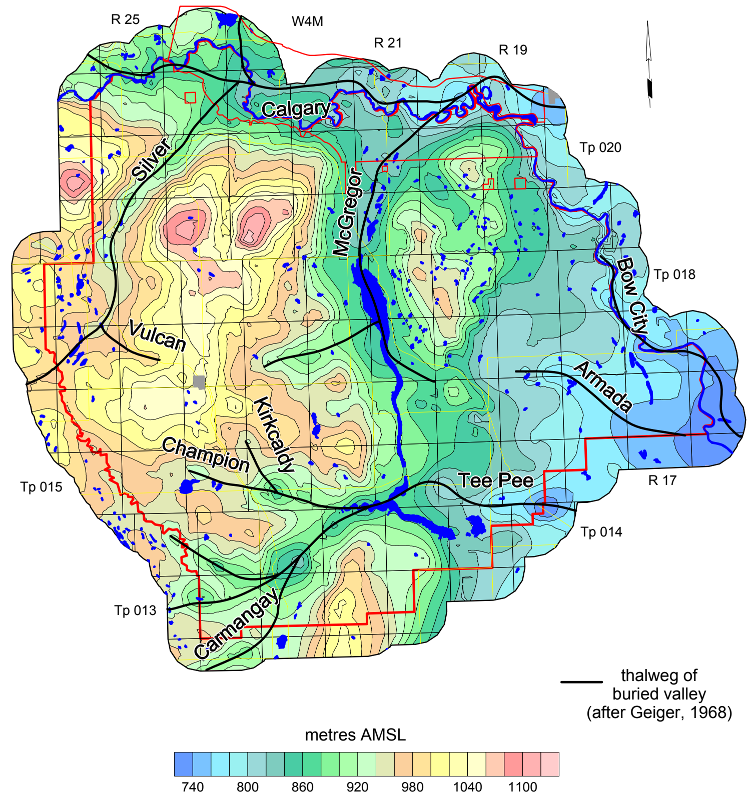


Figure 9. Bedrock Surface Topography

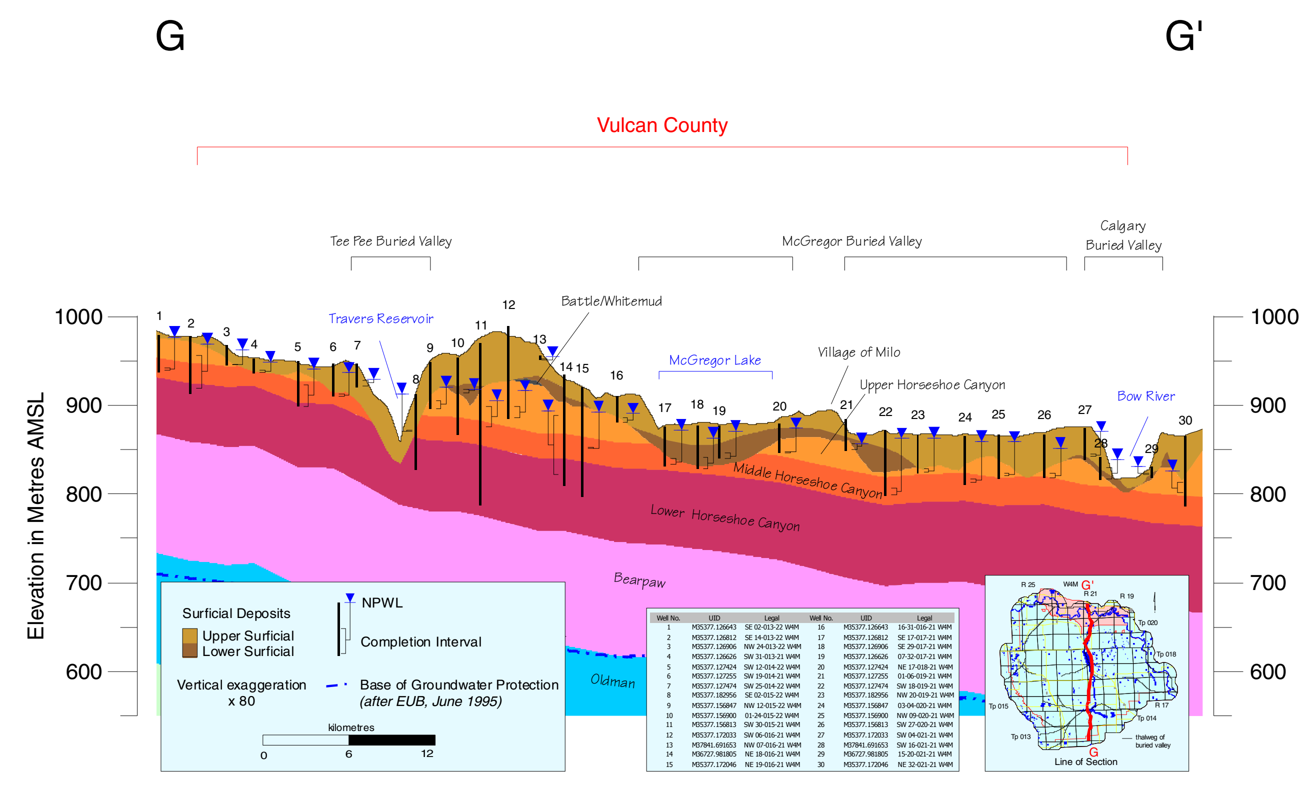
The Calgary Buried Valley is the main easterly-trending buried bedrock valley in the northern part of the County, and is partially coincidental with the Bow River at the County's northern border. The Valley ranges from approximately nine to 15 kilometres wide within the study area, with local bedrock relief being less than 60 metres. Sand and gravel deposits can be expected in association with the bedrock low, but the thickness of the sand and gravel deposits is expected to be mainly less than 15 metres (see page A-23).

The Tee Pee Buried Valley is the main easterly-trending buried bedrock valley in the southern part of the County. The Valley is four to nine kilometres wide, with local bedrock relief being up to 60 metres. The tributaries are less than five kilometres wide, with local bedrock relief being in the order of 40 metres. Sand and gravel deposits can be expected in association with the Tee Pee Buried Valley and its tributaries, with the sand and gravel deposits expected to be mainly less than ten metres thick, with the thicker sand and gravel deposits concentrated in parts of townships 014 and 015, ranges 19 and 20, W4M.

The Silver Buried Valley trends northeasterly in the western part of the County. The southern extent of the Valley is not clearly defined based on the available bedrock elevations, and has been approximated on Figure 9 based on Geiger's interpretation (Geiger, 1968). The Valley is less than five kilometres wide, with local bedrock relief being in the order of 40 metres. Sand and gravel deposits can be expected in association with the Silver Buried Valley and its tributary, with the sand and gravel deposits expected to be mainly less than ten metres thick.

The McGregor Buried Valley trends mainly northerly in the central part of the County. A part of the Valley is coincidental with McGregor Lake. The Valley ranges mainly from six to nine kilometres wide, with local bedrock relief being in the order of 40 metres. Sand and gravel deposits can be expected in association with the McGregor Buried Valley and its tributaries, with the sand and gravel deposits expected to be mainly less than ten metres thick.

Lower surficial deposits occur over the County, but mainly in buried bedrock valleys. The total thickness of the lower surficial deposits is mainly less than 30 metres, but can be more than 35 metres in the buried bedrock valleys (see CD-ROM). The lowest part of the lower surficial deposits includes pre-glacial sand and gravel deposits. These deposits would generally overlie the bedrock surface in the McGregor Buried Valley and the Calgary Buried Valley, as shown below on Cross-Section G-G’ and page A-20. The lowest sand and gravel deposits are of fluvial origin, are usually less than five metres thick and may be discontinuous (see CD-ROM).



Well No.	UID	Legal	Well No.	UID	Legal
1	M35377.126643	SE 02-013-22 W4M	16	M35377.126643	16-31-016-21 W4M
2	M35377.126812	SE 14-013-22 W4M	17	M35377.126812	SE 17-017-21 W4M
3	M35377.126906	NW 24-013-22 W4M	18	M35377.126906	SE 29-017-21 W4M
4	M35377.126626	SW 31-013-21 W4M	19	M35377.126626	07-32-017-21 W4M
5	M35377.127424	SW 12-014-22 W4M	20	M35377.127424	NE 17-018-21 W4M
6	M35377.127255	SW 19-014-21 W4M	21	M35377.127255	01-06-019-21 W4M
7	M35377.127474	SW 25-014-22 W4M	22	M35377.127474	SW 18-019-21 W4M
8	M35377.182956	SE 02-015-22 W4M	23	M35377.182956	NW 20-019-21 W4M
9	M35377.156847	NW 12-015-22 W4M	24	M35377.156847	03-04-020-21 W4M
10	M35377.156900	01-24-015-22 W4M	25	M35377.156900	NW 09-020-21 W4M
11	M35377.156813	SW 30-015-21 W4M	26	M35377.156813	SW 27-020-21 W4M
12	M35377.172033	SW 06-016-21 W4M	27	M35377.172033	SW 04-021-21 W4M
13	M37841.691653	NW 07-016-21 W4M	28	M37841.691653	SW 16-021-21 W4M
14	M36727.981805	NE 18-016-21 W4M	29	M36727.981805	15-20-021-21 W4M
15	M35377.172046	NE 19-016-21 W4M	30	M35377.172046	NE 32-021-21 W4M

Figure 10. Cross-Section G - G'

The upper surficial deposits are either directly or indirectly a result of glacial activity. The deposits include till, with minor sand and gravel deposits of meltwater origin, which are expected to occur mainly as isolated pockets. The thickness of the upper surficial deposits is mainly less than 50 metres. Upper surficial deposits are present throughout most of the County (see CD-ROM). The upper sand and gravel deposits are mainly less than two metres thick (see CD-ROM).

Sand and gravel deposits can occur throughout the surficial deposits. The total thickness of sand and gravel deposits is generally less than five metres but can be more than five metres in association with buried bedrock valleys and concentrated in the area bordered by the Calgary Buried Valley, the Silver Buried Valley, and the McGregor Buried Valley (see page A-23 and on CD-ROM).

The combined thickness of all sand and gravel deposits has been determined as a function of the total thickness of the surficial deposits. Where sand and gravel deposits are present, the sand and gravel deposits are less than 25% of the total thickness of the surficial deposits, as shown on the adjacent figure. The areas where sand and gravel deposits constitute more than 25% of the total thickness of the surficial deposits are in association with buried bedrock valleys, and concentrated in the area bordered by the Calgary Buried Valley, the Silver Buried Valley, and the McGregor Buried Valley, as shown on the adjacent figure.

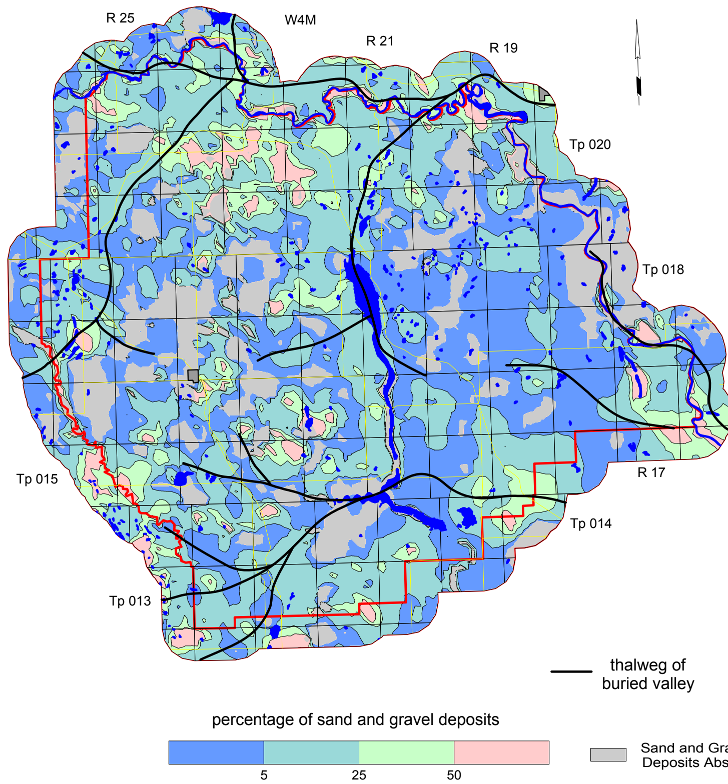


Figure 11. Percentage of Sand and Gravel in Surficial Deposits

6.2.2 Sand and Gravel Aquifer(s)

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 non-pumping water level in water wells that are less than 20 metres deep. The base of the surficial deposits is the bedrock surface.

Since the Sand and Gravel Aquifer(s) are not present everywhere, the actual aquifer that is developed at a given location is usually dictated by the aquifer that is present. Over 30% of the County, saturated sand and gravel deposits are not present; these areas are designated as grey on the adjacent map. In the County, the thickness of the Sand and Gravel Aquifer(s) is generally less than five metres, but can be more than five metres in areas of, or near buried bedrock valleys, as shown in Figure 12, in Appendix A and on the CD-ROM.

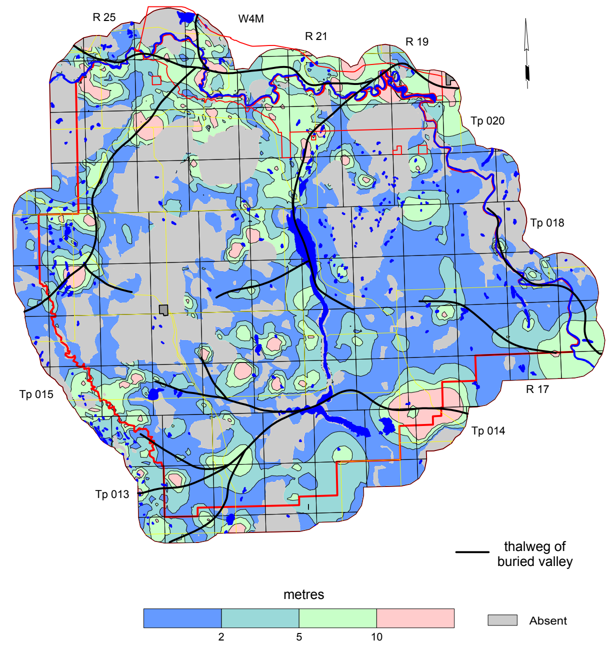


Figure 12. Thickness of Sand and Gravel Aquifer(s)

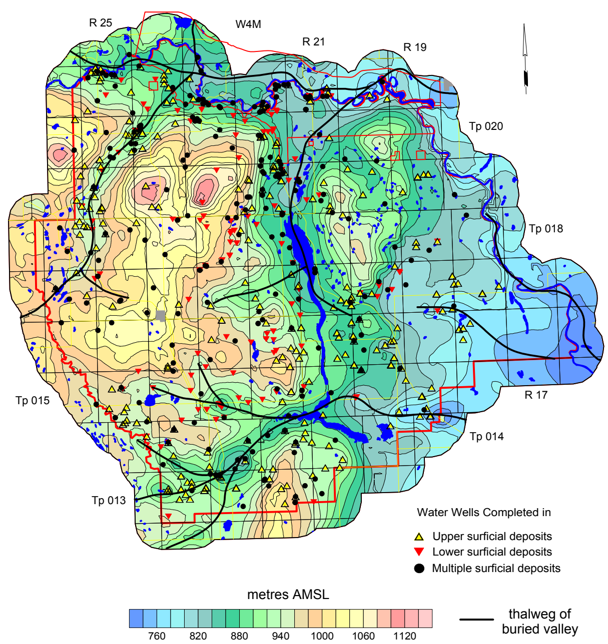


Figure 13. Location of Surficial Water Wells Relative to Bedrock Topography

Of the 2,799 water wells in the database, 243 were defined as being completed in surficial aquifers, based on lithologic information and water well completion details. From the present hydrogeological analysis, 709 water wells are completed in aquifers in the surficial deposits. Of the 709 water wells, 296 are completed in aquifers in the Upper Surficial deposits, 144 are completed in aquifers in the Lower Surficial deposits, and 269 water wells are completed in multiple surficial aquifers. This number of water wells (709) is nearly three times the number (243) 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 topographic 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 surficial deposits are largely absent in areas of higher bedrock elevations. Water wells completed in the Lower Surficial deposits are mainly in buried bedrock valleys, and water wells completed in the Upper Surficial deposits are frequently in buried bedrock valleys but are also located throughout the County, as shown on Figure 13.

In the County, there are 175 records for surficial water wells with apparent yield data, which is 25% of the 709 surficial water wells. Twenty-seven (15.4%) of the 175 water wells completed in the Sand and Gravel Aquifer(s) have apparent yields that are less than ten m³/day, 76 (43.4%) have apparent yield values that range from 10 to 100 m³/day, 41 (23.4%) have apparent yield values that range from 100 to 300 m³/day, and 31 (17.7%) have apparent yields that are greater than 300 m³/day. In addition to the 175 records for surficial water wells with apparent yield data, there are 22 records that indicate that the water test hole is "dry". In order to depict a more accurate yield map, an apparent yield of 0.1 m³/day was assigned to each of the ten "dry" water test holes prior to gridding.

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 to 300 m³/day	>300 m³/day
Upper Surficial	48	12	19	12	5
Lower Surficial	32	2	20	5	5
Multiple Completions	95	13	37	24	21
Totals	175	27	76	41	31

* - does not include dry test holes

Table 4. Apparent Yields of Sand and Gravel Aquifer(s)

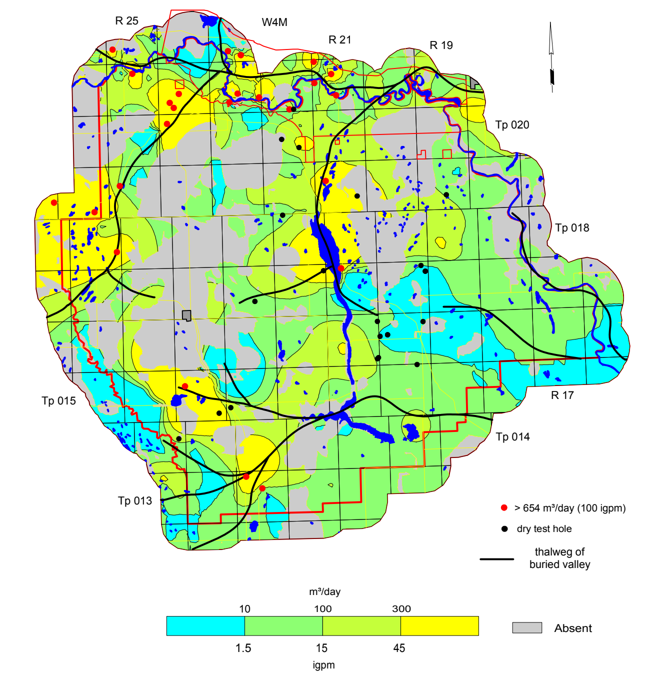


Figure 14. Apparent Yield for Water Wells Completed in Sand and Gravel Aquifer(s)

The adjacent figure shows expected yields for water wells completed in the Sand and Gravel Aquifer(s).

Based on the aquifers that have been developed by existing water wells, these data show that water wells with yields of more than 654 m³/day (100 igpm) from the Sand and Gravel Aquifer(s) can be expected in the buried bedrock valleys, with the exceptions of most of the Tee Pee Buried Valley, the Armada Buried Valley, and the Bow City Buried Valley, where the Sand and Gravel Aquifer(s) are present.

Apparent yields for water wells completed in the Sand and Gravel Aquifer(s) vary significantly over the County both with location and with depth. As Figure 15 shows, most apparent yields are less than 100 m³/day, and the majority of the water wells completed in the Sand and Gravel Aquifer(s) are less than 60 metres deep.

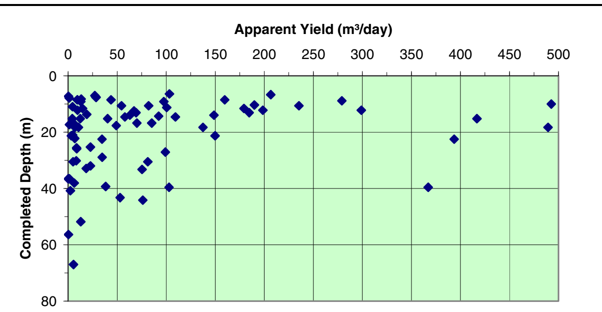


Figure 15. Upper Sand and Gravel Water Well Yields vs Completed Depth

Most of the water wells completed in the Upper Sand and Gravel Aquifer that have apparent yields of greater than 100 m³/day are less than 20 metres deep. Most of the water wells completed in the Lower Sand and Gravel Aquifer that have apparent yields of greater than 100 m³/day are less than 40 metres deep.

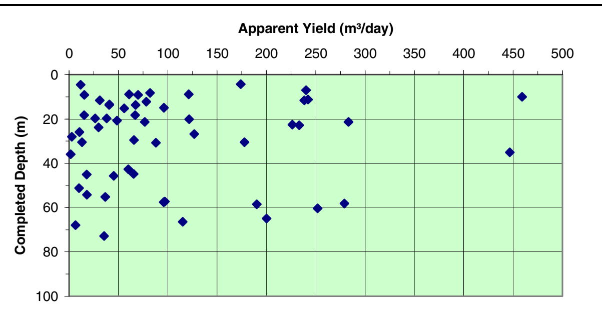


Figure 16. Lower Sand and Gravel Water Well Yields vs Completed Depth

6.2.2.1 Chemical Quality of Groundwater from Surficial Deposits

Groundwaters from an aquifer in the surficial deposits can be expected to be chemically hard, with a total hardness of at least a few hundred mg/L (see CD-ROM), and a dissolved iron concentration such that the groundwater must be treated before being used for domestic needs. Forty percent of the groundwaters from the surficial deposits are reported to have dissolved iron concentrations of more than the aesthetic objective (AO) of 0.3 mg/L. However, many iron analyses results are questionable due to varying sampling and analytical methodologies.

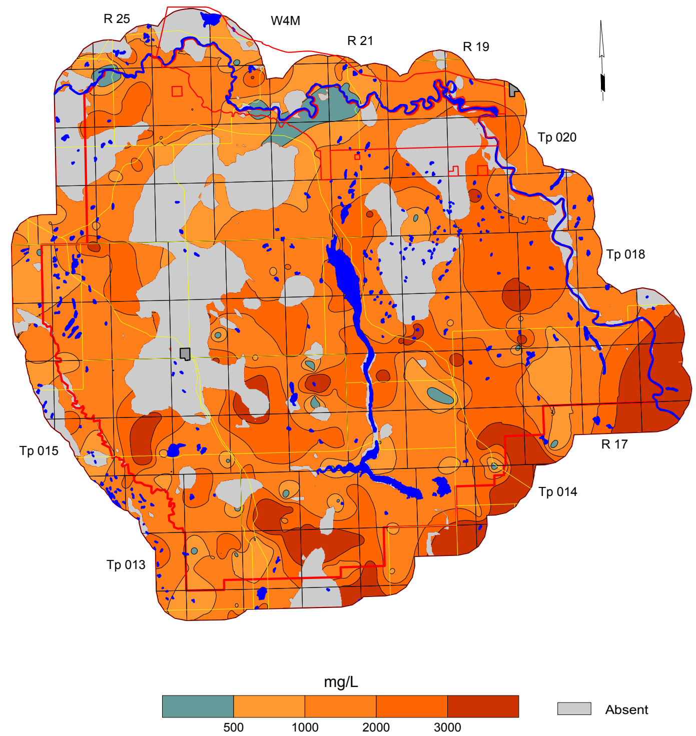


Figure 17. Total Dissolved Solids in Groundwater from Surficial Deposits

The Piper tri-linear diagram[20] for the surficial deposits (see page A-32) shows that the groundwaters from the surficial deposits have no dominant cation[21] or anion[22]. More than 60% of the groundwaters from the surficial deposits have a TDS concentration of more than 1,000 mg/L.

In some areas, the groundwater chemistry of the surficial deposits is such that sulfate is the major 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; in more than 86% of the samples analyzed for surficial deposits in the County, the chloride ion concentration is less than 50 mg/L (see CD-ROM). In the County, the Nitrate + Nitrite (as N) concentrations in the groundwaters from the surficial deposits exceed the maximum acceptable concentrations (MAC) of ten mg/L in 23 of the 297 groundwater samples analyzed (up to about 1986). A plot of Nitrate + Nitrite (as N) in surficial aquifers is on the accompanying CD-ROM.

The minimum, maximum and median[23] 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 Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ) in the adjacent table. The range of concentrations shown in Table 5 is from values in the groundwater database; however, the extreme minimum and maximum concentrations generally represent less than 0.2% of the total number of analyses and should have little effect on the median values. These extreme values are not used in the preparation of the figures.

Of the five constituents that have been compared to the SGCDWQ, median concentrations of TDS and sodium exceed the guidelines.

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	416	133	8,432	1,459	500
Sodium	300	0	570	235	200
Sulfate	417	4	4,004	500	500
Chloride	421	0	1,750	21	250
Nitrate + Nitrite (as N)	297	0	75	0	10

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Nitrate + Nitrite (as N), which is for Maximum Acceptable Concentration (MAC)
SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality Federal-Provincial-Territorial Committee on Drinking Water, March 2006

Table 5. Concentrations of Constituents in Groundwaters from Surficial Deposits

20 See glossary
21 See glossary
22 See glossary
23 See glossary

6.2.3 Upper Sand and Gravel Aquifer

The Upper Sand and Gravel Aquifer includes saturated sand and gravel deposits in the Upper Surficial deposits. Typically, these aquifers are present within the surficial deposits at no particular depth. Saturated sand and gravel deposits in the Upper Surficial deposits are not usually continuous over large areas but are expected over approximately 70% of the County.

6.2.3.1 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 surficial deposits; and (2) the depth to the bedrock surface or the depth to the top of the Lower Surficial deposits, when present. In the County, the thickness of the Upper Sand and Gravel Aquifer is mainly less than two metres but can be more than five metres in the buried bedrock valleys.

6.2.3.2 Apparent Yield

The permeability of the Upper Sand and Gravel Aquifer can be high. The high permeability combined with significant thickness leads to an extrapolation of high yields for water wells; however, because the sand and gravel deposits occur mainly as hydraulically discontinuous pockets, the long-term yields of the water wells are expected to be less than the apparent yields. The long-term yields for water wells completed through this Aquifer are expected to be mainly less than those shown on the adjacent figure.

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, and construction of a water supply well into the underlying bedrock may be the only alternative, provided that yields and quality of groundwater from the bedrock aquifer(s) are suitable.

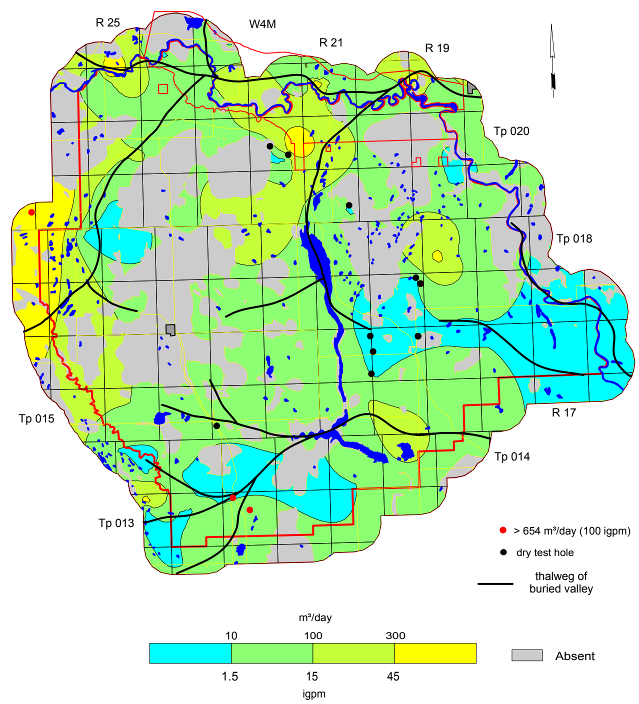


Figure 18. Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer

Figure 18 indicates that in 80% of the County, water wells completed through the Upper Sand and Gravel Aquifer are expected to have apparent yields that are less than 100 m³/day. In the County, there are 14 "dry" water test holes completed in the Upper Sand and Gravel Aquifer.

In the County, there are 61 licensed and registered water wells that are completed through the Upper Sand and Gravel Aquifer, for a total authorized diversion of 481 m³/day (Table 2, page 11), with a median authorized amount of 1.3 m³/day. Twenty-eight of the 61 licences and registrations for water wells completed through the Upper Sand and Gravel Aquifer could be linked to a water well in the AENV groundwater database.

The highest authorized groundwater use is for a water supply well completed to a depth of 6.7 metres below ground level (BGL) in the Upper Sand and Gravel Aquifer that is licensed to divert 341 m³/day for irrigation purposes in 04-26-020-23 W4M.

6.2.4 Lower Sand and Gravel Aquifer

The Lower Sand and Gravel Aquifer, the oldest of the surficial deposits, is a saturated sand and gravel deposit that occurs at or near the base of the surficial deposits in the deeper part of the buried bedrock valleys. The thickness of the Lower Sand and Gravel Aquifer is generally less than five metres but can be more than seven metres in association with buried bedrock valleys and concentrated in the area bordered by the Calgary Buried Valley, the Silver Buried Valley, and the McGregor Buried Valley (see page A-23 and on CD-ROM).

6.2.4.1 Depth to Top

The depth to the top of the Lower Sand and Gravel Aquifer ranges from ground surface to more than 60 metres BGL (see CD-ROM).

6.2.4.2 Apparent Yield

The apparent yield values for individual water wells completed through the Lower Sand and Gravel Aquifer range from less than ten to greater than 300 m³/day, and have a median apparent yield of 96 m³/day. Water wells with yields of greater than 100 m³/day are expected to be in areas of linear bedrock lows, as shown on Figure 19.

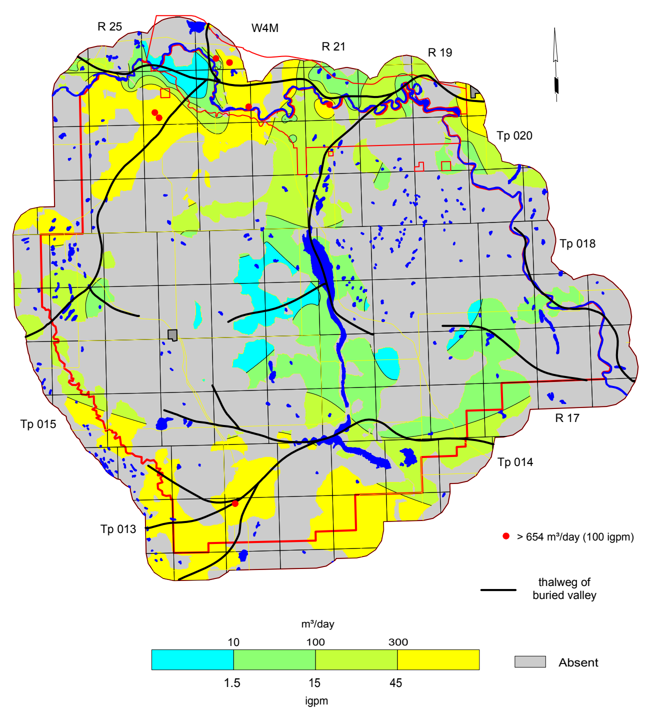


Figure 19. Apparent Yield for Water Wells Completed through Lower Sand and Gravel Aquifer

In the County, there are no "dry" water test holes completed in the Lower Sand and Gravel Aquifer.

In the County, there are 52 licensed and registered water wells that are completed through the Lower Sand and Gravel Aquifer, for a total authorized diversion of 731 m³/day (Table 2, page 11), with a median authorized amount of 3.3 m³/day. Twenty-seven of the 52 licences and registrations for water wells completed through the Lower Sand and Gravel Aquifer could be linked to a water well in the AENV groundwater database.

The highest authorized groundwater use is for a water supply well completed to a depth of 32.0 metres BGL in the Lower Sand and Gravel Aquifer that is licensed to divert 389 m³/day for municipal (subdivision) purposes in NE 09-021-21 W4M. The water supply well is licensed to divert a maximum pumping rate of 654 m³/day. An extended aquifer test conducted in 1975 with the NE 09-021-21 W4M water supply well indicated a long-term yield of at least 1,050 m³/day (EPEC, 1977). A chemical analysis of a groundwater sample from the water supply well after 24 hours of pumping had a TDS concentration of 291 mg/L, a sulfate concentration of <10 mg/L, a chloride concentration of 6 mg/L, and a Nitrate + Nitrate (as N) of 0.099 mg/L (EPEC, 1977).

In May 1963, an extended aquifer test conducted with the Village of Arrowwood water supply well completed to a depth of 23.7 metres BGL in the Lower Sand and Gravel Aquifer indicated a long-term yield of at least 654 m³/day (Tokarsky, 1975). A chemical analysis of a groundwater sample collected in April 1963 from the Village of Arrowwood water supply well had a TDS concentration of 606 mg/L, a sulfate concentration of 134 mg/L, a chloride concentration of 9 mg/L, and a nitrate concentration of 4.3 mg /L (Tokarsky, 1975). In his report, Tokarsky surmises that the elevated nitrate content "may have been due to the introduction of contaminants into the groundwater system at a time prior to the building of a sewage system."

6.3 Bedrock

6.3.1 Geological Characteristics

The upper bedrock in the County includes the Paskapoo Formation, the Edmonton Group, the Bearpaw Formation and the Oldman Formation of the Belly River Group. The adjacent bedrock geology map and cross-section on the following page, showing the subcrop of different geologic units, has been prepared in part from the interpretation of geophysical logs related to oil and gas activity. A generalized geologic column is illustrated in Figure 8, in Appendix A and on the CD-ROM.

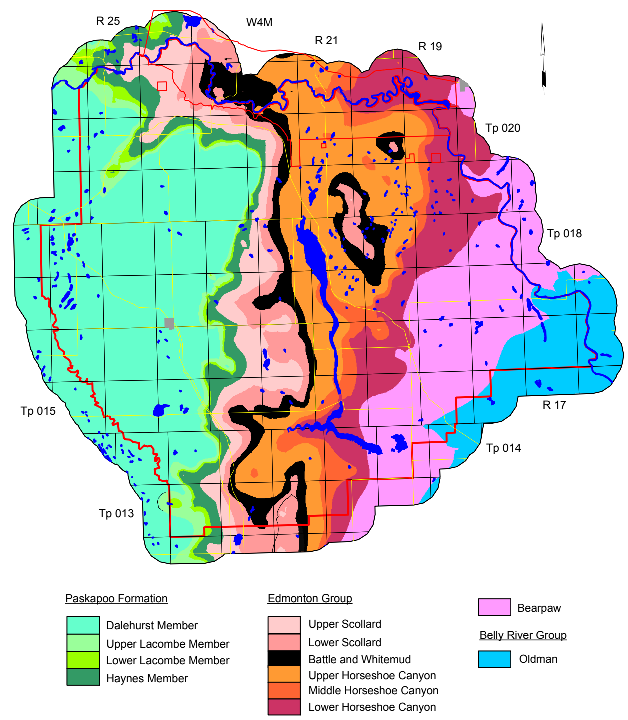


Figure 20. Bedrock Geology

The Paskapoo Formation in Alberta consists of the Dalehurst, Lacombe and Haynes members (Demchuk and Hills, 1991). The Paskapoo Formation consists of cycles of thick, tabular sandstone, siltstone and mudstone layers (Glass, 1990). The Edmonton Group underlies the Paskapoo Formation, and includes the Scollard, Battle and Whitemud, and Horseshoe Canyon formations. The Belly River Group underlies the Edmonton Group, and includes the Oldman and Foremost formations. Some of this bedrock contains saturated rocks that are permeable enough to transmit groundwater for a specific need.

The Dalehurst Member is the upper bedrock in the western third of the County. This Member has a maximum thickness of 200 metres within the County and is mostly composed of shale and siltstone with sandstone, bentonite and coal seams or zones. Two prominent coal zones within the Dalehurst are the Obed-Marsh Coal (up to 30 metres thick) and the Lower Dalehurst Coal (up to 50 metres thick). The bottom of the Lower Dalehurst Coal is the border between the Dalehurst and Lacombe members (Demchuk and Hills, 1991).

The Lacombe Member underlies the Dalehurst Member, and has a maximum thickness of 100 metres, and has two separate designations: Upper and Lower. The Upper Lacombe Member is mostly composed of shale interbedded with sandstone and has a maximum thickness of 65 metres. The Lower Lacombe Member is composed of sandstone and coal layers. In the middle of the Lower Lacombe Member is a coal zone, which can be up to five metres thick. The Lower Lacombe Member has a maximum thickness of 35 metres.

The Haynes Member underlies the Lacombe Member and is composed mainly of sandstone with some siltstone, shale and coal. In the County, the Haynes Member has a maximum thickness of 45 metres.

The Scollard Formation underlies the Haynes Member, has a maximum thickness of 135 metres, and has two separate designations: Upper and Lower. The Upper Scollard consists mainly of sandstone, siltstone, shale and coal seams or zones. Two prominent coal zones within the Upper Scollard are the Ardley Coal (up to 20 metres thick) and the Nevis Coal (up to 3.5 metres thick). The bottom of the Nevis Coal Seam is the border between the Upper and Lower Scollard formations. In the County, the Upper Scollard has a maximum thickness of 85 metres; the Lower Scollard Formation has a maximum thickness of 50 metres, and is composed mainly of shale and sandstone.

Beneath the Scollard Formation are two formations having a maximum thickness of 30 metres; the two are the Battle and Whitemud formations. The Battle Formation is composed mainly of claystone, tuff, shale and bentonite, and includes the Kneehills Member, a 2.5- to 30-cm thick tuff bed. The Whitemud Formation is composed mainly of shale, siltstone, sandstone and bentonite. The Battle and Whitemud formations are significant geologic markers, and were used in the preparation of various geological surfaces within the bedrock. Because of the ubiquitous nature of the bentonite in the Battle and Whitemud formations, there is very little significant permeability within these two formations.

The Horseshoe Canyon Formation is the lower part of the Edmonton Group and is the upper bedrock in the central third of the County. The Horseshoe Canyon Formation consists of deltaic[24] 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 sandstones, when present, tend to be finer grained. The lower 60 to 70 metres and the upper 30 to 50 metres of the Horseshoe Canyon Formation can include coarser grained sandstone deposits. In the County, the Horseshoe Canyon Formation has a maximum thickness of 290 metres and has three separate designations: Upper, Middle and Lower. The Upper Horseshoe Canyon can be up to 95 metres thick, the Middle Horseshoe Canyon can be up to 50 metres thick, and the Lower Horseshoe Canyon can be up to 145 metres thick.

The Bearpaw Formation underlies the Horseshoe Canyon Formation and has a maximum thickness of 145 metres within the County. The Bearpaw Formation consists of marine shale, siltstone and minor sandstone layers, except in some areas where the thickness of the sandstone layers can be significant. The Bearpaw Formation "represents the final widespread marine unit in the Western Canada Foreland Basin" (Catuneanu et al, 1997).

The Oldman Formation is present in the southeastern part of the County, and has a maximum thickness of 130 metres. The Oldman Formation is composed of continental deposits, sandstone, siltstone, shale and coal. The Formation is the upper part of the Belly River Group.

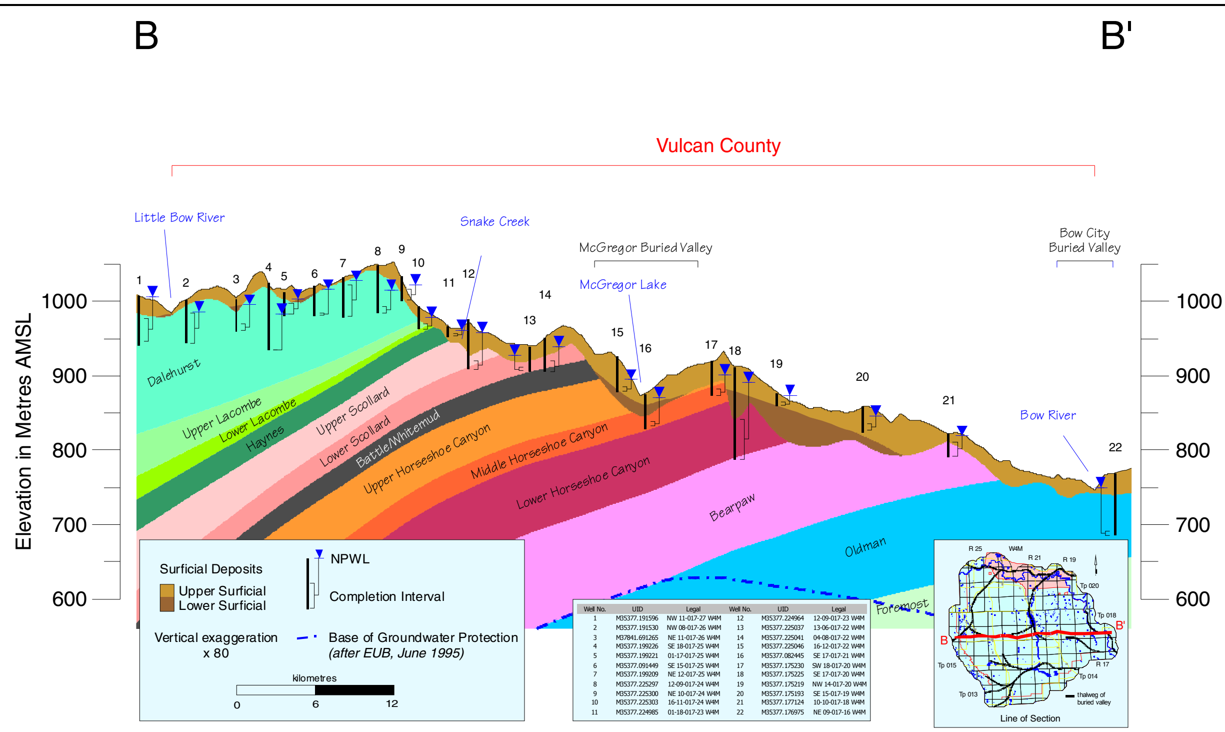


Figure 21. Cross-Section B - B'

6.3.2 Upper Bedrock Completion Aquifer(s)

Of the 2,799 water wells in the database, 895 were defined as being completed below the top of bedrock, based on lithologic information and water well completion details. However, at least a reported completion depth is available for 1,962 water wells completed below the bedrock surface. Assigning a water well to a specific geologic unit 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 the completion interval was the bottom 20% of the total completed depth of a water well. With this assumption, it has been possible to designate the specific bedrock aquifer of completion to 1,590 bedrock water wells. The remaining 372 of the total 1,962 upper bedrock water wells are identified as being completed in more than one bedrock aquifer, as shown in Table 6. The bedrock water wells are mainly completed in the Dalehurst Aquifer.

Geologic Unit	No. of Bedrock Water Wells
Dalehurst	916
Upper Lacombe	50
Lower Lacombe	12
Haynes	78
Upper Scollard	144
Lower Scollard	107
Battle and Whitemud	1
Upper Horseshoe Canyon	156
Middle Horseshoe Canyon	43
Lower Horseshoe Canyon	52
Bearpaw	25
Oldman	4
Milk River	2
Multiple Bedrock Completions	372
Total	1,962

Table 6. Completion Aquifer for Upper Bedrock Water Wells

There are 563 records for bedrock water wells that have apparent yield values, which is 29% of the 1,962 bedrock water wells in the County.

Nearly 90% of the water wells completed in the Upper Bedrock Aquifer(s) have apparent yield values of less than 100 m³/day, with a median apparent yield of 13 m³/day. Many of the areas with yields of more than 100 m³/day are in the southwestern part of the County where the Upper Horseshoe Canyon is the upper bedrock, and in association with the buried bedrock valleys. These higher yield areas may identify areas of increased permeability resulting from the weathering process.

In addition to the 563 records for bedrock water wells with apparent yield values, there are 73 records that indicate that the water well/water test hole is "dry", or abandoned with "insufficient water". In order to depict a more accurate yield map, an apparent yield of 0.1 m³/day was assigned to the 117 "dry" water test holes prior to gridding.

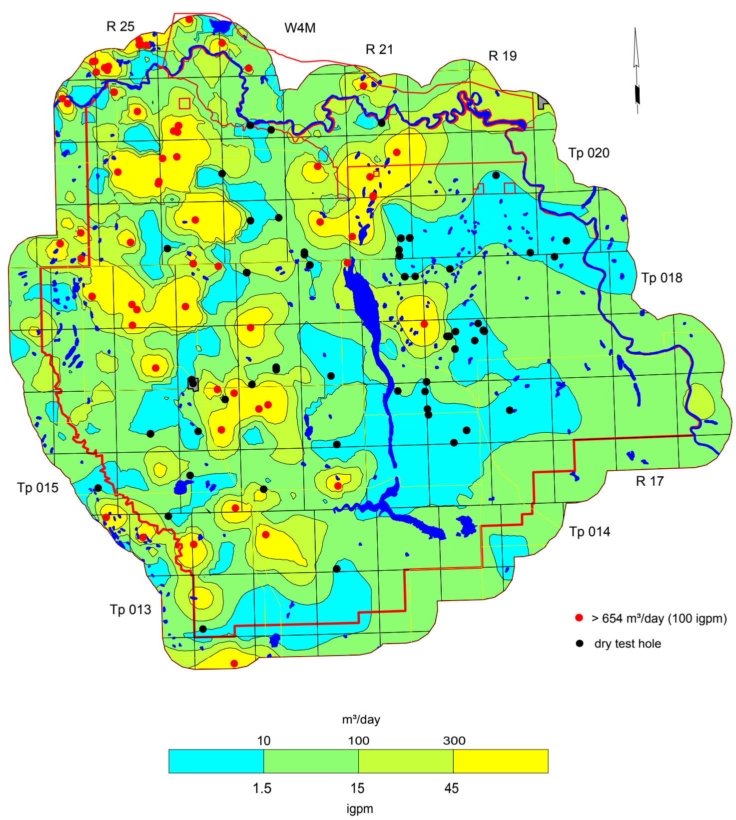


Figure 22. Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)

24 See glossary

Of the 563 water well records with apparent yield values, 445 have been assigned to aquifers associated with specific geologic units. One hundred and nineteen (21%) of the 563 water wells completed in bedrock aquifers have apparent yields that are less than ten m³/day, 272 (48%) have apparent yield values that range from 10 to 100 m³/day, 89 (16%) have apparent yield values that range from 100 to 300 m³/day, and 83 (15%) have apparent yield values that are greater than 300 m³/day, as shown in Table 7.

Aquifer	No. of Water Wells with Values for Apparent Yield (*)	<10 m³/day	10 to 100 m³/day	100 to 300 m³/day	>300 m³/day
		Number of Water Wells with Apparent Yields			
Dalehurst	230	44	114	43	29
Upper Lacombe	9	2	4	2	1
Lower Lacombe	1	0	1	0	0
Haynes	20	1	6	6	7
Upper Scollard	46	7	19	7	13
Lower Scollard	41	7	28	2	4
Battle and Whitemud	0	0	0	0	0
Upper Horseshoe Canyon	51	13	23	7	8
Middle Horseshoe Canyon	24	4	12	4	4
Lower Horseshoe Canyon	20	5	10	1	4
Bearpaw	1	0	1	0	0
Oldman	2	1	1	0	0
Multiple Completions	118	35	53	17	13
Totals	563	119	272	89	83

* - does not include dry test holes

Table 7. Apparent Yields of Bedrock Aquifers

Apparent yields for water wells completed in the Upper Bedrock Aquifer(s) vary significantly over the County both with location and with depth. As Figure 23 shows, most apparent yields are less than 100 m³/day and the majority of the water wells are less than 100 metres deep. Most of the water wells with apparent yields of greater than 200 m³/day are less than 75 metres deep.

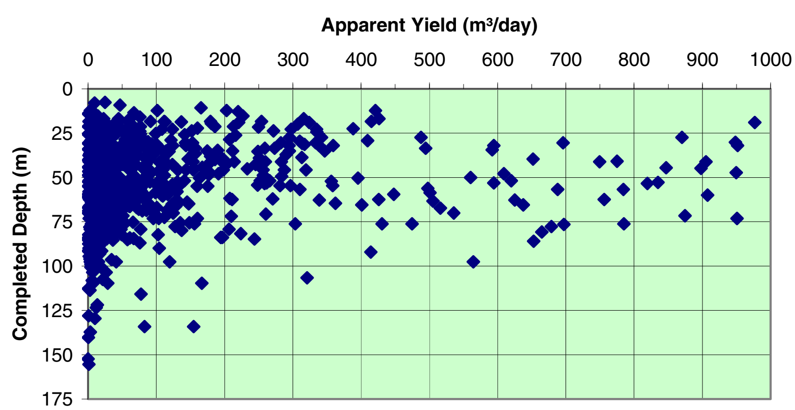


Figure 23. Bedrock Water Well Yields vs Completed Depth

6.3.3 Chemical Quality of Groundwater

The Piper tri-linear diagram for Upper Bedrock Aquifer(s) (page A-32) shows that groundwaters from bedrock aquifers are mainly sodium-sulfate-type waters; the majority of these groundwaters have a sodium ion concentration that exceeds 200 mg/L. Because the sodium concentration can be elevated, the groundwater can pose a risk to people on low-sodium diets.

In the County, approximately 47% of the groundwater samples from Upper Bedrock Aquifer(s) have fluoride concentrations that are too low (less than 0.5 mg/L) to meet the recommended daily needs of people. Approximately 30% of the groundwater samples from the entire County are between 0.5 and 1.5 mg/L and approximately 23% exceed the MAC for fluoride of 1.5 mg/L, with fluoride concentrations of greater than five mg/L occurring in the western part of the County (see CD-ROM).

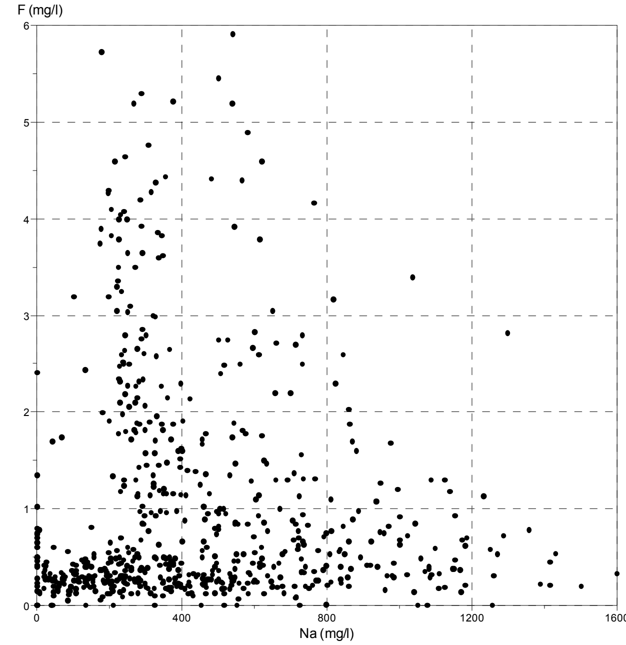


Figure 24. Fluoride vs Sodium Concentrations in Groundwater in Upper Bedrock Aquifer(s)

The fluoride concentrations in the groundwaters appear to be a function of the sodium concentration. Below a sodium concentration of 200 mg/L, there is generally very little fluoride in the groundwater. When the sodium concentration reaches 250 mg/L, the maximum fluoride concentration can increase dramatically. As the sodium concentration increases, the maximum solubility of fluoride decreases and once the sodium concentration reaches 900 mg/L, the maximum solubility of fluoride is mainly below the MAC of 1.5 mg/L, as shown above in Figure 24 and on page A-36.

The TDS concentrations in the groundwaters from the Upper Bedrock Aquifer(s) range from less than 500 mg/L to 5,000 mg/L, with most of the groundwaters with higher TDS concentrations occurring in the southern half of the County (see page A-35). In the County, the relationship between TDS and sulfate concentrations shows that when TDS values in the groundwaters from the Upper Bedrock Aquifer(s) exceed 800 mg/L, the sulfate concentrations exceed 400 mg/L.

In the County, 97% of the chloride concentrations in the groundwaters from the Upper Bedrock Aquifer(s) are less than 250 mg/L. In the County, there were 45 groundwater samples that had Nitrate + Nitrite (as N) concentrations that were greater than the SGCDWQ for the Upper Bedrock Aquifer(s). Approximately 70% of the total hardness values in the groundwaters from the Upper Bedrock Aquifer(s) are less than 300 mg/L.

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	1,178	115	9,520	1,456	500
Sodium	761	0	2,810	363	200
Sulfate	1,190	0	5,040	480	500
Chloride	1,190	0	3,850	25	250
Fluoride	1,178	0	9.66	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)

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Table 8. Concentrations of Constituents in Groundwaters from Upper Bedrock Aquifer(s)

The minimum, maximum and median 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 SGCDWQ in Table 8. Of the five constituents compared to the SGCDWQ, median concentrations of TDS and sodium exceed the guidelines.

6.3.4 Dalehurst Aquifer

The Dalehurst Aquifer comprises the permeable parts of the Dalehurst Member, as defined for the present program. The Dalehurst Member subcrops under the surficial deposits in the western third of the County. The thickness of the Dalehurst Member varies from less than two metres at the eastern edge of the subcrop to 200 metres in the western part of the County. The regional groundwater flow direction in the Dalehurst Aquifer is downgradient, southwest toward the Little Bow River and northeast toward the Bow River (see CD-ROM).

6.3.4.1 Depth to Top

The depth to the top of the Dalehurst Member is mainly less than 20 metres and is a reflection of the thickness of the surficial deposits.

6.3.4.2 Apparent Yield

The apparent yields for individual water wells completed through the Dalehurst Aquifer range mainly from 10 to 300 m³/day, and have a median apparent yield value of 32 m³/day. The higher yielding areas appear to be mainly north of township 017 and west of range 23, W4M, as shown on Figure 25.

There are ten "dry" water test holes that are completed in the Dalehurst Aquifer.

There are 165 licensed and/or registered groundwater users that have water wells completed through the Dalehurst Aquifer, for a total groundwater diversion of 1,386 m³/day, with a median authorized amount of 1.6 m³/day. The highest authorized groundwater use is for a water supply well completed to a depth of 54.9 metres BGL in the Dalehurst Aquifer that is licensed to divert 681 m³/day for agricultural (stockwater) purposes in 01-22-018-26 W4M.

Eighty-five of the 165 licences and/or registrations could be linked to water wells in the AENV groundwater database.

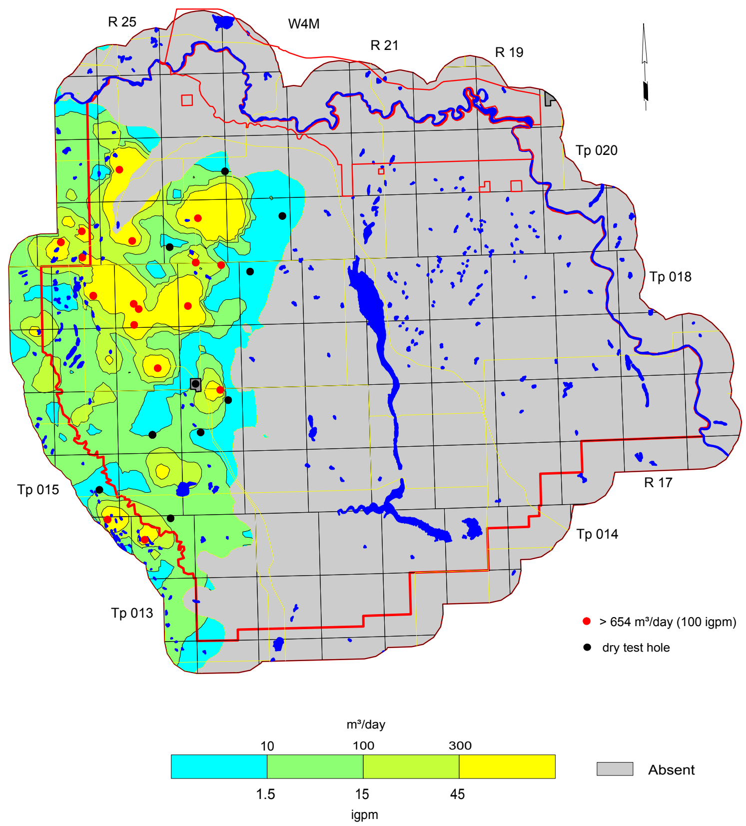

Figure 25. Apparent Yield for Water Wells Completed through Dalehurst Aquifer

6.3.4.3 Quality

The groundwaters from the Dalehurst Aquifer are mainly a sodium-sulfate-type (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging from less than 500 to more than 3,000 mg/L (page A-39). Sixty percent of the TDS concentrations in groundwater from the Dalehurst Aquifer are greater than 1,000 mg/L. The higher TDS values are expected at the eastern edge of the Aquifer. Fifty percent of the sulfate concentrations in groundwaters from the Dalehurst Aquifer are greater than 500 mg/L. The sulfate concentrations of greater than 1,000 mg/L are expected mainly at the eastern edge of the Aquifer. Eighty percent of the chloride concentrations from the Dalehurst Aquifer are less than 50 mg/L, and 30% of the groundwater samples have fluoride concentrations that are greater than 1.5 mg/L.

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS and sodium exceed the guidelines. The median concentrations of fluoride from water wells completed in the Dalehurst Aquifer are greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	592	117	7,918	1200	1,456	500
Sodium	356	0.0	1,619	348	363	200
Sulfate	594	0	4,848	479	480	500
Chloride	595	0	815	25	25	250
Fluoride	500	0	10	0.8	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)
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Table 9. Apparent Concentrations of Constituents in Groundwater from Dalehurst Aquifer

6.3.5 Upper Lacombe Aquifer

The Upper Lacombe Aquifer comprises the permeable parts of the Upper Lacombe Member that underlie the Dalehurst Member. Structure contours have been prepared for the top of the Upper Lacombe Member. The structure contours show that the Upper Lacombe Member ranges in elevation from less than 830 to more than 890 metres AMSL and has a maximum thickness of 65 metres. The regional groundwater flow direction in the Upper Lacombe Aquifer is downgradient, southwest toward the Little Bow River and northeast toward the Bow River (see CD-ROM).

6.3.5.1 Depth to Top

The depth to the top of the Upper Lacombe Member ranges from less than 25 metres to more than 200 metres in the extreme western part of the County (page A-40).

6.3.5.2 Apparent Yield

The apparent yields for individual water wells completed through the Upper Lacombe Aquifer are mainly in the range of 10 to 300 m³/day, and have a median apparent yield value of 13 m³day. The higher yielding areas appear to be at the eastern edge of the Aquifer, as shown on Figure 26. There are little or no data for the Aquifer in the western parts of the County. In these areas, the depth to burial is more than 100 metres below ground surface.

There are no “dry” water test holes completed in the Upper Lacombe Aquifer.

There are seven licensed and/or registered groundwater users that have water wells completed through the Upper Lacombe Aquifer, for a total authorized groundwater diversion of 18 m³/day, with a median authorized amount of 1.3 m³/day. The highest authorized groundwater use is for a water supply well completed to a depth of 33.5 metres BGL in the Upper Lacombe Aquifer that is registered to divert nine m³/day in SW 22-020-24 W4M.

Three of the seven licences and/or registrations could be linked to water wells in the AENV groundwater database.

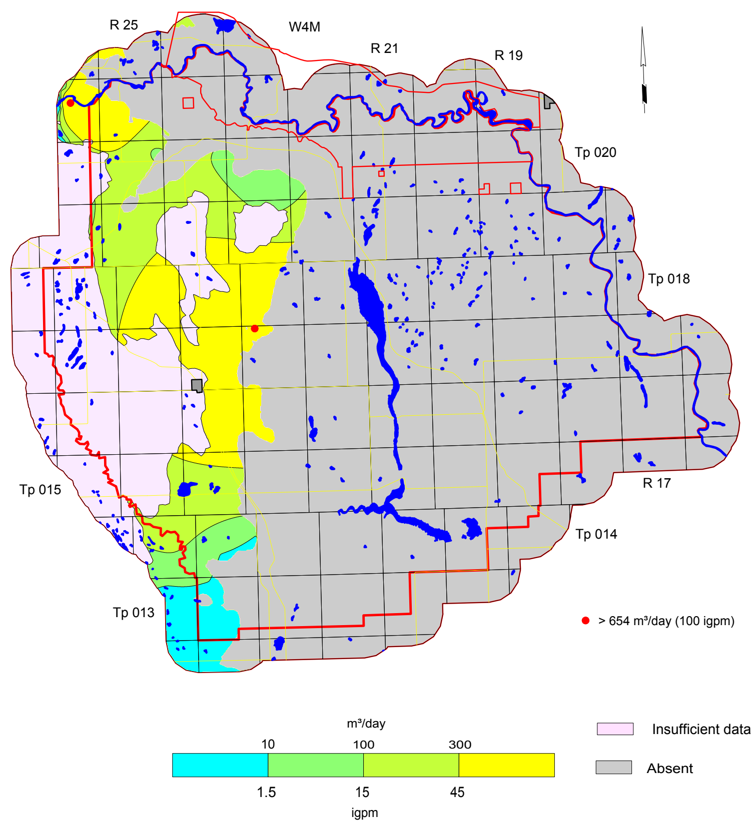

Figure 26. Apparent Yield for Water Wells Completed through Upper Lacombe Aquifer

6.3.5.3 Quality

The groundwaters from the Upper Lacombe Aquifer are mainly a sodium-sulfate-type (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging from less than 500 to more than 3,000 mg/L (page A-42). Sixty-seven percent of the TDS concentrations in groundwater from the Upper Lacombe Aquifer are greater than 1,000 mg/L. The higher TDS values are expected at the southeastern and northeastern edge of the Aquifer. Forty-six percent of the sulfate concentrations in groundwaters from the Upper Lacombe Aquifer are greater than 500 mg/L. The sulfate concentrations of greater than 1,000 mg/L are expected mainly at the southeastern edge of the Aquifer. Ninety percent of the chloride concentrations from the Upper Lacombe Aquifer are less than 50 mg/L, and 30% of the groundwater samples have fluoride concentrations that are greater than 1.5 mg/L.

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS and sodium exceed the guidelines. The median concentrations of sulfate and fluoride from water wells completed in the Upper Lacombe Aquifer are greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	46	158	4,416	1242	1,456	500
Sodium	27	68	798	326	363	200
Sulfate	46	5	2,811	496	480	500
Chloride	46	3	206	18	25	250
Fluoride	42	0	4	0.6	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)

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Federal-Provincial Subcommittee on Drinking Water, March 2006

Table 10. Apparent Concentrations of Constituents in Groundwaters from Upper Lacombe Aquifer

6.3.6 Lower Lacombe Aquifer

The Lower Lacombe Aquifer comprises the permeable parts of the Lower Lacombe Member that underlie the Upper Lacombe Member. Structure contours have been prepared for the top of the Lower Lacombe Member. The structure contours show that the Lower Lacombe Member ranges in elevation from less than 770 to more than 990 metres AMSL and has a maximum thickness of 35 metres. The regional groundwater flow direction in the Lower Lacombe Aquifer is downgradient, southwest toward the Little Bow River and northeast toward the Bow River (see CD-ROM).

6.3.6.1 Depth to Top

The depth to the top of the Lower Lacombe Member ranges from less than 25 metres below ground surface at the eastern extent to more than 250 metres in the extreme western part of the County (page A-43).

6.3.6.2 Apparent Yield

In the County, there is one water well completed in the Lower Lacombe Aquifer with an apparent yield value. The water well is completed to a depth of 96.3 metres BGL in SW 29-019-25 W4M, and has an apparent yield of 34 m³/day.

There are five registered groundwater users that have water wells completed through the Lower Lacombe Aquifer, for a total registered groundwater diversion of 11 m³/day, with a median authorized amount of 1.7 m³/day. The highest authorized groundwater use is for a water supply well completed to a depth of 67.0 metres BGL in the Lower Lacombe Aquifer that is registered to divert 3.9 m³/day in NW 20-018-23 W4M. Three of the five registrations could be linked to water wells in the AENV groundwater database.

6.3.6.3 Quality

The groundwaters from the Lower Lacombe Aquifer are a sodium-bicarbonate to sulfate-type (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging from less than 500 to nearly 3,000 mg/L (page A-44). Seventy-three percent of the TDS concentrations in groundwater from the Lower Lacombe Aquifer are greater than 1,000 mg/L. The higher TDS values are expected at the southeastern and northeastern edge of the Aquifer. Fifty-six percent of the sulfate concentrations in groundwaters from the Lower Lacombe Aquifer are greater than 500 mg/L. The sulfate concentrations of greater than 1,000 mg/L are expected mainly at the eastern edges of the Aquifer. Eighty-seven percent of the chloride concentrations from the Lower Lacombe Aquifer are less than 50 mg/L, and 86% of the groundwater samples have fluoride concentrations that are less than 1.5 mg/L.

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	15	487	2,980	1494	1,456	500
Sodium	10	88	807	235	363	200
Sulfate	16	170	1,338	649	480	500
Chloride	15	4	145	20	25	250
Fluoride	14	0	3	0.5	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)

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Table 11. Apparent Concentrations of Constituents in Groundwaters from Lower Lacombe Aquifer

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS, sodium and sulfate exceed the guidelines. The median concentrations of TDS, sulfate and fluoride from water wells completed in the Lower Lacombe Aquifer are greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

6.3.7 Haynes Aquifer

The Haynes Aquifer comprises the permeable parts of the Haynes Member that underlie the Lower Lacombe Member. Structure contours have been prepared for the top of the Haynes Member. The structure contours show that the Haynes Member ranges in elevation from less than 730 to more than 990 metres AMSL and has a maximum thickness of 45 metres. The regional groundwater flow direction in the Haynes Aquifer is downgradient, southwest toward the Little Bow River and northeast toward the Bow River (see CD-ROM).

6.3.7.1 Depth to Top

The depth to the top of the Haynes Member ranges from less than 25 metres below ground surface at the eastern extent to more than 300 metres in the extreme western part of the County (page A-45).

6.3.7.2 Apparent Yield

The apparent yields for individual water wells completed through the Haynes Aquifer are mainly greater than 100 m³/day, and have a median apparent yield value of 83 m³/day. The higher yielding areas appear to be mainly at the eastern edge of the Aquifer, as shown on Figure 27.

There are little or no data for the Aquifer in the western parts of the County. In these areas, the depth to burial is more than 100 metres below ground surface.

There are two “dry” water test holes that are completed in the Haynes Aquifer.

There are 16 licensed and/or registered groundwater users that have water wells completed through the Haynes Aquifer, for a total authorized groundwater diversion of 188 m³/day, with a median authorized amount of 8.9 m³/day. The highest allocation is for a water supply well completed to a depth of 62.4 metres below ground surface in the Haynes Aquifer that is licensed to divert 47 m³/day for agricultural (stock) purposes in 04-22-021-25 W4M.

Seven of the 16 licences and/or registrations could be linked to water wells in the AENV groundwater database.

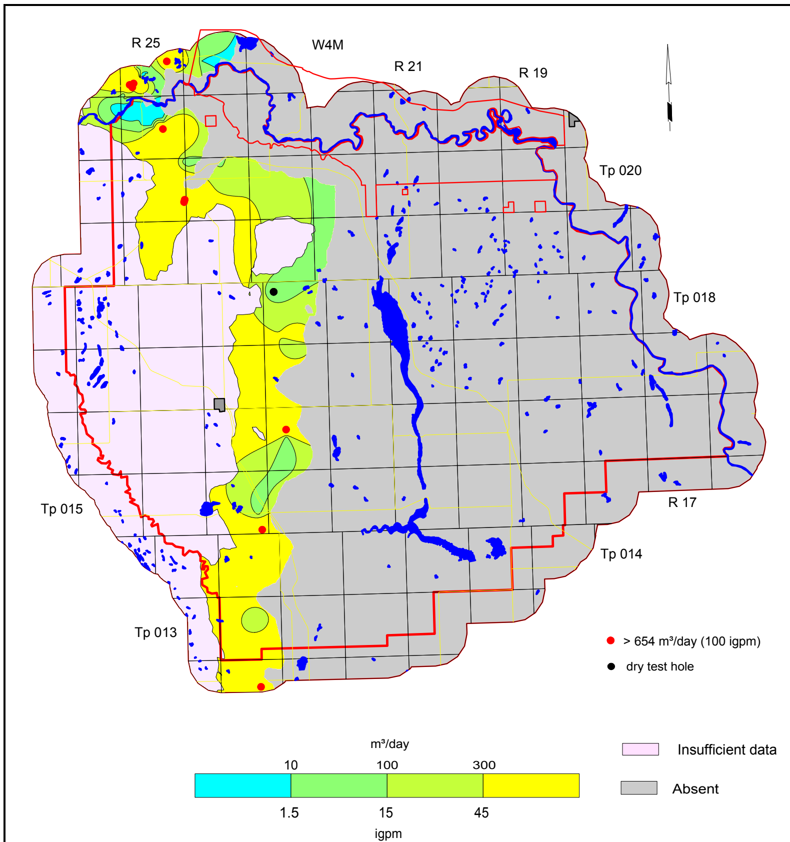

Figure 27. Apparent Yield for Water Wells Completed through Haynes Aquifer

6.3.7.3 Quality

The groundwaters from the Haynes Aquifer are mainly a sodium-bicarbonate to sodium-sulfate-type (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging from less than 500 to more than 3,000 mg/L (page A-47). Eighty-five percent of the TDS concentrations in groundwater from the Haynes Aquifer are greater than 1,000 mg/L. The higher TDS values are expected at the eastern edge of the Aquifer. Fifty-seven percent of the sulfate concentrations in groundwaters from the Haynes Aquifer are greater than 500 mg/L. The sulfate concentrations of greater than 1,000 mg/L are expected mainly at the eastern edge of the Aquifer. Eighty percent of the chloride concentrations from the Haynes Aquifer are less than 50 mg/L, and 80% of the groundwater samples have fluoride concentrations that are less than 1.5 mg/L.

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS, sodium and sulfate exceed the guidelines. The median concentrations of the five constituents from water wells completed in the Haynes Aquifer are greater than or equal to the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	60	422	7,952	1,616	1,456	500
Sodium	33	8	1,946	481	363	200
Sulfate	61	75	5,040	686	480	500
Chloride	61	2	255	25	25	250
Fluoride	50	0	5	0.6	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)

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Table 12. Apparent Concentrations of Constituents in Groundwaters from Haynes Aquifer

6.3.8 Upper Scollard Aquifer

The Upper Scollard Aquifer comprises the permeable parts of the Upper Scollard Formation that underlie the Haynes Member. Structure contours have been prepared for the top of the Formation. The structure contours show that the Upper Scollard Formation ranges in elevation from less than 680 to more than 1,000 metres AMSL and has a maximum thickness that is in the order of 85 metres. The regional groundwater flow direction in the Upper Scollard Aquifer is downgradient, northeast toward the Bow River (see CD-ROM).

6.3.8.1 Depth to Top

The depth to the top of the Upper Scollard Formation ranges from less than 25 metres below ground surface at the eastern extent to more than 325 metres in the extreme western part of the County (page A-48).

6.3.8.2 Apparent Yield

The apparent yields for individual water wells completed through the Upper Scollard Aquifer range from less than ten to greater than 300 m³/day, and have a median apparent yield value of 56 m³/day.

There are little or no data for the Aquifer in the western parts of the County. In these areas, the depth to burial is more than 100 metres below ground surface.

There two “dry” water test holes that are completed in the Upper Scollard Aquifer.

There are 31 licensed and/or registered groundwater users that have water wells completed through the Upper Scollard Aquifer, for a total authorized groundwater diversion of 1,379 m³/day, of which 1,055 m³/day (77%) is used to divert groundwater from three water supply wells for agricultural (stock) purposes in section 08, township 021, range 24, W4M.

Fifteen of the 31 licences and/or registrations could be linked to water wells in the AENV groundwater database.

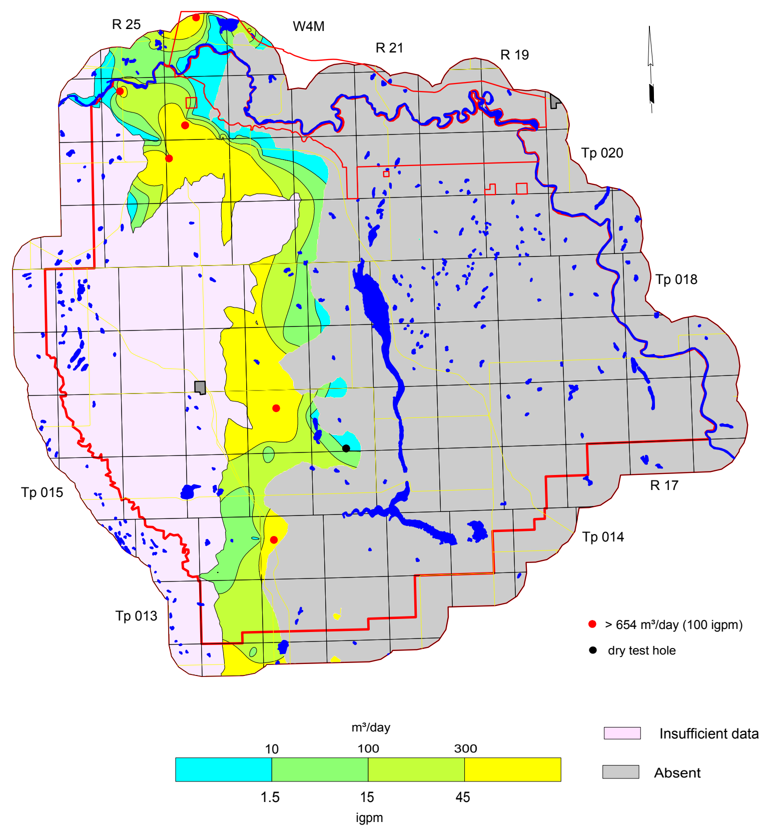

Figure 28. Apparent Yield for Water Wells Completed through Upper Scollard Aquifer

6.3.8.3 Quality

The groundwaters from the Upper Scollard Aquifer are mainly a sodium-bicarbonate to sodium-sulfate-type (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging from less than 500 to more than 3,000 mg/L (page A-50). Fixty-six percent of the TDS concentrations in groundwater from the Upper Scollard Aquifer are greater than 1,000 mg/L. The higher TDS values are expected at the eastern edge of the Aquifer. Fifty percent of the sulfate concentrations in groundwaters from the Upper Scollard Aquifer are greater than 500 mg/L. The sulfate concentrations of greater than 1,000 mg/L are expected mainly at the southeastern edge of the Aquifer. Nearly 90% of the chloride concentrations from the Upper Scollard Aquifer are less than 50 mg/L, and 86% of the groundwater samples have fluoride concentrations that are less than 1.5 mg/L.

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS and sodium exceed the guidelines. The median concentrations for TDS, sodium, sulfate, chloride, and fluoride from water wells completed in the Upper Scollard Aquifer are all less than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	84	414	3,058	1,358	1,456	500
Sodium	52	0	857	278	363	200
Sulfate	85	10	1,728	385	480	500
Chloride	85	3	290	21	25	250
Fluoride	74	0	6	0.3	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)

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Table 13. Apparent Concentrations of Constituents in Groundwaters from Upper Scollard Aquifer

6.3.9 Lower Scollard Aquifer

The Lower Scollard Aquifer comprises the porous and permeable parts of the Lower Scollard Formation that underlie the Upper Scollard Formation. Structure contours have been prepared for the top of the Formation. The structure contours show that the Lower Scollard Formation ranges in elevation from less than 600 to more than 1,020 metres AMSL and has a maximum thickness of 50 metres. The regional groundwater flow direction in the Lower Scollard Aquifer is downgradient, northeast toward the Bow River (see CD-ROM).

6.3.9.1 Depth to Top

The depth to the top of the Lower Scollard Formation ranges from less than 25 metres below ground surface at the eastern extent to more than 400 metres in the extreme western part of the County (page A-51).

6.3.9.2 Apparent Yield

The apparent yields for individual water wells completed through the Lower Scollard Aquifer range mainly from 10 to 100 m³/day, and have a median apparent yield value of 34 m³/day. There are little or no data for the Aquifer in the western parts of the County. In these areas, the depth to burial is more than 130 metres below ground surface.

There are two “dry” water test holes that are completed in the Lower Scollard Aquifer.

In the County, there are 18 licensed and/or registered groundwater users that have water wells that are completed in the Lower Scollard Aquifer, for a total authorized diversion of 83 m³/day, of which 57 m³/day (69%) is used to divert groundwater from two water supply wells for municipal (cooperative) and agricultural (stock) purposes in NW 32-021-24 W4M.

Seven of the 18 licences and/or registrations could be linked to water wells in the AENV groundwater database

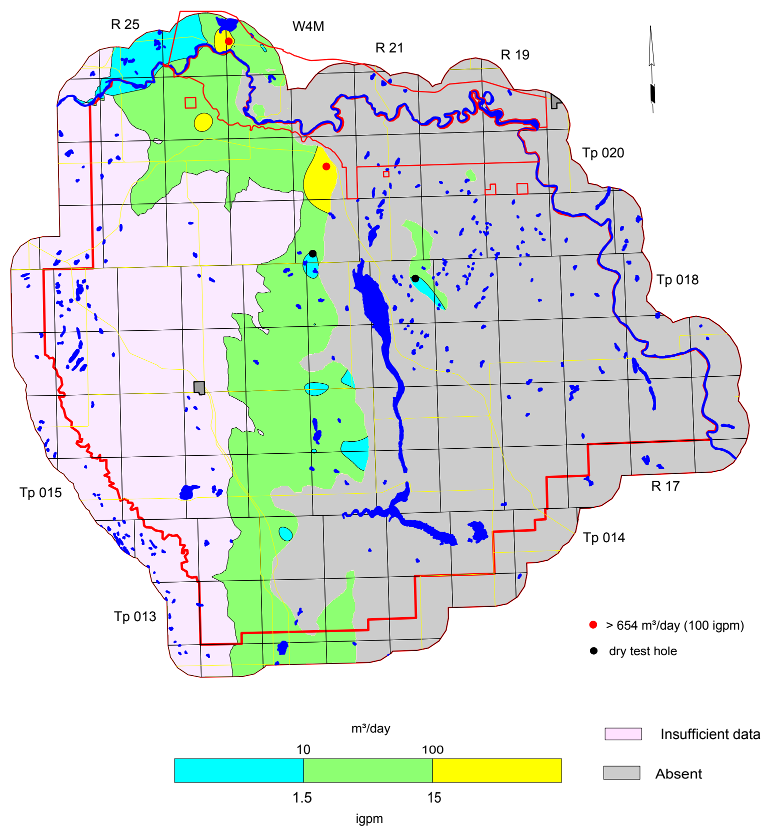

Figure 29. Apparent Yield for Water Wells Completed through Lower Scollard Aquifer

6.3.9.3 Quality

The groundwaters from the Lower Scollard Aquifer are mainly a sodium-bicarbonate to sodium-sulfate-type (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging from less than 500 to more than 3,000 mg/L (page A-53). More than 70% of the TDS concentrations in groundwater from the Lower Scollard Aquifer are greater than 1,000 mg/L. The higher TDS values are expected at the southeastern edge of the Aquifer. Forty-six percent of the sulfate concentrations in groundwaters from the Lower Scollard Aquifer are greater than 500 mg/L. The sulfate concentrations of greater than 1,000 mg/L are expected mainly at the southeastern edge of the Aquifer. Nearly eighty percent of the chloride concentrations from the Lower Scollard Aquifer are less than 50 mg/L, and 85% of the groundwater samples have fluoride concentrations that are less than 1.5 mg/L.

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS and sodium exceed the guidelines. The median concentrations of TDS and sodium from water wells completed in the Lower Scollard Aquifer are also greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	57	248	5,250	1,538	1,456	500
Sodium	36	0	1,600	430	363	200
Sulfate	59	0	2,500	480	480	500
Chloride	58	0	455	19	25	250
Fluoride	53	0	4	0.4	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)
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Table 14. Apparent Concentrations of Constituents in Groundwaters from Lower Scollard Aquifer

6.3.10 Upper Horseshoe Canyon Aquifer

The Upper Horseshoe Canyon Aquifer comprises the permeable parts of the Upper Horseshoe Canyon Formation that underlie the Battle Formation. Structure contours have been prepared for the top of the Formation. The structure contours show that the Upper Horseshoe Canyon Formation ranges in elevation from less than 540 to more than 960 metres AMSL and has a maximum thickness of 95 metres. The regional groundwater flow direction in the Upper Horseshoe Canyon Aquifer is downgradient, north toward the Bow River and toward McGregor Lake from the east and west (see CD-ROM).

6.3.10.1 Depth to Top

The depth to the top of the Upper Horseshoe Canyon Formation is variable, ranging from less than 25 metres at the eastern extent to more than 500 metres in the extreme western part of the County (page A-55).

6.3.10.2 Apparent Yield

The apparent yields for individual water wells completed through the Upper Horseshoe Canyon Aquifer range mainly from 10 to 100 m³/day, and have a median apparent yield value of 36 m³/day. There are little or no data for the Aquifer in the western parts of the County. In these areas, the depth to burial is more than 150 metres below ground surface.

There are 11 "dry" water test holes that are completed in the Upper Horseshoe Canyon Aquifer.

In the County, there are 21 licensed and/or registered groundwater users with water wells that are completed in the Upper Horseshoe Canyon Aquifer, for a total authorized diversion of 38 m³/day, with a median authorized amount of 1.3 m³/day. The highest allocation is for a water supply well completed to a depth of 25.6 metres below ground surface in the Upper Horseshoe Canyon Aquifer that is registered to divert 4.6 m³/day in NE 28-018-20 W4M.

Ten of the 21 licensed and/or registered water wells could be linked to a water well in the AENV groundwater database.

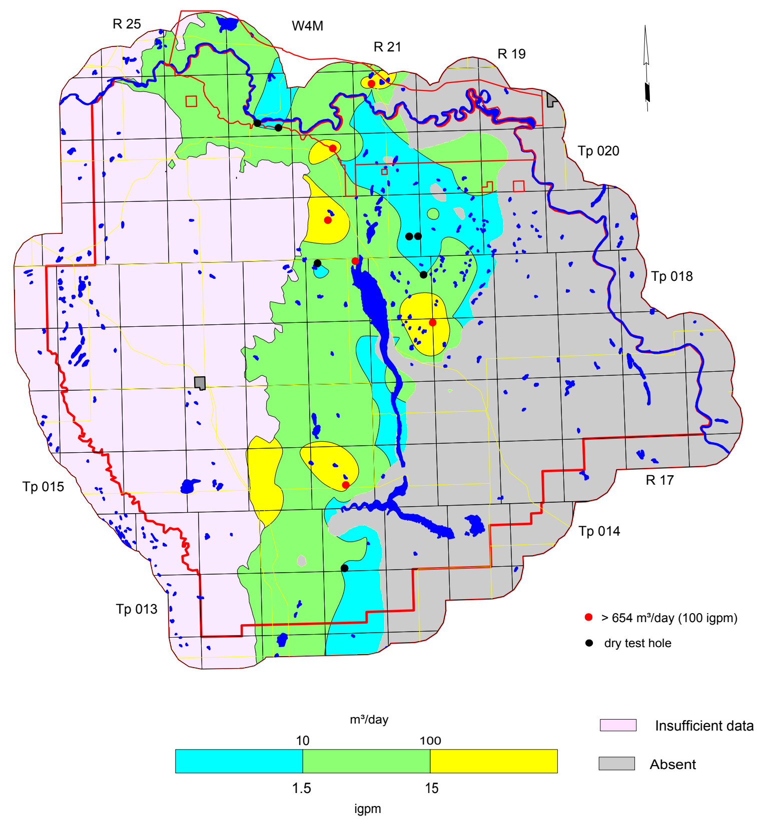

Figure 30. Apparent Yield for Water Wells Completed through Upper Horseshoe Canyon Aquifer

6.3.10.3 Quality

The groundwaters from the Upper Horseshoe Canyon Aquifer are mainly a sodium-type with no dominant anion (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging mainly from 500 to 3,000 mg/L (page A-57). Nearly 60% of the TDS concentrations in groundwater from the Upper Horseshoe Canyon Aquifer are greater than 2,000 mg/L. The higher TDS values are expected at the eastern edge of the Aquifer. Forty-three percent of the sulfate concentrations in groundwaters from the Upper Horseshoe Canyon Aquifer are greater than 500 mg/L. The sulfate concentrations of greater than 1,000 mg/L are expected mainly at the southeastern edge of the Aquifer. Nearly 80% of the chloride concentrations from the Upper Horseshoe Canyon Aquifer are less than 100 mg/L. The fluoride concentrations in the groundwaters from the Upper Horseshoe Canyon Aquifer exceed the MAC of 1.5 mg/L in one of the 75 groundwater samples analyzed (up to about 1986).

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	94	292	6,420	2,194	1,456	500
Sodium	71	0	1,420	460	363	200
Sulfate	99	0	2,802	396	480	500
Chloride	99	0	694	40	25	250
Fluoride	75	0	4	0.4	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)
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Table 15. Apparent Concentrations of Constituents in Groundwaters from Upper Horseshoe Canyon Aquifer

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS and sodium exceed the guidelines. The median concentrations of TDS, sodium and chloride from water wells completed in the Upper Horseshoe Canyon Aquifer are greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

6.3.11 Middle Horseshoe Canyon Aquifer

The Middle Horseshoe Canyon Aquifer comprises the permeable parts of the Middle Horseshoe Canyon Formation that underlie the Upper Horseshoe Canyon Formation. The structure contours show that the Middle Horseshoe Canyon Formation ranges in elevation from less than 450 to more than 930 metres AMSL and has a maximum thickness of 50 metres. The regional groundwater flow direction in the Middle Horseshoe Canyon Aquifer is downgradient, northwest toward the Bow River (see CD-ROM).

6.3.11.1 Depth to Top

The depth to the top of the Middle Horseshoe Canyon Formation is variable, ranging from less than 25 metres at the eastern extent to more than 525 metres in the extreme southwestern part of the County (page A-58).

6.3.11.2 Apparent Yield

The apparent yields for individual water wells completed through the Middle Horseshoe Canyon Aquifer range mainly from 10 to 100 m³/day, and have a median apparent yield value of 40 m³/day. There are little or no data for the Aquifer in the western parts of the County. In these areas, the depth to burial is more than 130 metres below ground surface.

There is one "dry" water test hole that is completed in the Middle Horseshoe Canyon Aquifer.

In the County, there are 12 licensed and/or registered groundwater users with water wells that are completed in the Middle Horseshoe Canyon Aquifer, for a total authorized diversion of 42 m³/day, with a median authorized amount of 3.7 m³/day. The highest allocation is for a water supply well completed to a depth of 73.2 metres below ground surface in the Middle Horseshoe Canyon Aquifer that is registered to divert 11.7 m³/day in SW 18-019-021 W4M.

Three of the 12 licensed and/or registered water wells could be linked to a water well in the AENV groundwater database.

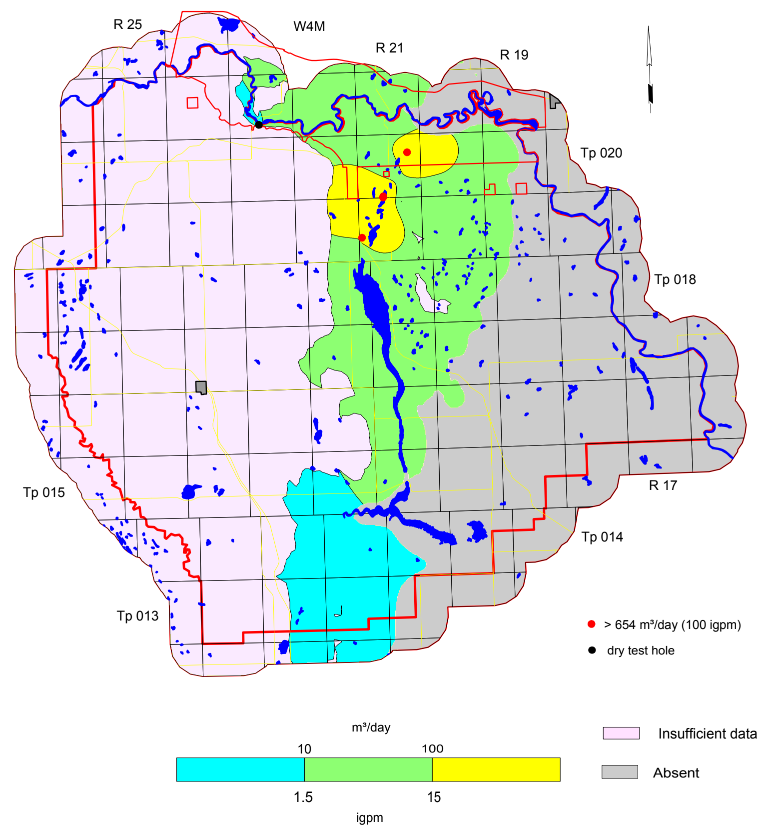

Figure 31. Apparent Yield for Water Wells Completed through Middle Horseshoe Canyon Aquifer

6.3.11.3 Quality

The groundwaters from the Middle Horseshoe Canyon Aquifer are mainly a sodium-type with no dominant anion (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging mainly from more than 1,000 to more than 3,000 mg/L (page A-60). All 16 groundwater samples analyzed from the Middle Horseshoe Canyon Aquifer have TDS concentrations of greater than 1,000 mg/L. The higher TDS values are expected within the southern part of the Aquifer. Seventy-five percent of the sulfate concentrations in groundwaters from the Middle Horseshoe Canyon Aquifer are less than 500 mg/L. The sulfate concentrations of greater than 1,000 mg/L are expected mainly at the southeastern edge of the Aquifer. Sixty-three percent of the chloride concentrations from the Middle Horseshoe Canyon Aquifer are less than 100 mg/L. All 12 groundwater samples analyzed for fluoride from the Middle Horseshoe Canyon Aquifer have fluoride concentrations of less than the MAC of 1.5 mg/L.

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS and sodium exceed the guidelines. The median concentrations of TDS, sodium and chloride in the Middle Horseshoe Canyon Aquifer are greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	16	1070	7,300	1,950	1,456	500
Sodium	14	0	2,810	572	363	200
Sulfate	16	0	1,580	153	480	500
Chloride	16	5	3850	48	25	250
Fluoride	12	0	1.2	0.4	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)
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Federal-Provincial Subcommittee on Drinking Water, March 2006

Table 16. Apparent Concentrations of Constituents in Groundwaters from Middle Horseshoe Canyon Aquifer

6.3.12 Lower Horseshoe Canyon Aquifer

The Lower Horseshoe Canyon Aquifer comprises the permeable parts of the Lower Horseshoe Canyon Formation that underlie the Lower Horseshoe Canyon Formation. The Lower Horseshoe Canyon Formation is present under the surficial deposits in most of the County. Structure contours have been prepared for the top of the Formation. The structure contours show that the Lower Horseshoe Canyon Formation ranges in elevation from less than 400 to more than 920 metres AMSL and has a maximum thickness of 145 metres. The regional groundwater flow direction in the Lower Horseshoe Canyon Aquifer is downgradient, north toward the Bow River and south and north toward McGregor Lake (see CD-ROM).

6.3.12.1 Depth to Top

The depth to the top of the Lower Horseshoe Canyon Formation is variable, ranging from less than 25 metres at the eastern extent to more than 600 metres in the extreme southwestern part of the County (page A-61).

6.3.12.2 Apparent Yield

The apparent yields for individual water wells completed through the Lower Horseshoe Canyon Aquifer range mainly from 10 to 100 m³/day, and have a median apparent yield value of 18 m³/day. There are little or no data for the Aquifer in the western half of the County. In this area, the depth to burial is more than 130 metres below ground surface.

There are 14 "dry" water test holes that are completed in the Lower Horseshoe Canyon Aquifer.

In the County, there are seven licensed and/or registered groundwater users with water wells that are completed in the Lower Horseshoe Canyon Aquifer, for a total authorized diversion of 11 m³/day, with a median authorized amount of 1.0 m³/day. The highest allocation is for a water supply well completed to a depth of 94.4 metres below ground surface in the Lower Horseshoe Canyon Aquifer that is licensed to divert 3.0 m³/day for agricultural (stock) purposes in 07-05-020-20 W4M.

Three of the seven licensed and/or registered water wells could be linked to a water well in the AENV groundwater database.

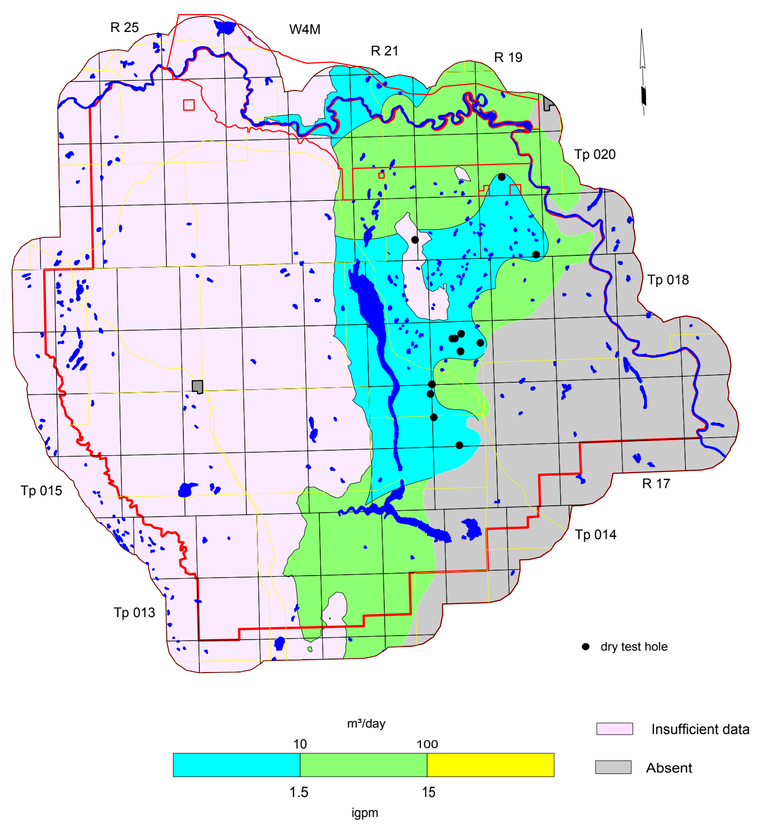

Figure 32. Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer

6.3.12.3 Quality

The groundwaters from the Lower Horseshoe Canyon Aquifer are mainly a sodium-bicarbonate to sodium-sulfate-type (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging mainly from 500 to more than 3,000 mg/L (page A-63). All 17 groundwater samples analyzed from the Lower Horseshoe Canyon Aquifer have TDS concentrations of greater than 1,000 mg/L. Fifty-three percent of the sulfate concentrations in groundwaters from the Lower Horseshoe Canyon Aquifer are greater than 500 mg/L. Eighty-two percent of the chloride concentrations from the Lower Horseshoe Canyon Aquifer are less than 50 mg/L. All 12 groundwater samples analyzed for fluoride from the Lower Horseshoe Canyon Aquifer have fluoride concentrations of less than the MAC of 1.5 mg/L.

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS, sodium and sulfate exceed the guidelines. The median concentrations of TDS, sodium and sulfate from water wells completed in the Lower Horseshoe Canyon Aquifer are also greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	17	1290	3,436	2,322	1,456	500
Sodium	11	0	979	690	363	200
Sulfate	17	31	1,335	560	480	500
Chloride	17	4	112	22	25	250
Fluoride	12	0	0.9	0.3	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)
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Table 17. Apparent Concentrations of Constituents in Groundwaters from Lower Horseshoe Canyon Aquifer

6.3.13 Bearpaw Aquifer

The Bearpaw Aquifer comprises the permeable parts of the Bearpaw Formation that underlie the Lower Horseshoe Canyon Formation. The structure contours show that the Bearpaw Formation ranges in elevation from less than 220 to more than 880 metres AMSL and has a thickness of up to 145 metres. The regional groundwater flow direction in the Upper Lacombe Aquifer is downgradient north and east toward the Bow River (see CD-ROM).

6.3.13.1 Depth to Top

The depth to the top of the Bearpaw Formation is variable, ranging from less than 25 metres at the eastern extent to more than 725 metres in the extreme southwestern part of the County (page A-64).

6.3.13.2 Apparent Yield

In the County, there are two water wells completed in the Bearpaw Aquifer with apparent yield values and eight "dry" water test holes that are completed in the Bearpaw Aquifer; one water well, in SE 25-017-19 W4M, has an apparent yield of 11.7 m³/day, and the second water well, in 12-13-014-20 W4M, has an apparent yield of 8.3 m³/day. There are little or no data for the Aquifer in the western two-thirds of the County. In these areas, the depth to burial is more than 120 metres below ground surface.

In the County, there are two registered groundwater users with water wells that are completed in the Upper Horseshoe Canyon Aquifer, for a total authorized diversion of five m³/day. One of the two registered water wells could be linked to a water well in the AENV groundwater database.

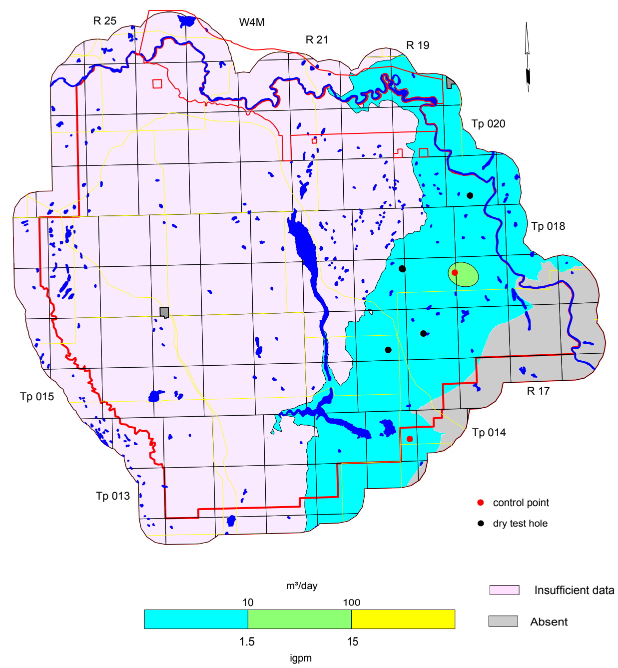

Figure 33. Apparent Yield for Water Wells Completed through Bearpaw Aquifer

6.3.13.3 Quality

The groundwaters from the Bearpaw Aquifer are mainly a sodium-bicarbonate to sodium-sulfate-type (see Piper diagram on CD-ROM), with groundwater samples having TDS concentrations ranging from less than 1,000 to more than 3,000 mg/L (page A-66). Twelve of the 13 groundwater samples analyzed from the Bearpaw Aquifer have TDS concentrations of greater than 1,000 mg/L. Seventy percent of the sulfate concentrations in groundwaters from the Bearpaw Aquifer are greater than 500 mg/L. More than 60% of the chloride concentrations from the Bearpaw Aquifer are less than 100 mg/L, and all 12 of the groundwater samples from the Bearpaw Aquifer have fluoride concentrations that are less than 1.5 mg/L.

Constituent	No. of Analyses	Range for County in mg/L Minimum	Maximum	Median	All Bedrock Median	Recommended Maximum Concentration SGCDWQ
Total Dissolved Solids	13	669	4,780	2,534	1,456	500
Sodium	12	0	1,076	0	363	200
Sulfate	13	10	2,265	677	480	500
Chloride	13	4	276	44	25	250
Fluoride	12	0	1	0.1	0.4	1.5

Concentration in milligrams per litre unless otherwise stated
Note: indicated concentrations are for Aesthetic Objectives except for Fluoride, which is for Maximum Acceptable Concentration (MAC)
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Table 18. Apparent Concentrations of Constituents in Groundwaters from Bearpaw Aquifer

Of the five constituents that have been compared to the SGCDWQ, the median values of TDS and sulfate exceed the guidelines. The median concentrations of TDS, sulfate and chloride from water wells completed in the Bearpaw Aquifer are greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s).

6.3.14 Oldman Aquifer

The Oldman Aquifer comprises the permeable parts of the Oldman Formation that underlie the Bearpaw Formation and is present under all of the County. Structure contours have been prepared for the top of the Formation. The structure contours show that the Oldman Formation ranges in elevation from less than 120 to more than 740 metres AMSL and has a maximum thickness of 130 metres. There are insufficient non-pumping water-level data to determine the gradient in the Oldman Aquifer.

6.3.14.1 Depth to Top

The depth to the top of the Oldman Formation is variable, ranging from less than 25 metres at the eastern extent to more than 900 metres in the southwestern part of the County (page A-67).

6.3.14.2 Apparent Yield

The apparent yields for individual water wells completed through the Oldman Aquifer range mainly from 10 to 100 m³/day, and have a median apparent yield value of 20 m³/day. There are little or no data for the Aquifer in most of the County. In these areas, the depth to burial is more than 90 metres below ground surface.

There is one "dry" water test hole that is completed in the Oldman Aquifer.

In the County, there are two registered groundwater users with water wells that are completed in the Oldman Aquifer, for a total authorized diversion of four m³/day. One of the two registered water wells could be linked to a water well in the AENV groundwater database.

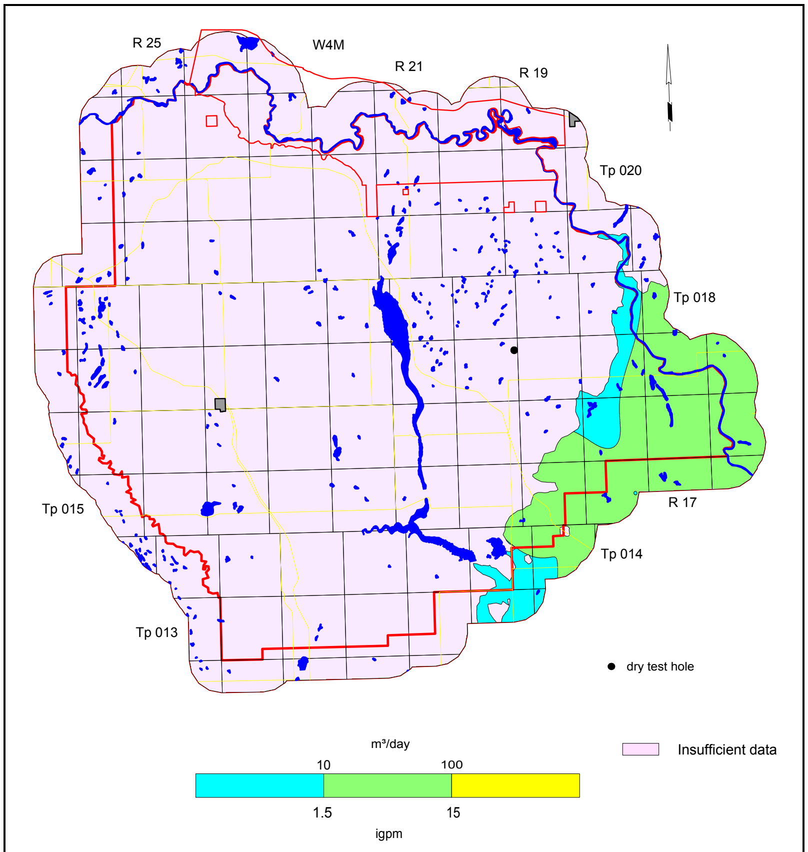

Figure 34. Apparent Yield for Water Wells Completed through Oldman Aquifer

6.3.14.3 Quality

In the County, there are two water wells completed in the Oldman Aquifer with sufficient data to determine the groundwater type; both water wells are a sodium-bicarbonate-type (see CD-ROM). There are four partial chemical analyses available for water wells completed in the Oldman Aquifer. Three of the four groundwater samples analyzed from the Oldman Aquifer have TDS concentrations of greater than 1,500 mg/L; three of the four analyses have sulfate concentrations of less than 500 mg/L; all four analyses have chloride concentrations of less than 250 mg/L, and all four analyses have fluoride concentrations of less than 1.5 mg/L.

7 GROUNDWATER BUDGET

7.1 Estimated Groundwater Use in Vulcan County

An estimate of the quantity of groundwater removed from each geologic unit in Vulcan County must include both the groundwater diversions with licences and/or registrations and the groundwater diversions without licences and/or registrations. As stated previously on page 12 of this report, the daily water requirement for livestock for the County based on the 2001 census is 4,952 cubic metres. As of late 2006, AENV has licensed the use of 7,373 m³/day for livestock, which includes both surface water (consumptive use) and groundwater. Based on these figures, it would appear that all livestock use is licensed and/or registered.

In the groundwater database for the County, there are records for 2,444 water wells that are used for domestic (1,617), domestic/stock (497) and stock (330) purposes. It is assumed that these 2,444 water wells are active; however, many are very old and may no longer be in use or may have been abandoned.

Groundwater for household use does not require a licence if the use is less than 1,250 m³/year. Under the *Water Act*, a residence is protected for up to 3.4 m³/day. However, the standard groundwater use for household purposes (a family of four) is 1.1 m³/day. Since there are 1,617 domestic water wells in Vulcan County serving a population of 3,778, and based on a family of four, the domestic use per water well is in the order of 0.5 m³/day. Because it does not statistically appear that there is any stock use without a licence and/or registration, 0.5 m³/day was also assigned for domestic/stock water wells, and no value was assigned for stock water wells.

Because of the limitations of the data, no attempt has been made to compensate for dugouts, springs or inactive water wells.

Based on using 0.5 m³/day for all available domestic or domestic/stock water wells, and the protected amount for licensed and/or registered water wells, an estimate of the groundwater use from each geologic unit was prepared, as shown below in Table 19. The data provided in Table 19 indicate that most of the 7,473 m³/day, estimated to be diverted from domestic or domestic/stock water wells, is from the Dalehurst Aquifer. The total estimated groundwater use is mainly from the Dalehurst and Upper Scollard aquifers.

	Domestic and Domestic/Stock Diversions					***Licensed and/or Registered Groundwater Diversions***	***Total Groundwater Diversions***
Aquifer Designation	Number of Domestic	Daily Use (0.5 m³/day)	Number of Domestic and Stock	Daily Use (0.5 m³/day)	Totals m³/day	Totals (m³/day)	Totals m³/day
Multiple Surficial Completions	142	71	43	22	93	38	131
Upper Sand and Gravel	177	89	39	20	108	481	589
Lower Sand and Gravel	86	43	29	15	58	1,072	1,130
Multiple Bedrock Completions	187	94	86	43	137	1,113	1,250
Dalehurst	576	288	144	72	360	1,386	1,746
Upper Lacombe	36	18	9	5	23	18	41
Lower Lacombe	7	4	3	2	5	11.0	16
Haynes	47	24	20	10	34	188	222
Upper Scollard	74	37	28	14	51	1,379	1,430
Lower Scollard	60	30	26	13	43	83	126
Upper Horseshoe Canyon	75	38	34	17	55	38	93
Middle Horseshoe Canyon	22	11	6	3	14	42	56
Lower Horseshoe Canyon	18	9	8	4	13	11	24
Bearpaw	8	4	9	5	9	5	14
Oldman	1	1	1	1	1	4	5
Unknown	101	51	12	6	57	546	603
Totals [(1)]	1,617	809	497	249	1,056	6,417	7,473

[(1)] The values given in the table have been rounded and, therefore, the columns and rows may not add up equally

Table 19. Total Groundwater Diversions by Aquifer

By assigning 0.5 m³/day for all available domestic or domestic/stock water wells, and using the total maximum authorized diversion associated with any licensed and/or registered water well, a map has been prepared that shows the estimated groundwater use in terms of volume per section per day for the County (not including springs).

There are 2,362 sections in the County. In 60% (1,417) of the sections in the County, there is no domestic, stock or licensed and/or registered groundwater user. The groundwater use for the remaining 945 sections varies from 0.4 m³/day to 1,550 m³/day, with an average use per section of three m³/day. Daily groundwater use of more than 50 m³/day is mainly in the vicinity of Mossleigh and Arrowwood. The estimated water well use per section can be more than ten m³/day in 61 of the 945 sections. Sixty-two of the total 517 licensed and/or registered groundwater users are in areas where the groundwater use is greater than ten m³/day.

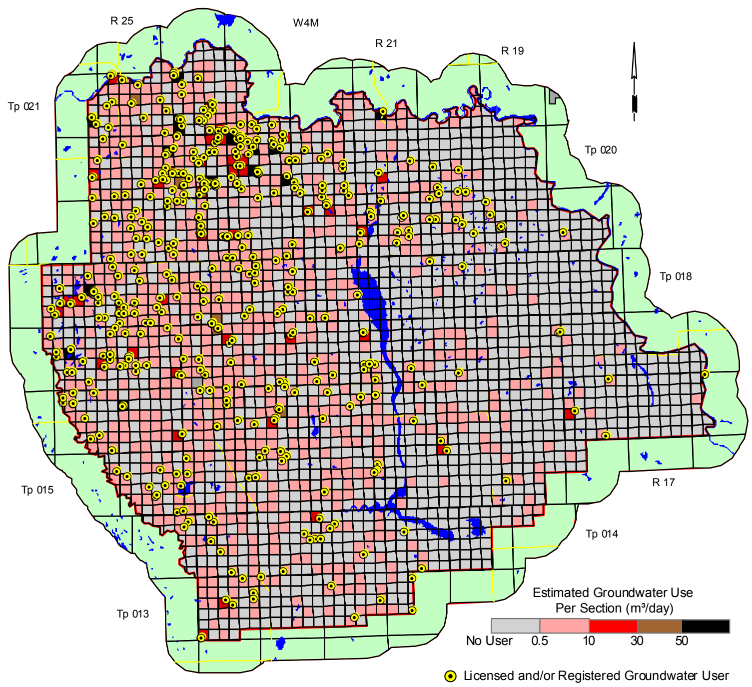

Figure 35. Estimated Water Well Use Per Section

In summary, the estimated total groundwater use within Vulcan County is 7,473 m³/day, with the breakdown as shown in Table 20. An estimated 5,489 m³/day is being withdrawn from a specific aquifer. Of the remaining 1,984 m³/day (36%), 131 m³/day is being withdrawn from multiple surficial aquifers, 1,250 m³/day is being withdrawn from multiple bedrock aquifers, and 603 m³/day is being withdrawn from unknown aquifer units. Approximately 85% of the total estimated groundwater use is from licensed and/or registered water wells.

Groundwater Use within Vulcan County (m³/day)		%
Domestic/Stock (including agriculture and/or registrations)	6,054	81
Municipal (licensed)	713	10
Irrigation/Commercial/Recreation/Industrial (licensed)	706	9
Total	7,473	100

Table 20. Total Groundwater Diversions

7.2 Groundwater Flow

A direct measurement of groundwater recharge or discharge is not possible from the data that are available for the County. One indirect method of measuring recharge is to determine the quantity of groundwater flowing laterally through each individual aquifer. This method assumes that there is sufficient recharge to the aquifer to

Aquifer/Area	Trans (m^2/day)	Gradient (m/m)	Width (km)	Flow (m^3/day)	Aquifer Flow (m^3/day)	Licensed and/or Registered Diversion (m^3/day)
Upper Surficial					66,006	481
Calgary Buried Valley						
Flow to east	160	0.002	10	2,672		
McGregor Buried Valley						
Flow to west	8	0.005	35	1,400		
Flow to east	40	0.006	45	11,250		
Bow City Buried Valley						
Flow to east	22	0.004	60	5,504		
Silver Valley						
Flow to north	126	0.002	5	1,462		
Arrowwood						
Flow to north	90	0.009	35	29,610		
Tee Pee Buried Valley						
Flow southeast	31	0.003	3	233		
Carmangay						
Flow to southeast	50	0.005	18	4,500		
Flow to northwest	50	0.006	30	9,375		
Lower Surficial					58,780	1,072
Arrowwood						
Flow to north	140	0.013	20	35,000		
McGregor Buried Valley						
North - Flow to east	100	0.008	16	13,280		
Central - Flow to east	100	0.005	6	3,000		
South - Flow to east	100	0.005	15	7,500		
Dalehurst					8,000	1,386
Regionally						
Flow to north	30	0.003	18	1,800		
Flow to south	10	0.003	18	600		
Flow to east	20	0.003	30	1,875		
Flow to west	20	0.003	30	1,875		
Silver Buried Valley						
West - Flow to northeast	30	0.003	7	650		
West - Flow to southeast	20	0.004	15	1,200		
Upper Lacombe					3,523	18
Regionally						
Flow to northeast	20	0.004	20	1,600		
Flow to northwest	20	0.003	25	1,538		
Flow to southeast	10	0.002	25	385		
Lower Lacombe					596	11
Regionally						
Flow to northwest	2	0.013	20	500		
Flow to west	2	0.001	16	43		
Flow to southwest	2	0.001	20	53		
Haynes					3,875	188
Regionally						
Flow to northwest	30	0.003	25	1,875		
Flow to southwest	30	0.002	40	2,000		

Aquifer/Area	Trans (m^2/day)	Gradient (m/m)	Width (km)	Flow (m^3/day)	Aquifer Flow (m^3/day)	Licensed and/or Registered Diversion (m^3/day)
Upper Scollard					3,525	1,379
Calgary Buried Valley						
Flow to North	25	0.010	6	1,500		
Regionally						
Flow to west	15	0.001	40	500		
Champion Buried Valley						
North - Flow to southwest	10	0.006	15	900		
South - Flow to northwest	10	0.006	10	625		
Lower Scollard					1,800	83
Regionally						
Flow to northeast	20	0.002	22	880		
Flow to northwest	10	0.001	50	333		
Champion Buried Valley						
North - Flow to southwest	5	0.005	19	480		
South - Flow to northwest	5	0.003	6	107		
Upper Horseshoe Canyon					15,163	38
Regionally						
Flow to northeast	50	0.001	60	3,750		
Calgary Buried Valley						
Flow to northwest	25	0.007	18	3,000		
Flow to northeast	25	0.008	11	2,200		
Flow to southwest of Bow River	25	0.008	10	2,000		
McGregor Buried Valley						
Flow to west	20	0.008	20	3,333		
Carmangay Buried Valley						
Flow to northwest	10	0.012	14			
Flow to southeast	10	0.004	22	880		
Middle Horseshoe Canyon					3,182	42
Regionally						
Flow to north	5	0.002	50	455		
Calgary Buried Valley						
Flow to northwest	30	0.002	50	2,727		
Lower Horseshoe Canyon					5,051	11
Regionally						
Flow to north	8	0.001	35	280		
Calgary Buried Valley						
Flow to northwest	15	0.003	40	2,000		
Flow to northeast	10	0.007	25	1,667		
McGregor Buried Valley						
Flow to southwest	4	0.002	15	120		
Travers Reservoir						
Flow to north	7	0.009	15	984		
Bearpaw					908	5
Regionally						
Flow to north	2	0.005	35	318		
Flow to northwest	3	0.002	50	250		
Flow to east	2	0.005	30	273		
Flow to southwest	2	0.001	50	67		
Oldman					200	4
Bow City Buried Valley						
Flow to east	2.5	0.004	20	200		

Table 21. Groundwater Budget

maintain the flow through the aquifer and the discharge is equal to the recharge. However, even the data that can be used to calculate the quantity of flow through an aquifer must be averaged and estimated. To determine the flow requires a value for the average transmissivity of the aquifer, an average hydraulic gradient and an estimate for the width of the aquifer. For the present program, the flow has been estimated for various parts of individual aquifers within the County.

The flow through each aquifer assumes that by taking a large enough area, an aquifer can be considered as homogeneous, the average gradient can be estimated from the non-pumping water-level surface, and flow takes place through the entire width of the aquifer; flow through the aquifers also takes into consideration hydrogeological conditions outside the County border. Based on these assumptions, the estimated lateral groundwater flow through the individual aquifers has been summarized in Table 21.

Table 21 indicates that there is more groundwater flowing through the aquifers than has been authorized to be diverted from the individual aquifers. However, even where use is less than the calculated aquifer flow, there can still be local impacts on water levels. The calculations of flow through individual aquifers as presented in the adjacent table are very approximate and are intended only as a guide for future investigations.

7.2.1 Quantity of Groundwater

An estimate of the volume of groundwater stored in the surficial deposits is 1.0 to 6.2 cubic kilometres. This volume is based on an areal extent of 4,150 square kilometres and a saturated thickness of five metres. The variation in the total volume is based on the value of porosity that is used for the surficial deposits. One estimate of porosity is 5%, which gives the low value of the total volume. The high estimate is based on a porosity of 30% (Ozoray, Dubord and Cowen, 1990).

The adjacent non-pumping water-level map has been prepared from water levels associated with water wells completed to depths of less than 20 metres in aquifers in the surficial deposits. The water levels from these water wells were used for the calculation of the saturated thickness of the surficial deposits and for calculations of recharge/discharge areas. In areas where the elevation of the water-level surface is below the bedrock surface, the surficial deposits are not saturated (indicated by grey areas on the map). The water-level map for the surficial deposits shows the main flow direction toward the Bow River Valley.

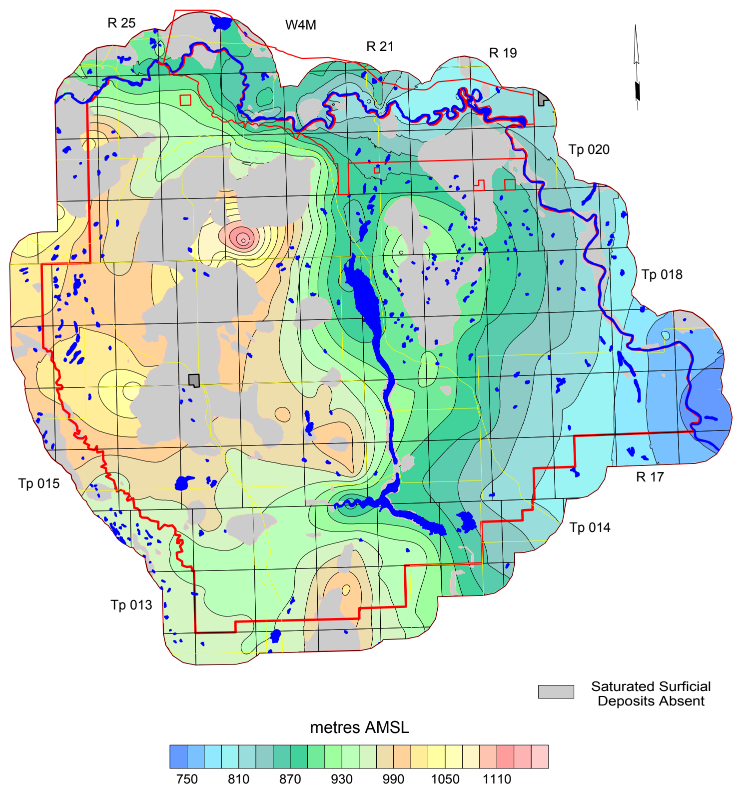

Figure 36. Non-Pumping Water-Level Surface in Surficial Deposits Based on Water Wells Less than 20 Metres Deep

7.2.2 Recharge/Discharge

The hydraulic relationship between the groundwater in the surficial deposits and the groundwater in the bedrock aquifers is given by the non-pumping water-level surface associated with each hydraulic unit. 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.

7.2.2.1 Bedrock Aquifers

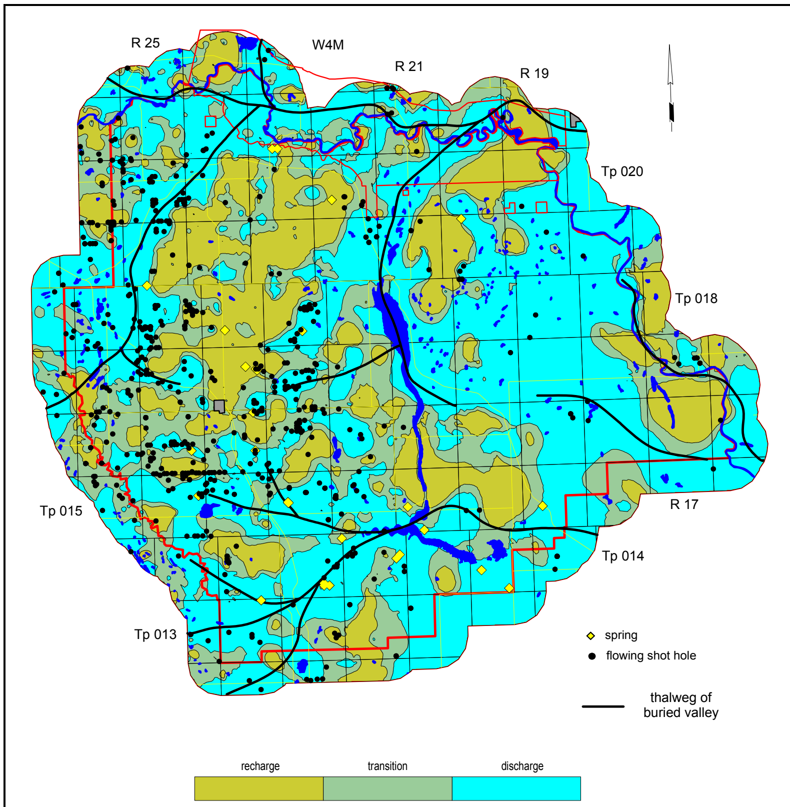

Figure 37. Bedrock Recharge/Discharge Areas

In the absence of sufficient water-level data in the surficial deposits, a reasonable hydraulic gradient between the surficial deposits and the upper bedrock aquifer(s) could not be determined. Therefore, an alternative approach has been used to establish approximate recharge and discharge areas. The first objective was to determine the location of springs, flowing shot holes and any water wells that had a water level measurement depth of less than 0.1 metres. These locations would reflect where there is an upward hydraulic gradient from the bedrock to the surficial deposits (i. e. discharge). The depth to water level for water wells completed in 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 bedrock surface. This resulting depth to water level grid was contoured to reflect the positioning of springs, flowing shot holes and flowing water wells (i. e. discharge). The recharge classification is used where the water level in the upper bedrock aquifer(s) is more than five metres below bedrock surface. The discharge areas are where the water level in the upper bedrock aquifer(s) is more than five metres above the bedrock surface. When the depth to water level in the upper bedrock aquifer(s) is between five metres below and five metres above the bedrock surface, the area is classified as a transition, that is, no recharge and no discharge.

Figure 37 shows that, in nearly 25% of the County, there is a downward hydraulic gradient from the bedrock surface toward the upper bedrock aquifer(s) (i. e. recharge). Areas where there is an upward hydraulic gradient from the bedrock to the bedrock surface (i. e. discharge) are mainly in the vicinity of creeks and river valleys and buried valley. The remaining parts of the County are areas where there is a transition condition.

Because of the paucity of data, recharge/discharge maps for the individual bedrock aquifers have not been attempted.

With nearly 25% of the County land area being one of recharge to the bedrock, and the average precipitation being 416 mm per year, three percent of the annual precipitation is sufficient to provide the total calculated quantity of groundwater flowing through the upper bedrock aquifer(s).

7.3 Areas of Groundwater Decline

In order to determine the areas of possible water-level decline in the Sand and Gravel Aquifer(s) and in the Upper Bedrock Aquifer(s), the following approach was used. The method of calculating changes in water levels is at best an estimate. The areas of groundwater decline in the Sand and Gravel Aquifer(s) and in the Upper Bedrock Aquifer(s) have been calculated by determining the frequency of non-pumping water level control points per five-year period. Additional data would be needed to verify water-level change.

7.3.1 Sand and Gravel Aquifer(s)

Of the 894 surficial water wells with a non-pumping water level and date in the County and buffer area, 416 are from water wells completed before 1980 and 478 are from water wells completed after 1980.

Where the earliest water level (before 1980) is at a higher elevation than the latest water level (after 1980), there is the possibility that some groundwater decline has occurred. The interpretation of the adjacent map should be limited to areas where both earliest and latest water level control points are present. Most of the areas in which the map suggests that there has been a rise or a decline in NPWL of more than ten metres may reflect the nature of gridding a limited number of control points.

Where the earliest water level is at a lower elevation than the latest water level, there is the possibility that the groundwater has risen at that location. The water level may have risen as a result of recharge in wetter years or may be a result of the water well being completed in a different surficial aquifer.

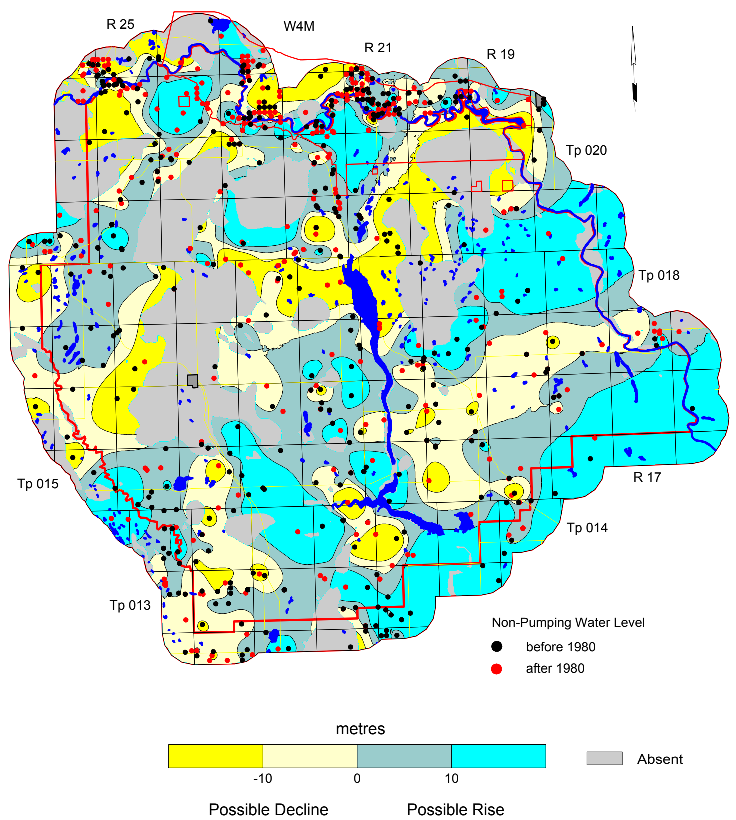

Figure 38. Changes in Water Levels in Surficial Deposits

Figure 38 indicates that in 60% of the County where surficial deposits are present, it is possible that the non-pumping water level has declined.

In areas where a water-level decline is indicated, 54% of the area has no estimated water well use; 43% of the use is less than ten m³/day; 2% of the use is between ten and 30 m³/day per section; and the remaining 1% of the declines occurred where the estimated groundwater use per section is greater than 50 m³/day, as shown in Table 22.

Estimated Water Well Use Per Section (m³/day)	*% of Area with a Decline*
<10	*43*
10 to 30	*2*
30 to 50	*0*
>50	*1*
no use	*54*
	100

Table 22. Water-Level Decline in Sand and Gravel Aquifer(s)

The areas of groundwater decline in the Sand and Gravel Aquifer(s) where there is no estimated water well use suggest that groundwater diversion is not having an impact and that the decline may be due to variations in recharge to the aquifer or because the water wells are not on file with AENV.

7.3.2 Upper Bedrock Aquifer(s)

Of the 2,152 bedrock water wells with a non-pumping water level and date in the County and buffer area, 995 are from water wells completed before 1980 and 1,157 are from water wells completed after 1980.

Where the earliest water level (before 1980) is at a higher elevation than the latest water level (after 1980), there is the possibility that some groundwater decline has occurred. Most of the areas in which the map suggests that there has been a rise in NPWL of more than ten metres may reflect the nature of gridding a limited number of control points.

The adjacent map indicates that in 40% of the County, it is possible that the NPWL has declined. Of the 315 licensed bedrock water wells, 253 are within one kilometre of where it is possible that there has been a water-level decline in the Upper Bedrock Aquifer(s).

In areas where a water-level decline is indicated, 52% of the area has no estimated water well use; 45% is less than ten m³/day; 2% is between ten and 30 m³/day per section; and the remaining 1% of the declines occurred where the estimated groundwater use per section is greater than 50 m³/day, as shown below in Table 23.

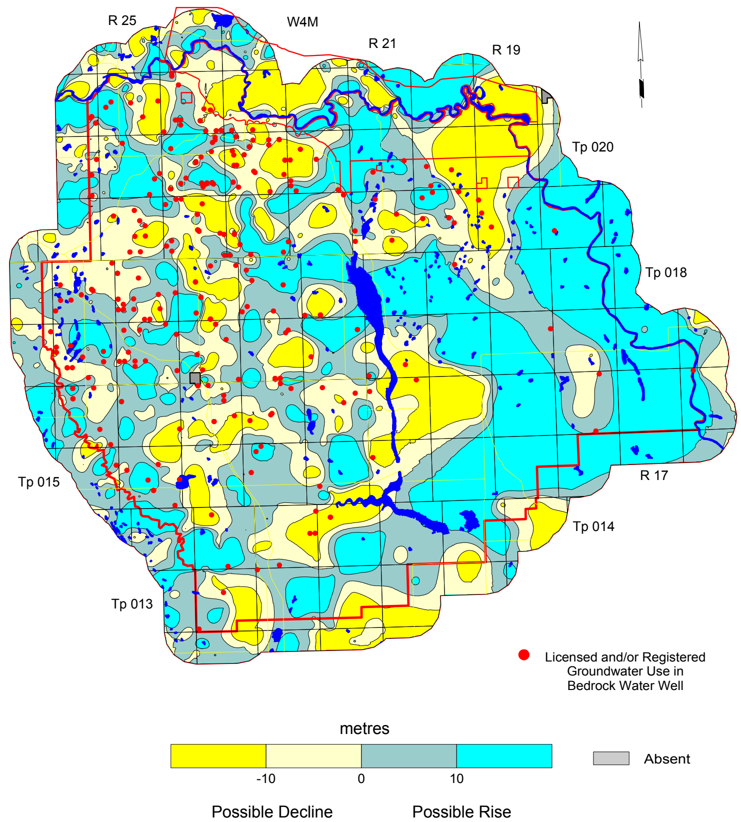

Figure 39. Areas of Potential Groundwater Decline – Upper Bedrock Aquifer(s)

Estimated Water Well Use Per Section (m³/day)	*% of Area with a Decline*
<10	*45*
10 to 30	*2*
30 to 50	*0*
>50	*1*
no use	*52*
	100

Table 23. Water-Level Decline in Upper Bedrock Aquifer(s)

The areas of groundwater decline in the Upper Bedrock Aquifer(s) where there is no estimated water well use suggest that groundwater production is not having an impact and that the decline may be due to variations in recharge to the aquifer or because the water wells are not on file with AENV

8 RECOMMENDATIONS

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

1) the quality of the data
2) the coordinate system used for the horizontal control
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 117 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. There are three water wells for which the County has responsibility; the County-operated water wells are included in Appendix E. It is recommended that the County-operated water wells plus the 117 water wells be field-verified, water levels be measured, a water sample be collected for analysis, and a short aquifer test be conducted. An attempt to update the quality of the entire database is not recommended.

Before an attempt is made to provide a major upgrade to the level of interpretation provided in this report, the accompanying maps and the groundwater query, it is recommended that the 117 water wells listed in Appendix E for which water well drilling reports are available, plus the County–operated water wells, 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 83 or some other system that will allow conversion to 10TM NAD 83 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.

This additional information would provide a baseline to be used for comparison to either existing chemical analyses or aquifer tests, or to determine if future monitoring would be necessary if significant changes in the aquifer parameters had occurred.

A list of the 120 water wells that could be considered for the above program is given in Appendix E and on the CD-ROM.

An attempt to link the AENV groundwater and licensing databases was 45% successful in this study (see CD-ROM); 55% of the licensed and/or registered water wells do not appear to have corresponding records in the AENV groundwater database. There is a need to improve the quality of the AENV licensing database. It is recommended that attempts be made in a future study to find and add missing drilling records to the AENV groundwater database and to determine the aquifer in which the authorized non-exempt water wells are completed.

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 were being provided with a tax credit if they accurately measured 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. Monitoring of water levels in domestic and stock water wells is a practice that is recommended by PFRA in the "Water Wells That Last for Generations" manual and accompanying videos (Buchanan, Bob (editor). Alberta Agriculture, Food and Rural Development, 1996).

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.

Communities that are concerned about apparent water-level declines in the aquifers in which their water supply wells are completed should implement a conscientious groundwater monitoring program.

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 AENV Resource Data Division in an electronic form. The funds presently being spent by AENV to transpose the paper form to the electronic form could 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.

In summary, for the next level of study, the database needs updating. The updating of information for existing water wells requires more details for the water wells listed in Appendix E; the additional information for new water wells is mainly better spatial control.

Groundwater is a renewable resource and it must be managed.

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10 GLOSSARY

AAFC-PFRA — Prairie Farm Rehabilitation Administration Branch of Agriculture and Agri-Food Canada

AENV — Alberta Environment

AMSL — above mean sea level

Anion — negatively charged ion

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

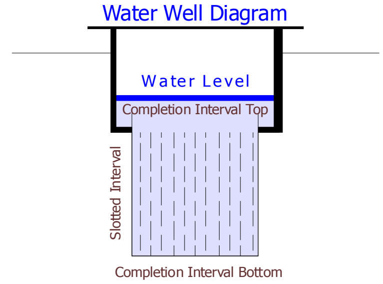
in an unconfined aquifer (water table aquifer), two thirds of the saturated thickness of the aquifer

BGP — Base of Groundwater Protection

Borehole — includes all “work types” except springs

Cation — positively charged ion

Completion Interval — see diagram



Completion Interval

Deltaic — a depositional environment in standing water near the mouth of a river

DEM — Digital Elevation Model

Dfb — one of the Köppen climate classifications; a Dfb climate consists of warm to cool summers, severe winters, and no dry season. The mean monthly temperature drops below -3° C in the coolest month, and exceeds 10° C in the warmest month.

DST — drill stem test

EUB — Alberta Energy and Utilities Board

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

Geologic Unit — a distinguishable rock unit based on rock type and/or rock age

Hydraulic Conductivity the rate of flow of water through a unit cross-section under a unit hydraulic gradient; units are length/time

Hydraulic Unit a rock type where changes in hydraulic head at one location directly impact hydraulic-head conditions at all locations measurable in less than a year

Hydrogeologic Unit a hydrogeologic setting comprised of one or more saturated rock types where groundwater characteristics are closely related

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

m²/day metres squared per day

m³ cubic metres

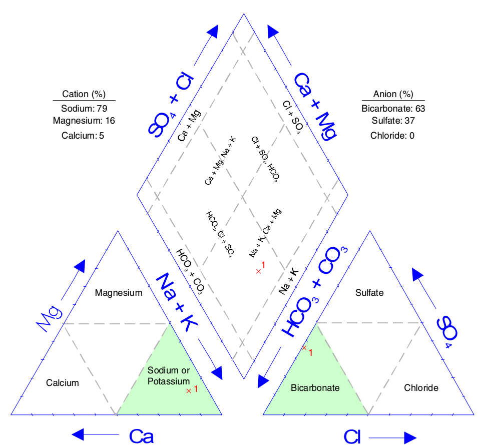
m³/day cubic metres per day

mg/L milligrams per litre

Median the value at the centre of an ordered range of numbers

NPWL non-pumping water level

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

SGCDWQ Summary of Guidelines for Canadian Drinking Water Quality

Surficial Deposits includes all sediments above the bedrock

Thalweg the lowest elevation of a linear bedrock low

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, discharge rate and time of discharge
	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” as defined by AENV 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 and 70% of available drawdown
	Long-Term Yield: the method used for determining the theoretical long-term yield in the Alberta Environment Groundwater Evaluation Guidelines, and based on effective transmissivity

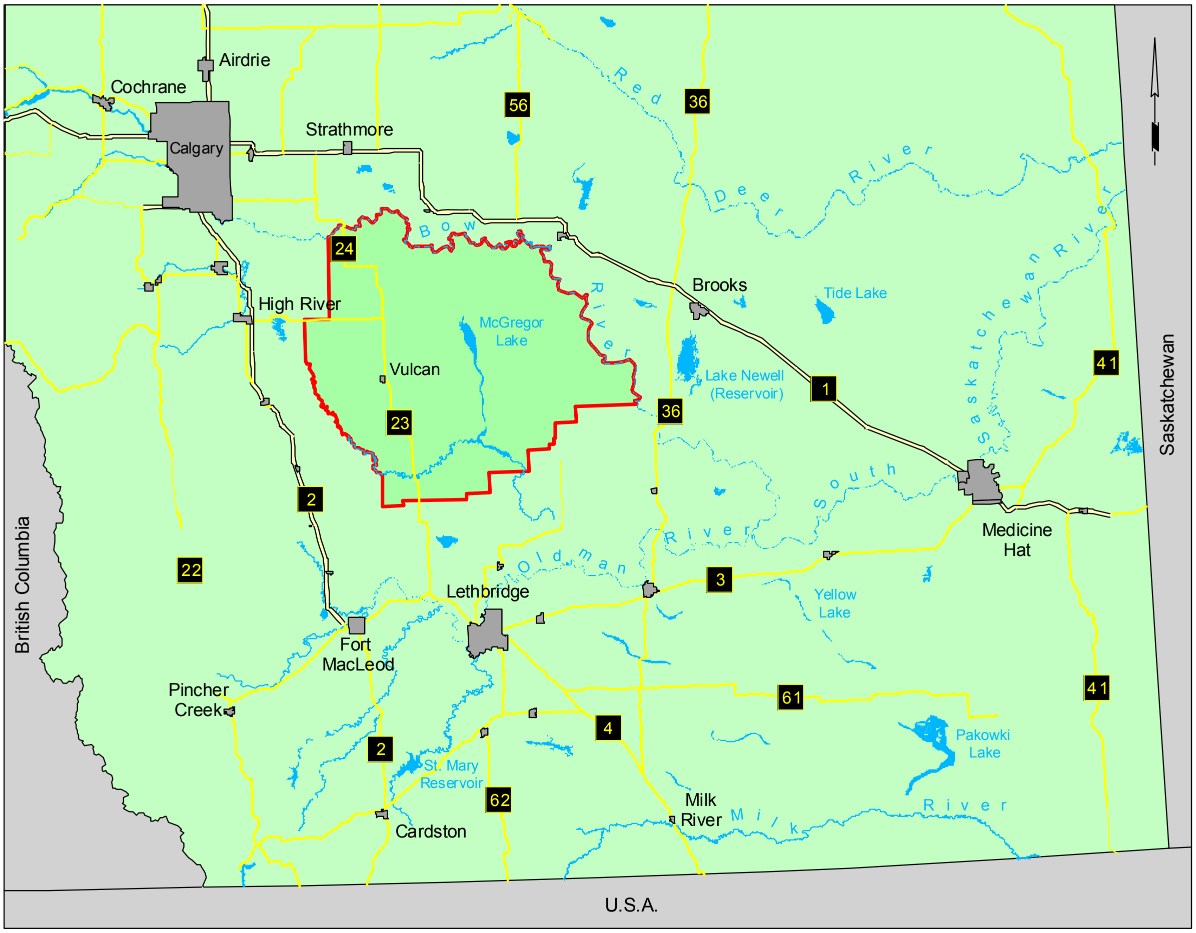
11 CONVERSIONS

Multiply	by	To Obtain
Length/Area		
feet (ft)	0.3 048	metres
metres (m)	3.2 810	feet
hectares (ha)	2.4 711	acres
centimetre (cm)	0.0 328	feet
centimetre	0.3 937	inches
acres (ac)	0.4 047	hectares
inches (in)	25.4 000	millimetres
miles (mi)	1.6 093	kilometres
kilometre (km)	0.6 214	miles (statute)
square feet (ft^2)	0.0 929	square metres (m^2)
square metres (m^2)	10.7 639	square feet (ft^2)
square metres (m^2)	0.0 000	square kilometres (km^2)
Concentration		
grains/gallon (UK)	14.2 700	parts per million (ppm)
ppm	0.9 989	mg/L
mg/L	1.0 011	ppm
Volume (capacity)		
acre feet	1233.4 818	cubic metres
cubic feet	0.0 283	cubic metres
cubic metres	35.3 147	cubic feet
cubic metres	219.9 692	gallons (UK)
cubic metres	264.1 721	gallons (US liquid)
cubic metres	1000.0 000	litres
gallons (UK)	0.0 045	cubic metres
imperial gallons	4.5 460	litres
Rate		
litres per minute (lpm)	0.2 200	UK gallons per minute (igpm)
litres per minute	1.4 400	cubic metres/day (m^3/day)
igpm	6.5 463	cubic metres/day (m^3/day)
cubic metres/day	0.1 528	igpm

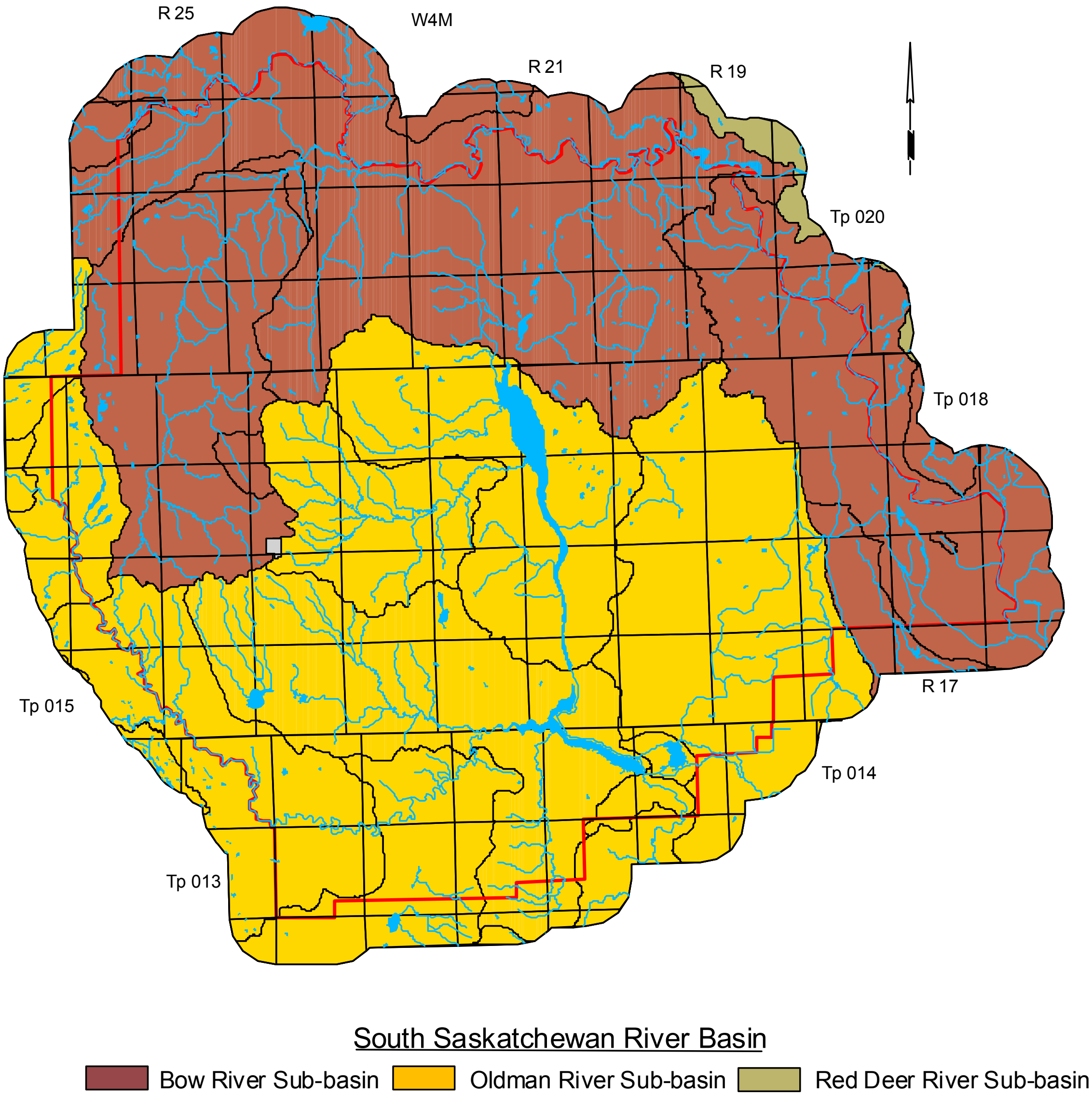
VULCAN COUNTY
Appendix A

Hydrogeological Maps and Figures

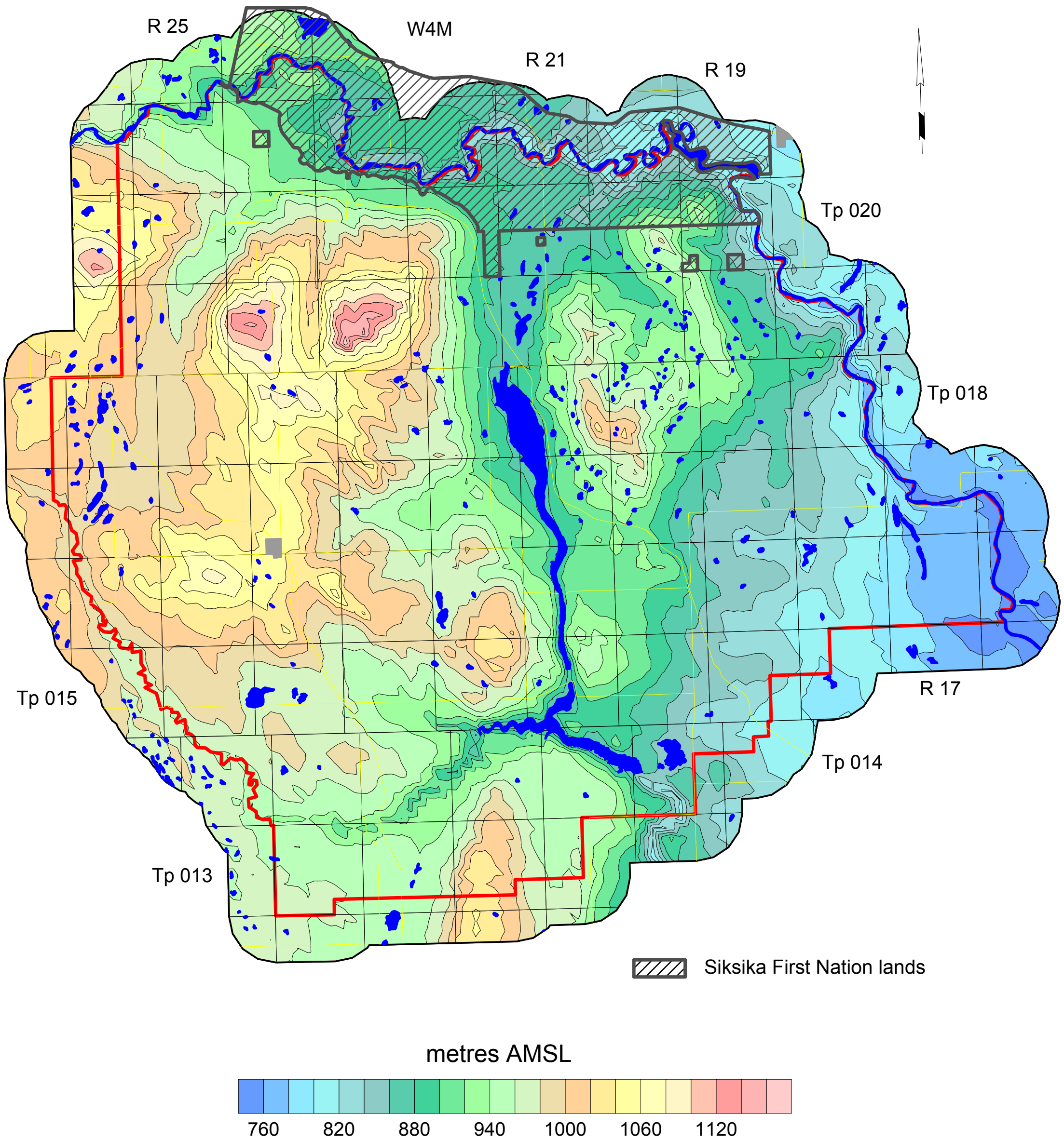
Index Map


Airdrie
Cochrane
Calgary
Strathmore
56
36
Red
Deer River
Bow
24
High River
McGregor Lake
Vulcan
River
23
Brooks
Tide Lake
Lake Newell (Reservoir)
1
36
South Saskatchewan River
41
Saskatchewan
2
Medicine Hat
South
River
Oldman
22
British Columbia
3
Yellow Lake
Lethbridge
Fort MacLeod
Pincher Creek
61
41
4
2
Pakowki Lake
St. Mary Reservoir
62
Milk River
Milk
River
Cardston
U.S.A.

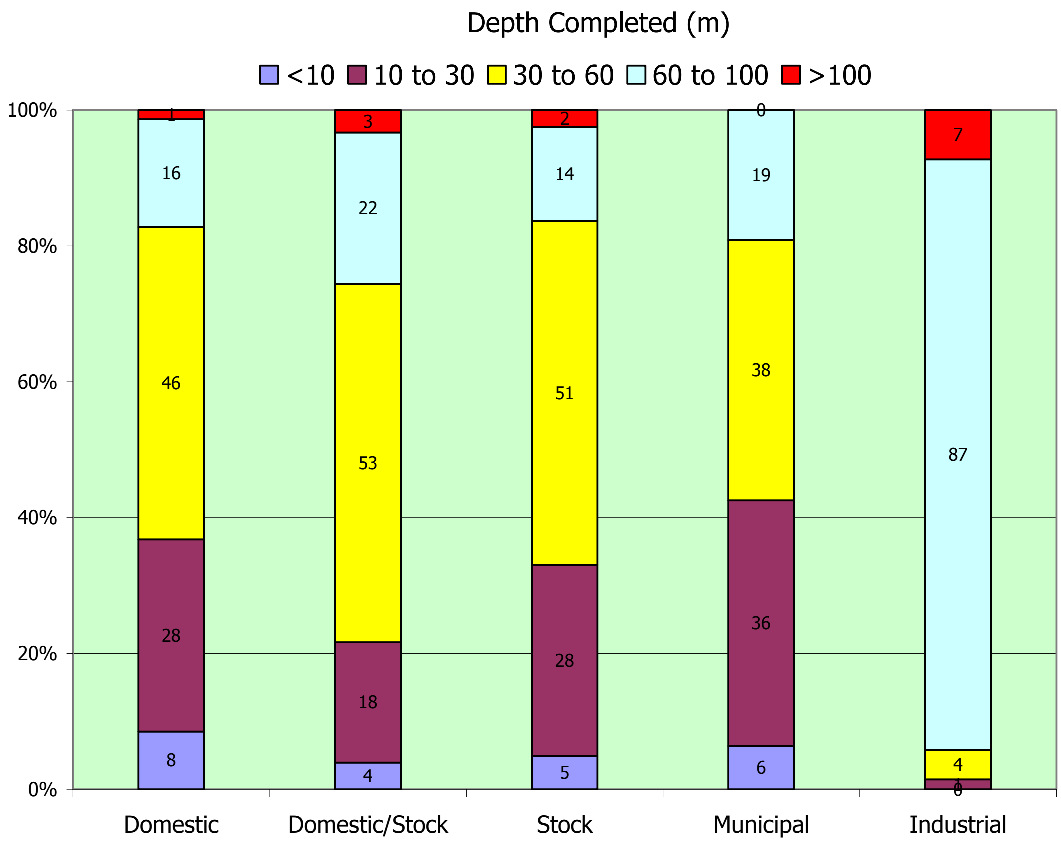
River Sub-Basins



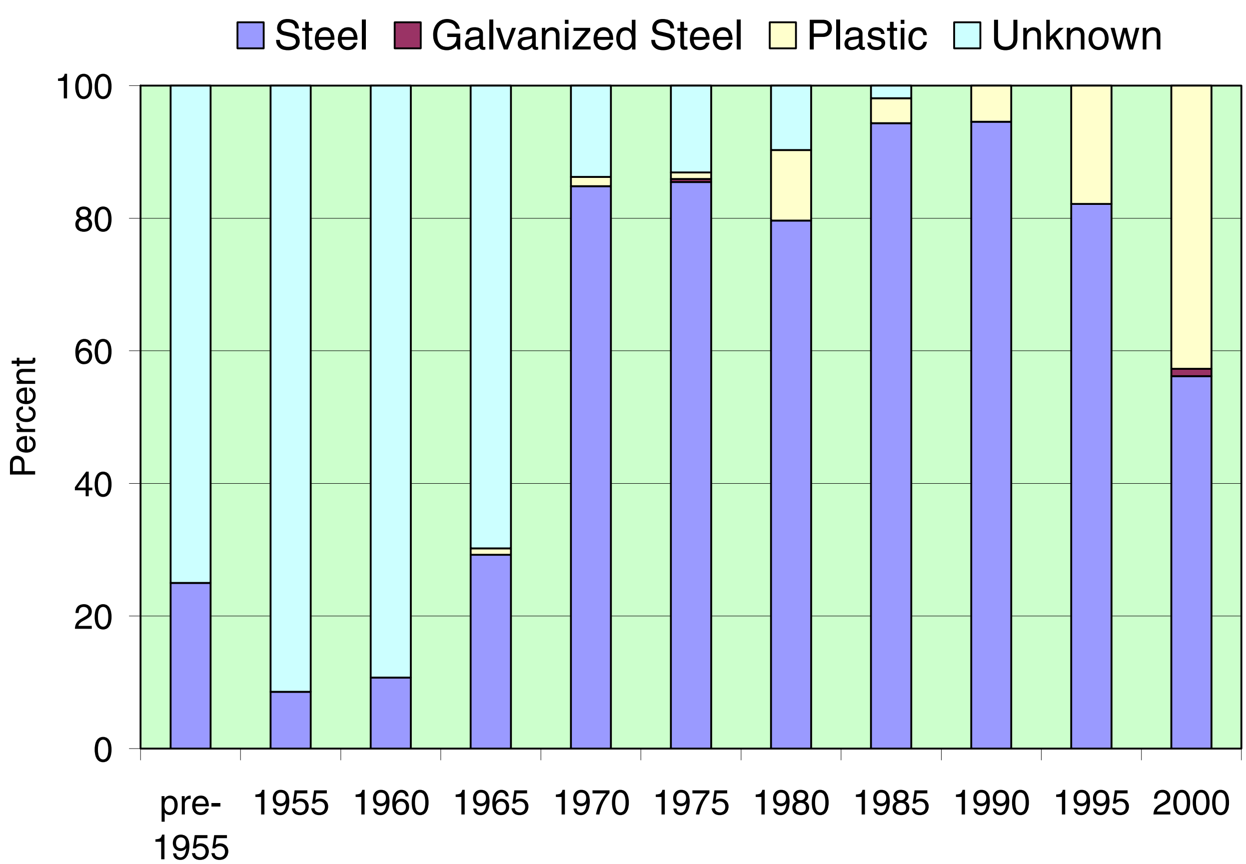
Surface Topography



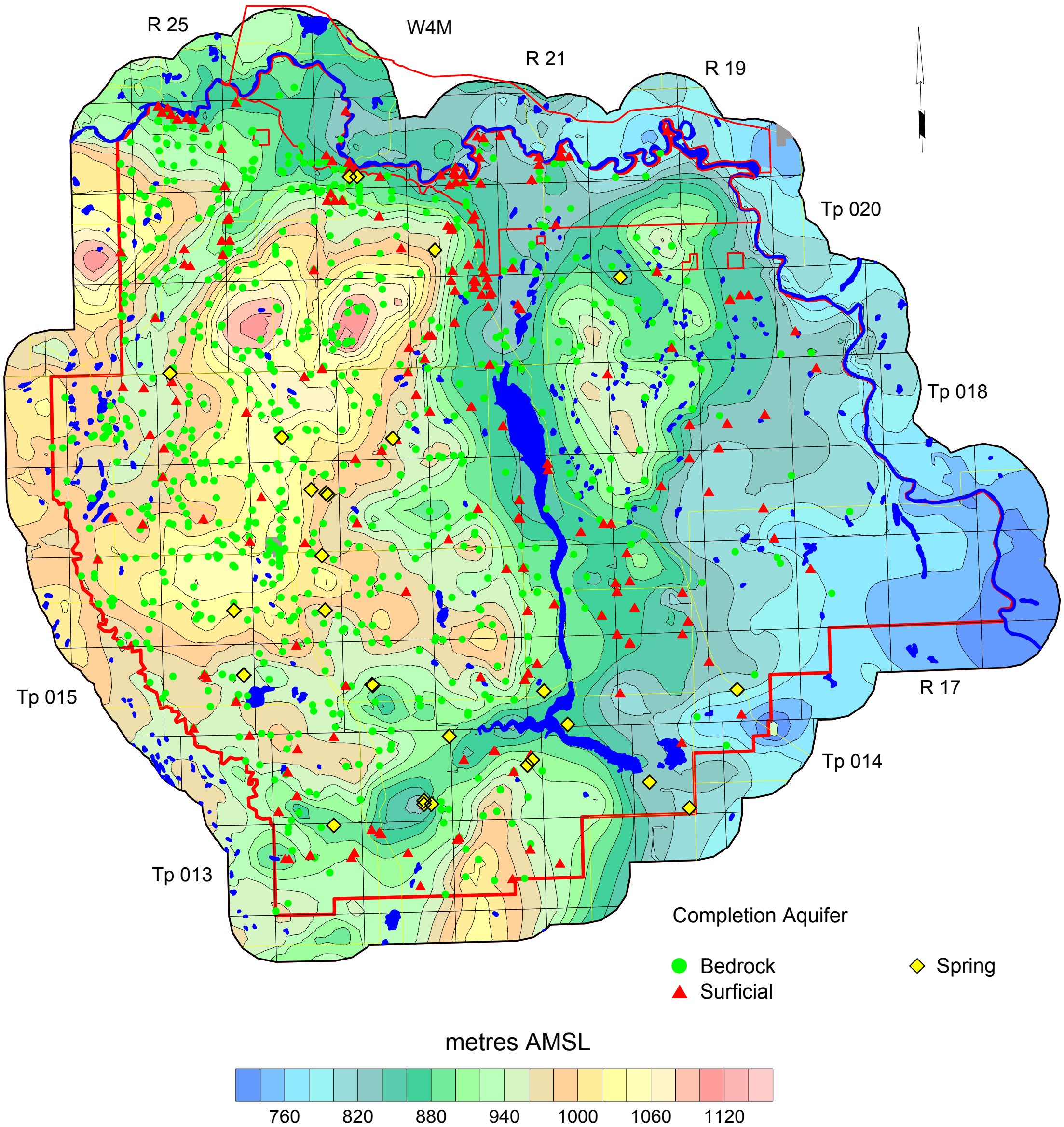
Proposed Use vs Completed Depth



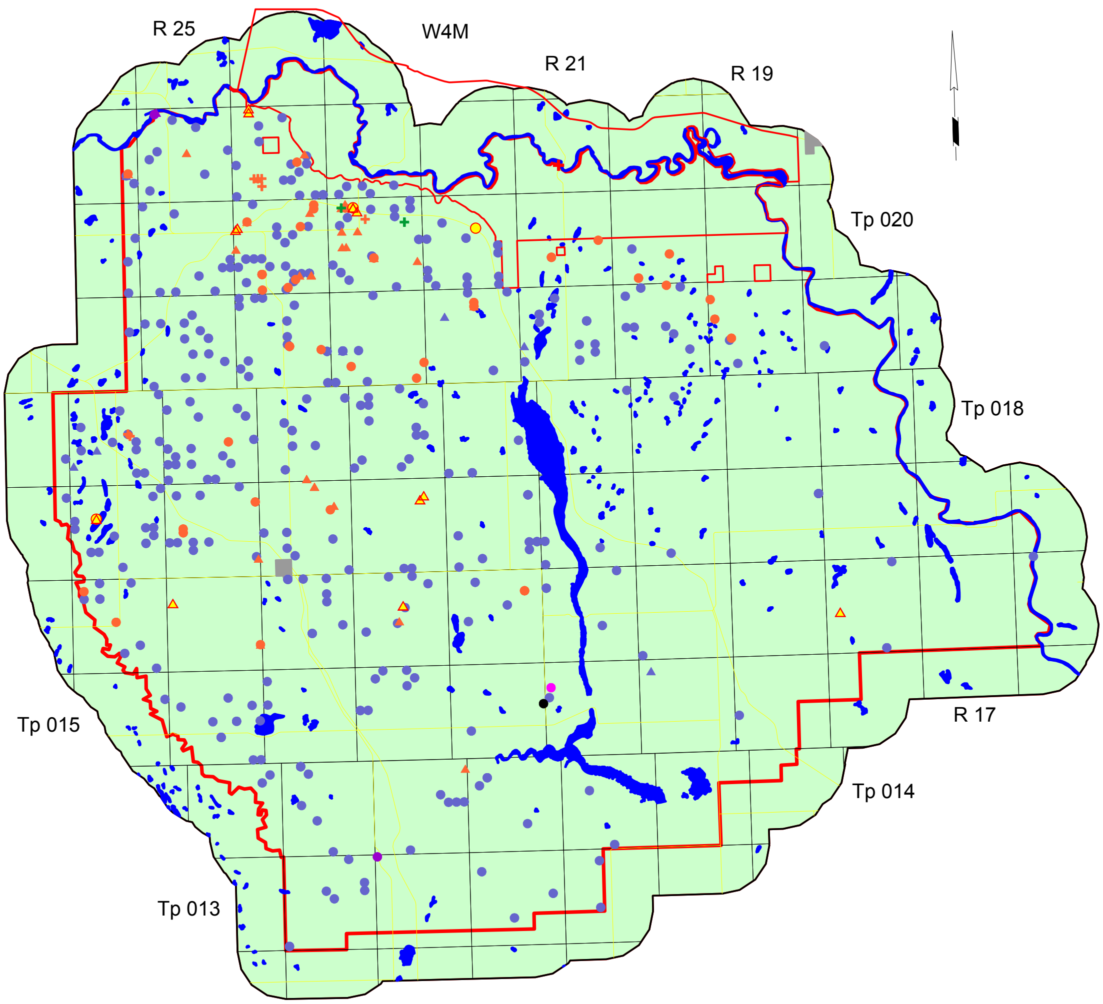
Surface Casing Types used in Drilled Water Wells



Location of Water Wells and Springs Relative to Bedrock Topography



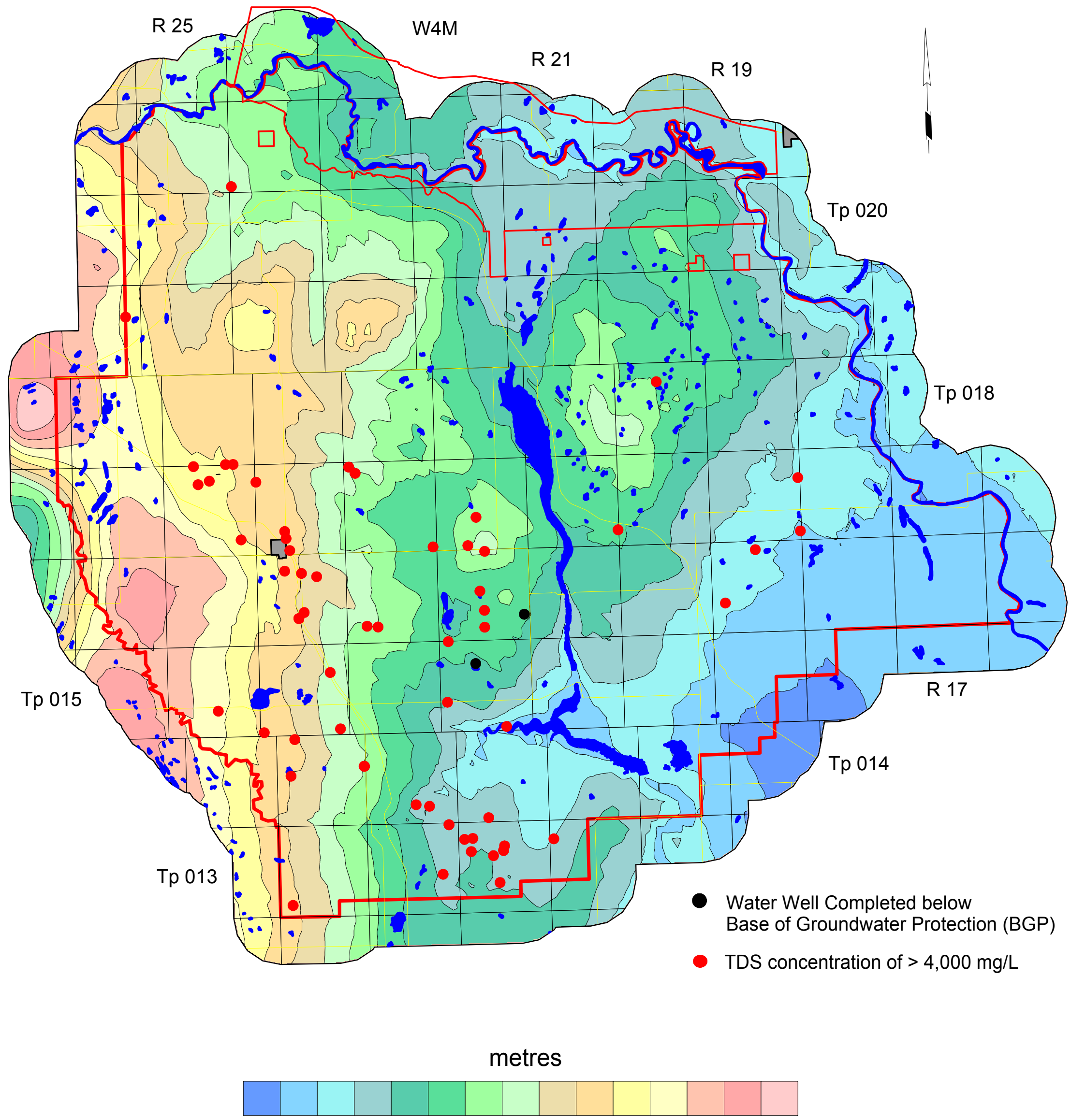
Licensed and Registered Groundwater Water Wells



m^3/day	registration	agricultural	municipal	irrigation	industrial	recreation	commercial
< 10	(395)	(46)	(3)	(0)	(1)	(2)	(1)
10 to 100	(7)	(38)	(13)	(0)	(0)	(1)	(0)
> 100	(0)	(8)	(1)	(2)	(0)	(0)	(0)

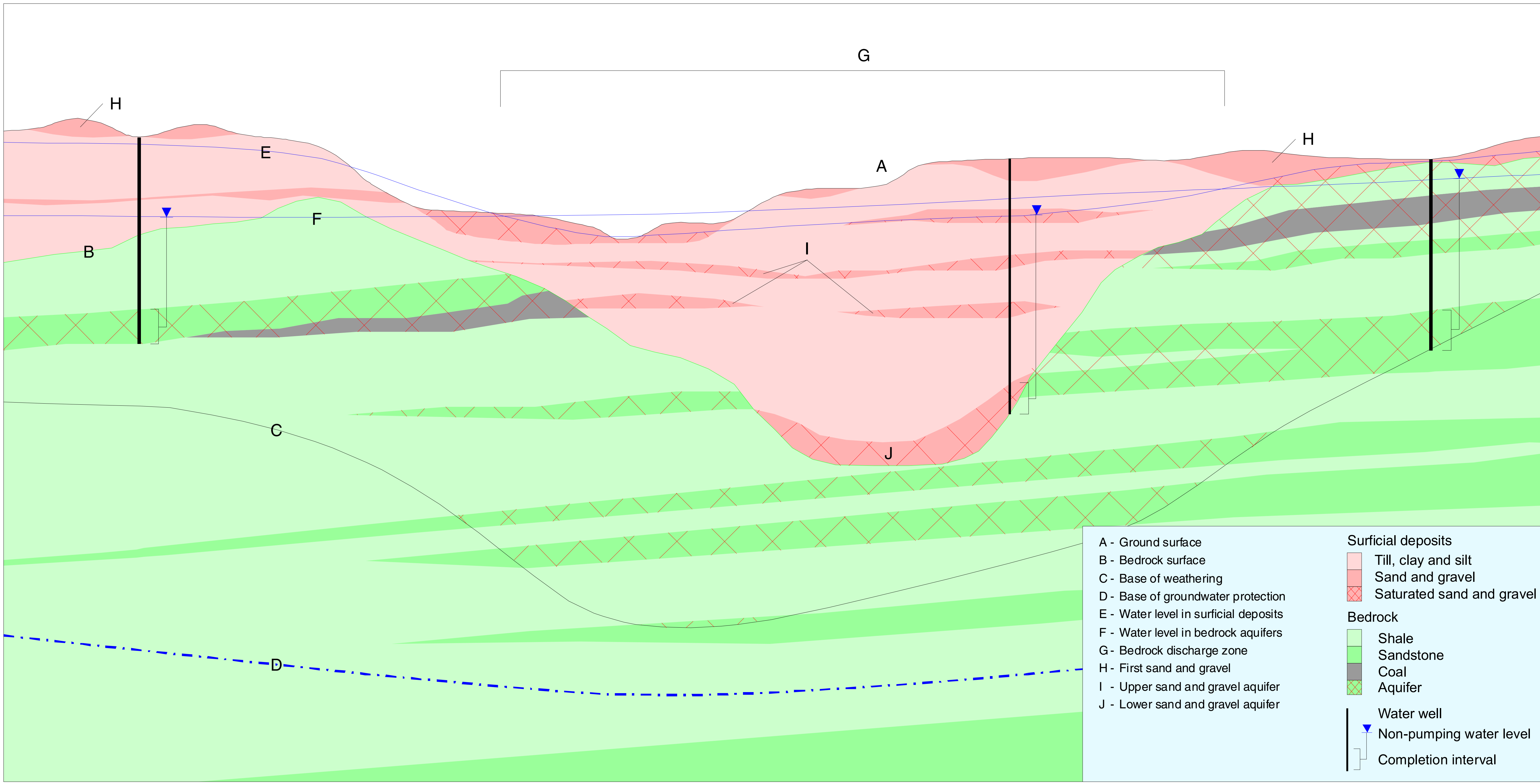
Depth to Base of Groundwater Protection

(modified after EUB, 1995)



Generalized Cross-Section

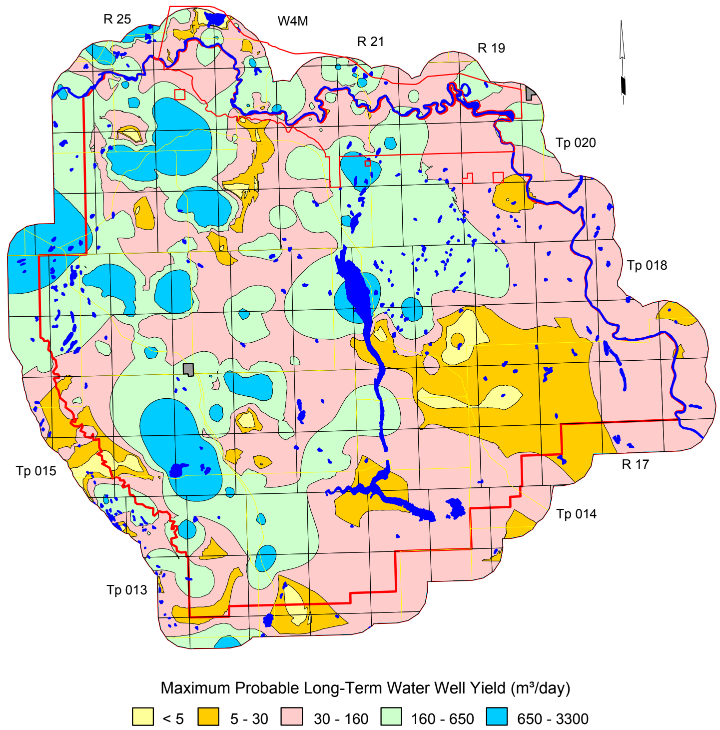
(for terminology only)



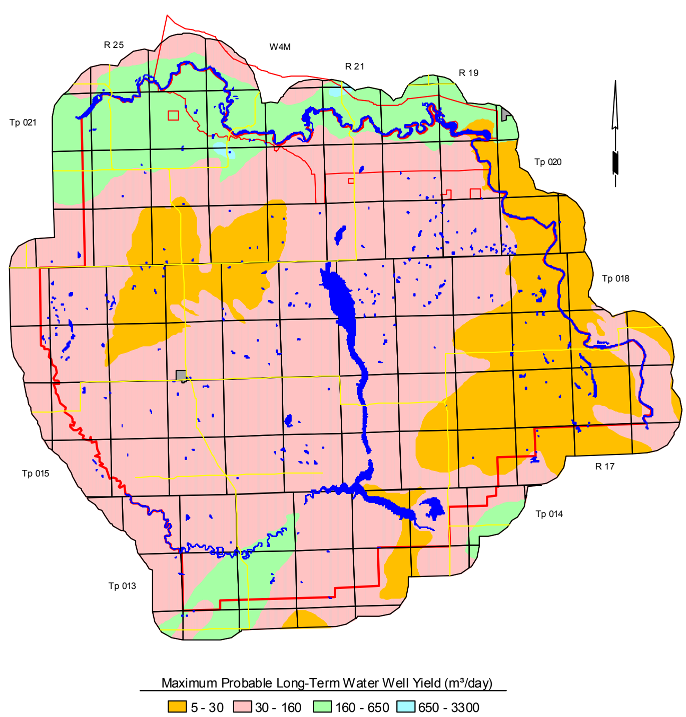
Geologic Column

Lithologic Description	Group and Formation: Average Thickness (m)	Group	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		
sandstone, shale, coal	<800		Paskapoo Formation	>300	Dalehurst Member		Obed-Marsh Coal Zone
							Lower Dalehurst Coal Zone
				100-250	Lacombe Member, Upper	Upper	Upper Sandstone
							Middle Sandstone
							Lower Sandstone
				30-100	Lacombe Member, Lower	Lower	Lower Lacombe Coal Zone
				20-100	Haynes		
shale, sandstone, coal	60-150		Scollard Formation	40-100	Upper	<2	Upper Ardley Coal Zone
						~20	Ardley Coal Zone (main seam)
						<1	Nevis Coal Seam
				20-60	Lower		
shale, clay, tuff	~25 5-10		Battle/Whitemud Formation	<0.3	Kneehill Member		
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		Belly River Group	40-130 Oldman Formation		Dinosaur Member	<25	Lethbridge Coal Zone
					Upper Siltstone Member		
					Comrey Member		

Hydrogeological Maps

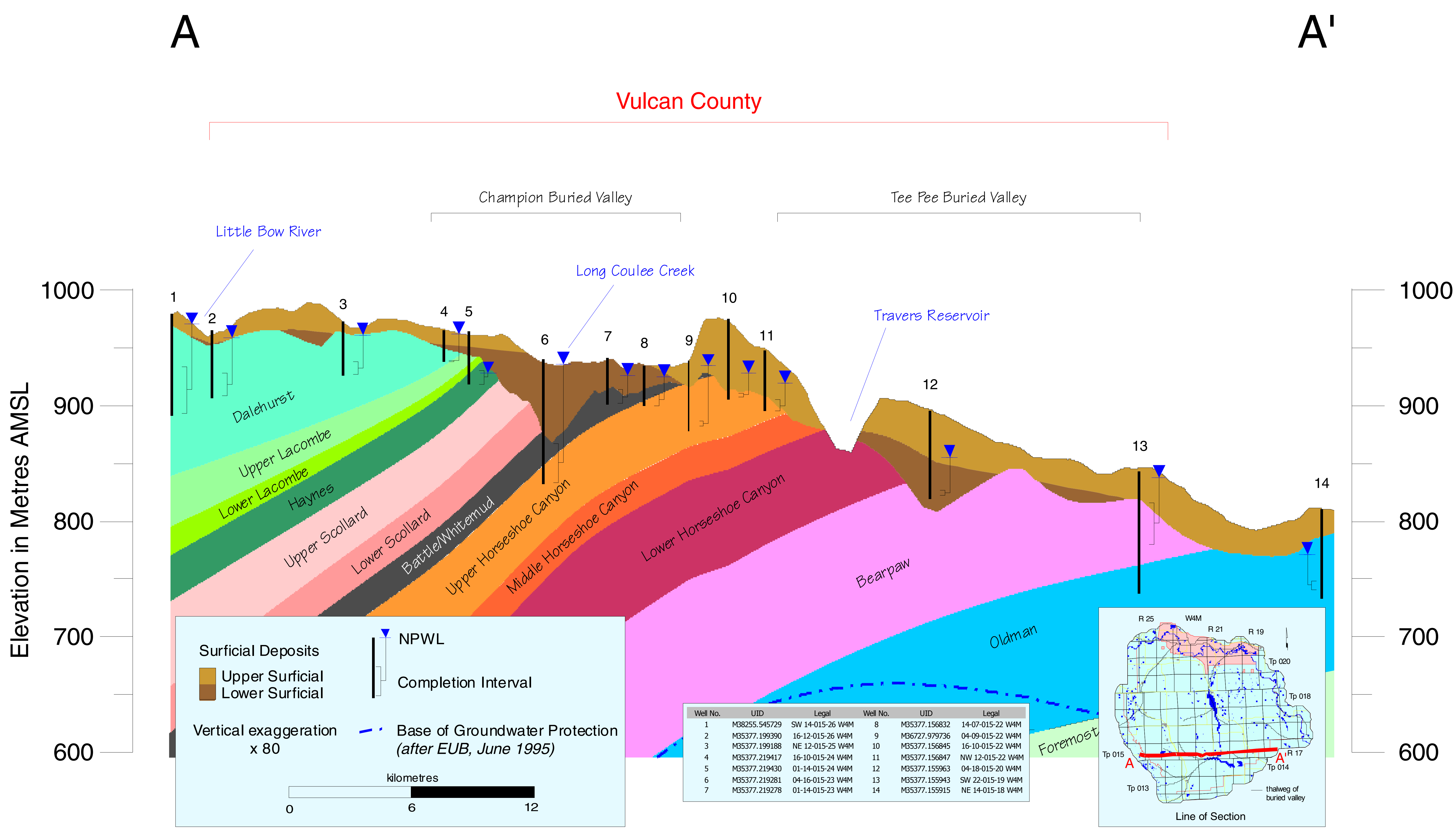


2007 Hydrogeological Consultants Ltd. (HCL)



1974 Alberta Geological Survey (Ozoray and Lytviak)

Cross-Section A - A'



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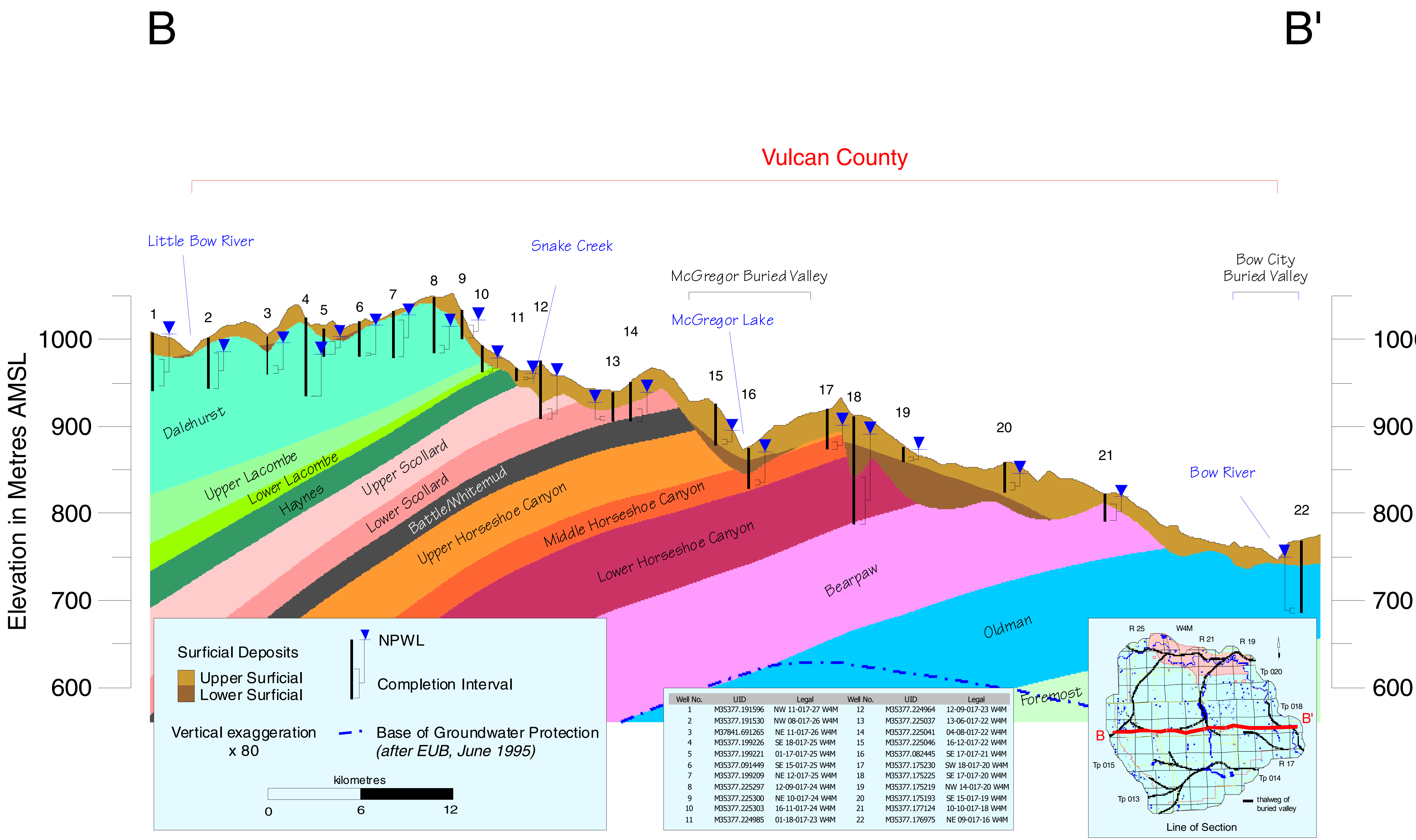
4	M35377.219417	16-10-015-24 W4M	11	M35377.156847	NW 12-015-22 W4M
5	M35377.219430	01-14-015-24 W4M	12	M35377.155963	04-18-015-20 W4M
6	M35377.219281	04-16-015-23 W4M	13	M35377.155943	SW 22-015-19 W4M
7	M35377.219278	01-14-015-23 W4M	14	M35377.155915	NE 14-015-18 W4M

Cross-Section B - B'



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4	M35377.199226	SE 18-017-25 W4M	15	M35377.225046	16-12-017-22 W4M
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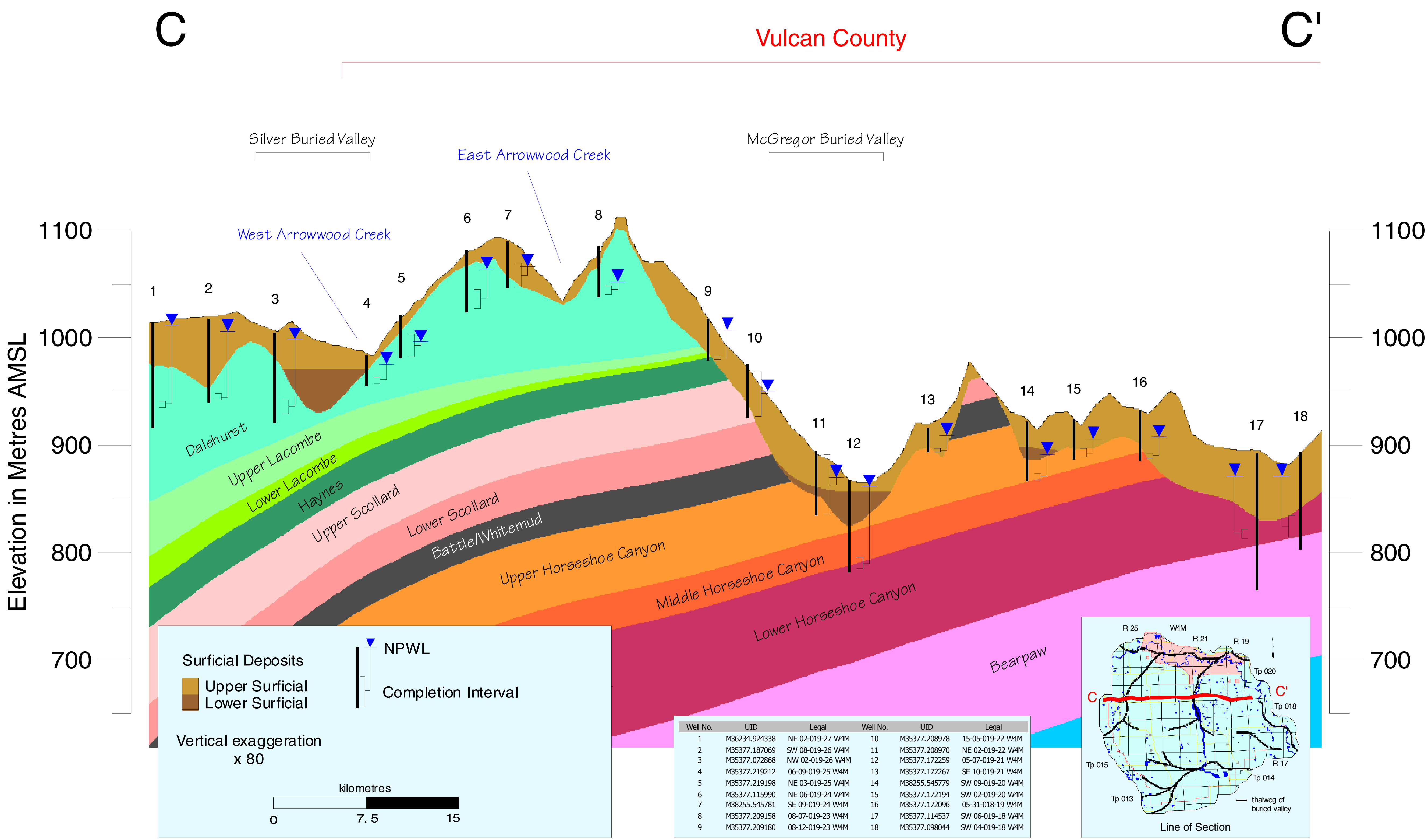
7	M35377.199209	NE 12-017-25 W4M	18	M35377.175225	SE 17-017-20 W4M
8	M35377.225297	12-09-017-24 W4M	19	M35377.175219	NW 14-017-20 W4M
9	M35377.225300	NE 10-017-24 W4M	20	M35377.175193	SE 15-017-19 W4M
10	M35377.225303	16-11-017-24 W4M	21	M35377.177124	10-10-017-18 W4M
11	M35377.224985	01-18-017-23 W4M	22	M35377.176975	NE 09-017-16 W4M

Cross-Section C - C'



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4	M35377.219212	06-09-019-25 W4M	13	M35377.172267	SE 10-019-21 W4M
5	M35377.219198	NE 03-019-25 W4M	14	M38255.545779	SW 09-019-20 W4M
6	M35377.115990	NE 06-019-24 W4M	15	M35377.172194	SW 02-019-20 W4M
7	M38255.545781	SE 09-019-24 W4M	16	M35377.172096	05-31-018-19 W4M
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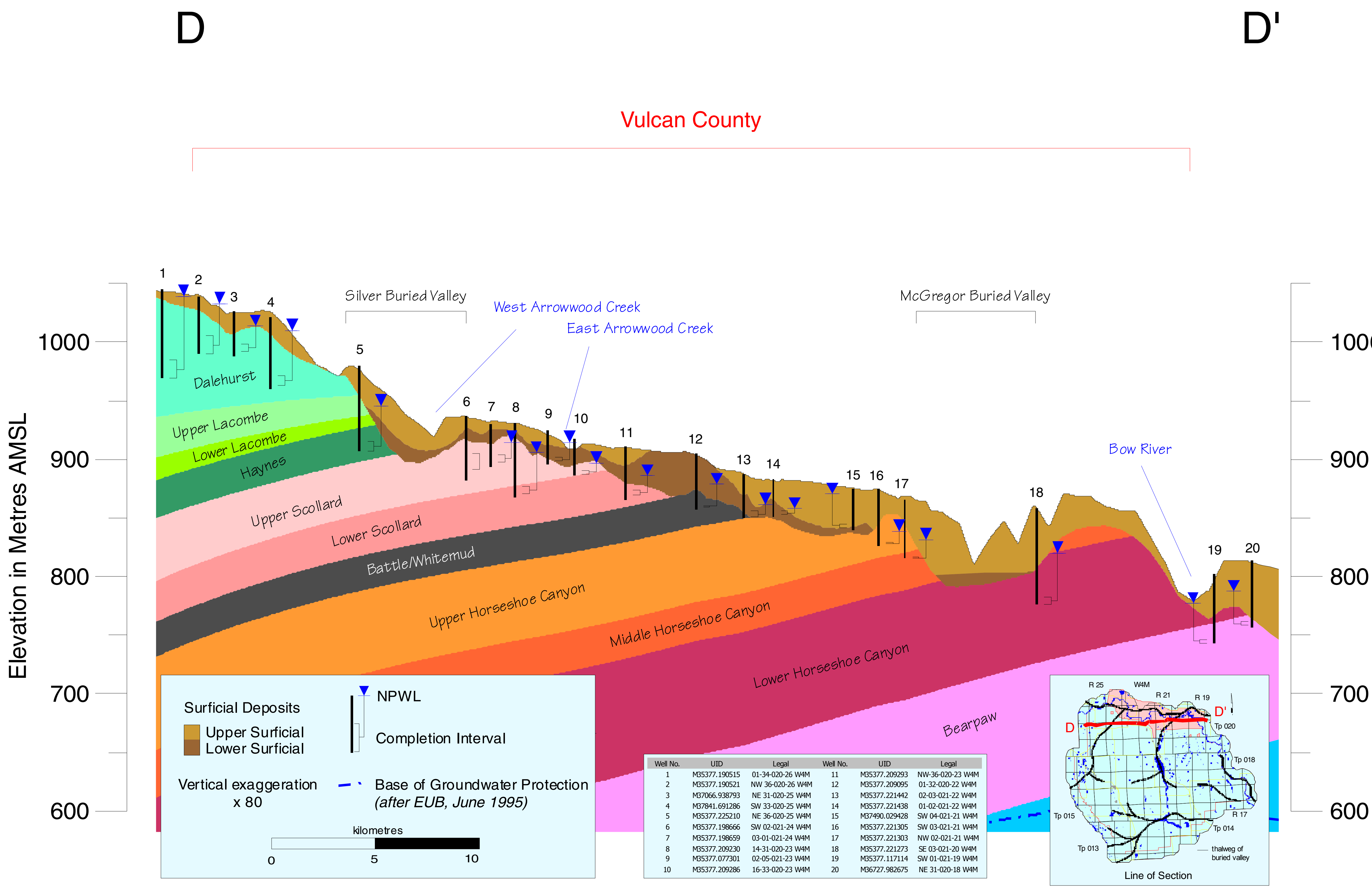
Cross-Section D - D'



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3	M37066.938793	NE 31-020-25 W4M	13	M35377.221442	02-03-021-22 W4M
4	M37841.691286	SW 33-020-25 W4M	14	M35377.221438	01-02-021-22 W4M
5	M35377.225210	NE 36-020-25 W4M	15	M37490.029428	SW 04-021-21 W4M
6	M35377.198666	SW 02-021-24 W4M	16	M35377.221305	SW 03-021-21 W4M
7	M35377.198659	03-01-021-24 W4M	17	M35377.221303	NW 02-021-21 W4M
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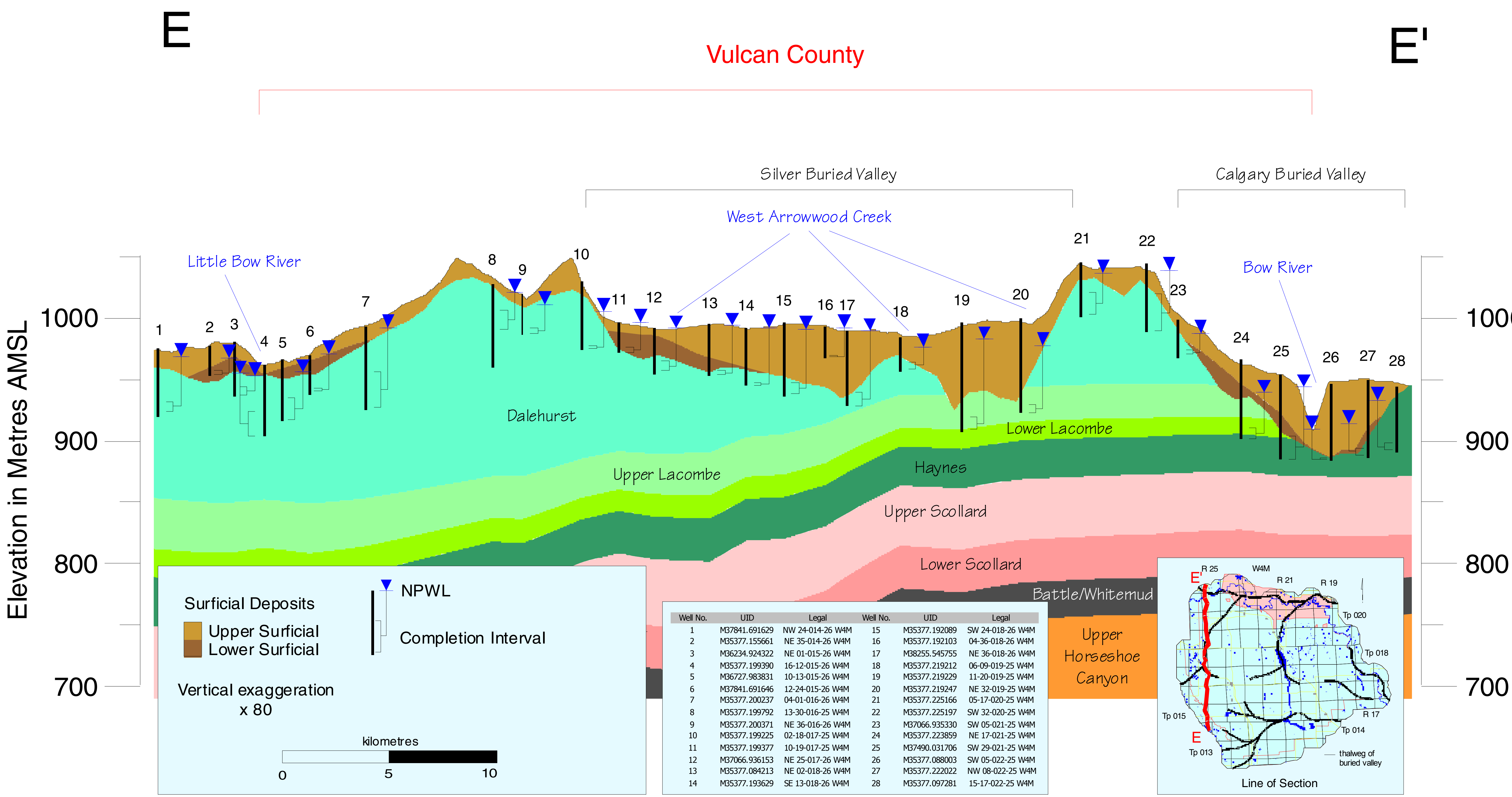
Cross-Section E - E'



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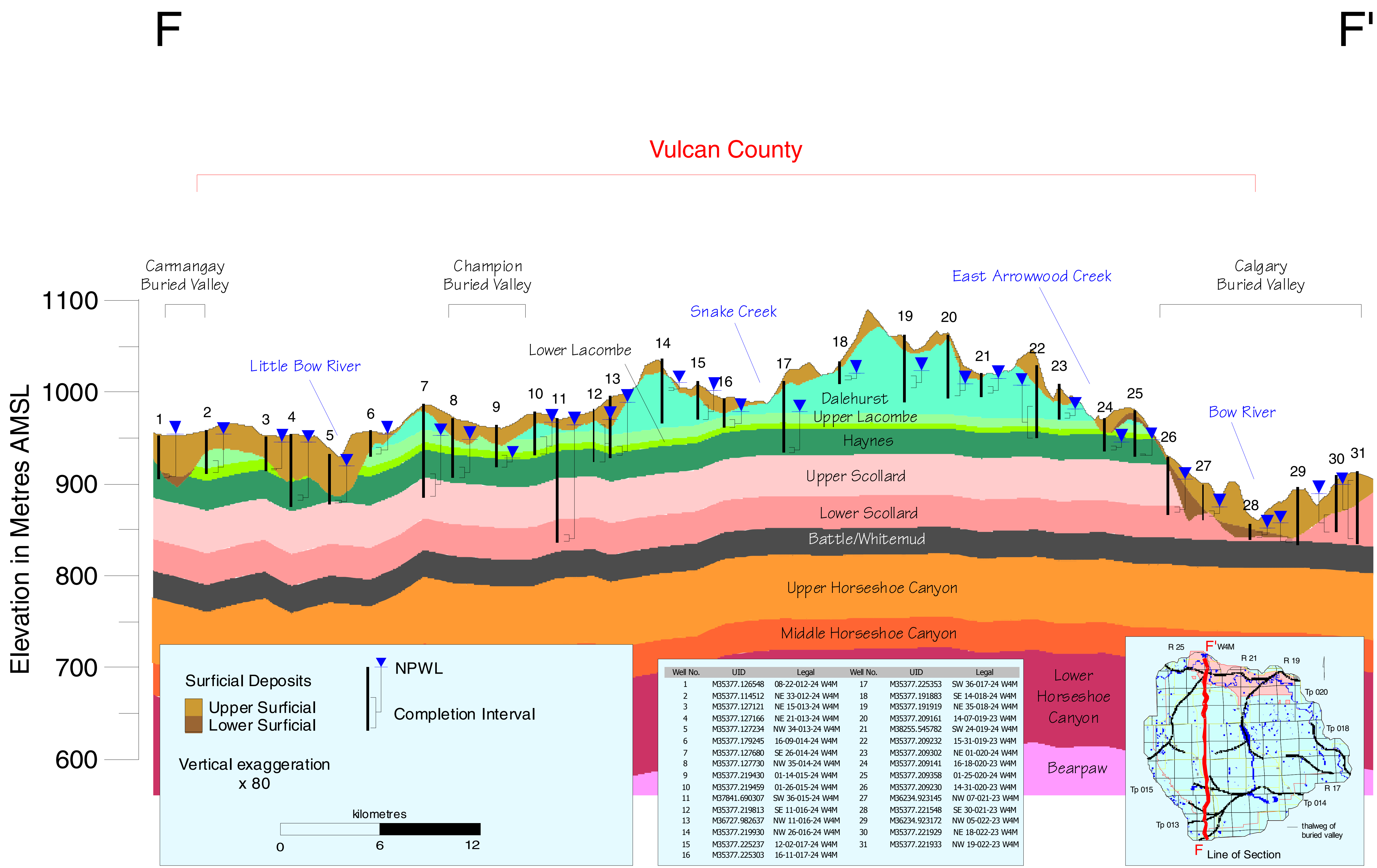
2	M35377.155661	NE 35-014-26 W4M	16	M35377.192103	04-36-018-26 W4M
3	M36234.924322	NE 01-015-26 W4M	17	M38255.545755	NE 36-018-26 W4M
4	M35377.199390	16-12-015-26 W4M	18	M35377.219212	06-09-019-25 W4M
5	M36727.983831	10-13-015-26 W4M	19	M35377.219229	11-20-019-25 W4M
6	M37841.691646	12-24-015-26 W4M	20	M35377.219247	NE 32-019-25 W4M
7	M35377.200237	04-01-016-26 W4M	21	M35377.225166	05-17-020-25 W4M
8	M35377.199792	13-30-016-25 W4M	22	M35377.225197	SW 32-020-25 W4M
9	M35377.200371	NE 36-016-26 W4M	23	M37066.935330	SW 05-021-25 W4M
10	M35377.199225	02-18-017-25 W4M	24	M35377.223859	NE 17-021-25 W4M
11	M35377.199377	10-19-017-25 W4M	25	M37490.031706	SW 29-021-25 W4M
12	M37066.936153	NE 25-017-26 W4M	26	M35377.088003	SW 05-022-25 W4M
13	M35377.084213	NE 02-018-26 W4M	27	M35377.222022	NW 08-022-25 W4M
14	M35377.193629	SE 13-018-26 W4M	28	M35377.097281	15-17-022-25 W4M

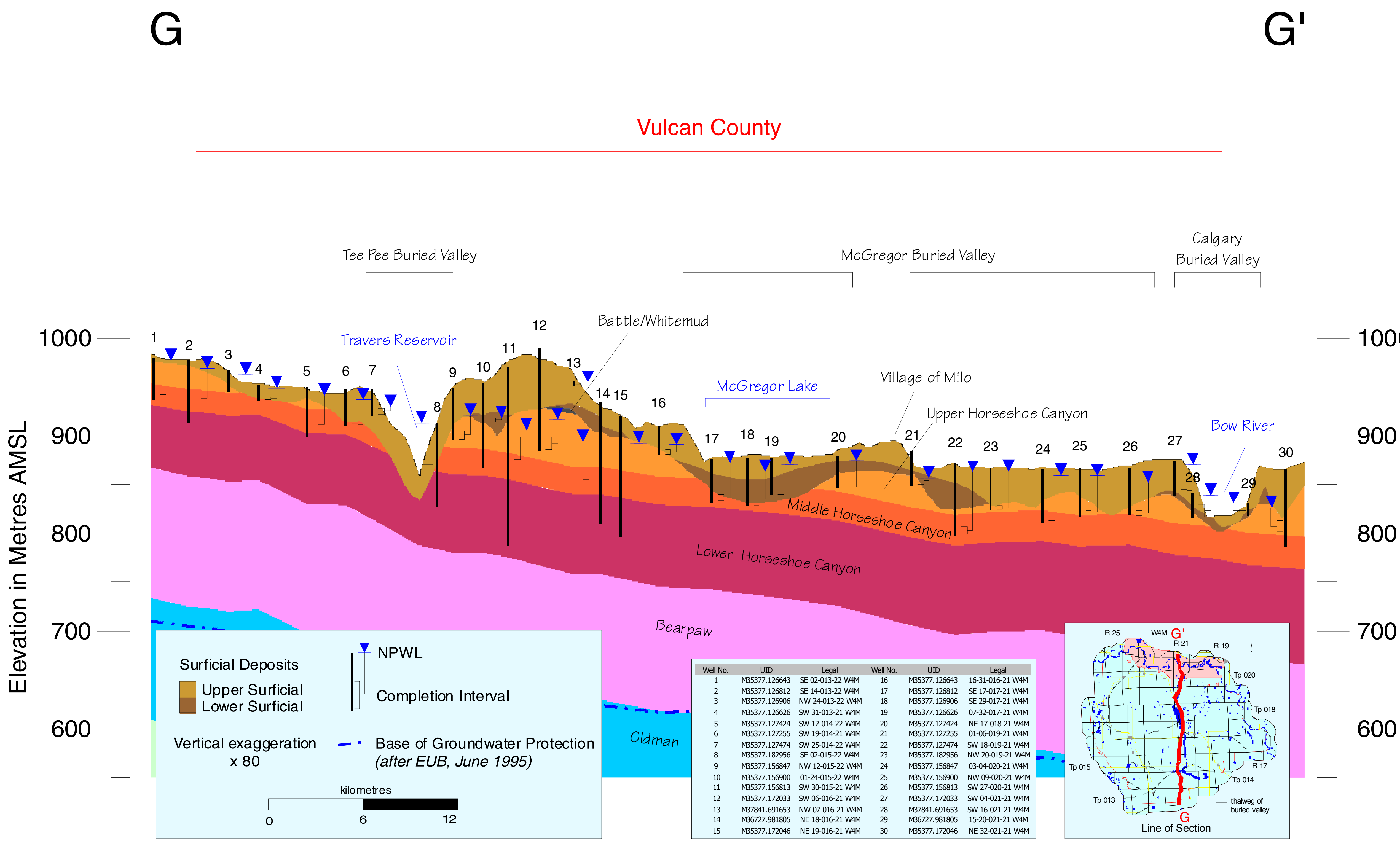
Line of Section

Cross-Section F - F'



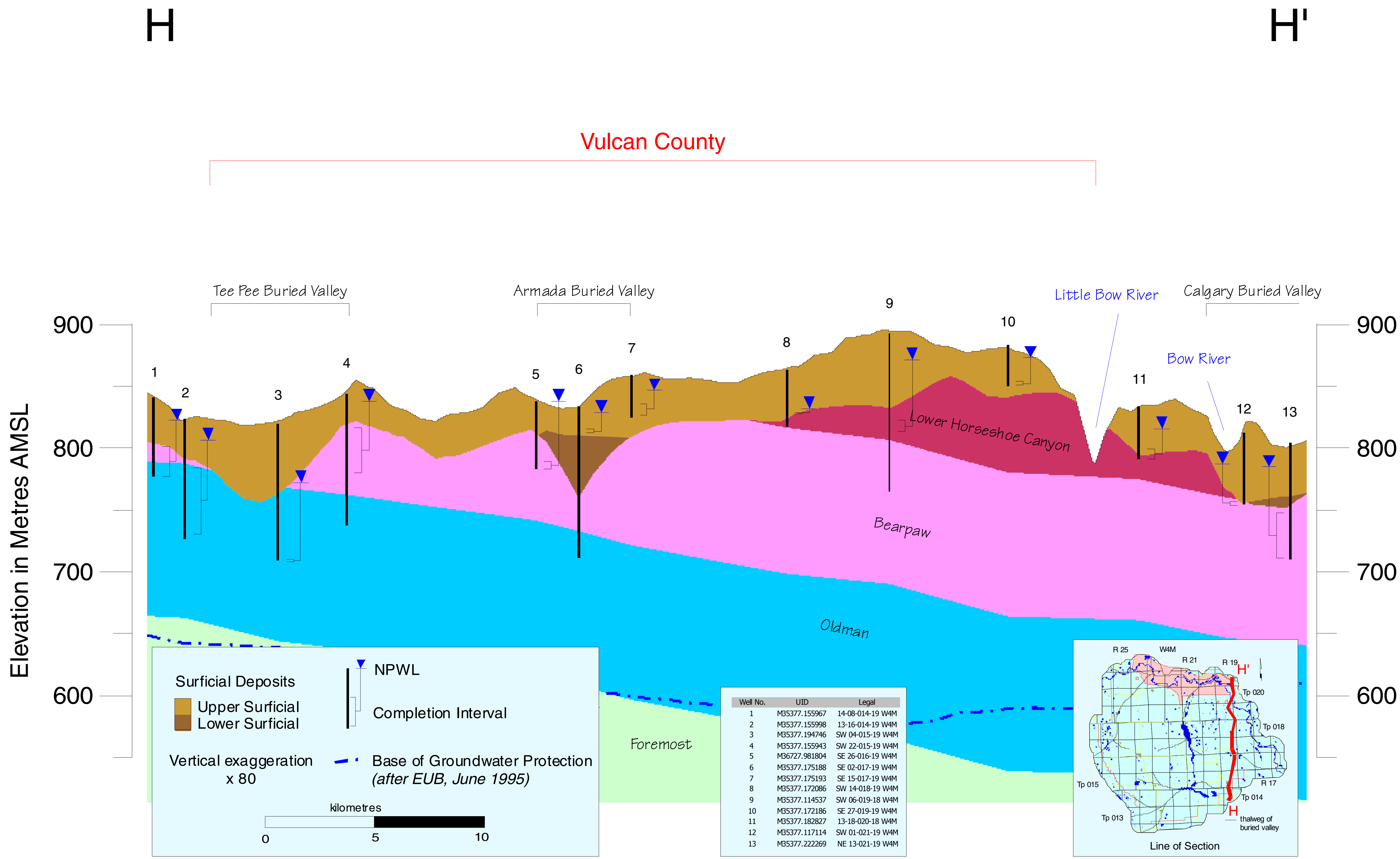
Well No.	UID	Legal	Well No.	UID	Legal
1	M35377.126548	08-22-012-24 W4M	17	M35377.225353	SW 36-017-24 W4M
2	M35377.114512	NE 33-012-24 W4M	18	M35377.191883	SE 14-018-24 W4M
3	M35377.127121	NE 15-013-24 W4M	19	M35377.191919	NE 35-018-24 W4M
4	M35377.127166	NE 21-013-24 W4M	20	M35377.209161	14-07-019-23 W4M
5	M35377.127234	NW 34-013-24 W4M	21	M38255.545782	SW 24-019-24 W4M
6	M35377.179245	16-09-014-24 W4M	22	M35377.209232	15-31-019-23 W4M
7	M35377.127680	SE 26-014-24 W4M	23	M35377.209302	NE 01-020-24 W4M
8	M35377.127730	NW 35-014-24 W4M	24	M35377.209141	16-18-020-23 W4M
9	M35377.219430	01-14-015-24 W4M	25	M35377.209358	01-25-020-24 W4M
10	M35377.219459	01-26-015-24 W4M	26	M35377.209230	14-31-020-23 W4M
11	M37841.690307	SW 36-015-24 W4M	27	M36234.923145	NW 07-021-23 W4M
12	M35377.219813	SE 11-016-24 W4M	28	M35377.221548	SE 30-021-23 W4M
13	M36727.982637	NW 11-016-24 W4M	29	M36234.923172	NW 05-022-23 W4M
14	M35377.219930	NW 26-016-24 W4M	30	M35377.221929	NE 18-022-23 W4M
15	M35377.225237	12-02-017-24 W4M	31	M35377.221933	NW 19-022-23 W4M
16	M35377.225303	16-11-017-24 W4M			

Cross-Section G - G'



Well No.	UID	Legal	Well No.	UID	Legal
1	M35377.126643	SE 02-013-22 W4M	16	M35377.126643	16-31-016-21 W4M
2	M35377.126812	SE 14-013-22 W4M	17	M35377.126812	SE 17-017-21 W4M
3	M35377.126906	NW 24-013-22 W4M	18	M35377.126906	SE 29-017-21 W4M
4	M35377.126626	SW 31-013-21 W4M	19	M35377.126626	07-32-017-21 W4M
5	M35377.127424	SW 12-014-22 W4M	20	M35377.127424	NE 17-018-21 W4M
6	M35377.127255	SW 19-014-21 W4M	21	M35377.127255	01-06-019-21 W4M
7	M35377.127474	SW 25-014-22 W4M	22	M35377.127474	SW 18-019-21 W4M
8	M35377.182956	SE 02-015-22 W4M	23	M35377.182956	NW 20-019-21 W4M
9	M35377.156847	NW 12-015-22 W4M	24	M35377.156847	03-04-020-21 W4M
10	M35377.156900	01-24-015-22 W4M	25	M35377.156900	NW 09-020-21 W4M
11	M35377.156813	SW 30-015-21 W4M	26	M35377.156813	SW 27-020-21 W4M
12	M35377.172033	SW 06-016-21 W4M	27	M35377.172033	SW 04-021-21 W4M
13	M37841.691653	NW 07-016-21 W4M	28	M37841.691653	SW 16-021-21 W4M
14	M36727.981805	NE 18-016-21 W4M	29	M36727.981805	15-20-021-21 W4M
15	M35377.172046	NE 19-016-21 W4M	30	M35377.172046	NE 32-021-21 W4M

Cross-Section H - H'



Well No.	UID	Legal
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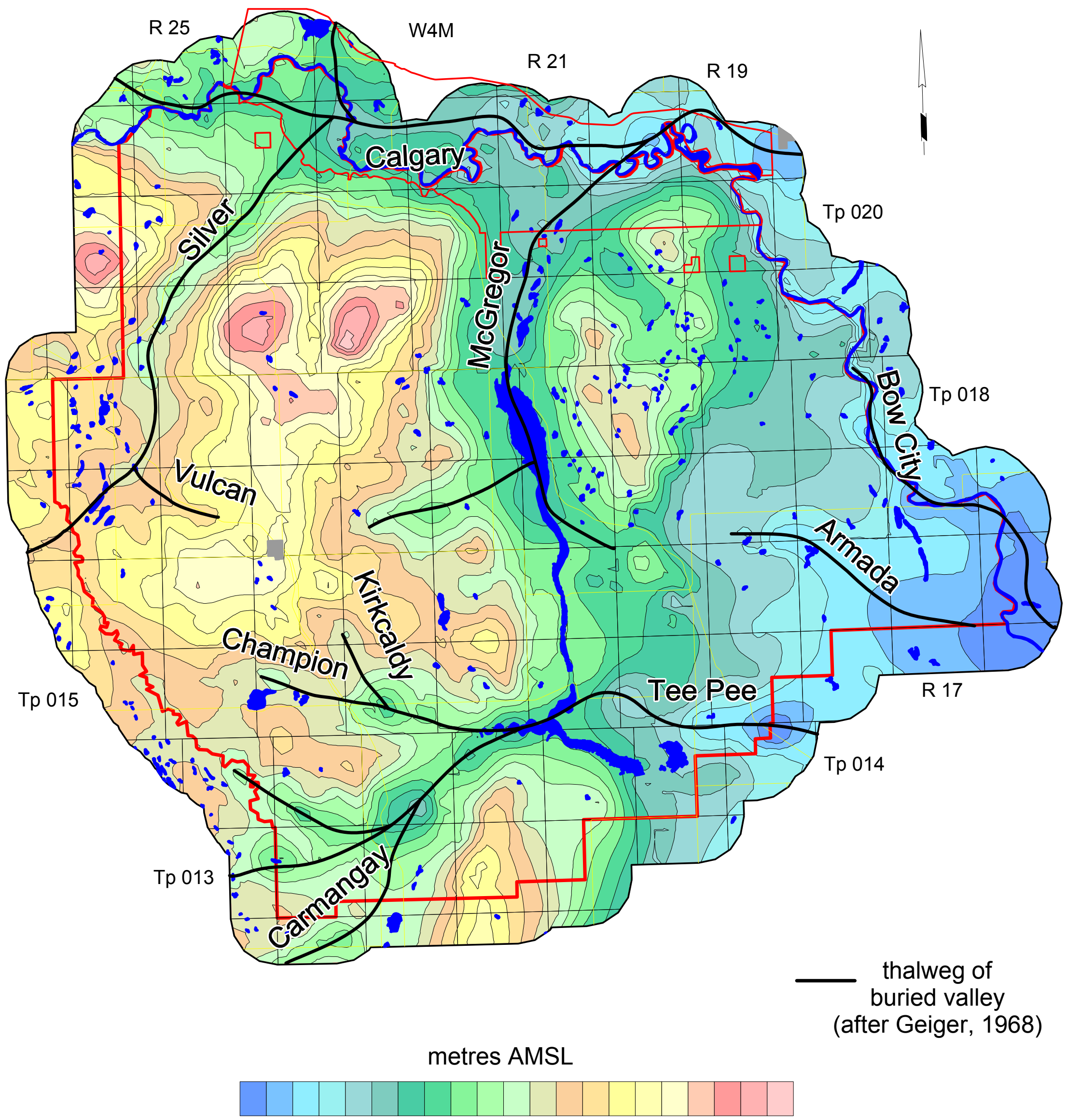
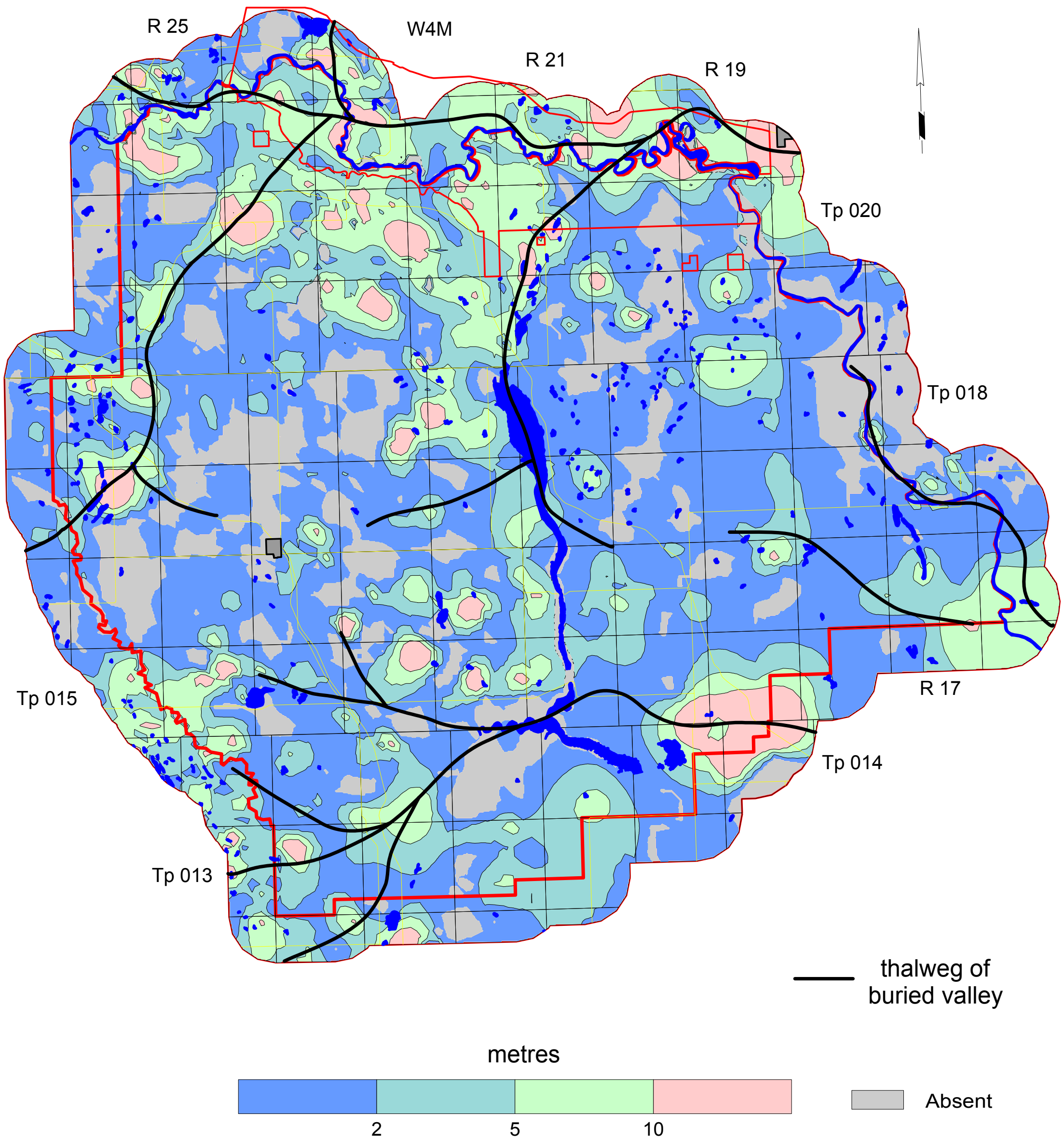
2	M35377.155998	13-16-014-19 W4M
3	M35377.194746	SW 04-015-19 W4M
4	M35377.155943	SW 22-015-19 W4M
5	M36727.981804	SE 26-016-19 W4M
6	M35377.175188	SE 02-017-19 W4M
7	M35377.175193	SE 15-017-19 W4M
8	M35377.172086	SW 14-018-19 W4M
9	M35377.114537	SW 06-019-18 W4M
10	M35377.172186	SE 27-019-19 W4M
11	M35377.182827	13-18-020-18 W4M
12	M35377.117114	SW 01-021-19 W4M
13	M35377.222269	NE 13-021-19 W4M

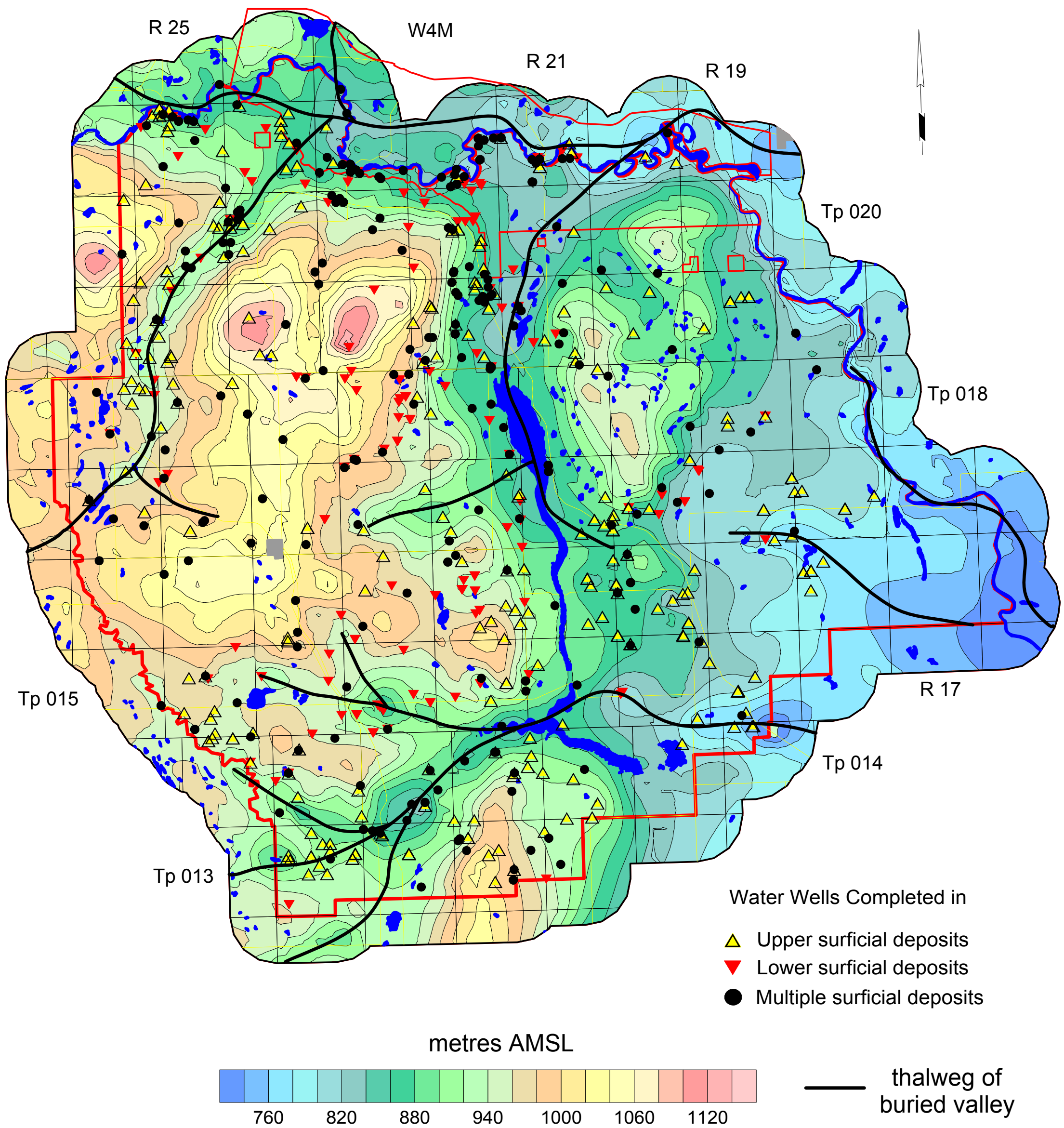
Bedrock Topography



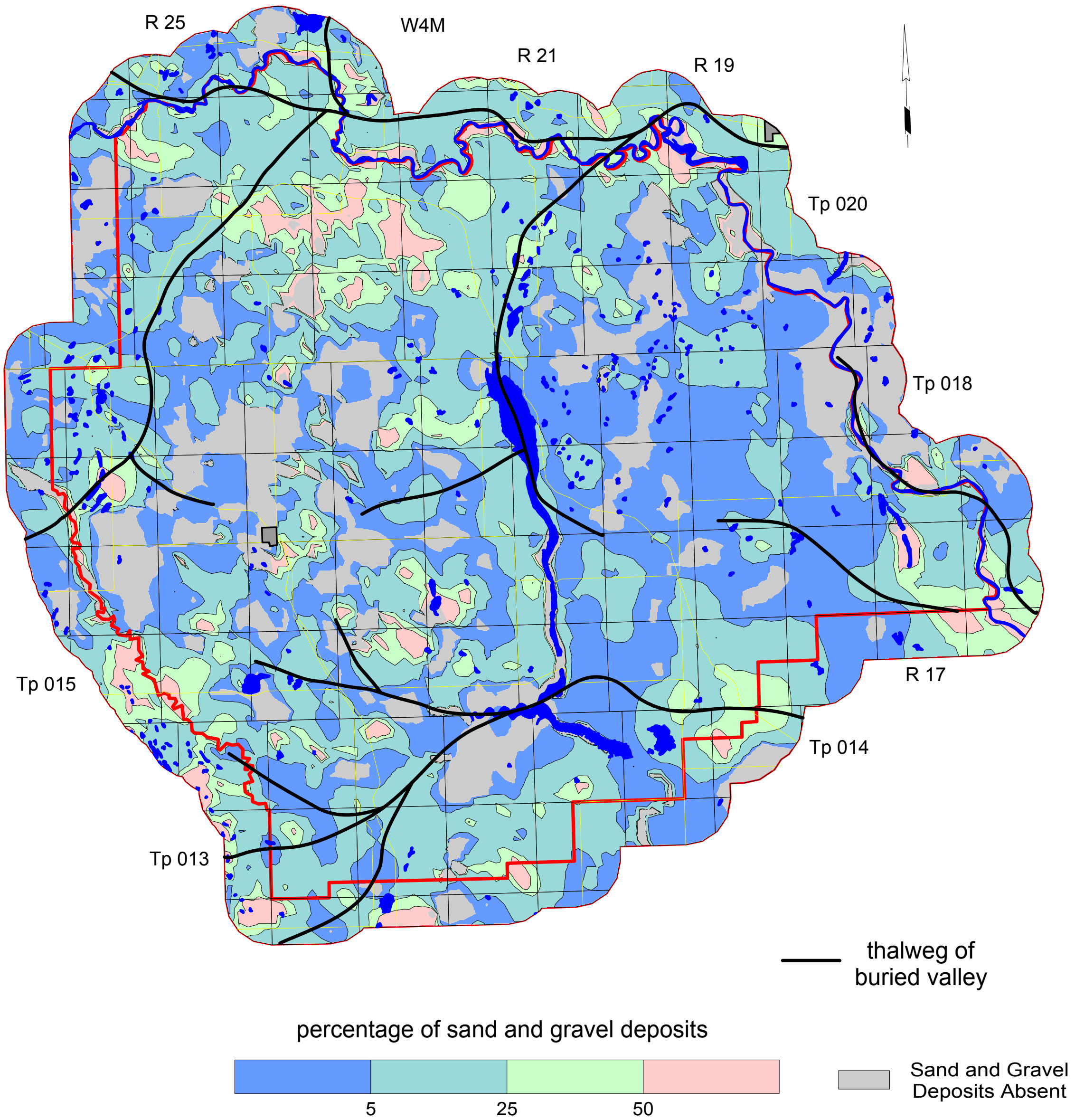
Thickness of Sand and Gravel Deposits



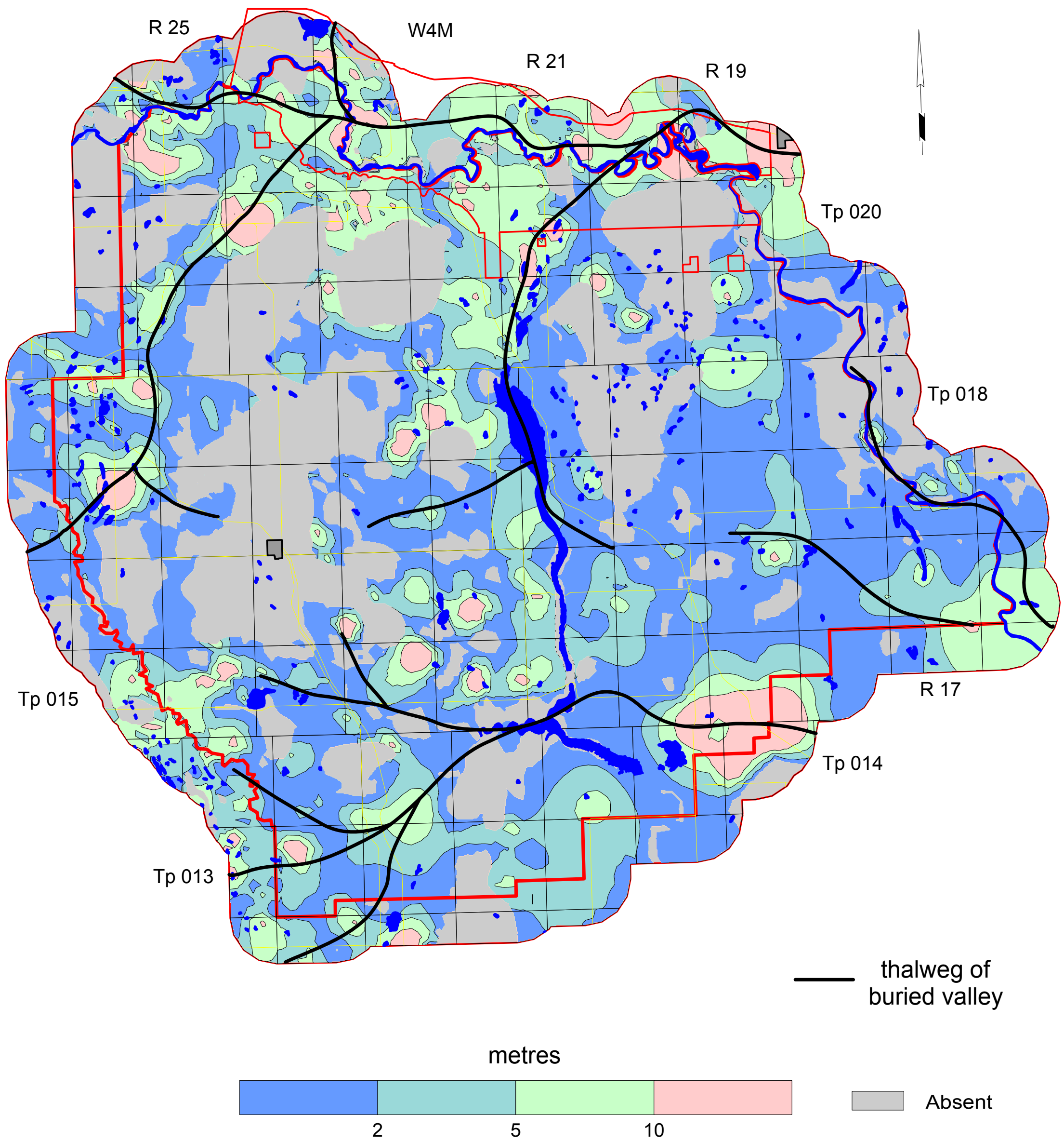
Location of Surficial Water Wells Relative to Bedrock Topography



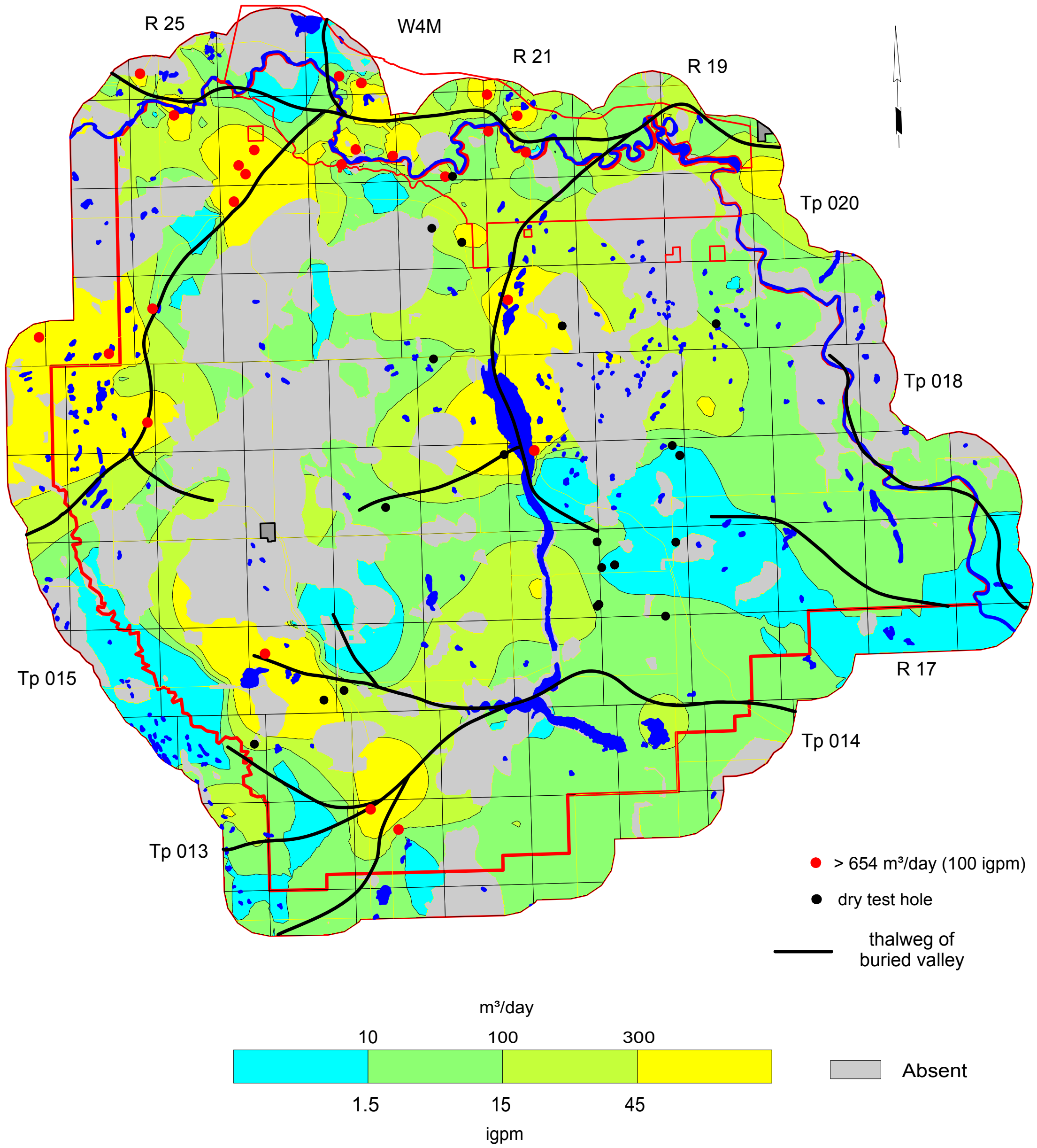
Percentage of Sand and Gravel in Surficial Deposits



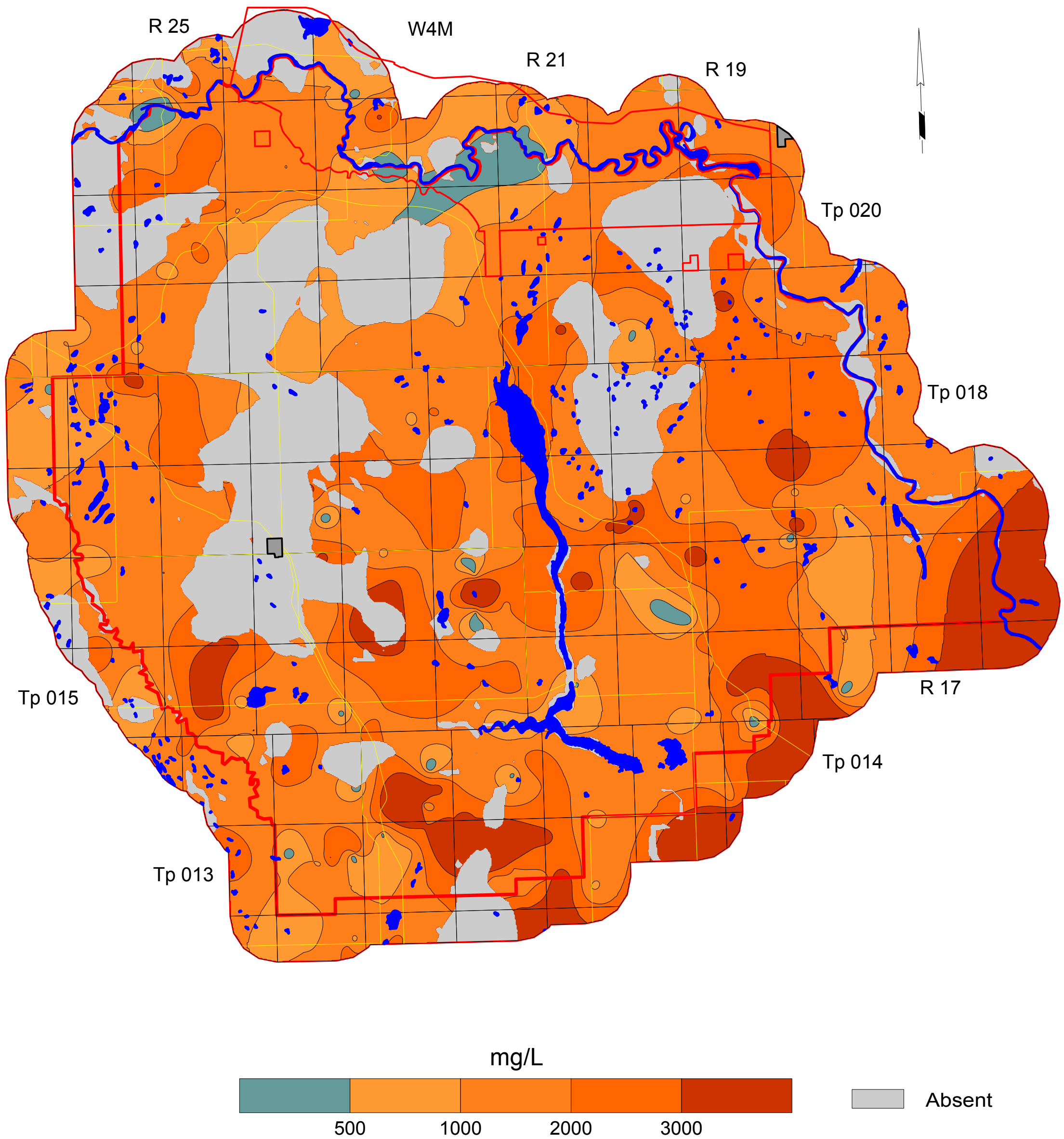
Thickness of Sand and Gravel Aquifer(s)



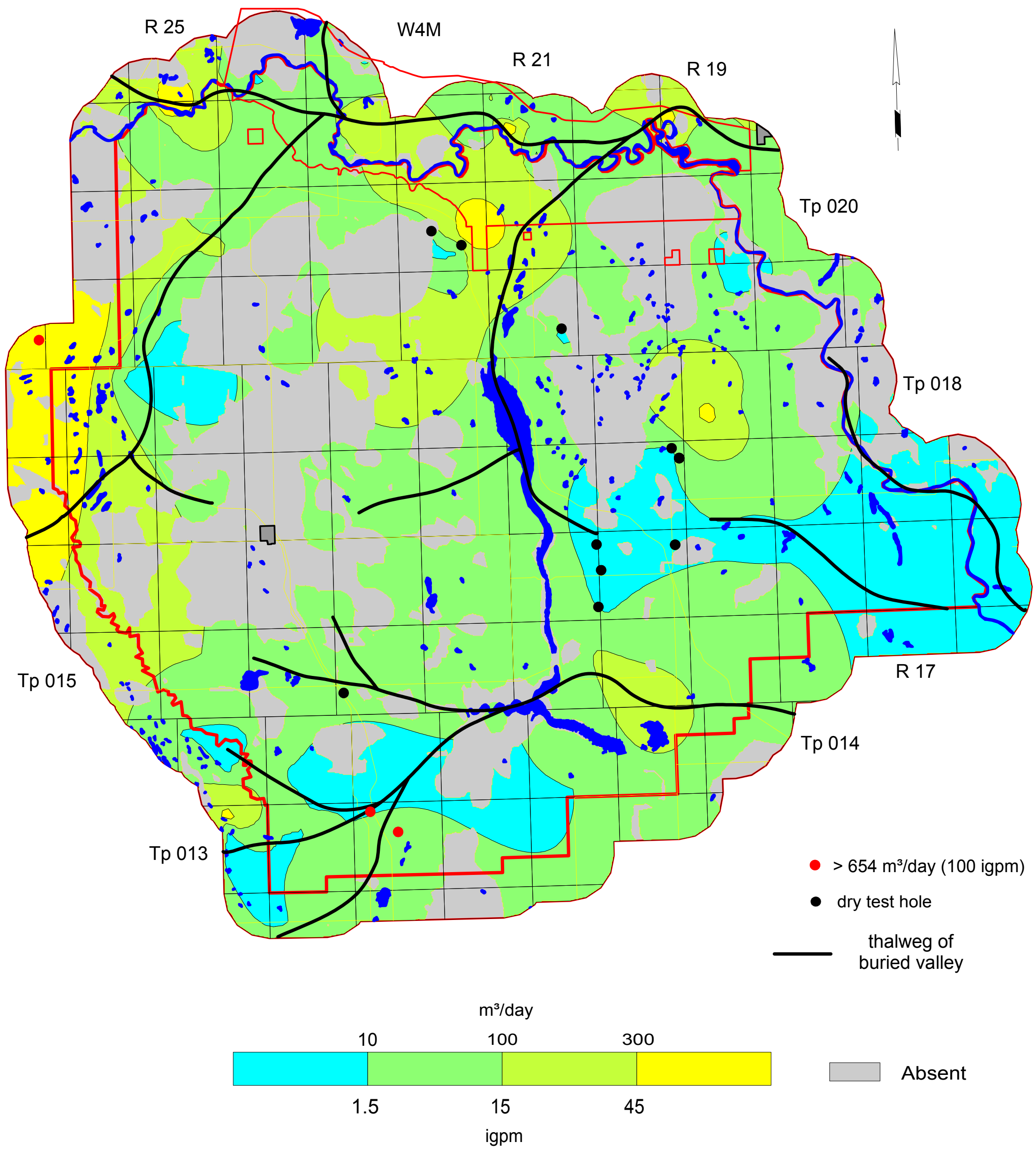
Apparent Yield of Water Wells Completed in Sand and Gravel Aquifer(s)



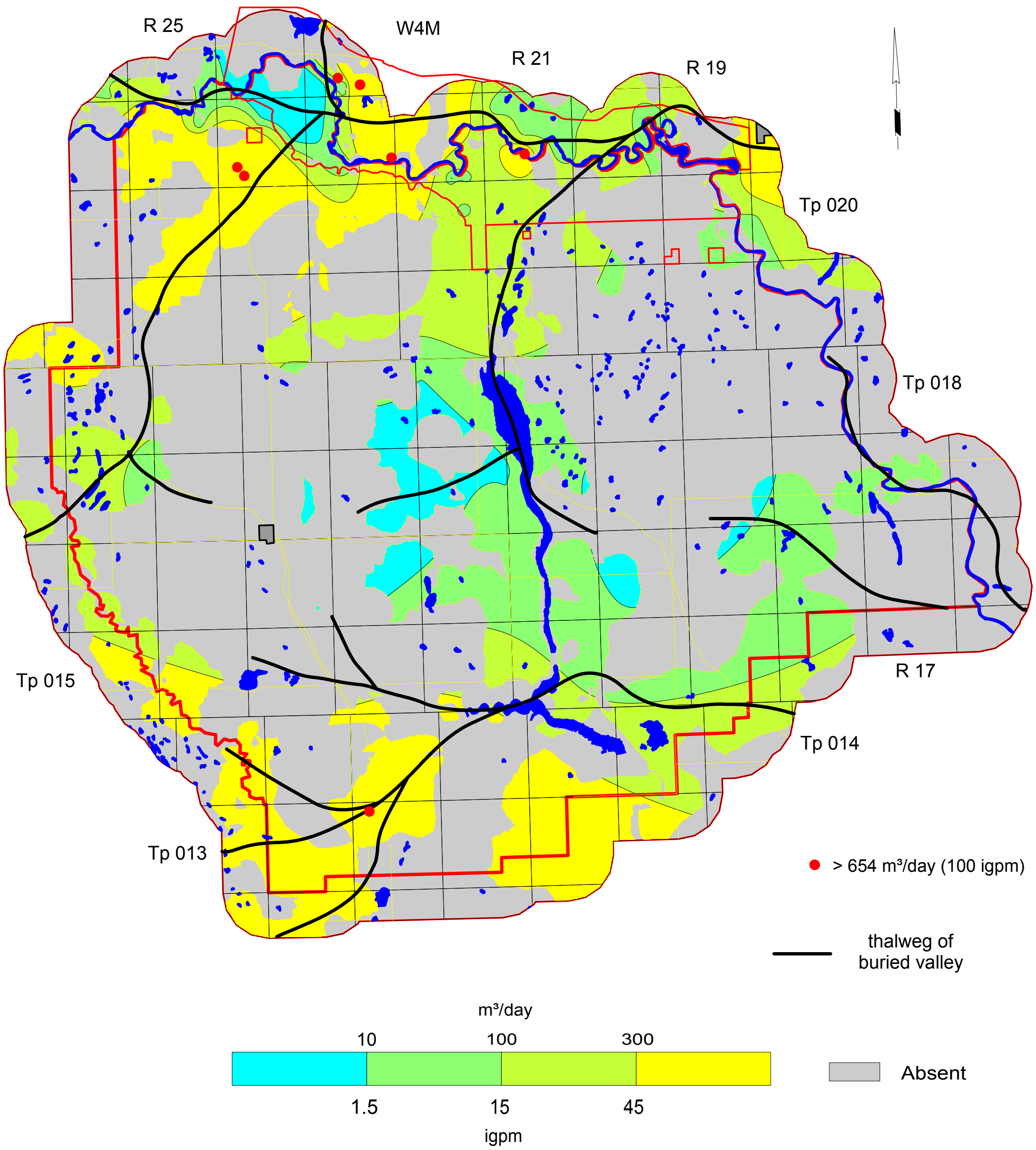
Total Dissolved Solids in Groundwater from Surficial Deposits



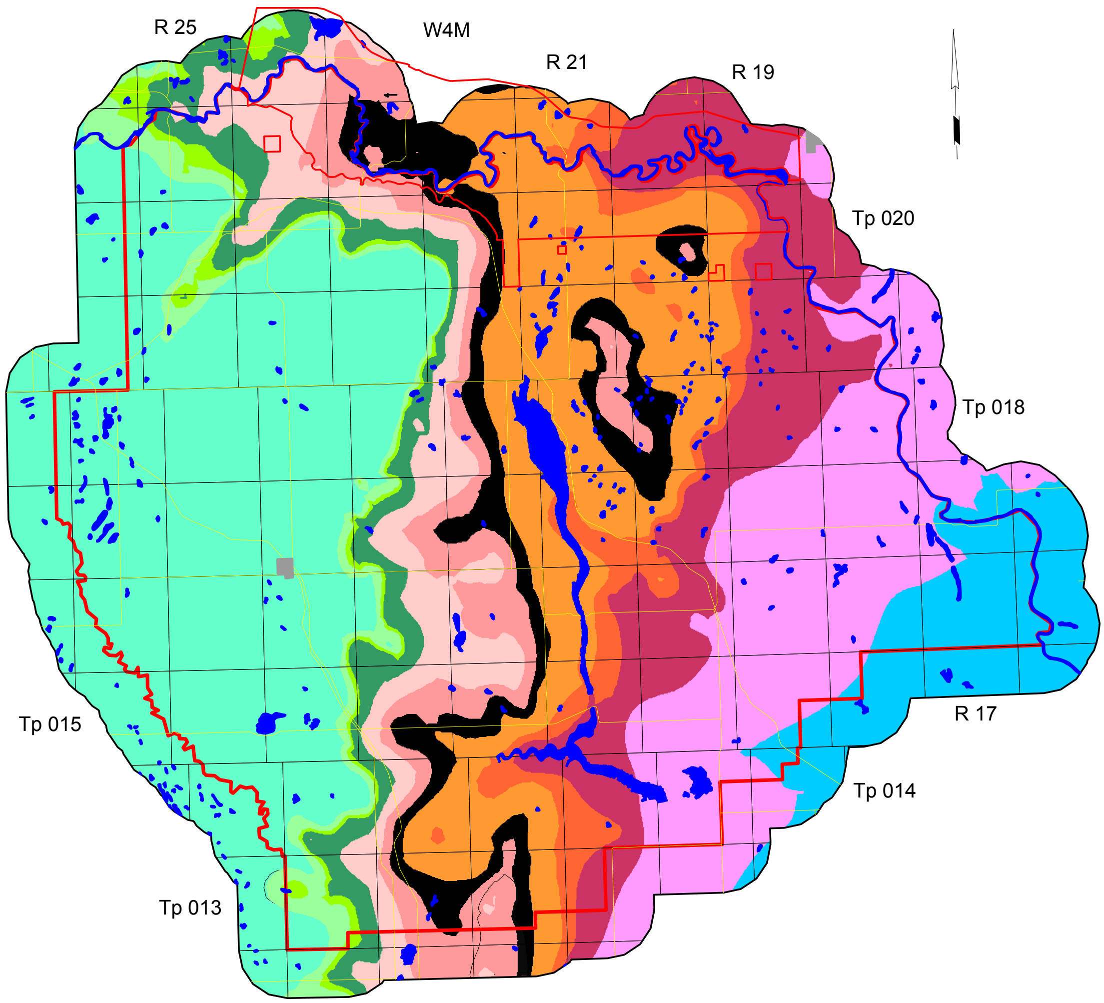
Apparent Yield for Water Wells Completed through Upper Sand and Gravel Aquifer



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



Bedrock Geology



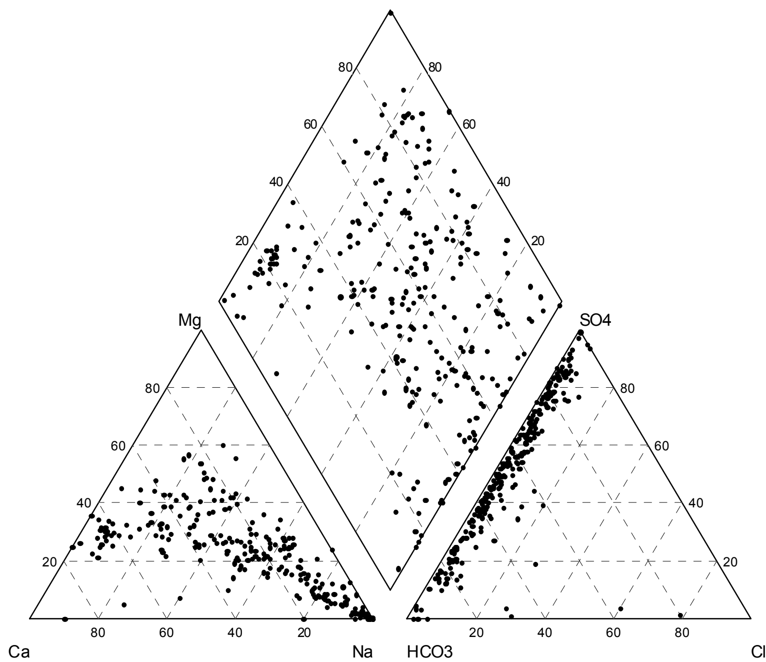
Paskapoo Formation
- Dalehurst Member
- Upper Lacombe Member
- Lower Lacombe Member
- Haynes Member

Edmonton Group
- Upper Scollard
- Lower Scollard
- Battle and Whitemud
- Upper Horseshoe Canyon
- Middle Horseshoe Canyon
- Lower Horseshoe Canyon

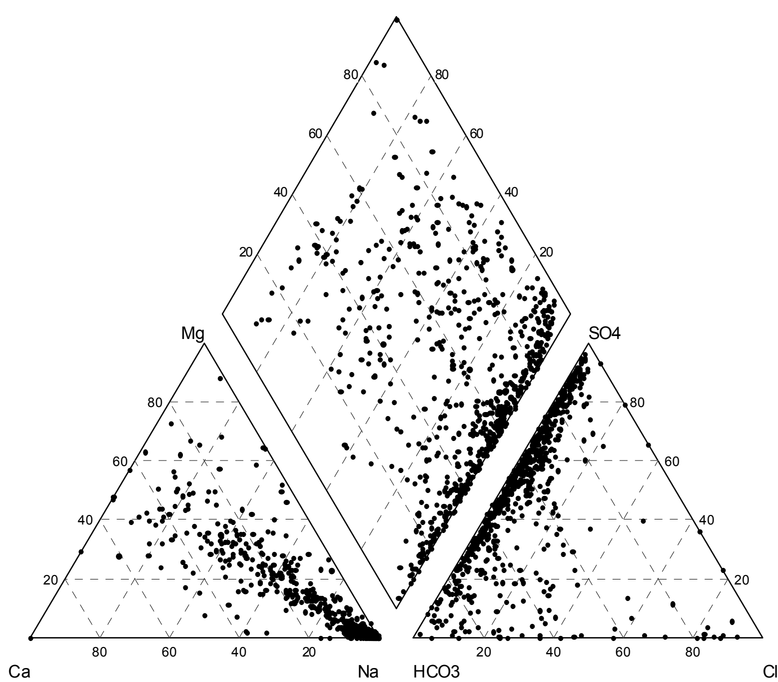
Bearpaw

Belly River Group
- Oldman

Piper Diagrams

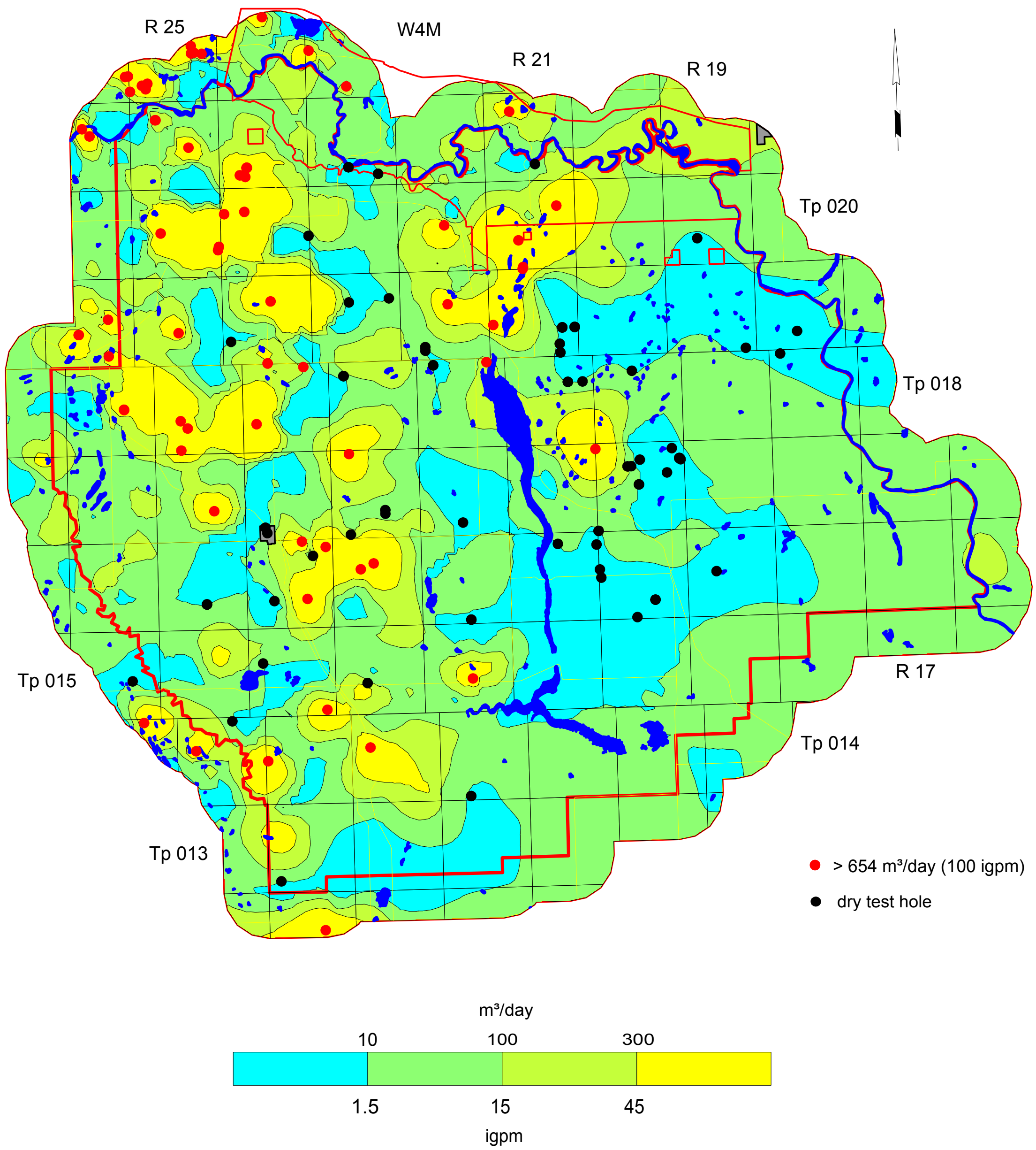


Surficial Deposits

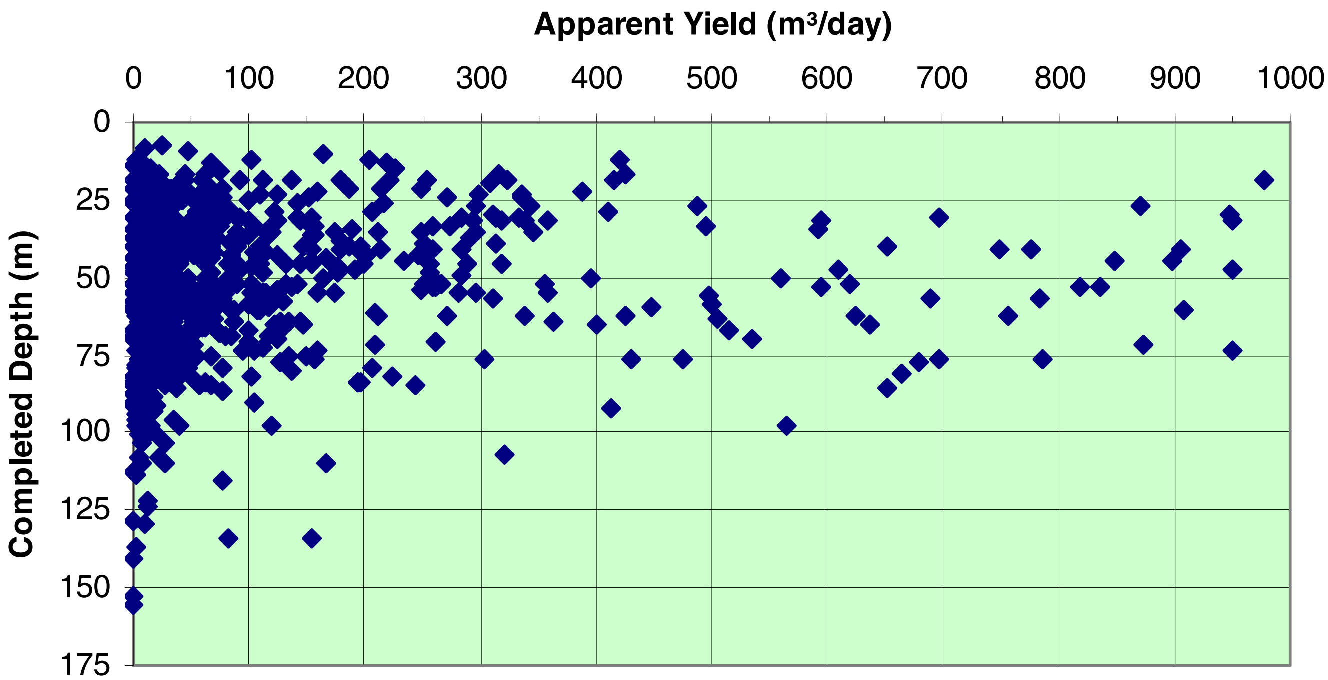


Bedrock Aquifers

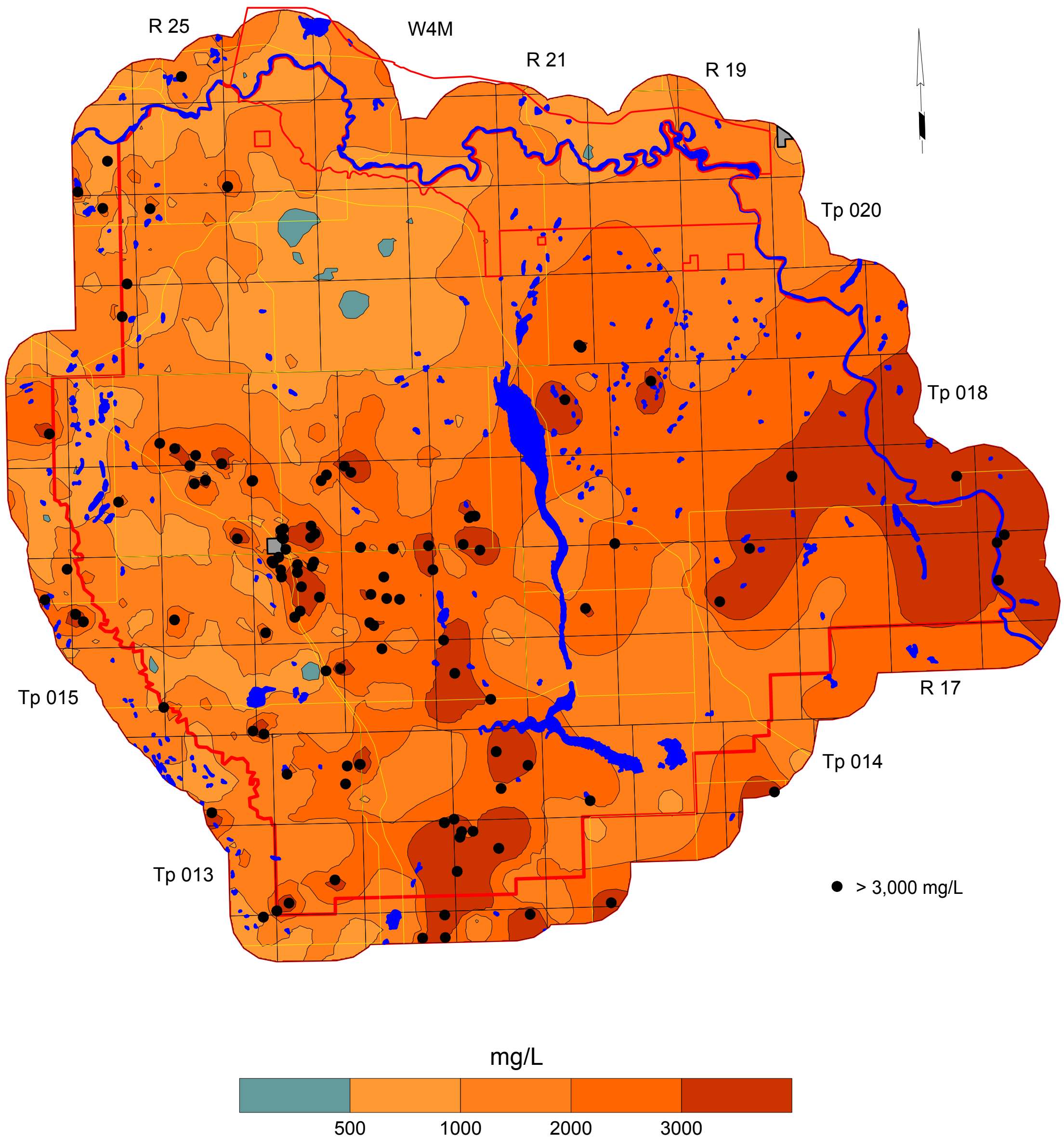
Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)



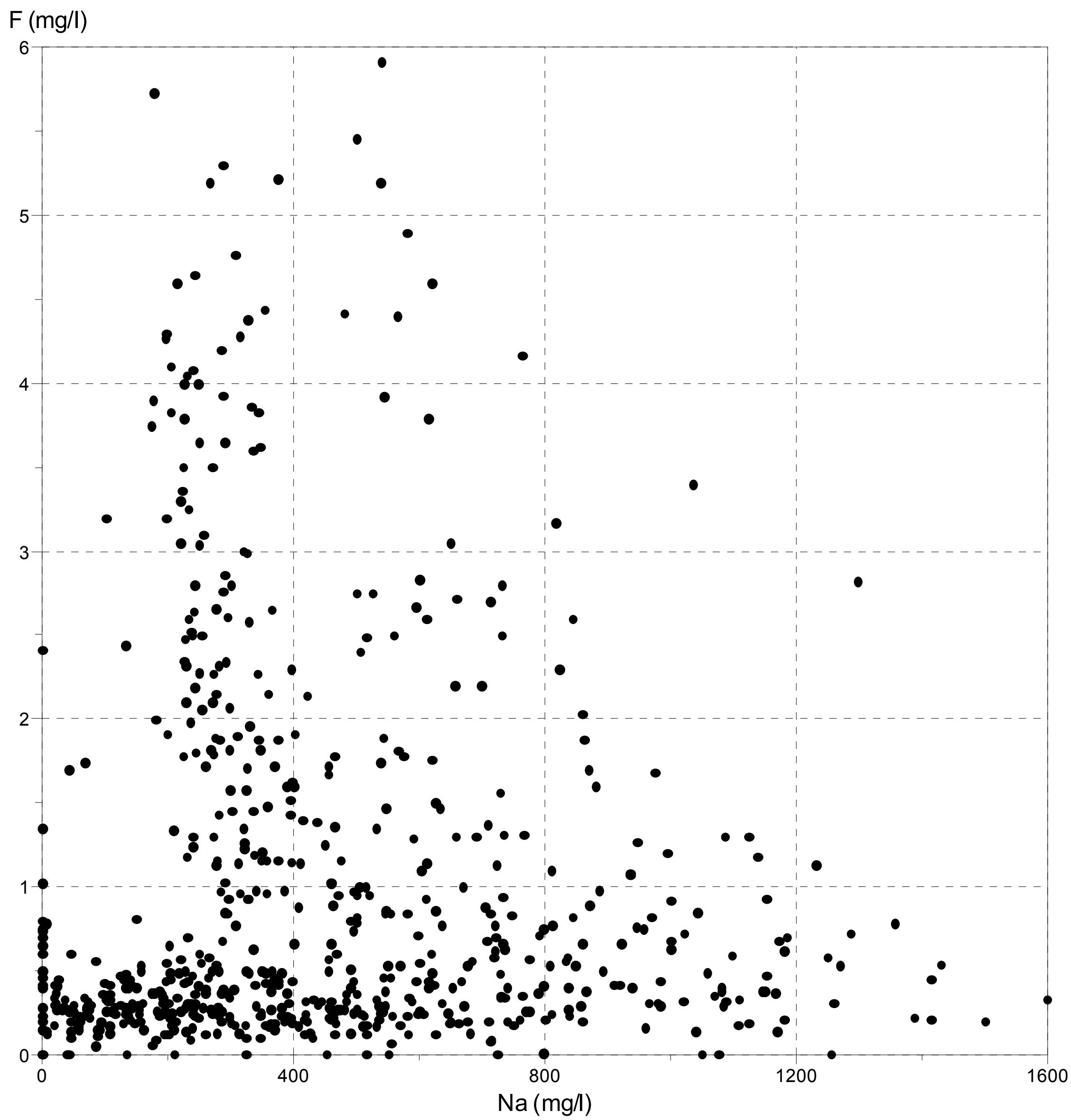
Bedrock Water Well Yields vs Completed Depth



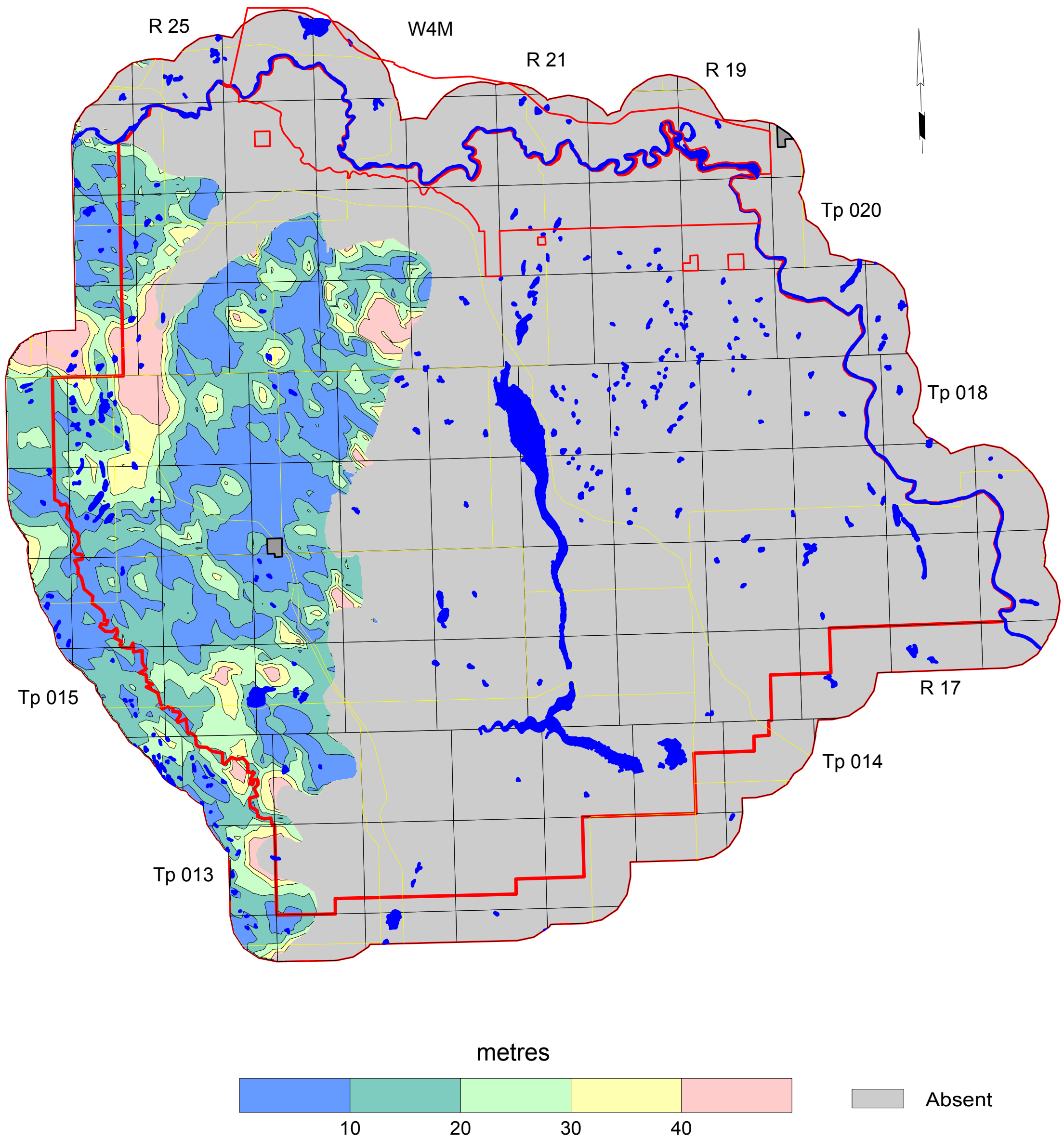
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)



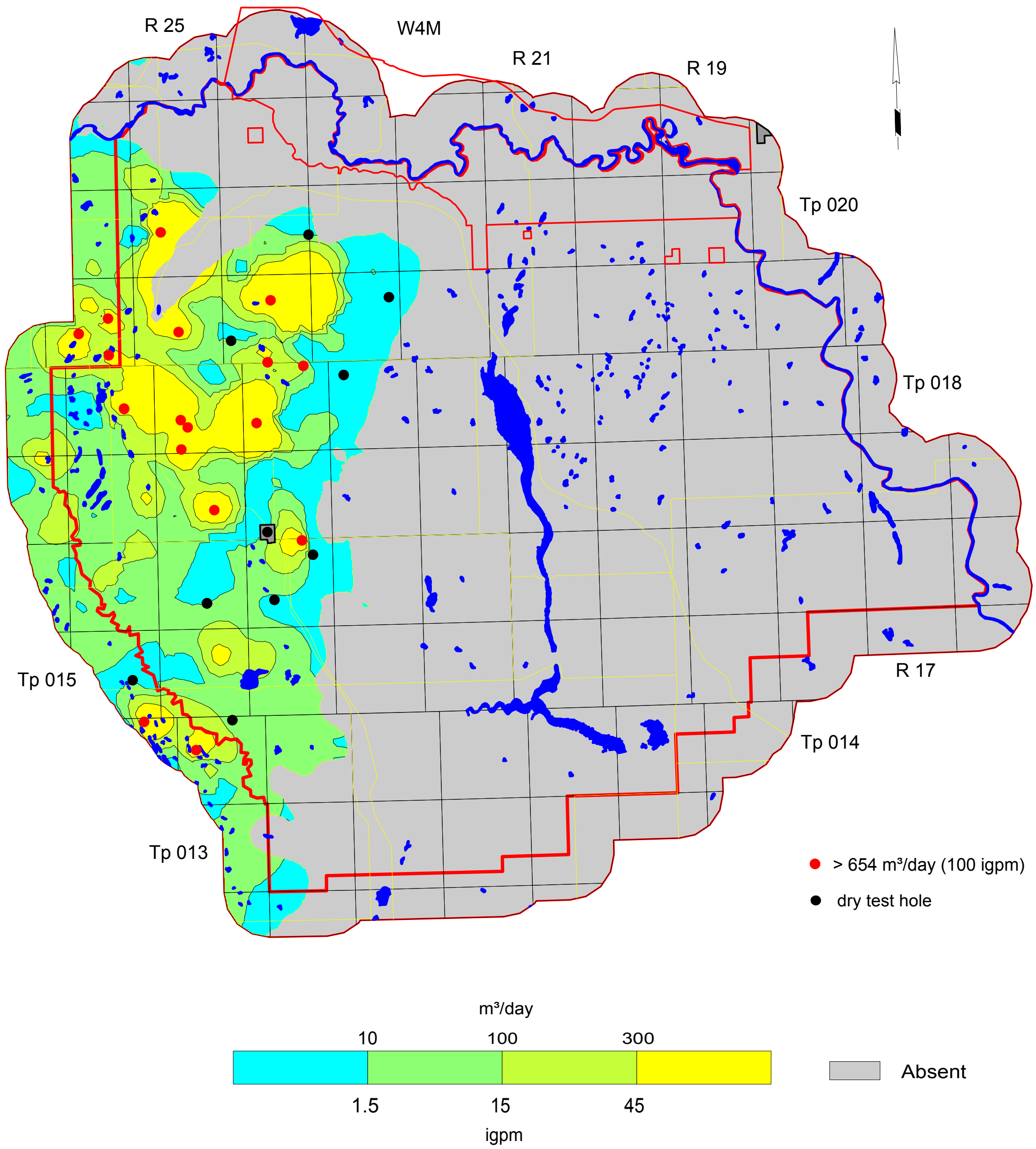
Fluoride vs Sodium Concentrations in Groundwater from Upper Bedrock Aquifer(s)



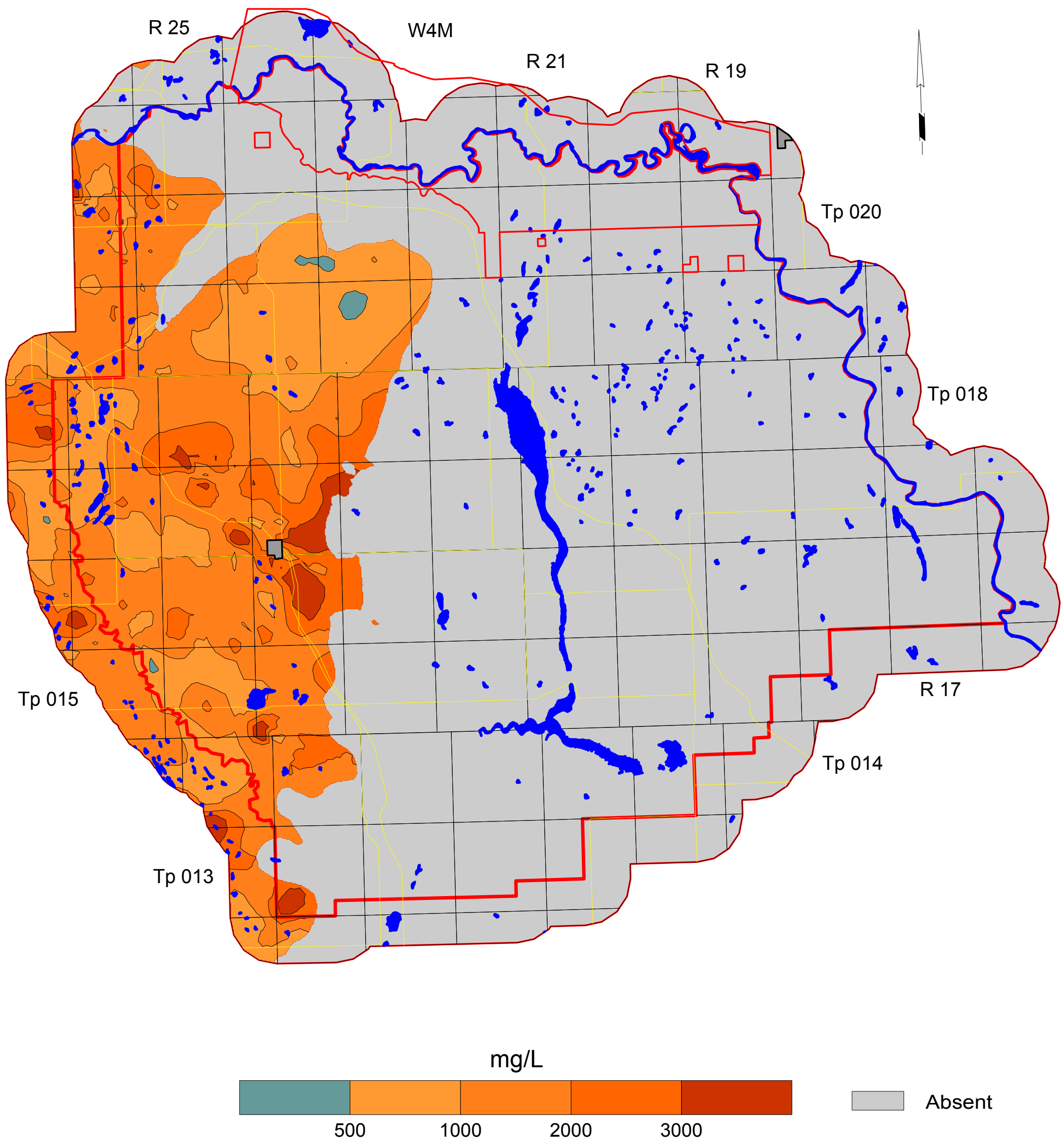
Depth to Top of Dalehurst Member



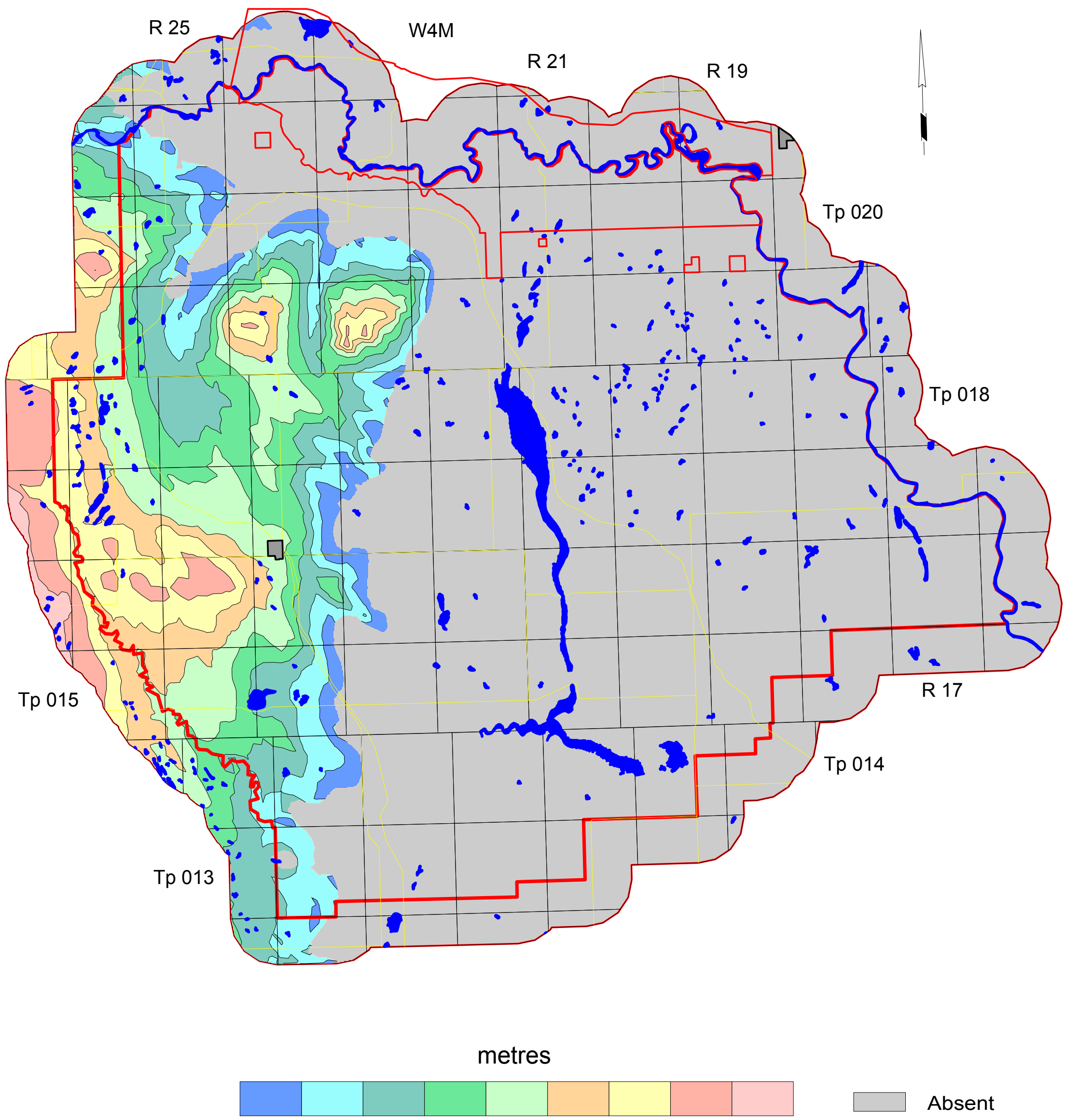
Apparent Yield for Water Wells Completed through Dalehurst Aquifer



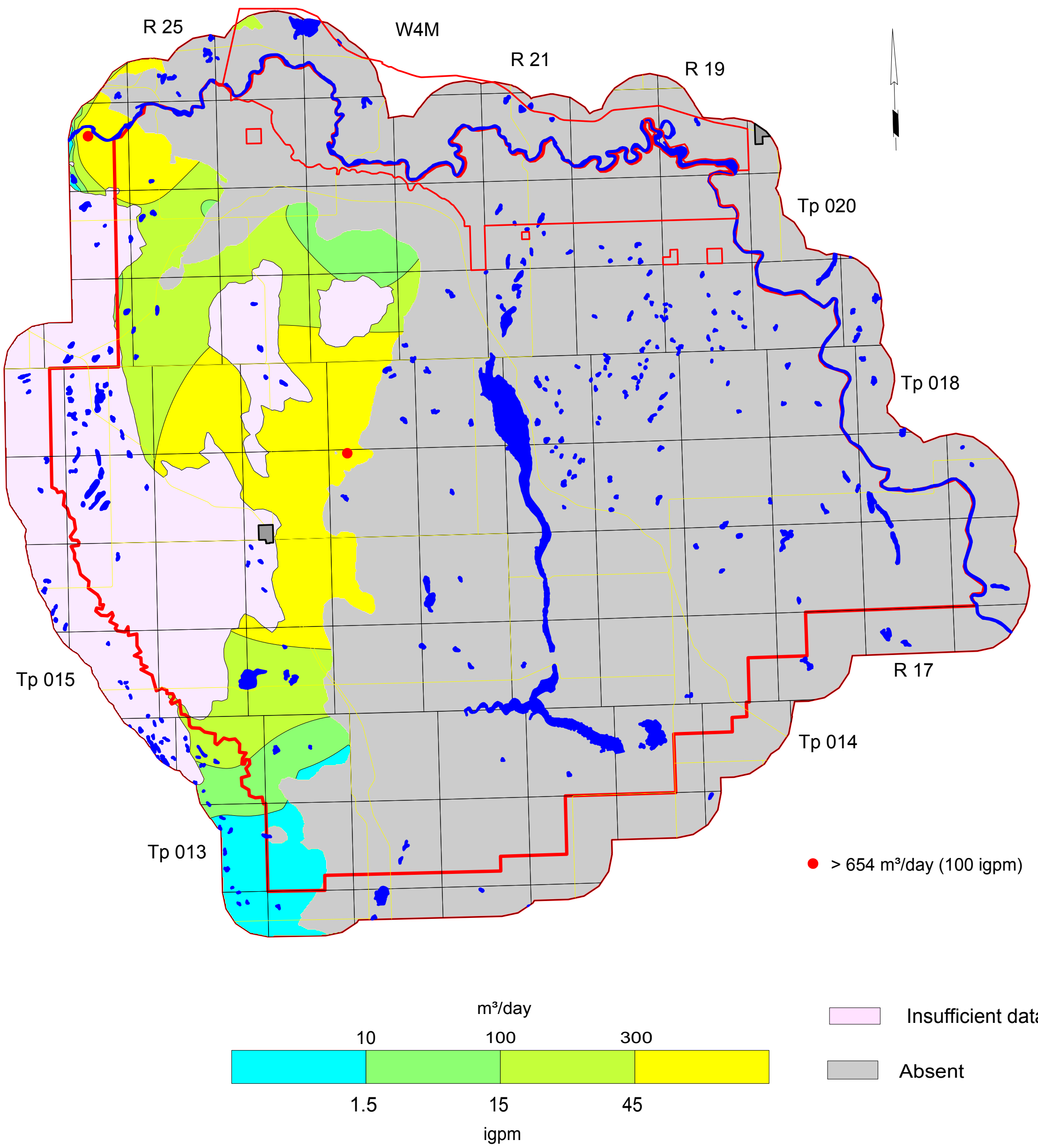
Total Dissolved Solids in Groundwater from Dalehurst Aquifer



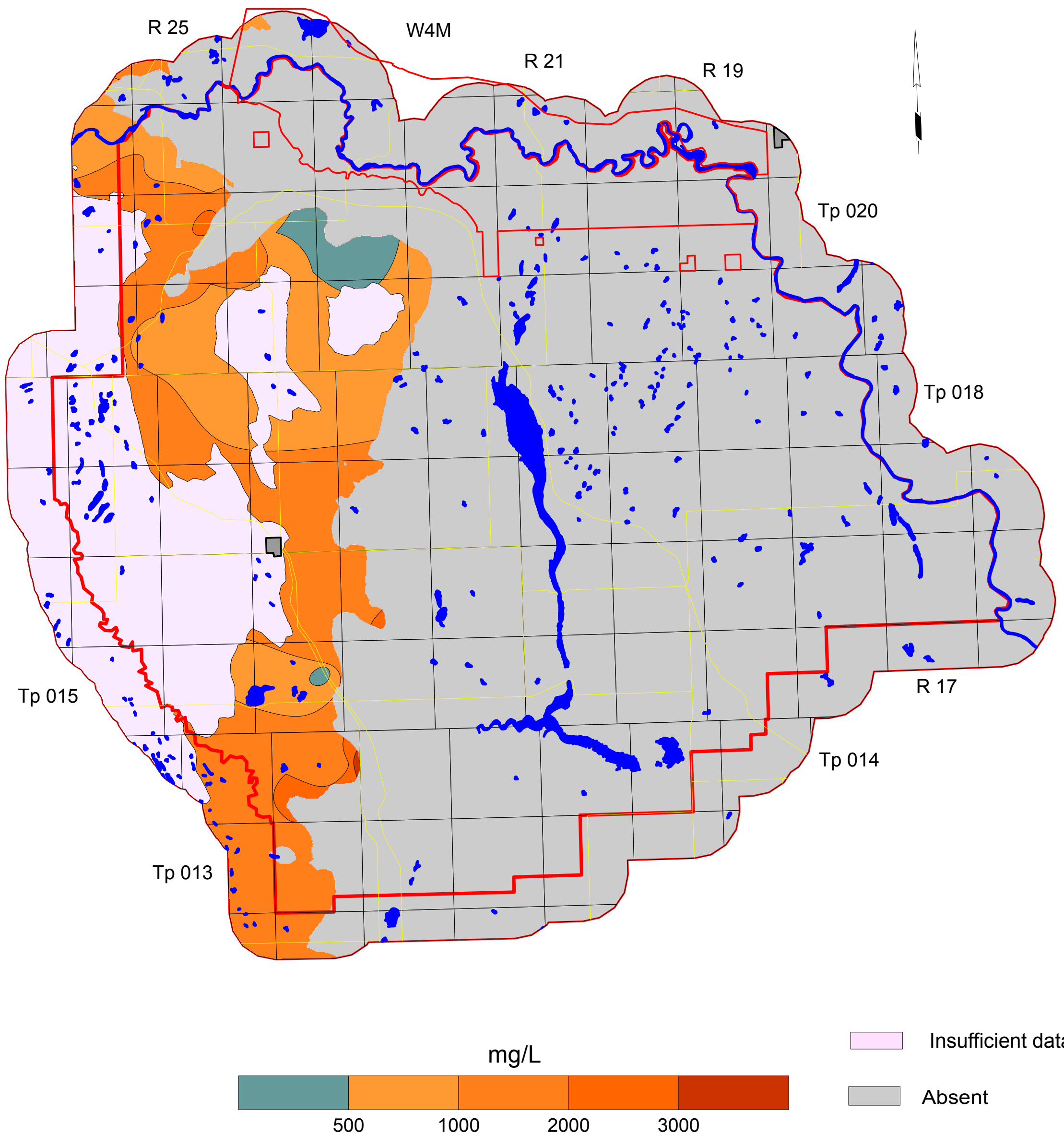
Depth to Top of Upper Lacombe Member



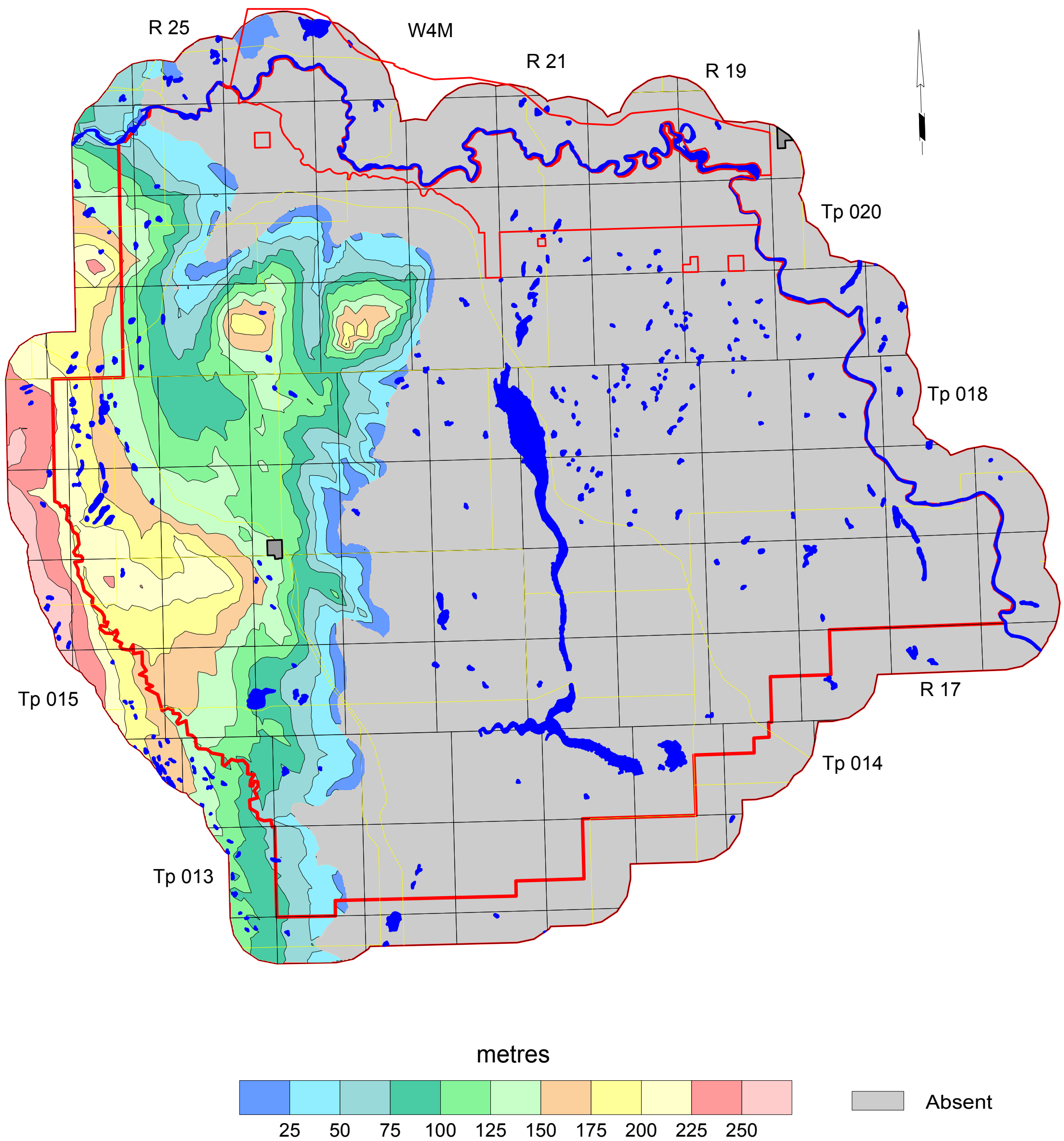
Apparent Yield for Water Wells Completed through Upper Lacombe Aquifer



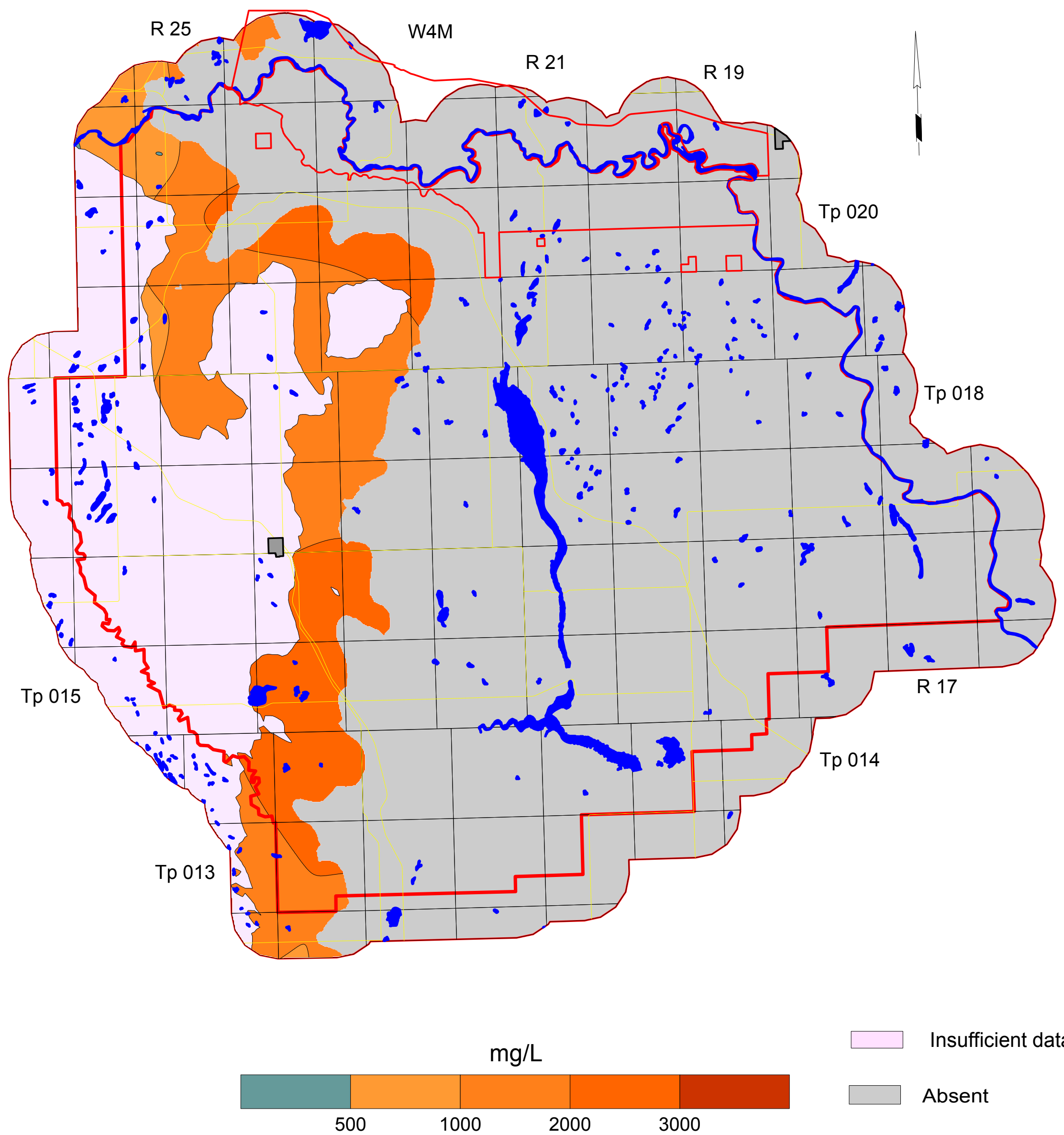
Total Dissolved Solids in Groundwater from Upper Lacombe Aquifer



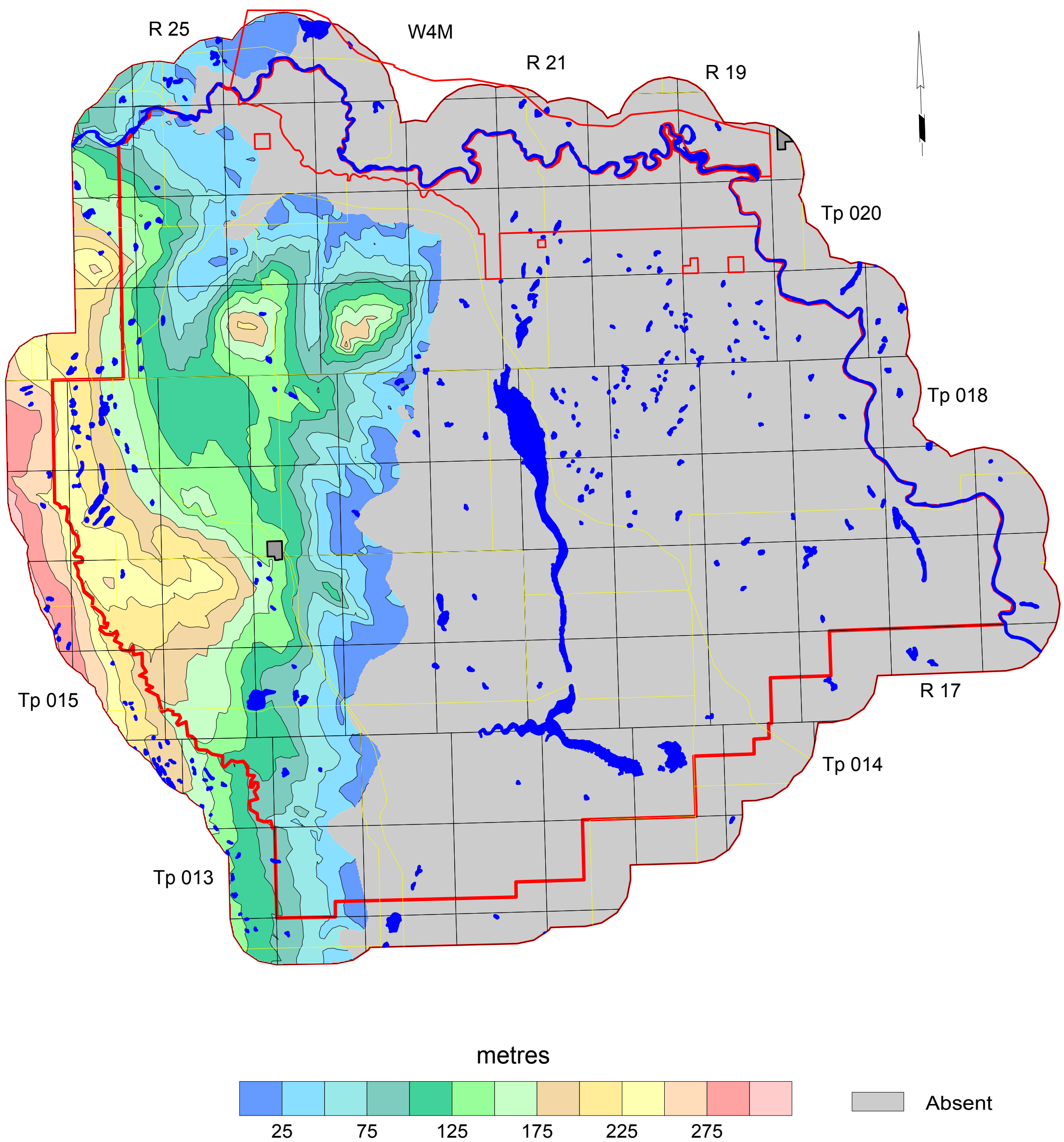
Depth to Top of Lower Lacombe Member



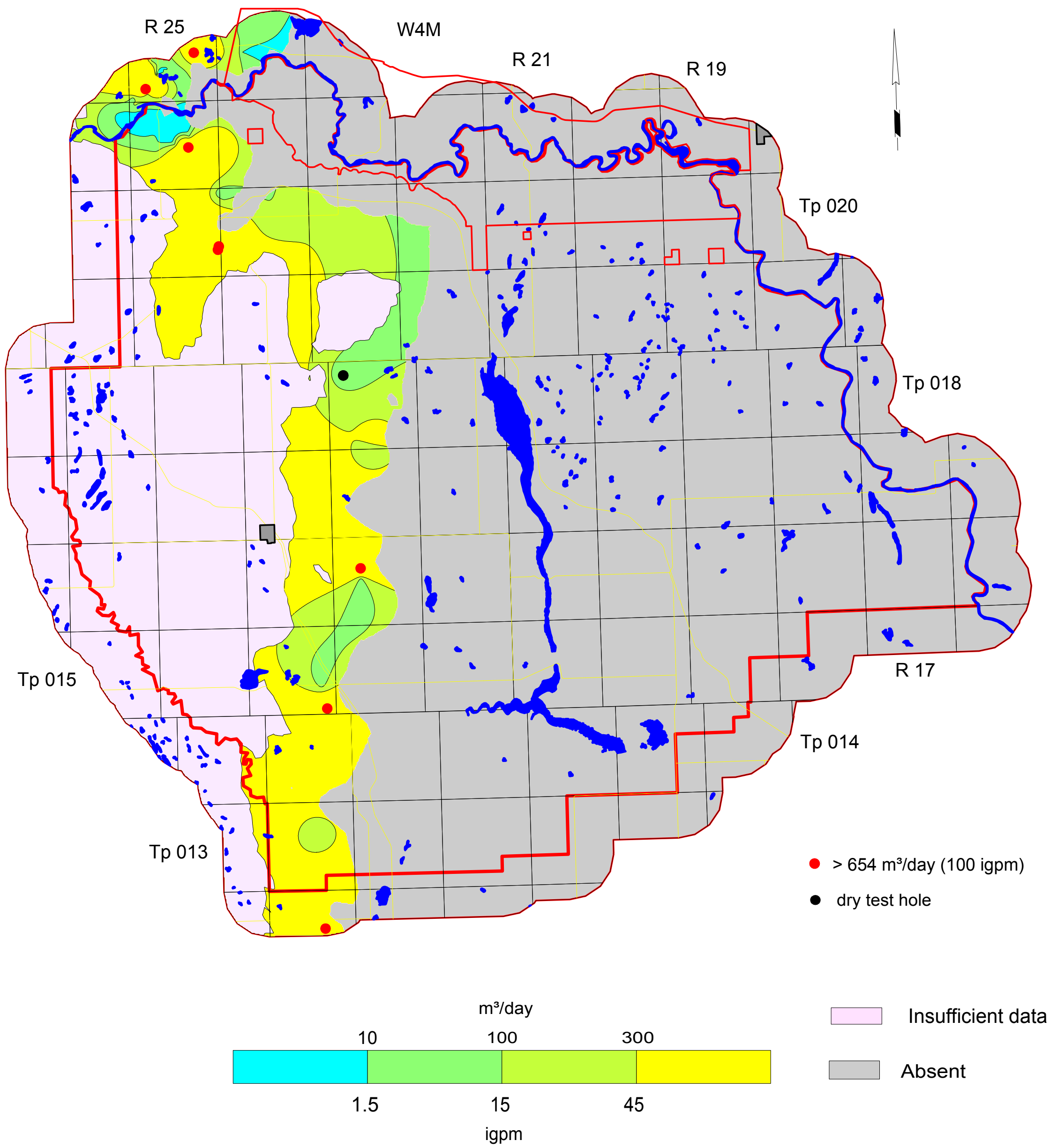
Total Dissolved Solids in Groundwater from Lower Lacombe Aquifer



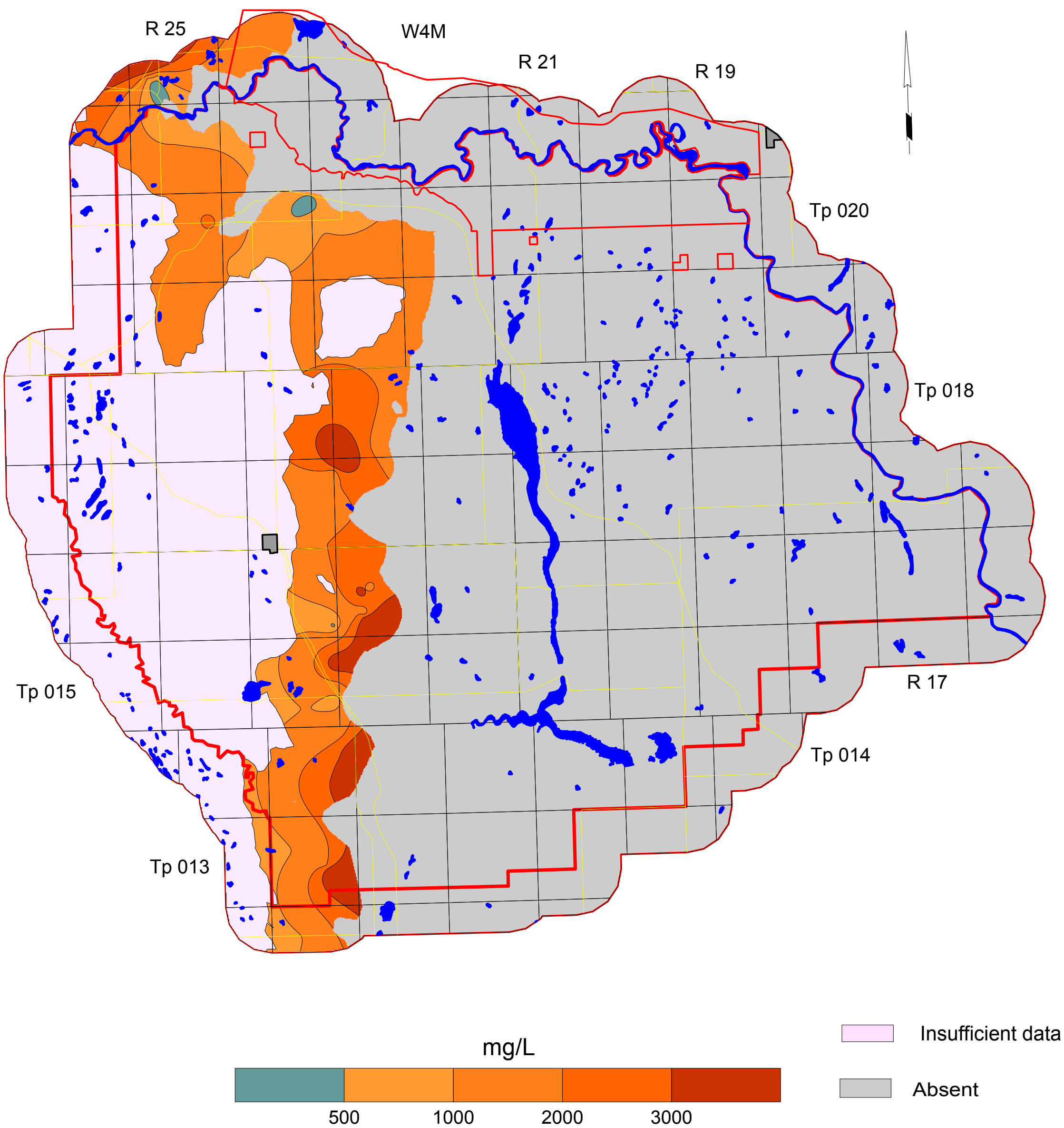
Depth to Top of Haynes Member



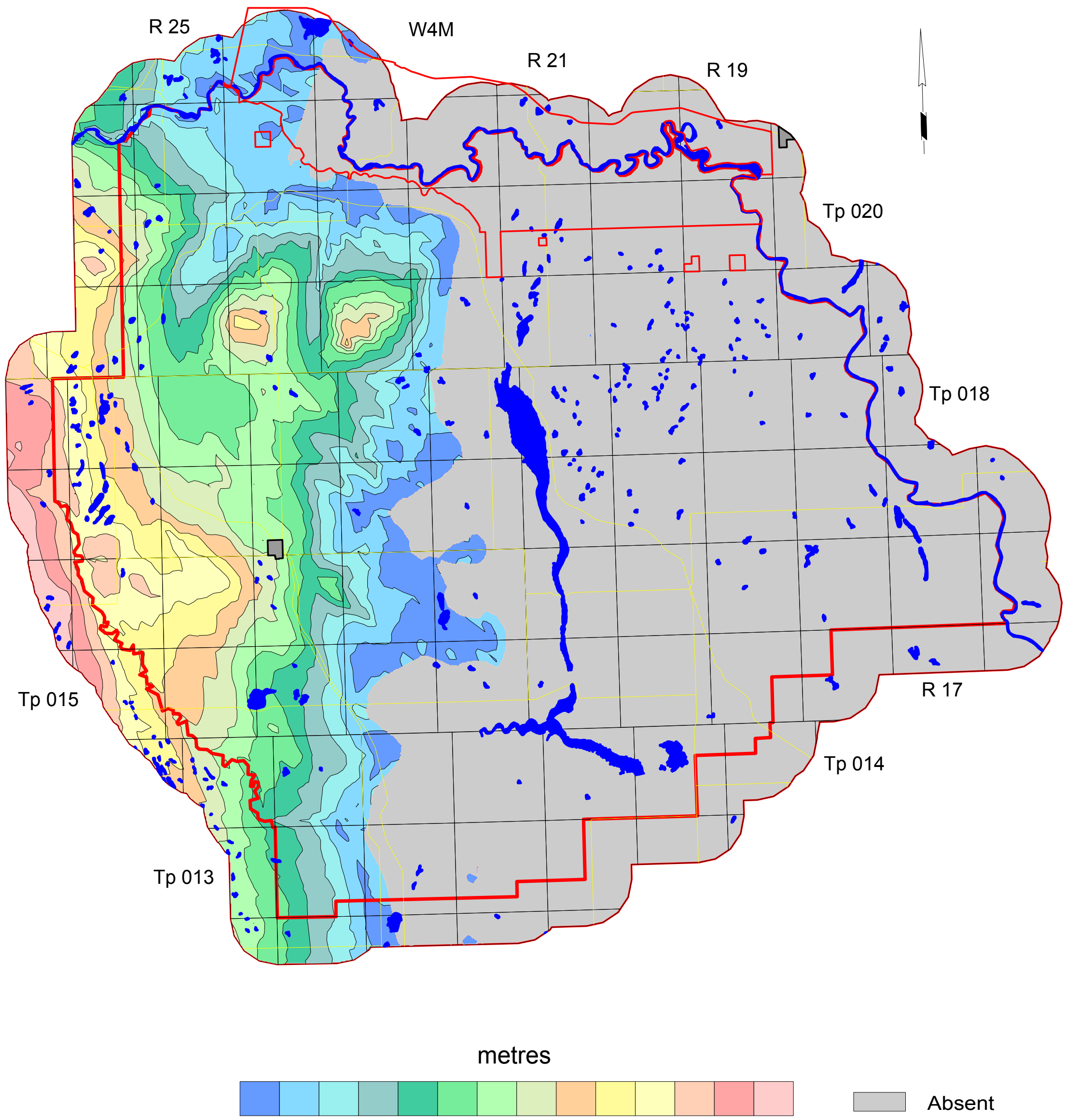
Apparent Yield for Water Wells Completed through Haynes Aquifer



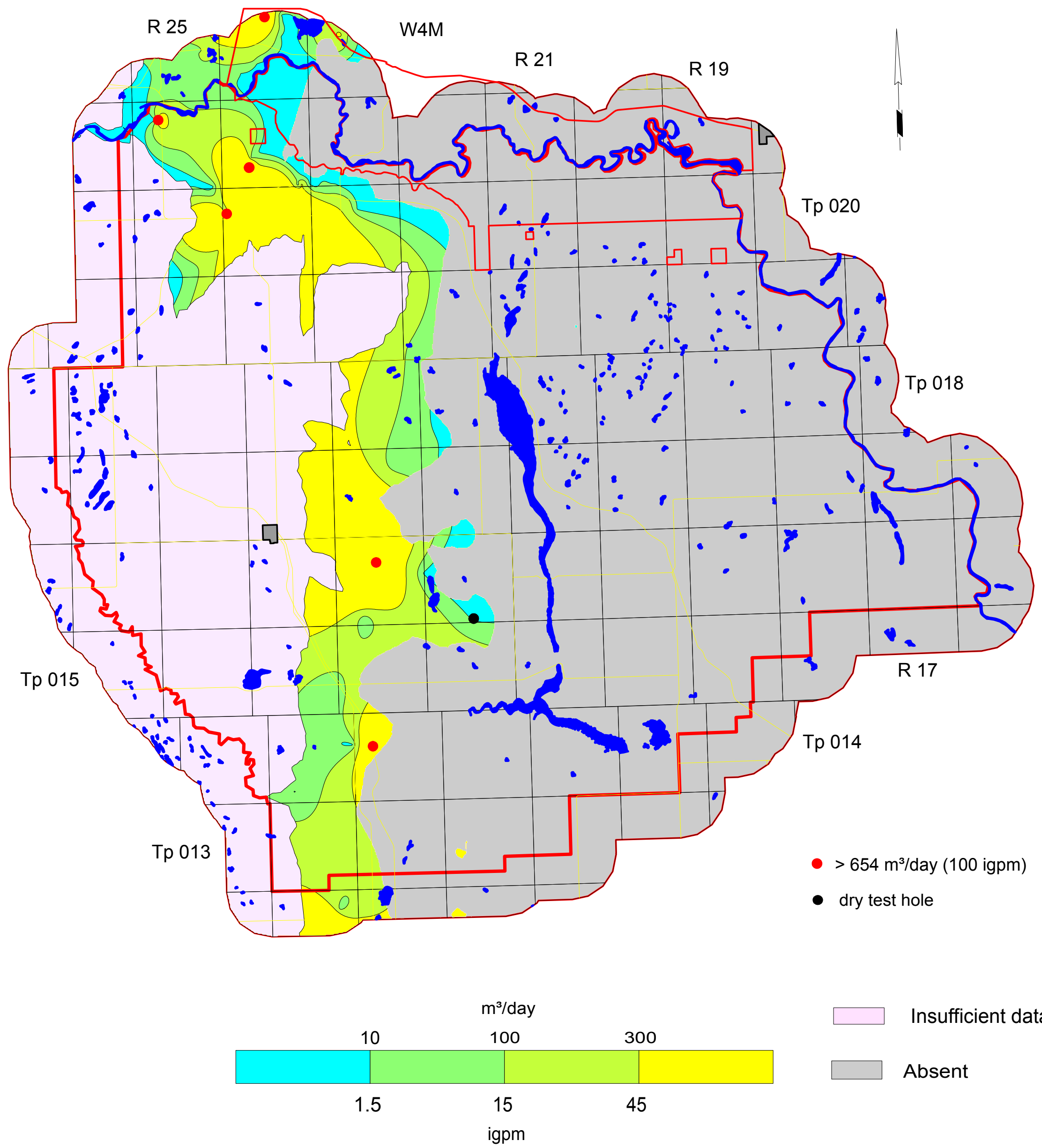
Total Dissolved Solids in Groundwater from Haynes Aquifer



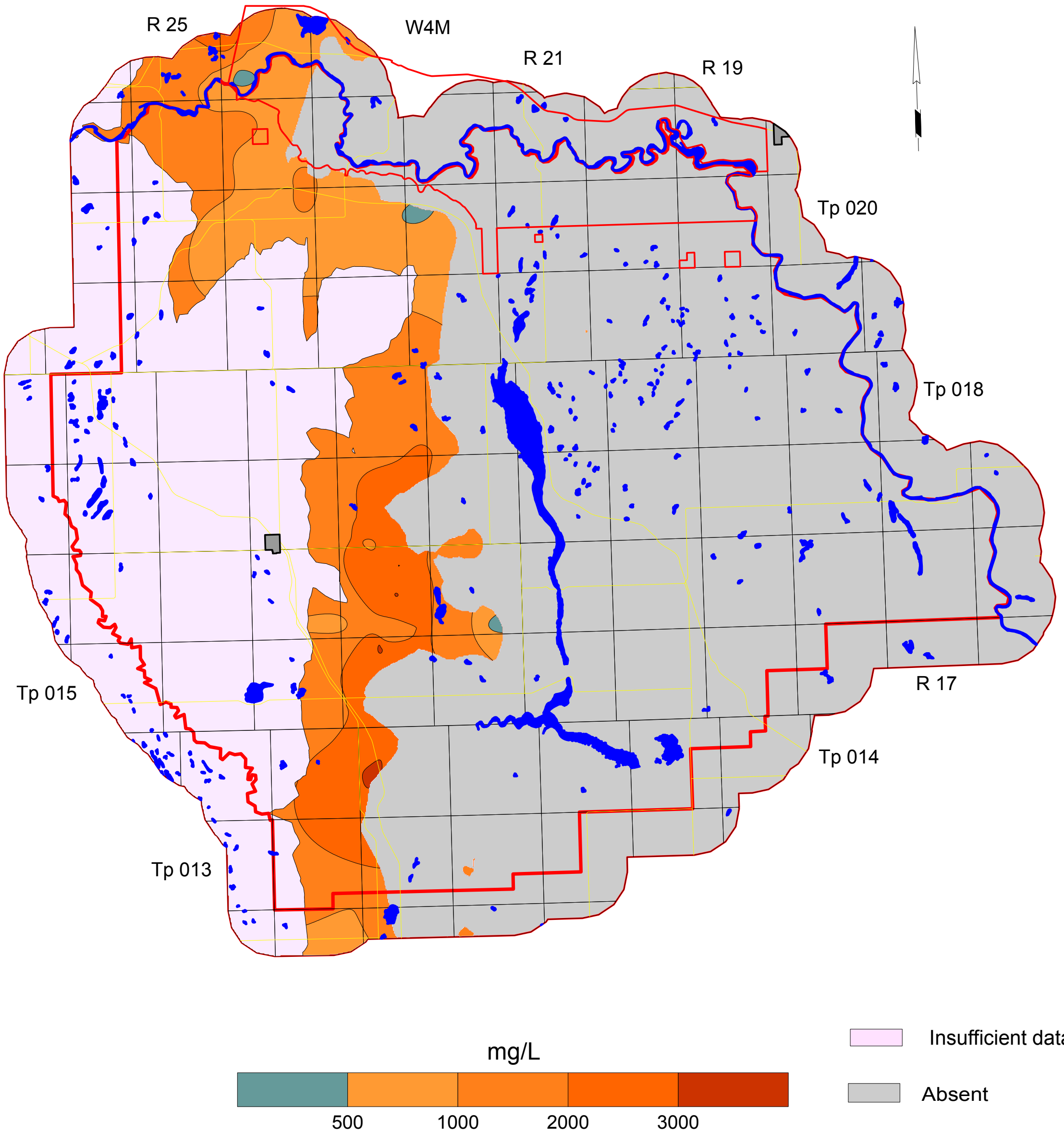
Depth to Top of Upper Scollard Formation



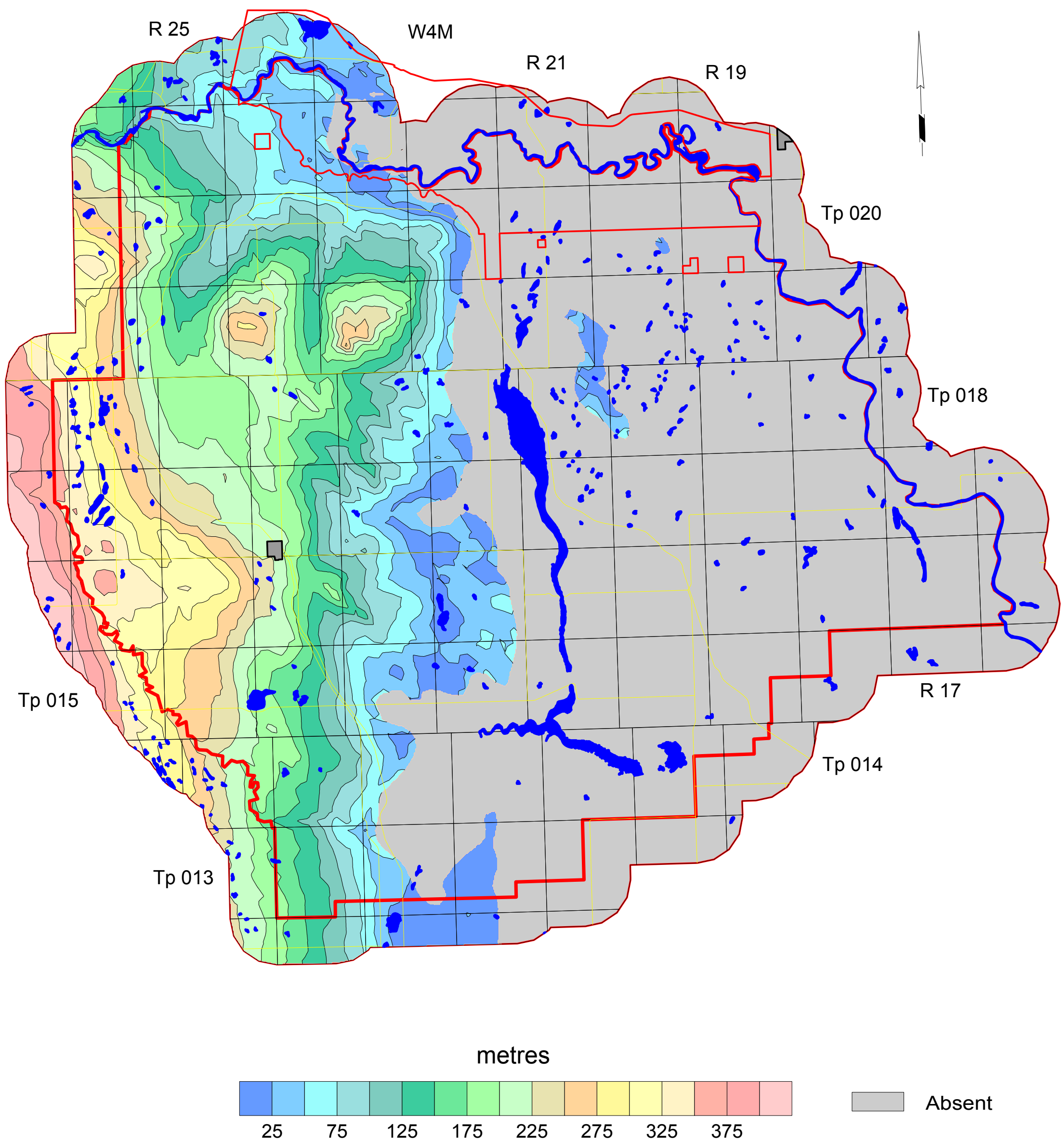
Apparent Yield for Water Wells Completed through Upper Scollard Aquifer



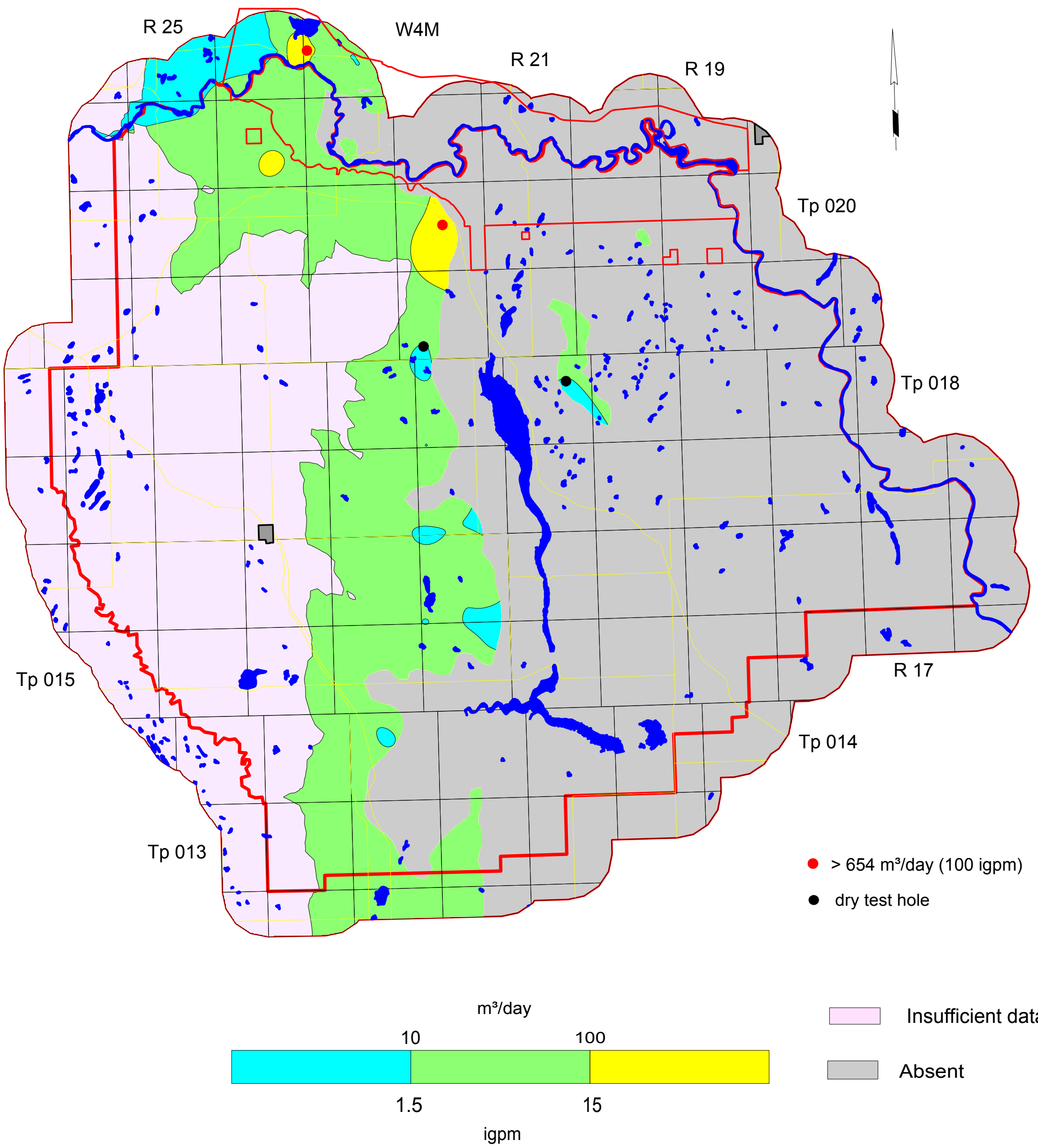
Total Dissolved Solids in Groundwater from Upper Scollard Aquifer



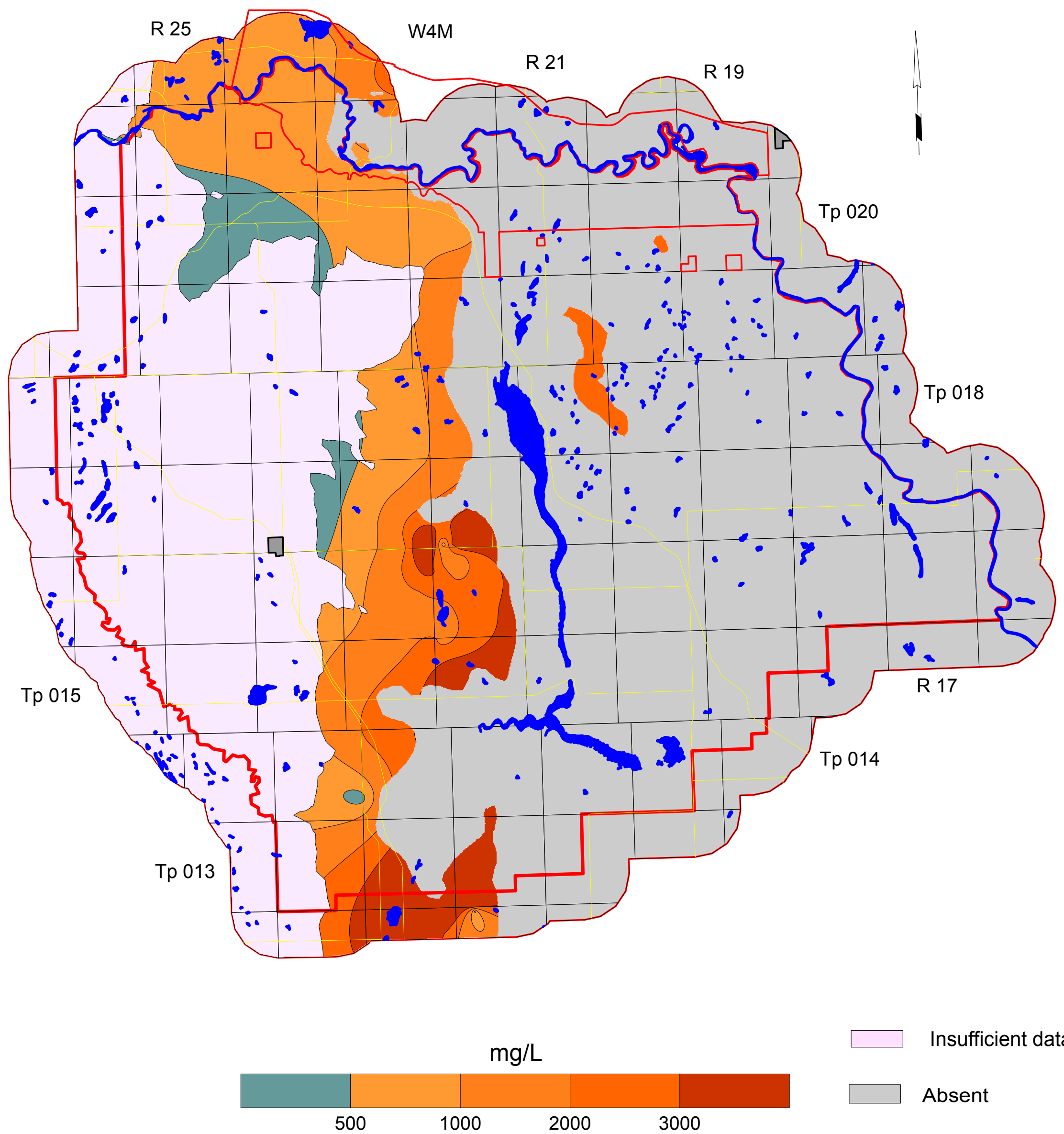
Depth to Top of Lower Scollard Formation



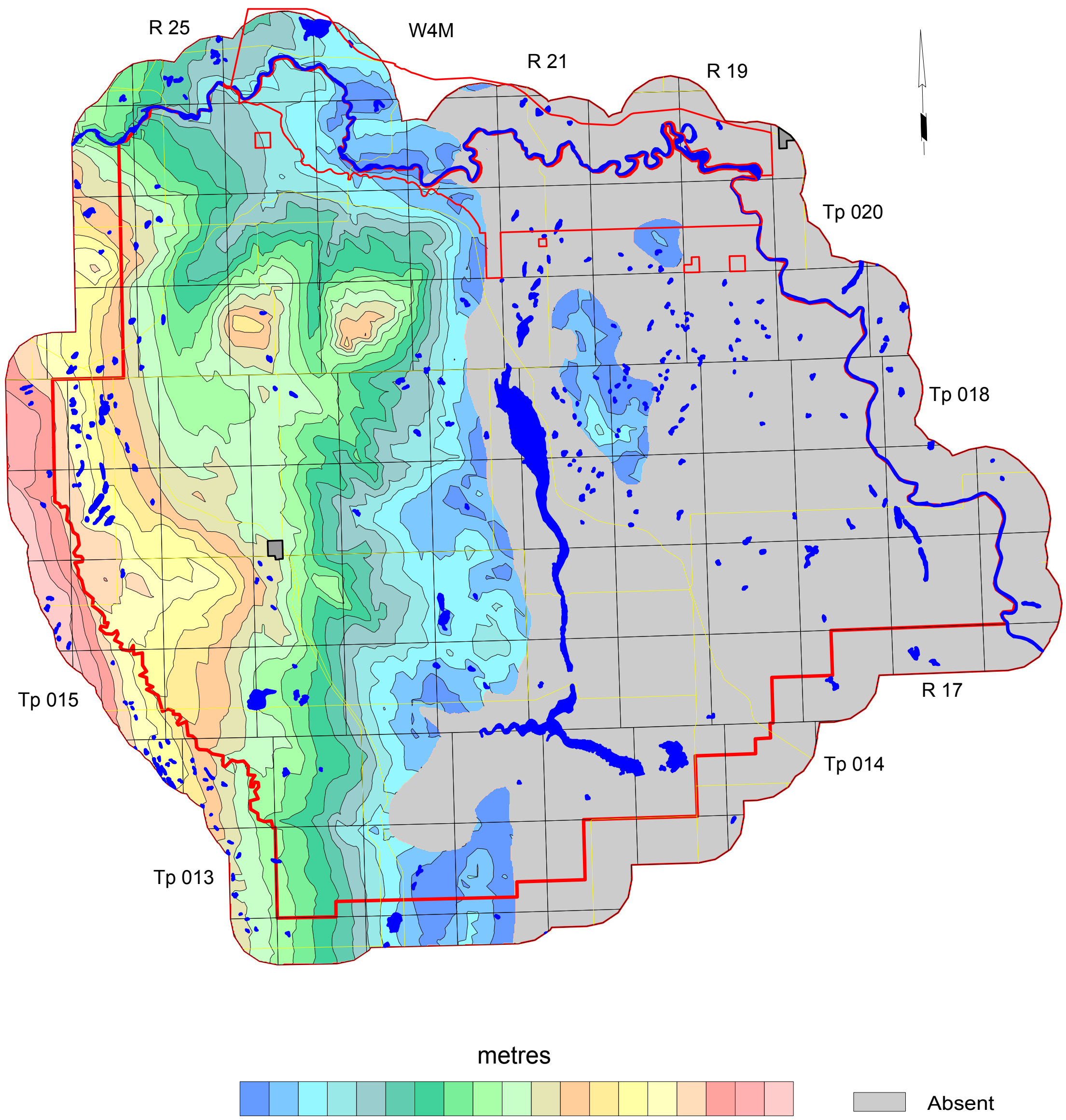
Apparent Yield for Water Wells Completed through Lower Scollard Aquifer



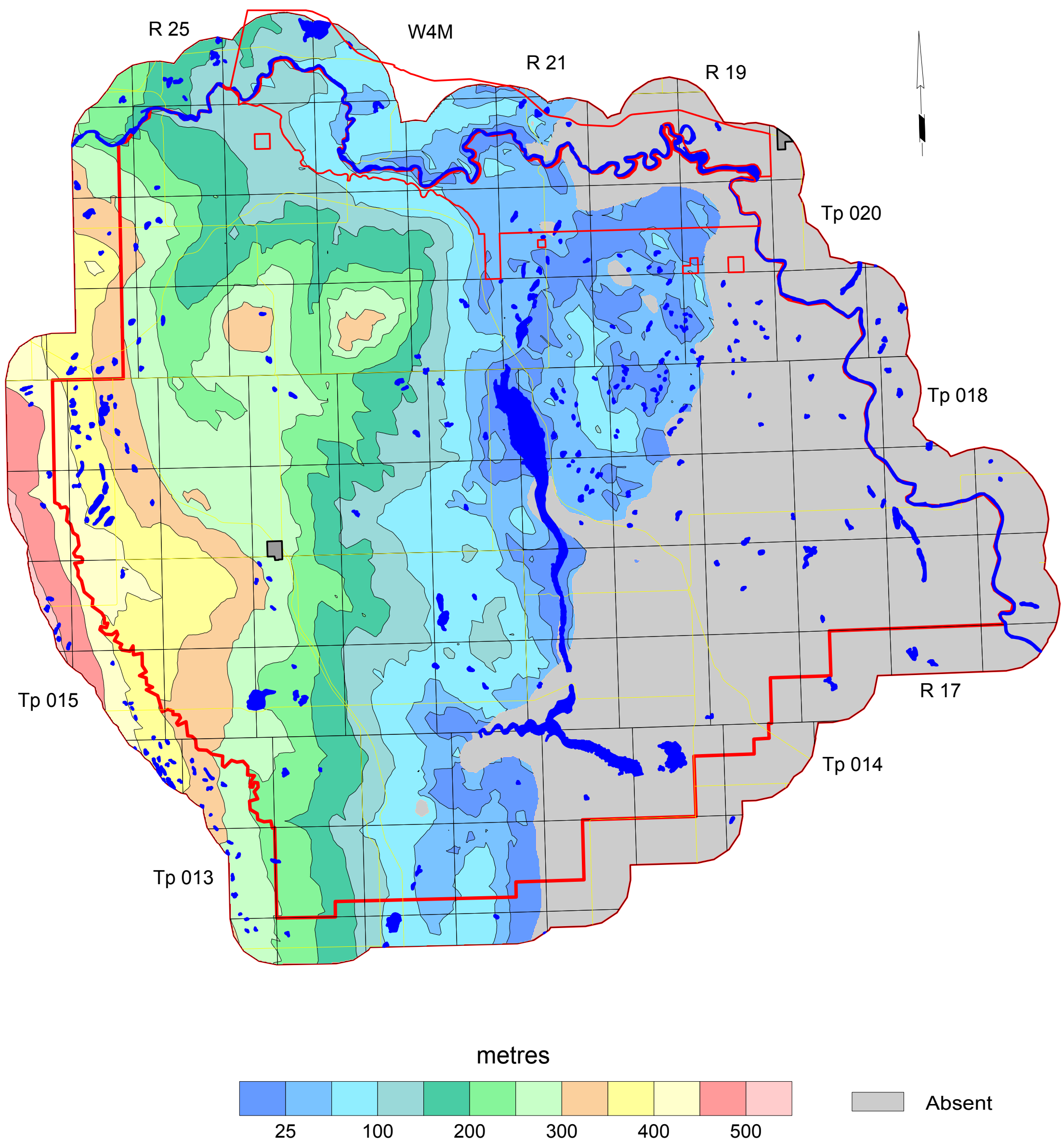
Total Dissolved Solids in Groundwater from Lower Scollard Aquifer



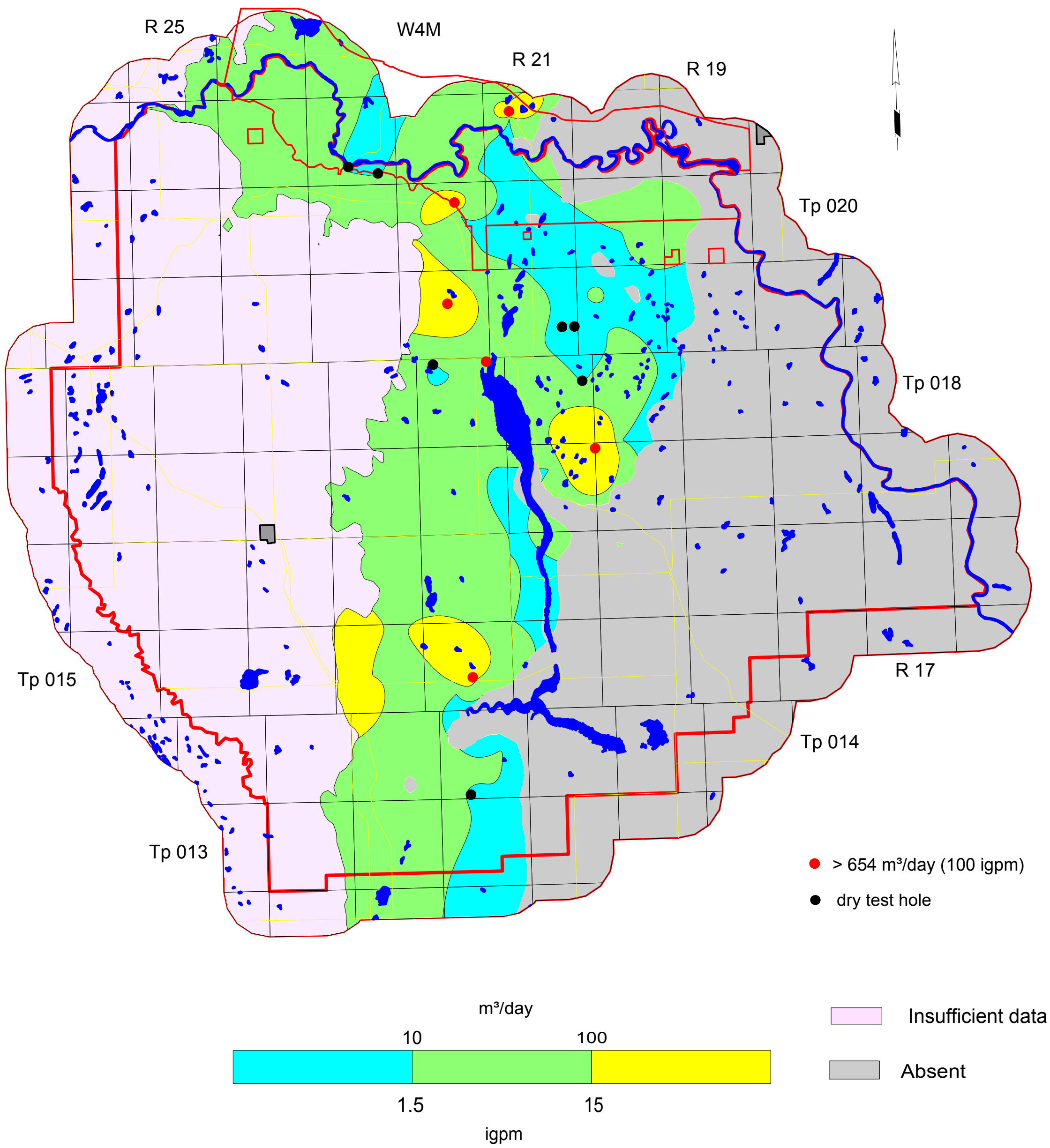
Depth to Top of Battle/Whitemud Formation



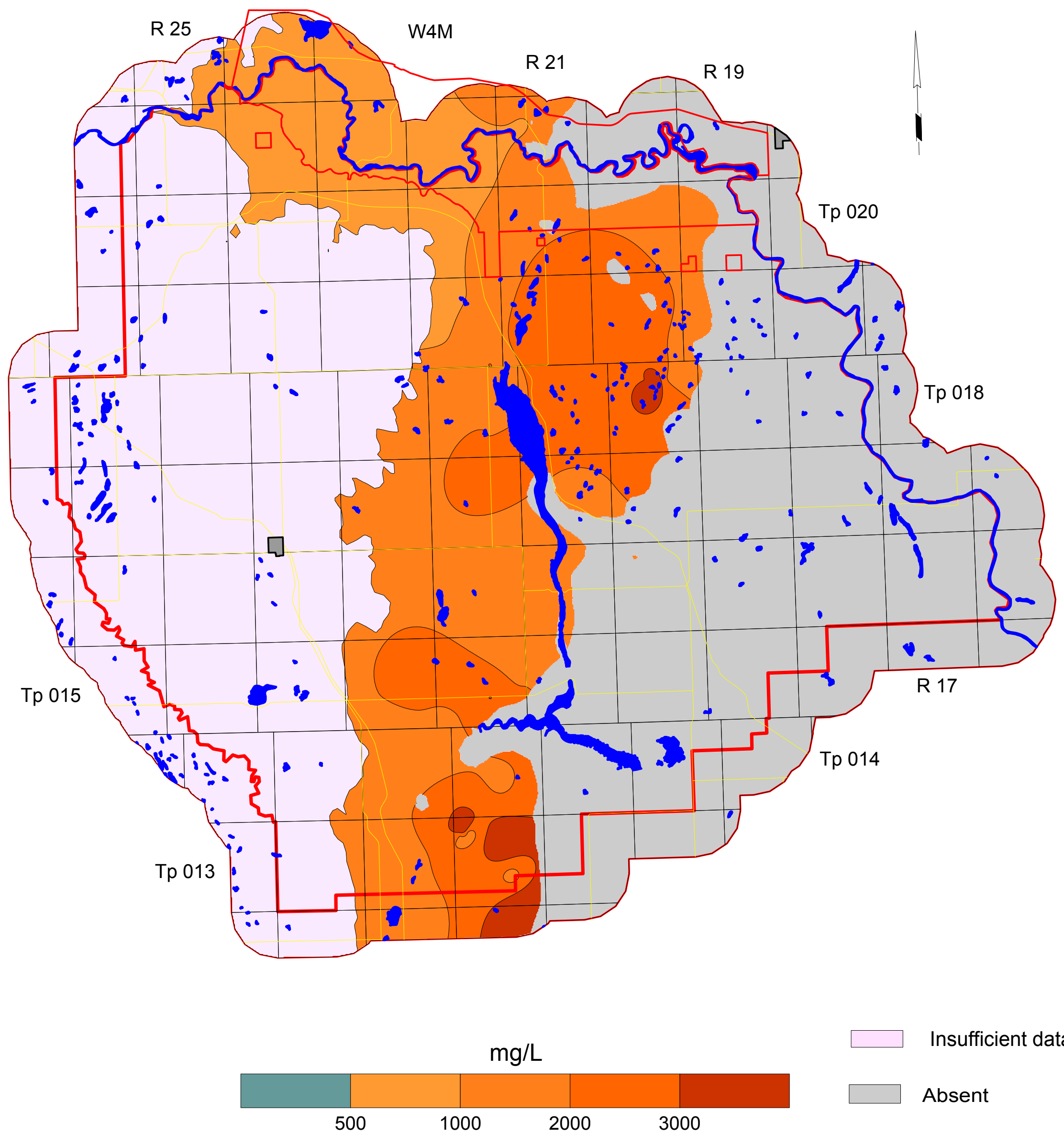
Depth to Top of Upper Horseshoe Canyon Formation



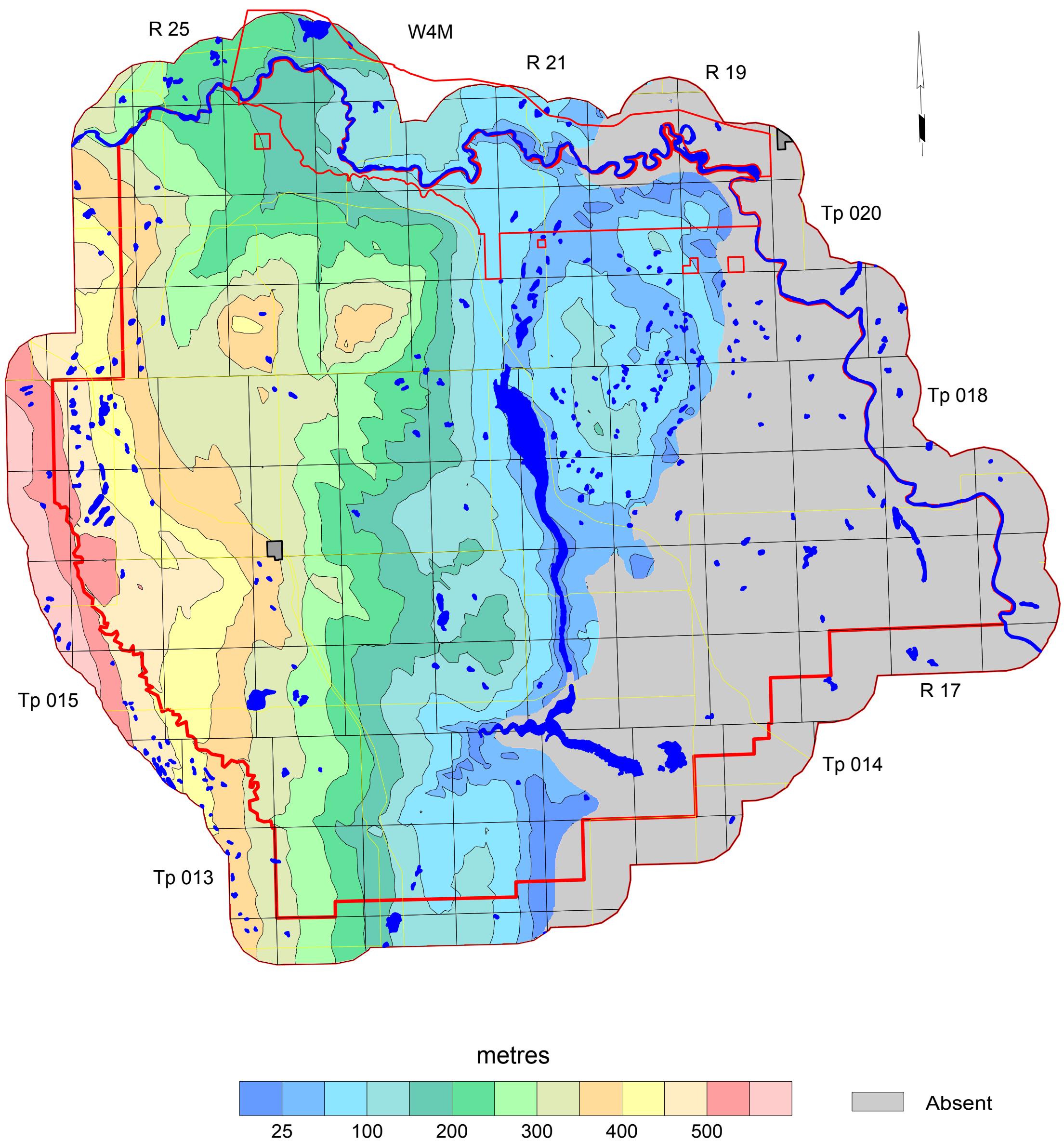
Apparent Yield for Water Wells Completed through Upper Horseshoe Canyon Aquifer



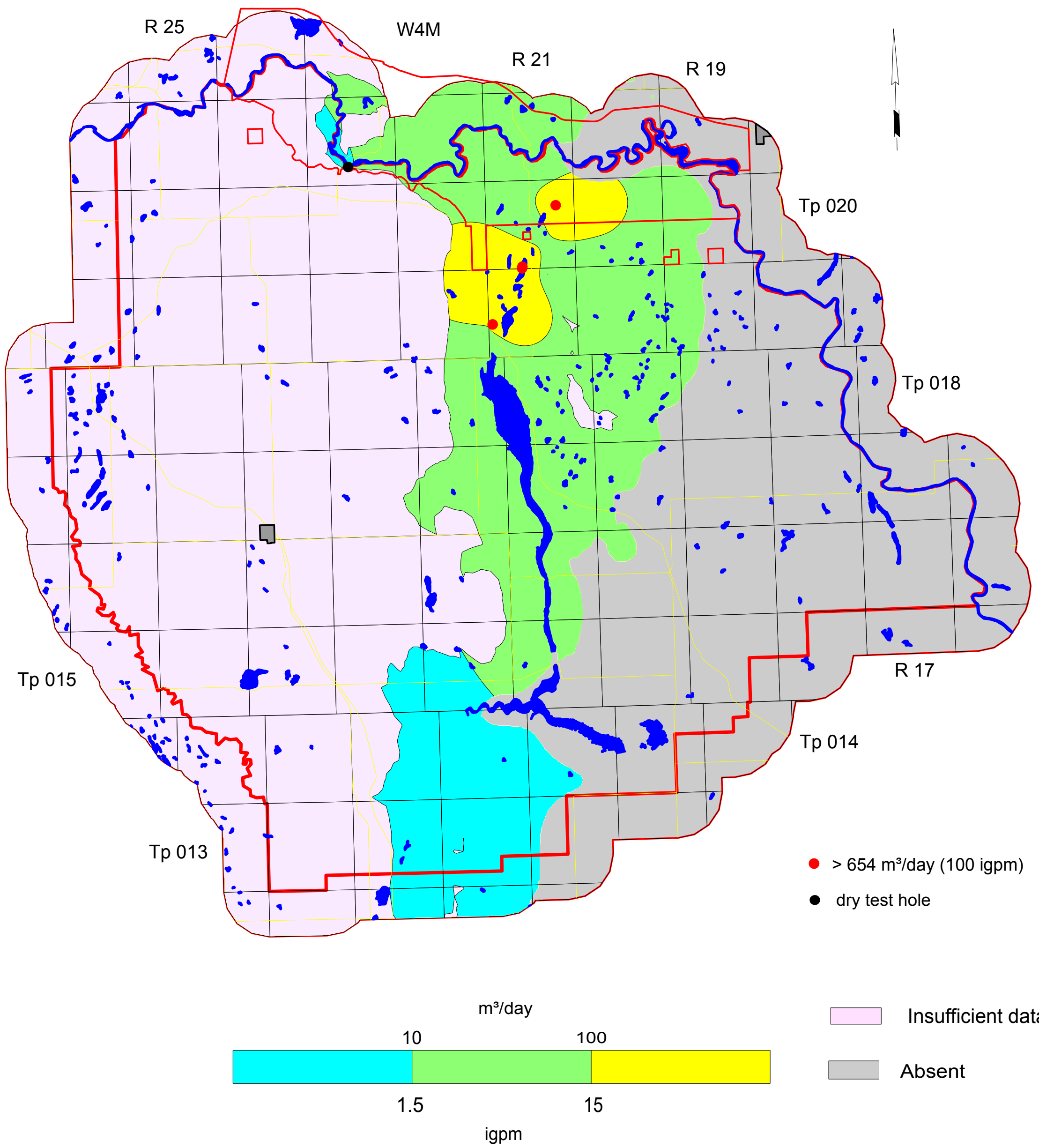
Total Dissolved Solids in Groundwater from Upper Horseshoe Canyon Aquifer



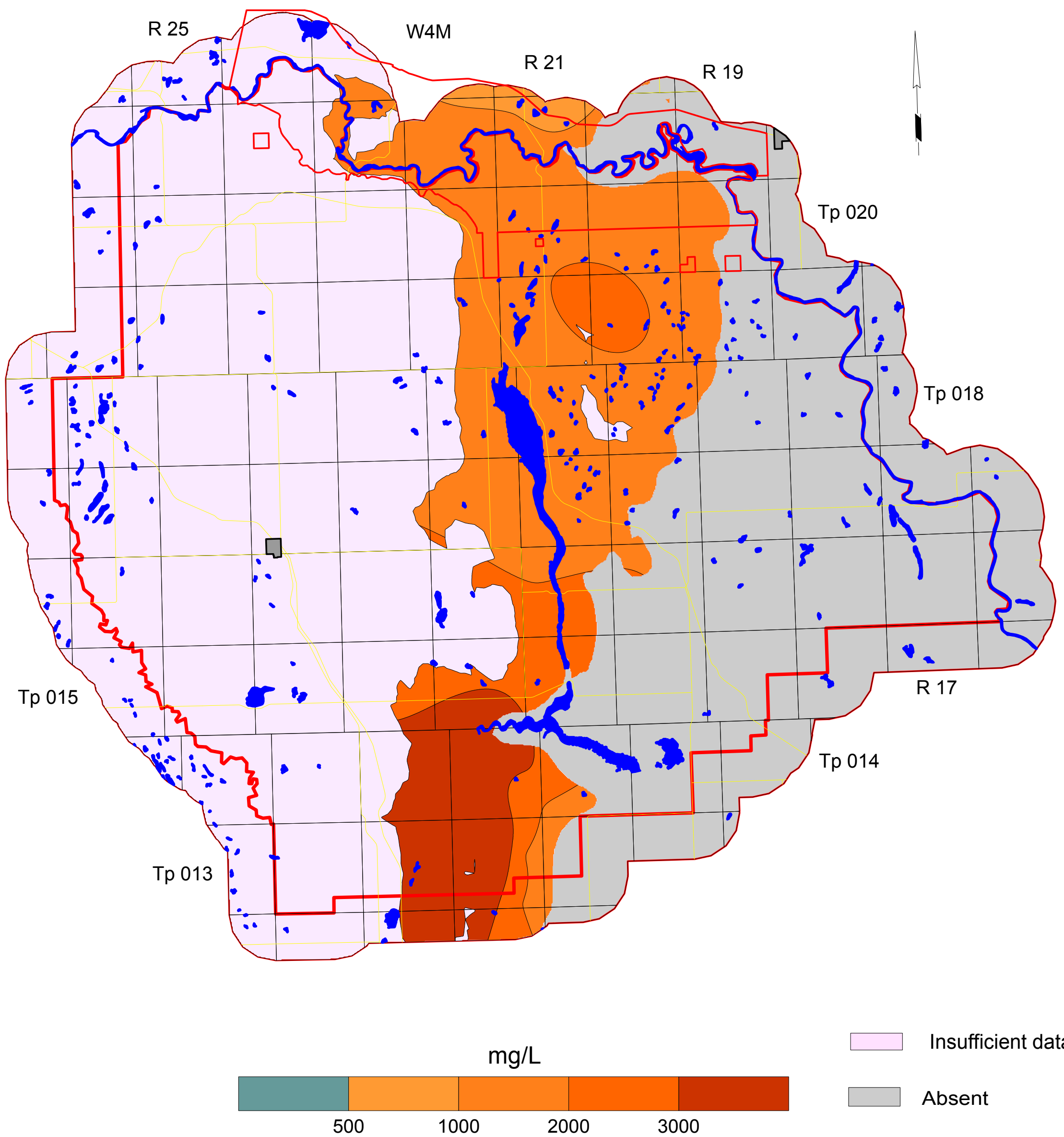
Depth to Top of Middle Horseshoe Canyon Formation



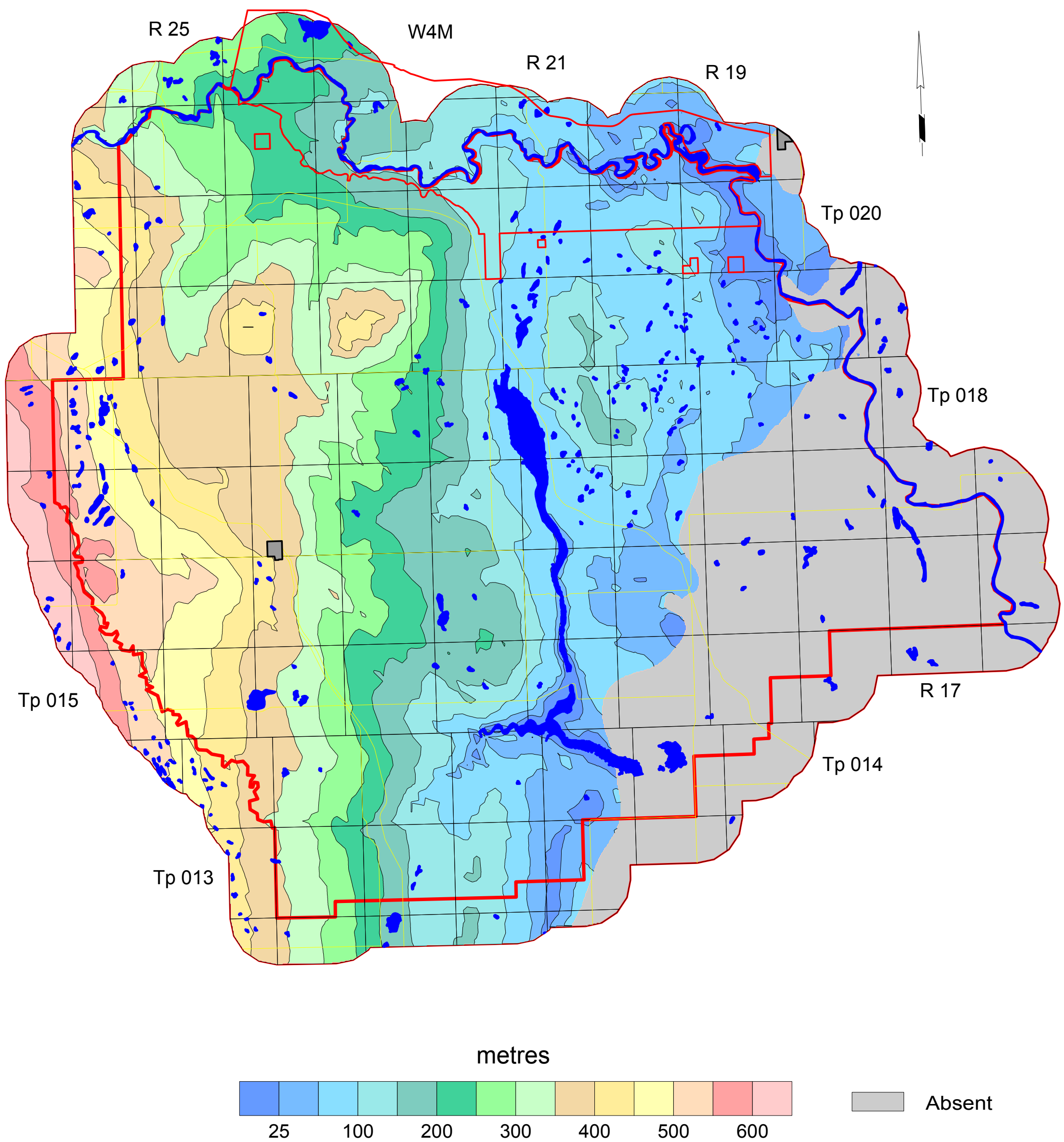
Apparent Yield for Water Wells Completed through Middle Horseshoe Canyon Aquifer



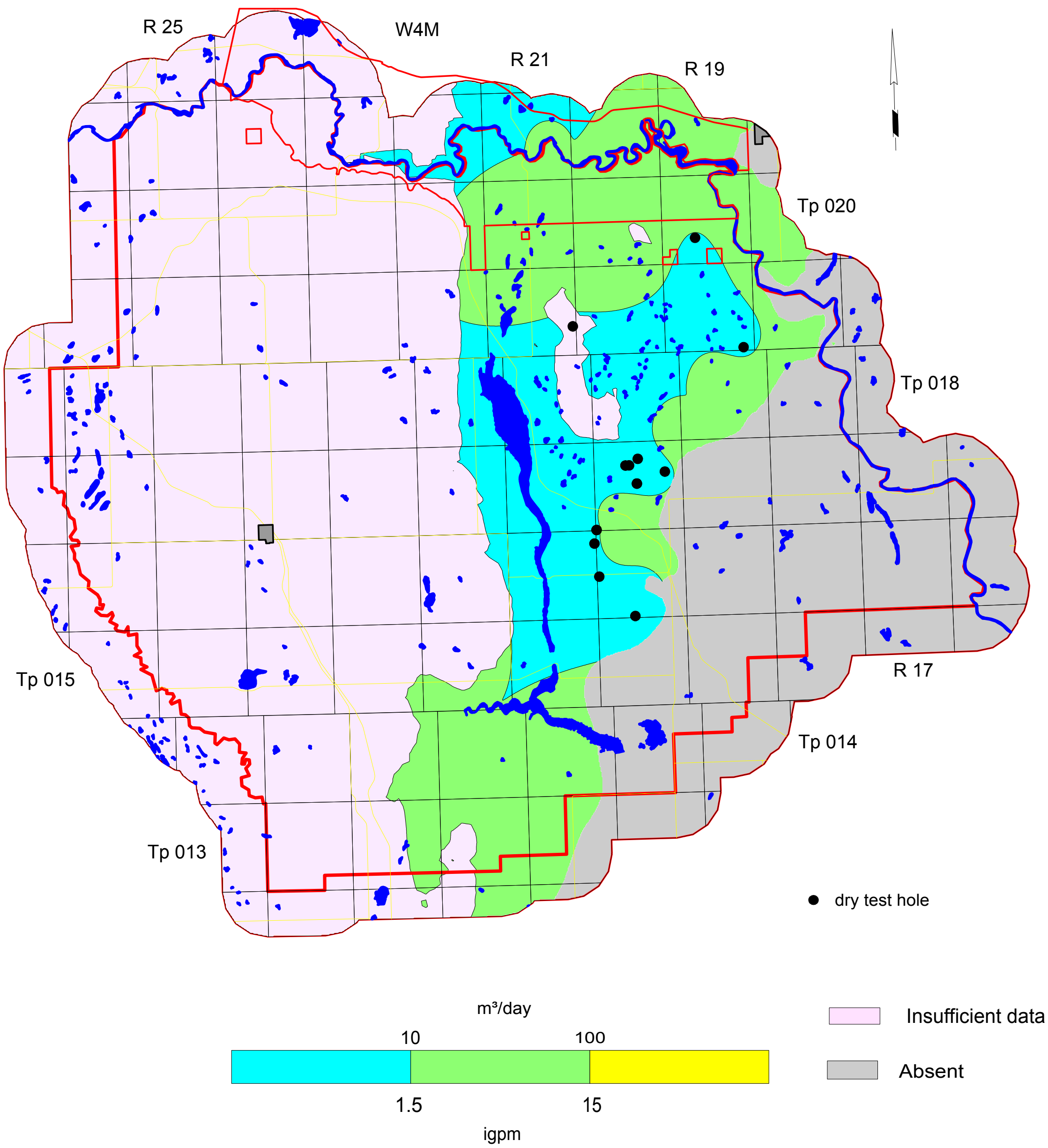
Total Dissolved Solids in Groundwater from Middle Horseshoe Canyon Aquifer



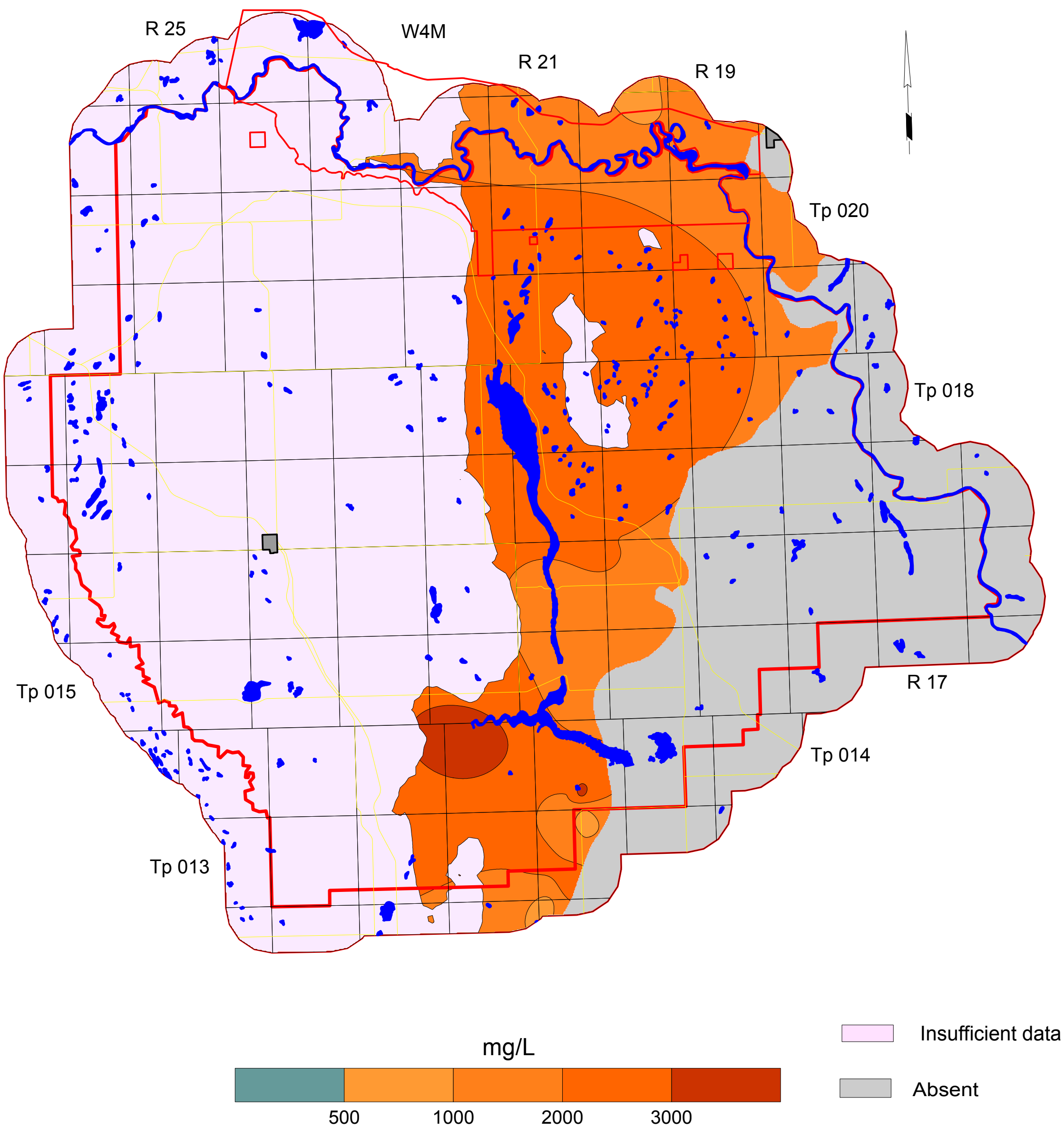
Depth to Top of Lower Horseshoe Canyon Formation



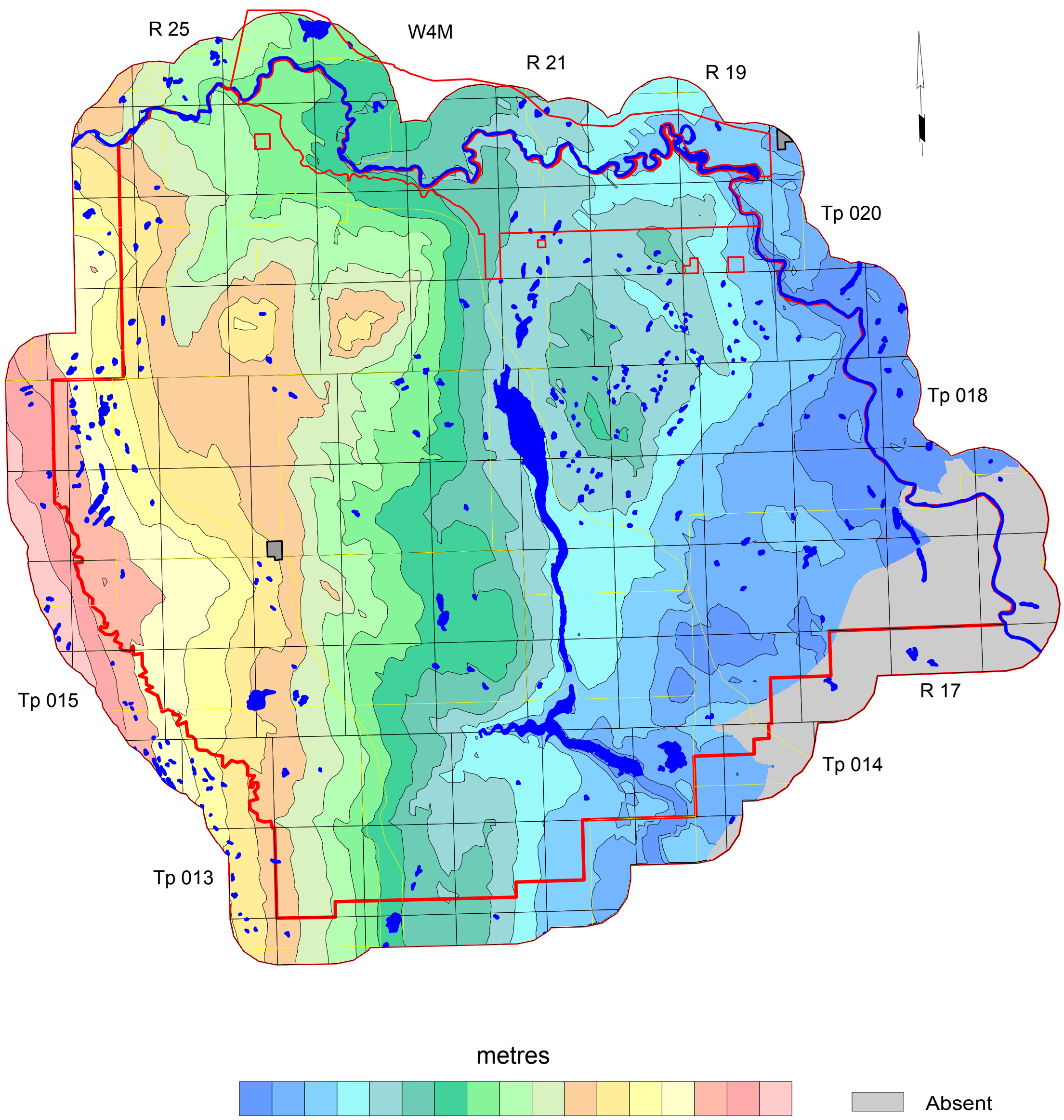
Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer



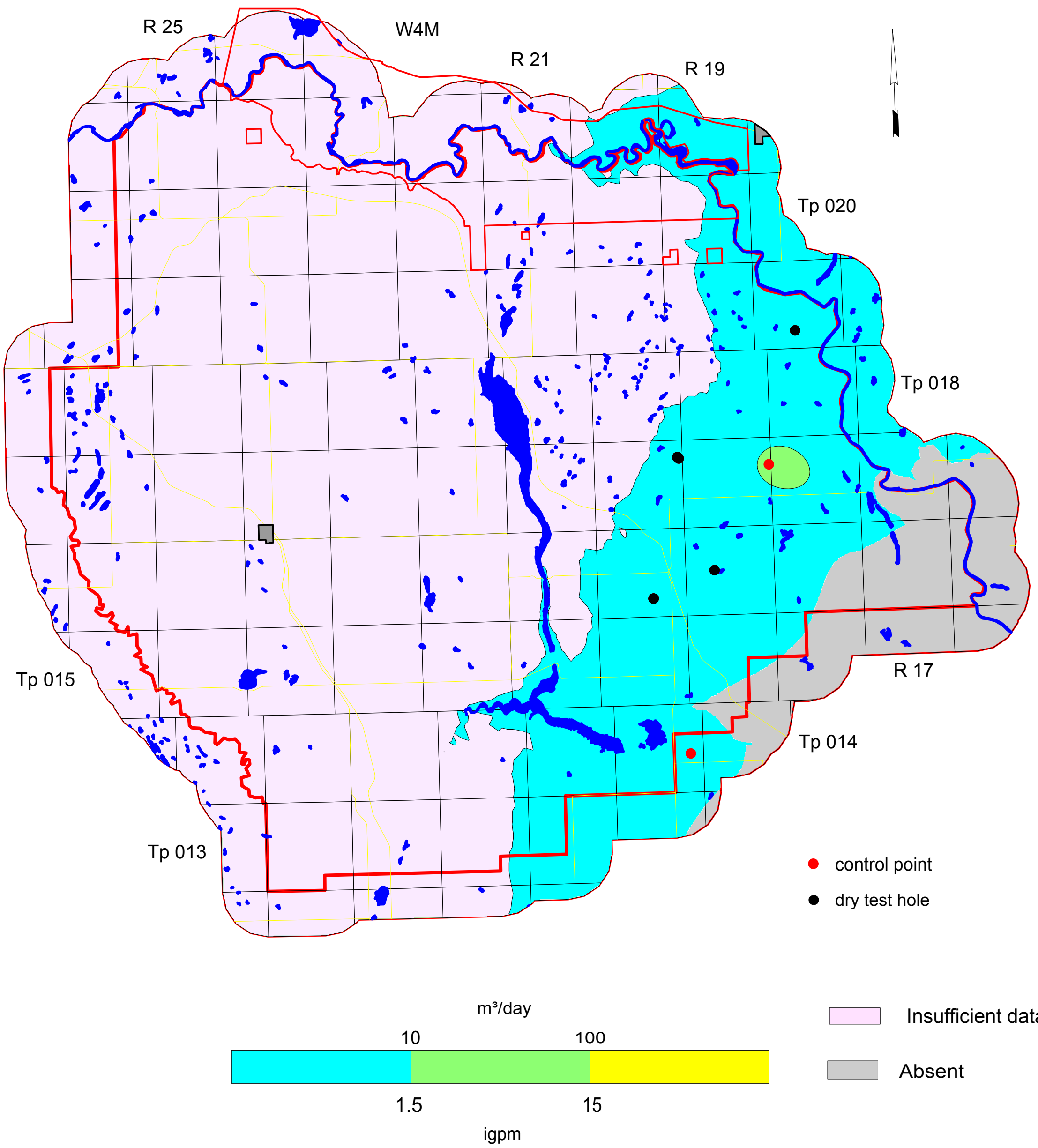
Total Dissolved Solids in Groundwater from Lower Horseshoe Canyon Aquifer



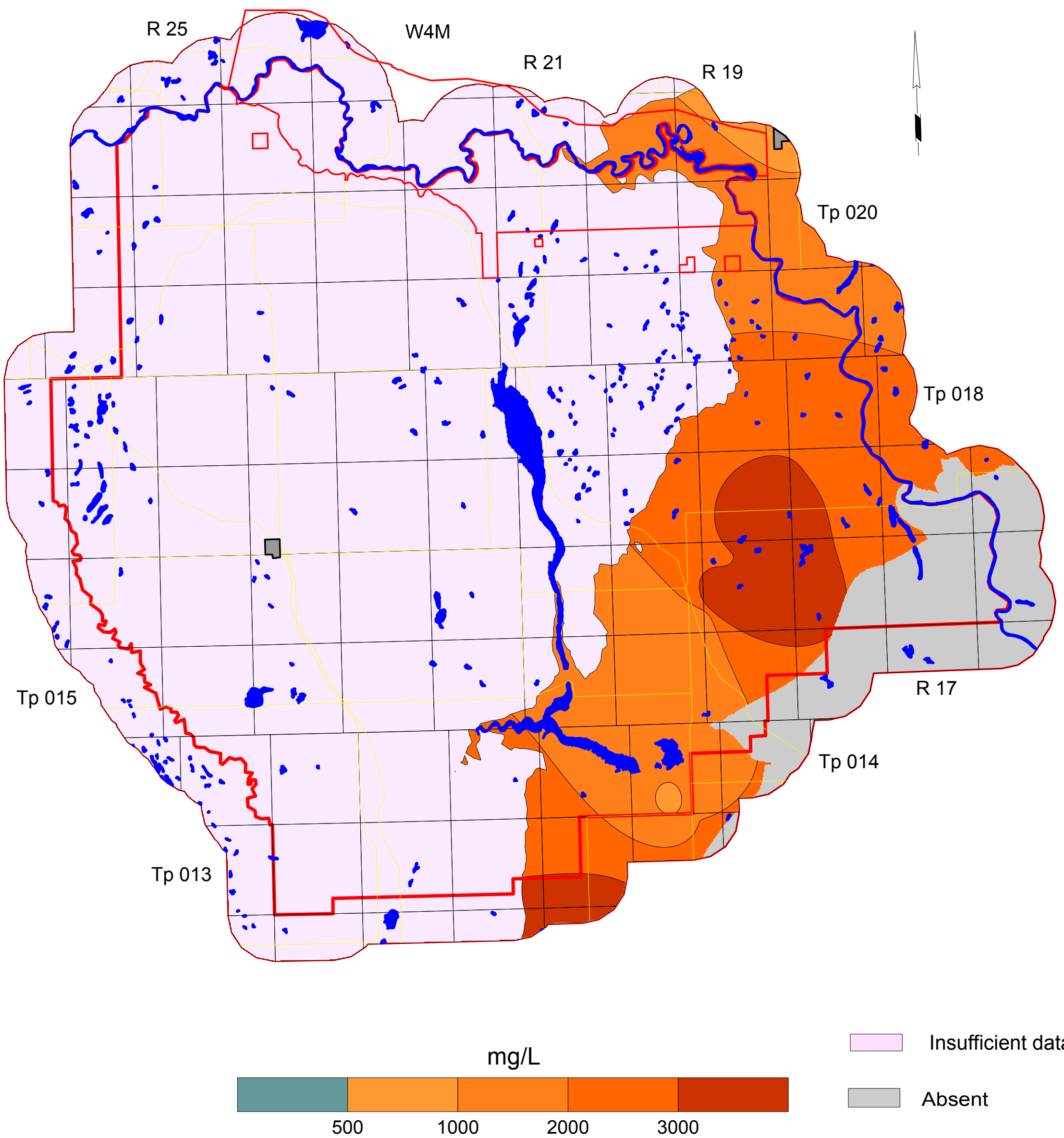
Depth to Top of Bearpaw Formation



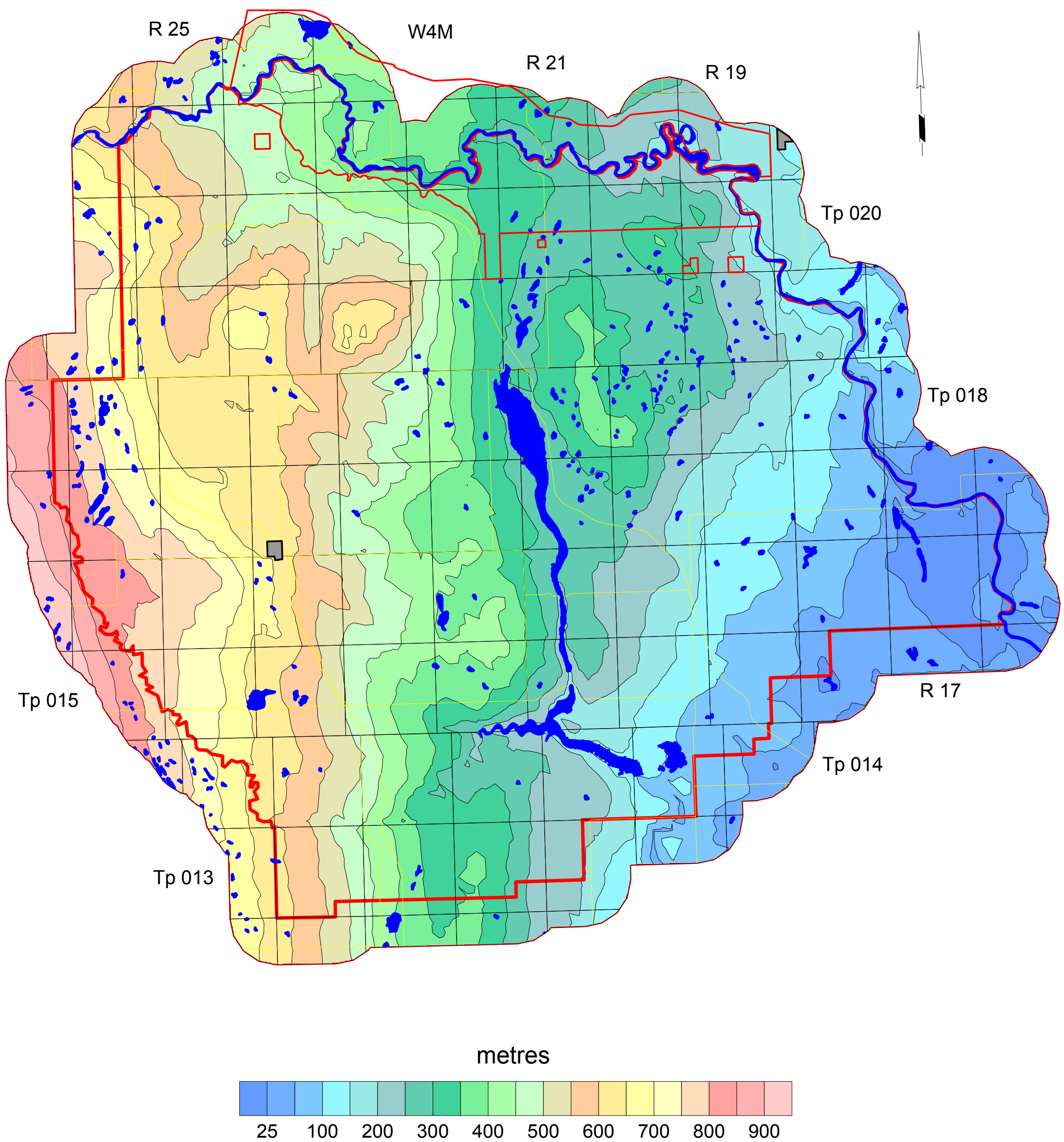
Apparent Yield for Water Wells Completed through Bearpaw Aquifer



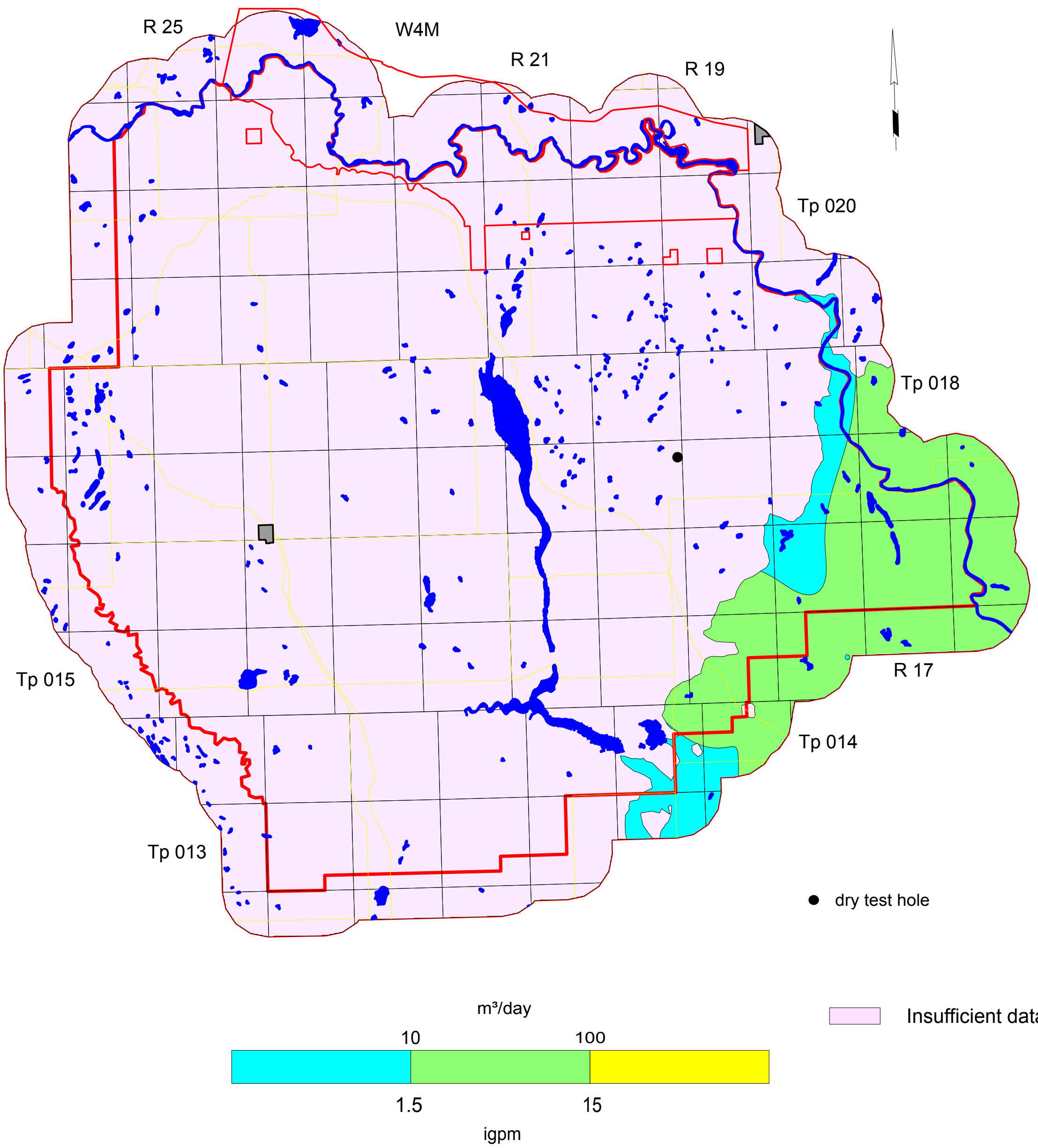
Total Dissolved Solids in Groundwater from Bearpaw Aquifer



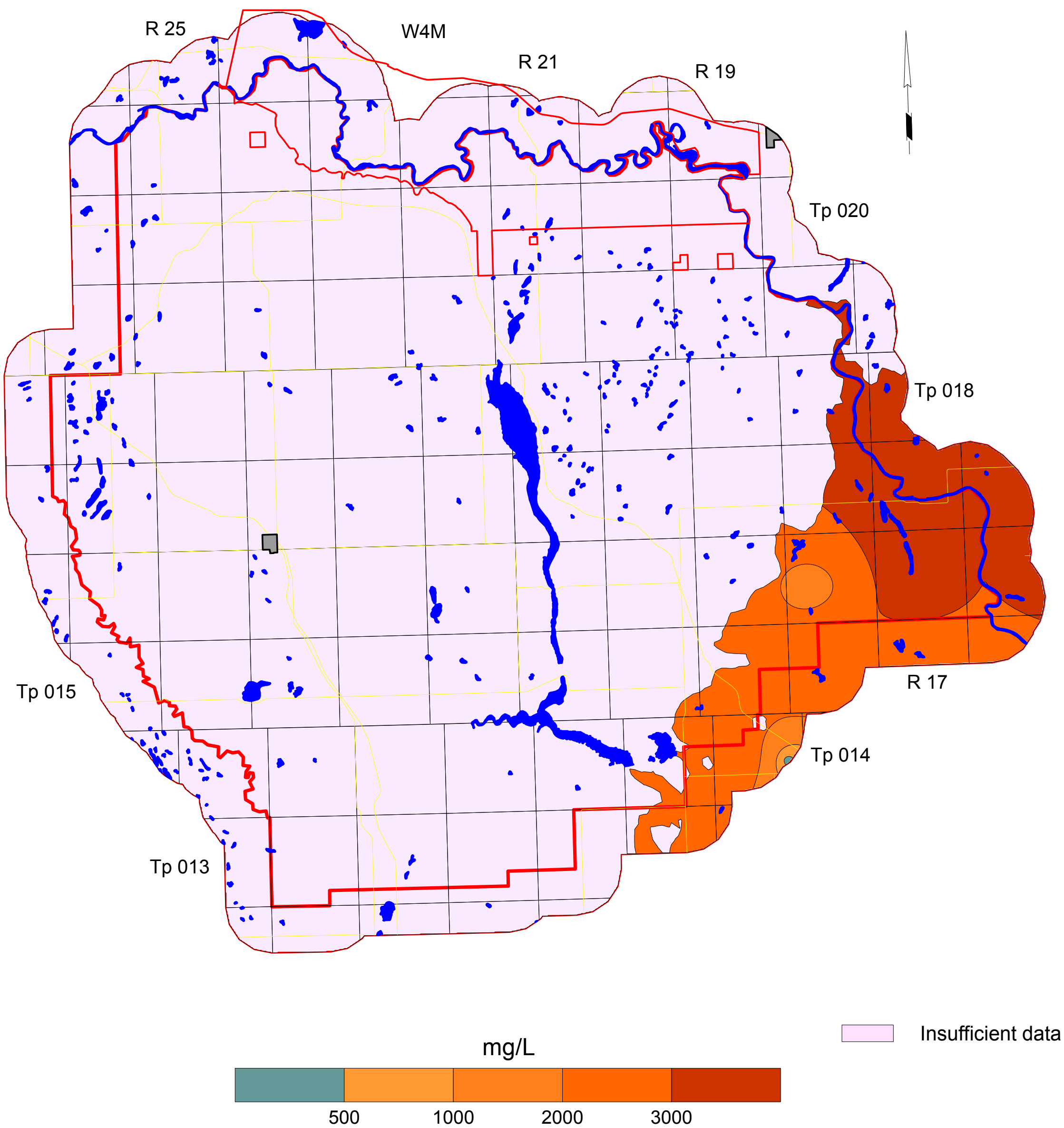
Depth to Top of Oldman Formation



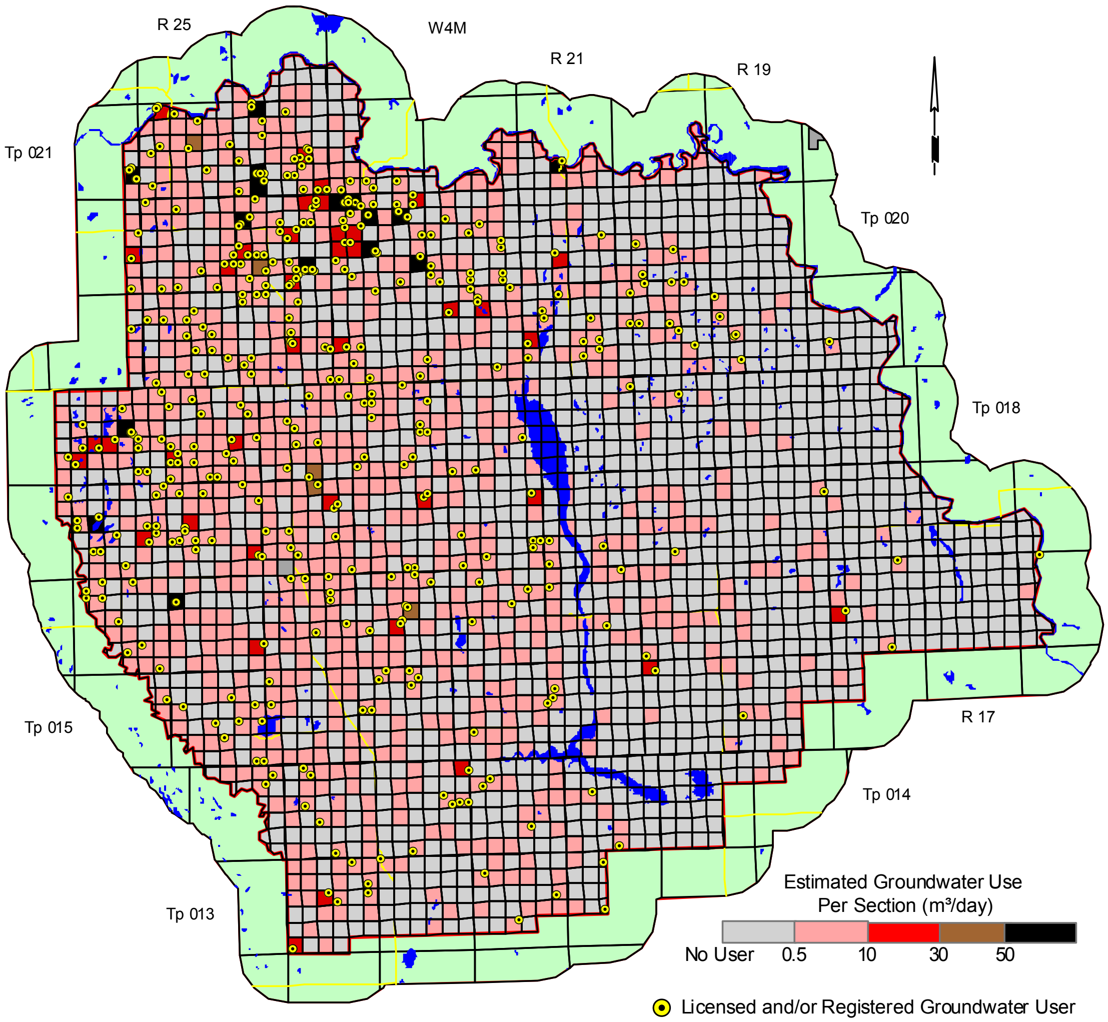
Apparent Yield for Water Wells Completed through Oldman Aquifer



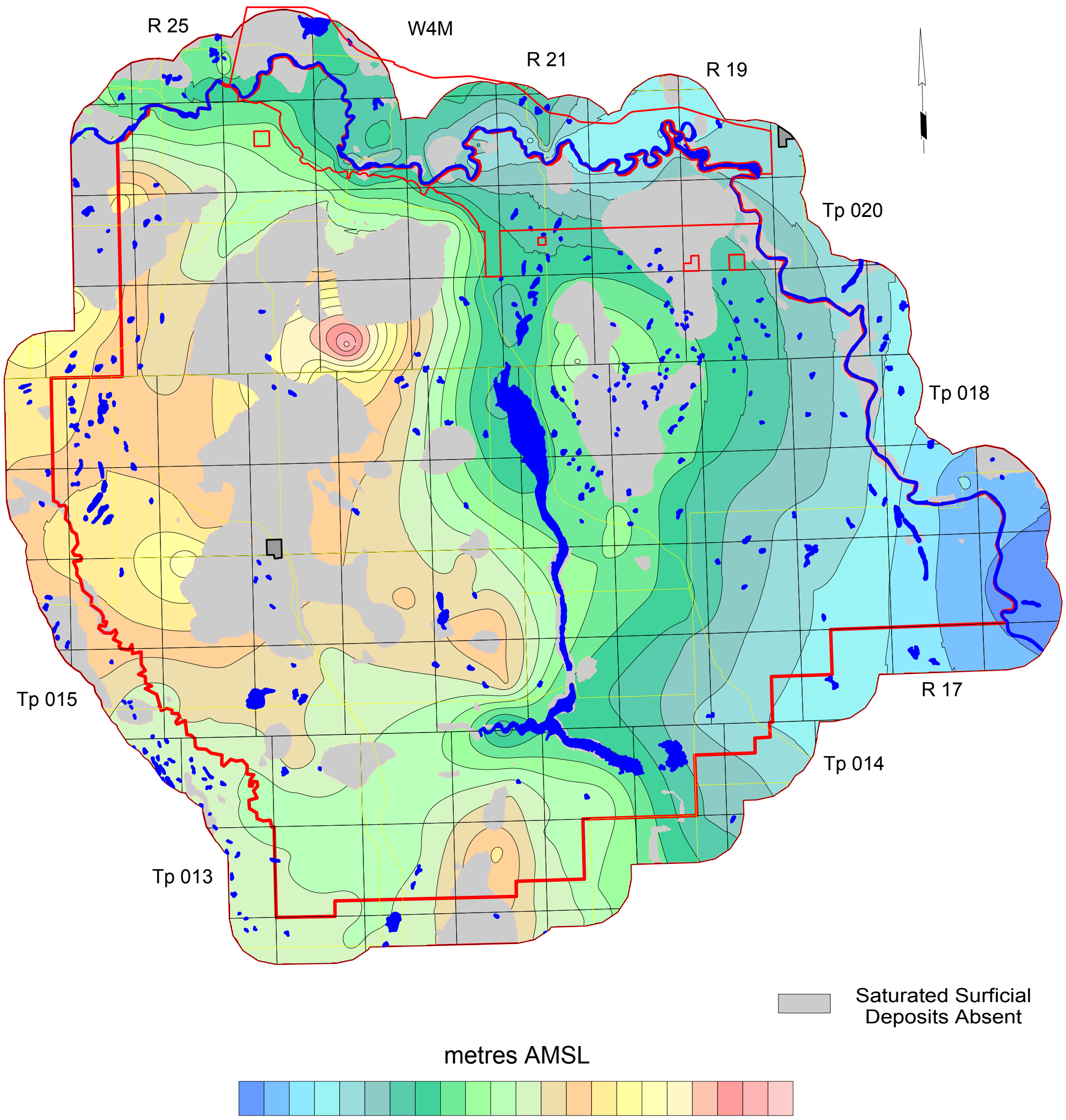
Total Dissolved Solids in Groundwater from Oldman Aquifer



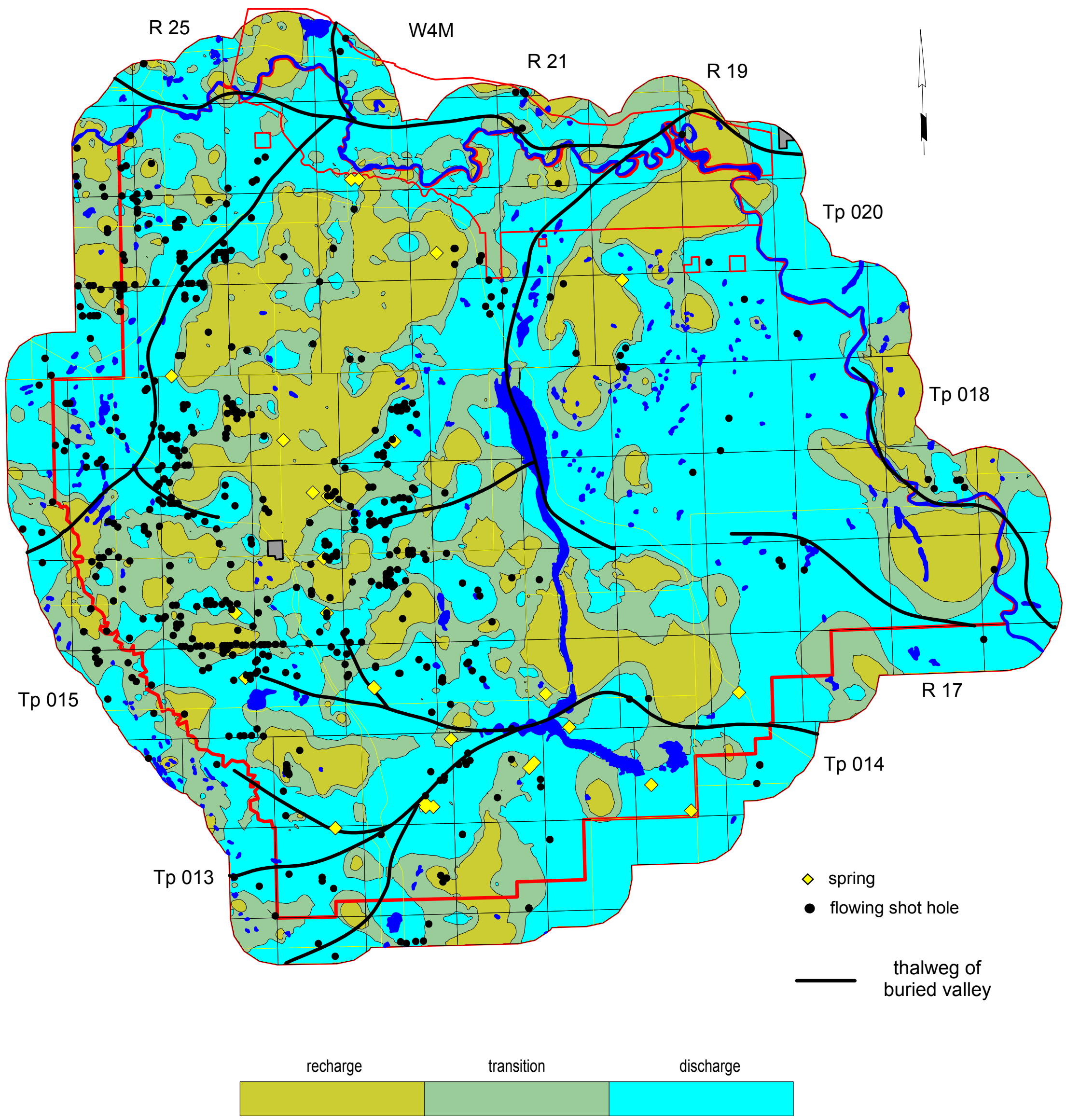
Estimated Water Well Use Per Section



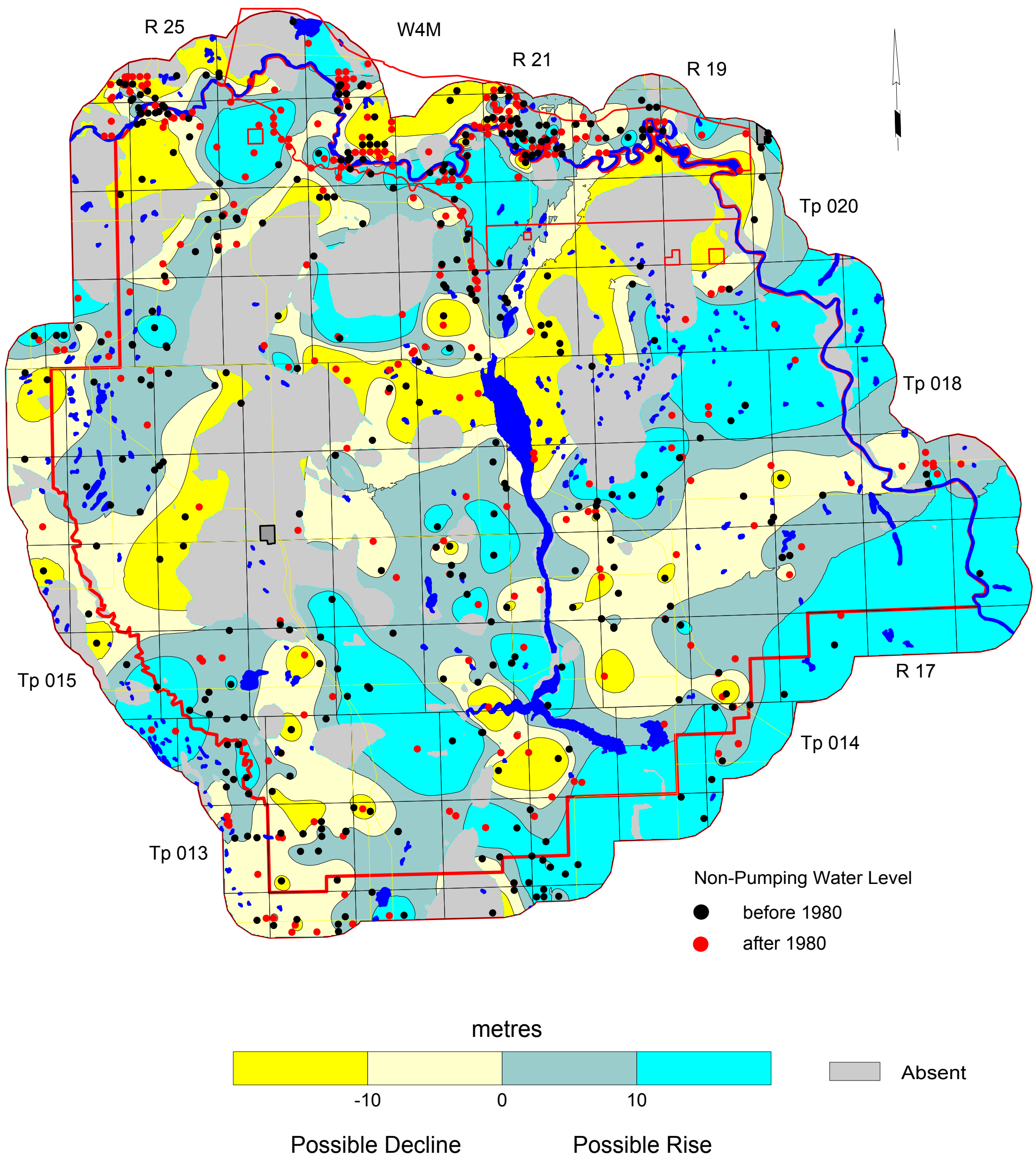
Non-Pumping Water-Level Surface in Surficial Deposits Based on Water Wells Less than 20 Metres Deep



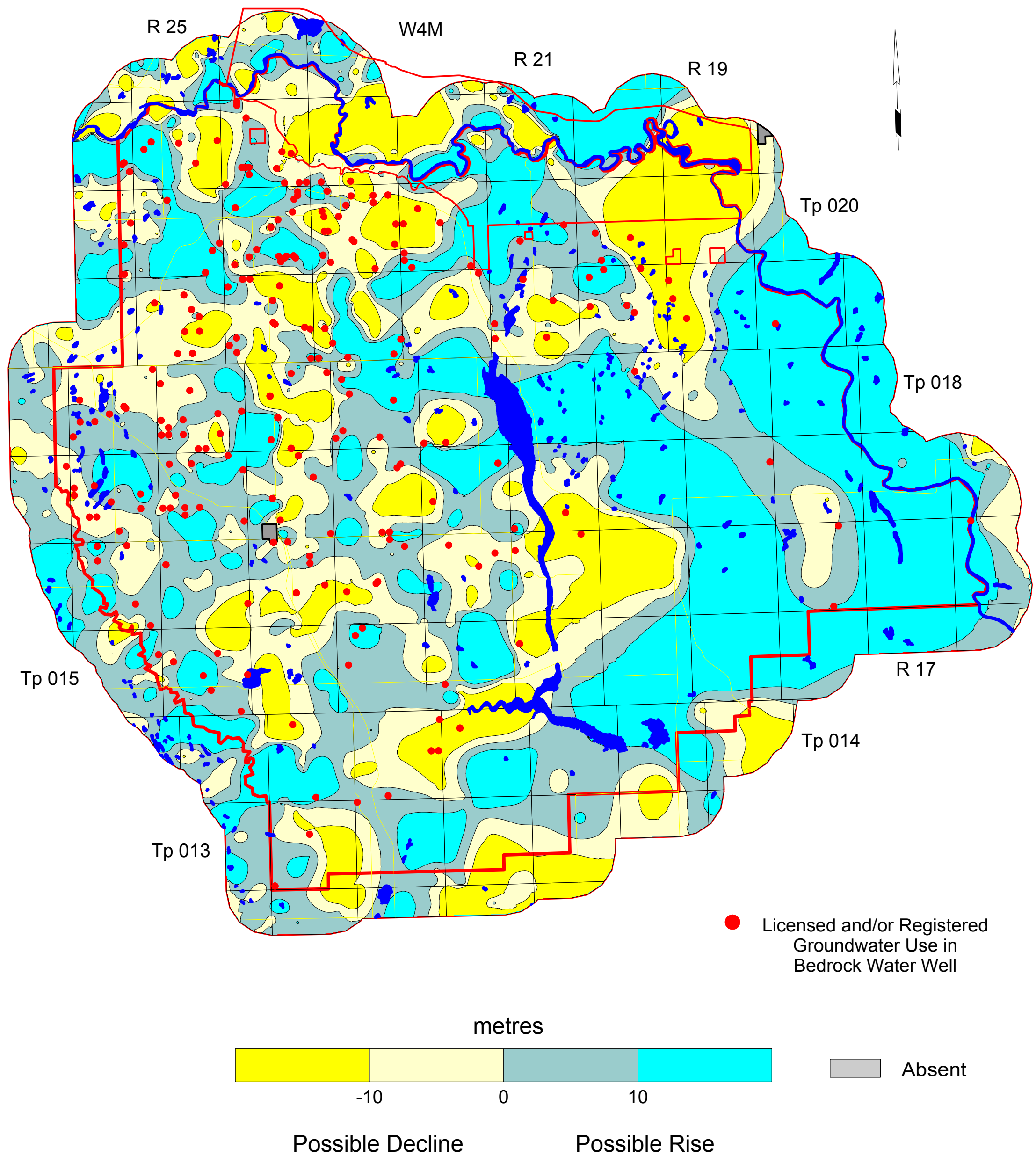
Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)



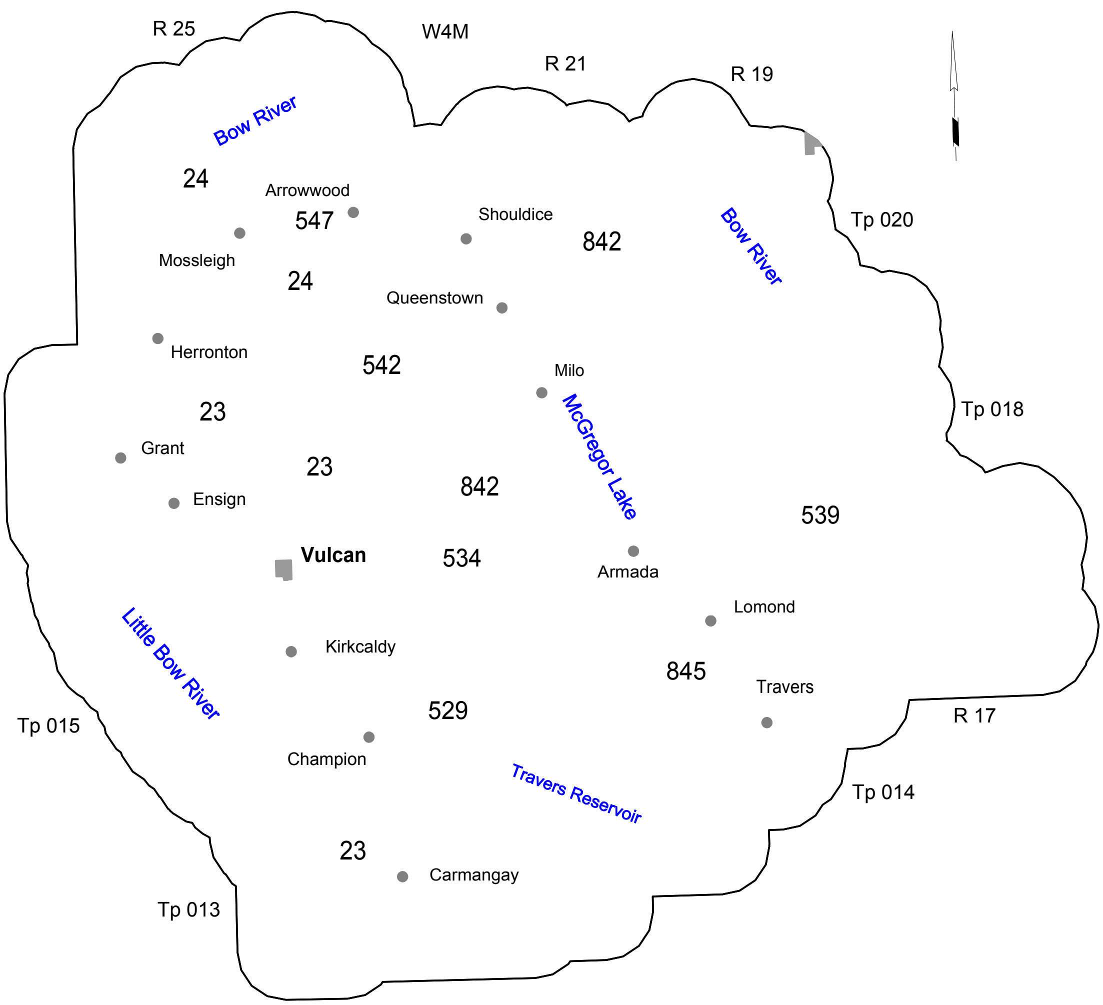
Changes in Water Levels in Surficial Deposits



Areas of Potential Groundwater Decline in Upper Bedrock Aquifer(s)



Overlay


R 25
W4M
R 21
R 19
Bow River
24
Arrowwood
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Shouldice
842
Bow River
Tp 020
Mossleigh
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Queenstown
Herronton
542
Milo
McGregor Lake
Tp 018
23
Grant
23
842
Ensign
539
Vulcan
534
Armada
Lomond
Little Bow River
Kirkcaldy
845
Travers
Tp 015
529
R 17
Champion
Travers Reservoir
Tp 014
23
Carmangay
Tp 013

VULCAN COUNTY
Appendix B

Maps and Figures on CD-ROM

MAPS AND FIGURES ON CD-ROM

VULCAN 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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ALBERTA REGULATION 205/98

Water Act

WATER (MINISTERIAL) REGULATION

Table of Contents

Chemical Analysis of Farm Water Supplies

Adapted from Agdex 716 (D04) Published April 1991

A routine chemical analysis tests the water for 15 chemical parameters. It will reveal the hardness and iron concentration as well as the presence of other chemicals such as chlorides, sulphates, nitrates and nitrites. Chemicals, other than those listed below, can be tested but arrangements should be made with the lab before the sample is submitted. These special requests' must be clearly specified on the request form. Your farm water supply should be analyzed whenever a new water source is constructed, or when a change in water quality is noticed.

Your local health unit can provide you with the necessary water sample containers. Water samples specifically for human consumption must be submitted to the health unit.

The water sample you take should be representative. Choose an outlet as close to the source as possible. For most domestic samples, allow the water to run through the faucet for about five minutes and then fill the sample container.

Once you have obtained a good water sample, take it to your local health unit for forwarding to the appropriate laboratory. After the laboratory analysis is completed, the health inspector or technologist will receive a copy of the analysis and will be able to help you interpret the results.

Water Quality Criteria

It is not essential for private supplies to meet these guidelines. People have different reactions and tolerances to different minerals. If any chemical in your water exceeds drinking water limits consult you family doctor or local health unit.

All levels listed below (except pH) are listed in parts per million (ppm). Many labs report results in milligrams/Litre (mg/L), which is equivalent to ppm.

Sodium

Sodium is not considered a toxic metal, and 5,000 to 10,000 milligrams per day are consumed by normal adults without adverse effects. The average intake of sodium from water is only a small fraction of that consumed in a normal diet.

Persons suffering from certain medical conditions such as hypertension may require a sodium restricted diet, in which case the intake of sodium from drinking water could become significant. Sodium levels as low as 20 ppm are sometimes a concern to them. A maximum level of 300 (200*) ppm sodium has traditionally been used as a guideline but the "Guidelines for Canadian Drinking Water Quality" list no maximum acceptable concentration.

Sodium is a significant factor in assessing water for irrigation and plant watering. High sodium levels affect soil structure and a plant's ability to take up water.

Potassium

Potassium is usually only found in quantities of a few ppm in water. There is no recommended limit for potassium but levels over 2,000 ppm may be harmful to human nervous systems. Alberta water supplies rarely contain more than 20 ppm.

Calcium
Calcium is one cause of "hardness" in water. Calcium is not a hazard to health but is undesirable because it may be detrimental for domestic uses such as washing, bathing and laundering. It also tends to cause encrustations in kettles, coffee makers and water heaters. 200 ppm is often considered an acceptable limit.

Magnesium
Magnesium is another constituent causing "hardness" in water. A suggested limit of 150 ppm is used because of taste considerations.

Iron
Iron levels as low as 0.2 to 0.3 ppm will usually cause the staining of laundry and plumbing fixtures. The presence of iron bacteria in water supplies will often cause these symptoms at even lower levels. Iron gives water a metallic taste that may be objectionable to some persons at one to two ppm. Most water contains less that five ppm iron but occasionally levels over 30 ppm are found. Iron and iron bacteria are not considered a health concern.

Sulphate (SO4)
Sulphate concentrations over 500 ppm can be laxative to some humans and livestock. Sulphate levels over 500 ppm may be a concern for livestock on marginal intakes of certain trace minerals. Very high levels of sulphates have been associated with some brain disorders in cattle and pigs.

Chloride
Due to taste considerations the suggested maximum level for chloride is 250 ppm. Most water in Alberta contains less than 20 ppm chloride, although chloride in the 2,000 ppm range can be found.

NO2 Nitrogen (Nitrite)
Due to its toxicity, the maximum acceptable concentration of nitrite in drinking water is one ppm. Nitrite is usually an indicator of very direct contamination by sewage or manure because nitrites are unstable and quickly become nitrates.

The concentration in livestock water should not exceed 10 ppm.

NO3 Nitrogen (Nitrate)
Nitrates are also an indicator of contamination by human or livestock wastes, excessive fertilization or seepage from dump sites. The maximum acceptable concentration in drinking water is 10 ppm. The figure is based on the potential for the nitrate poisoning of infants. Adults can tolerate higher levels but high nitrate levels may cause irritation of the stomach and bladder. The suggested maximum for livestock use is 1,000 ppm.

Fluoride
Fluorides occur naturally in most well waters and are desirable since they help prevent dental cavities. Between one and 1.5 ppm is desirable. As fluoride levels increase above this amount there is an increase in the tendency to cause tooth mottling.

Fluoride levels less than four ppm are not considered a problem for livestock.

TDS Inorganic (Total Dissolved Solids)
This is a measure of the inorganic minerals dissolved in the water. As a general rule less than 1,000 (500*) ppm TDS is considered satisfactory. Levels higher than this are not necessarily a problem; it depends on the specific minerals present.

The suitability for livestock deteriorates as TDS exceeds the 2,000 to 3,000 ppm range.

Conductivity

Conductivity is measured in micro Siemens per centimetre. It can be used to estimate the total dissolved solids in the water. Multiplying the conductivity by 0.65 will give a good approximation of the total dissolved solids. Conductivity tests are often used to assess water suitability for irrigation.

pH

pH is a measure of how acidic or basic the water is. The pH scale goes from zero (acidic) to 14 (basic) with seven being neutral. The generally accepted range for pH is 6.5 to 8.5 with an upper limit of 9.5.

Hardness

The harder the water is the greater its ability to neutralize soap suds. Hardness is caused primarily by calcium and magnesium, but is expressed as ppm equivalent of calcium carbonate. Hard water causes soap curd which makes bathroom fixtures difficult to keep clean and causes greying of laundry.

Hard water will also tend to form scale in hot water tanks, kettles, piping systems, etc.

Type of Water	Amount of Hardness	
	ppm	grains per gallon
Soft	0- 50	0-3
Moderately Soft	50 - 100	3-6
Moderately Hard	100 - 200	6-12
Hard	200 - 400	12- 23
Very Hard	400 - 600	23 - 35
Extremely Hard	Over 600	Over 35

Alkalinity

Alkalinity is not a specific substance but rather a combined effect of several substances. It is a measure of the resistance of a water to a change in pH. The alkalinity of most Alberta waters is in the range of 100 - 500 ppm, which is considered acceptable. Water with higher levels is often used. Alkalinity is a factor in corrosion or scale deposition and may affect some livestock when over 1,000 ppm.

Water Treatment

Water treatment equipment can often improve water quality significantly. Each type of water treatment equipment has its limitations and thus should be selected carefully. For more information on water treatment please refer to the Agdex 71 6 D series of fact sheets.

Helpful Conversions

1 ppm (part per million) = 1 mg/L (milligram per litre)
1 gpg (grain per gallon) = 17.1 ppm (parts per million)

References

Guidelines for Canadian Drinking Water Quality (1987) Health and Welfare Canada

*Federal-Provincial Subcommittee on Drinking Water of the Federal-Provincial-Territorial Committee on Environment and Occupational Health. March 2001. Summary of Guidelines for Canadian Drinking Water Quality.

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);
http://www.agric.gov.ab.ca/water/wells/index.html
Quality Farm Dugouts - http://www.agric.gov.ab.ca/esb/dugout.html

ALBERTA ENVIRONMENT

WATER - http://www3.gov.ab.ca/env/water/

GROUNDWATER INFORMATION SYSTEM - http://www.telusgeomatics.com/tgpub/ag_water/

WATER WELL INSPECTORS
Jennifer MacPherson (Edmonton: 780-427-9517)

WATER WELL LICENSING
Glenn Winner (Edmonton: 780-427-9773)

GEOPHYSICAL INSPECTION SERVICE
Edmonton: 780-427-3932

COMPLAINT INVESTIGATIONS
Jerry Riddell (Edmonton: 780-422-4851)

UNIVERSITY OF ALBERTA – Department of Earth and Atmospheric Sciences - Hydrogeology
Carl Mendoza (Edmonton: 780-492-2664)

UNIVERSITY OF CALGARY – Department of Geology and Geophysics - Hydrogeology
Larry Bentley (Calgary: 403-220-4512)

FARMERS' ADVOCATE
Jim Kiss (Edmonton: 780-427-2433)

PRAIRIE FARM REHABILITATION ADMINISTRATION (PFRA) BRANCH OF AGRICULTURE AND AGRI-FOOD CANADA (AAFC)

Vic Brown (Lethbridge: 403-382-3145) - brownv@agr.gc.ca
Tony Cowen (Edmonton: 780-495-4911) - cownent@agr.gc.ca.
Terry Dash (Calgary: 403-292-5719) - dasht@agr.gc.ca

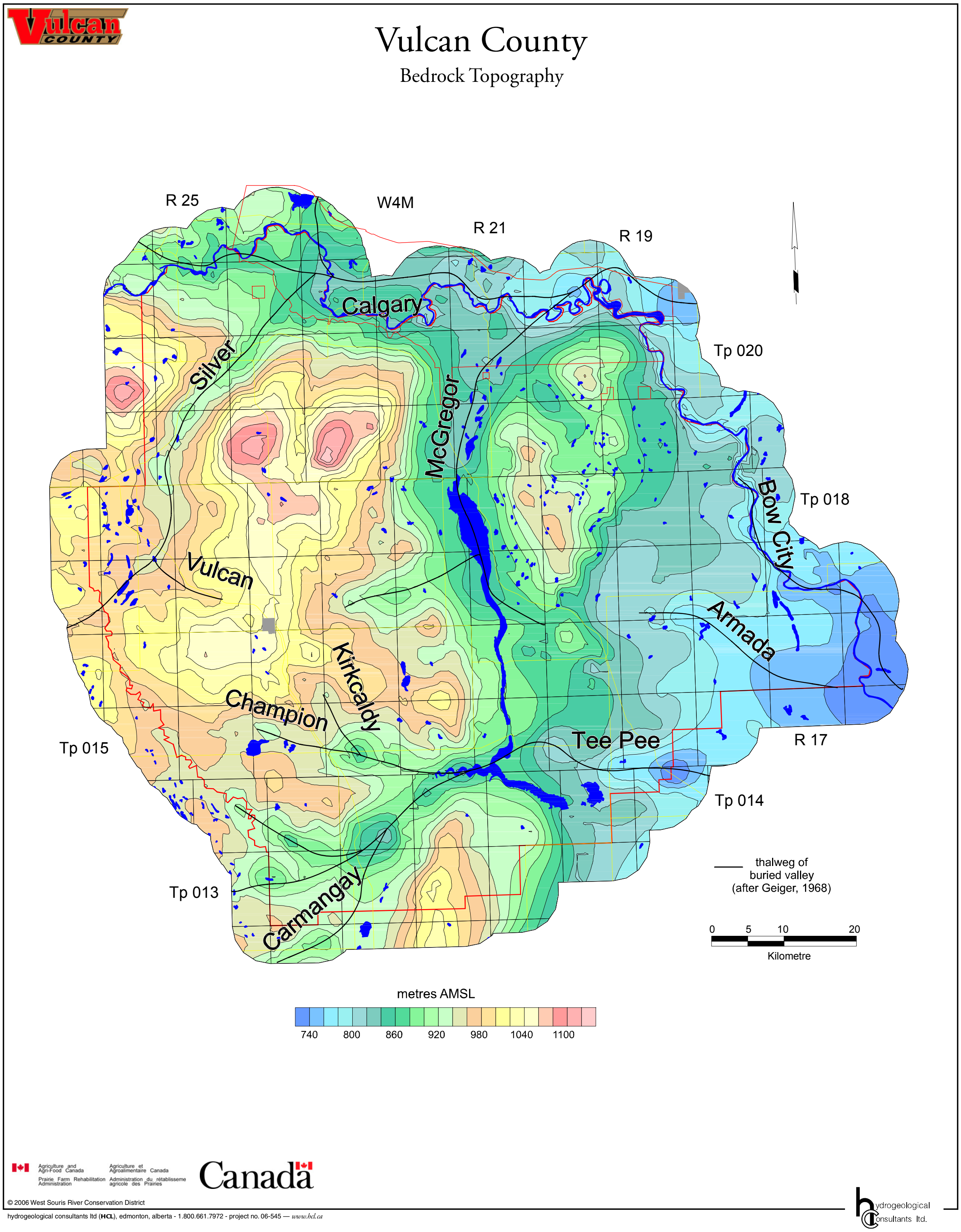
WILDROSE COUNTRY GROUND WATER MONITORING ASSOCIATION
Dave Andrews (Irricana: 403-935-4478)

LOCAL HEALTH DEPARTMENTS

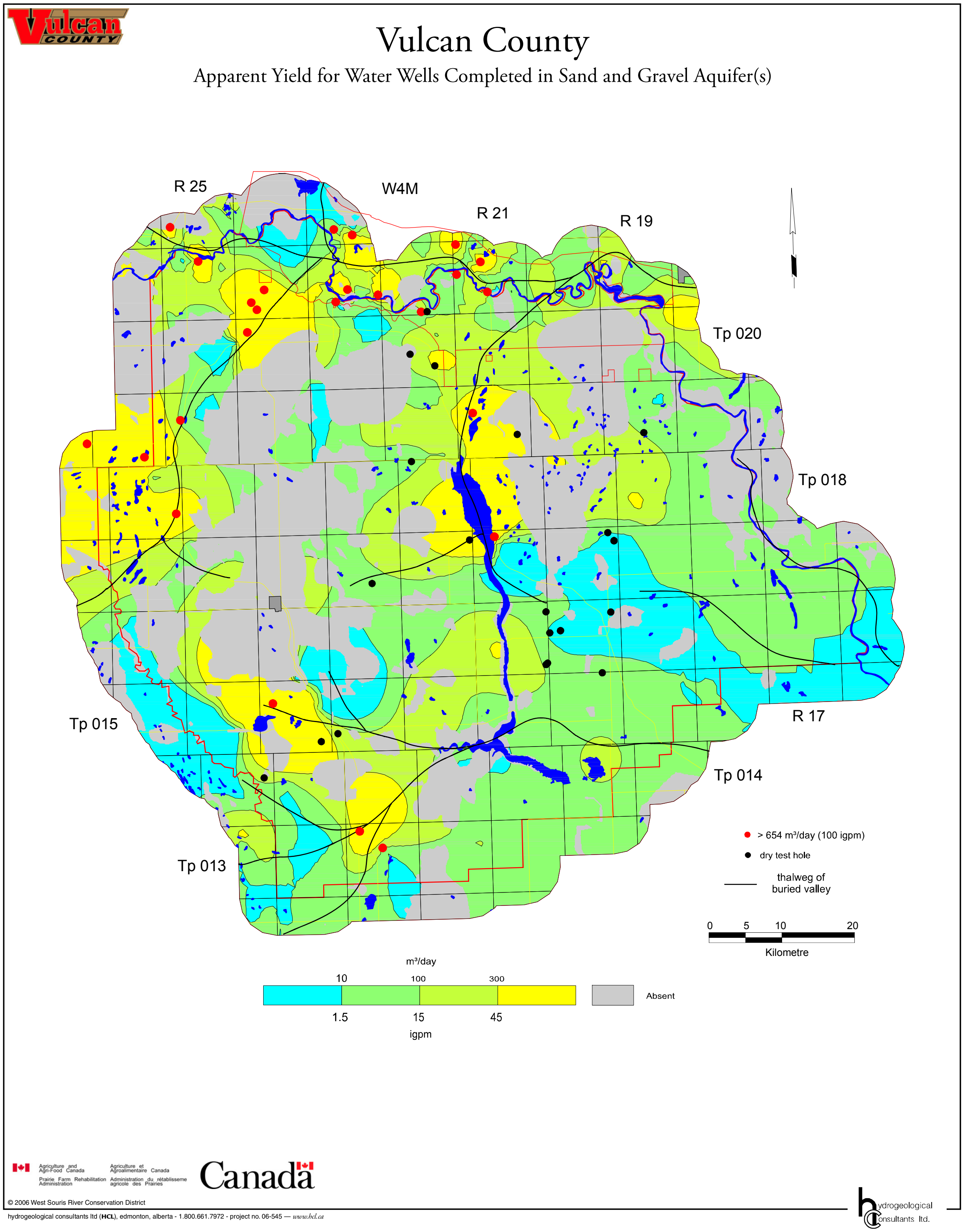
VULCAN COUNTY
Appendix D

Maps and Figures Included as Large Plots

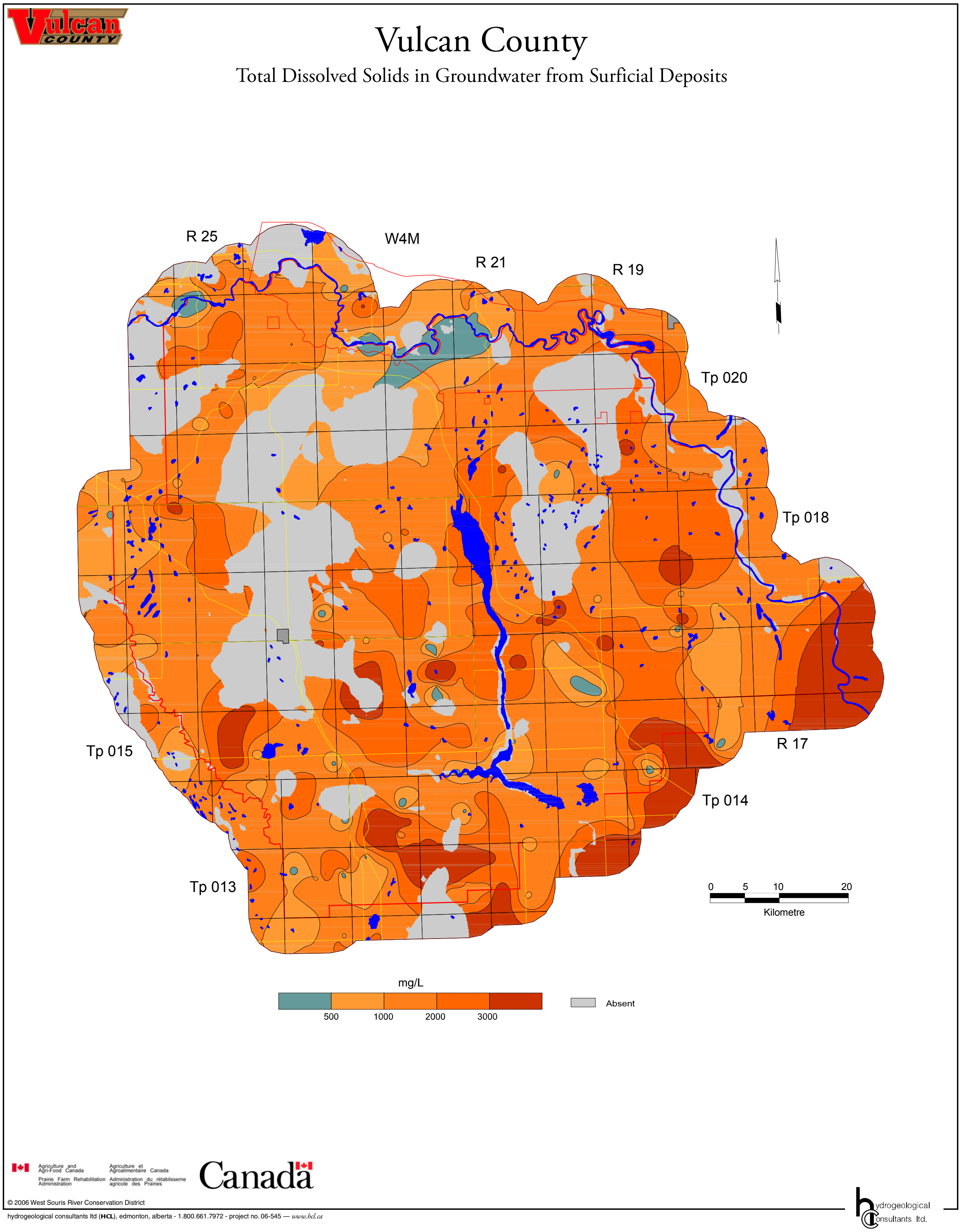
Bedrock Topography



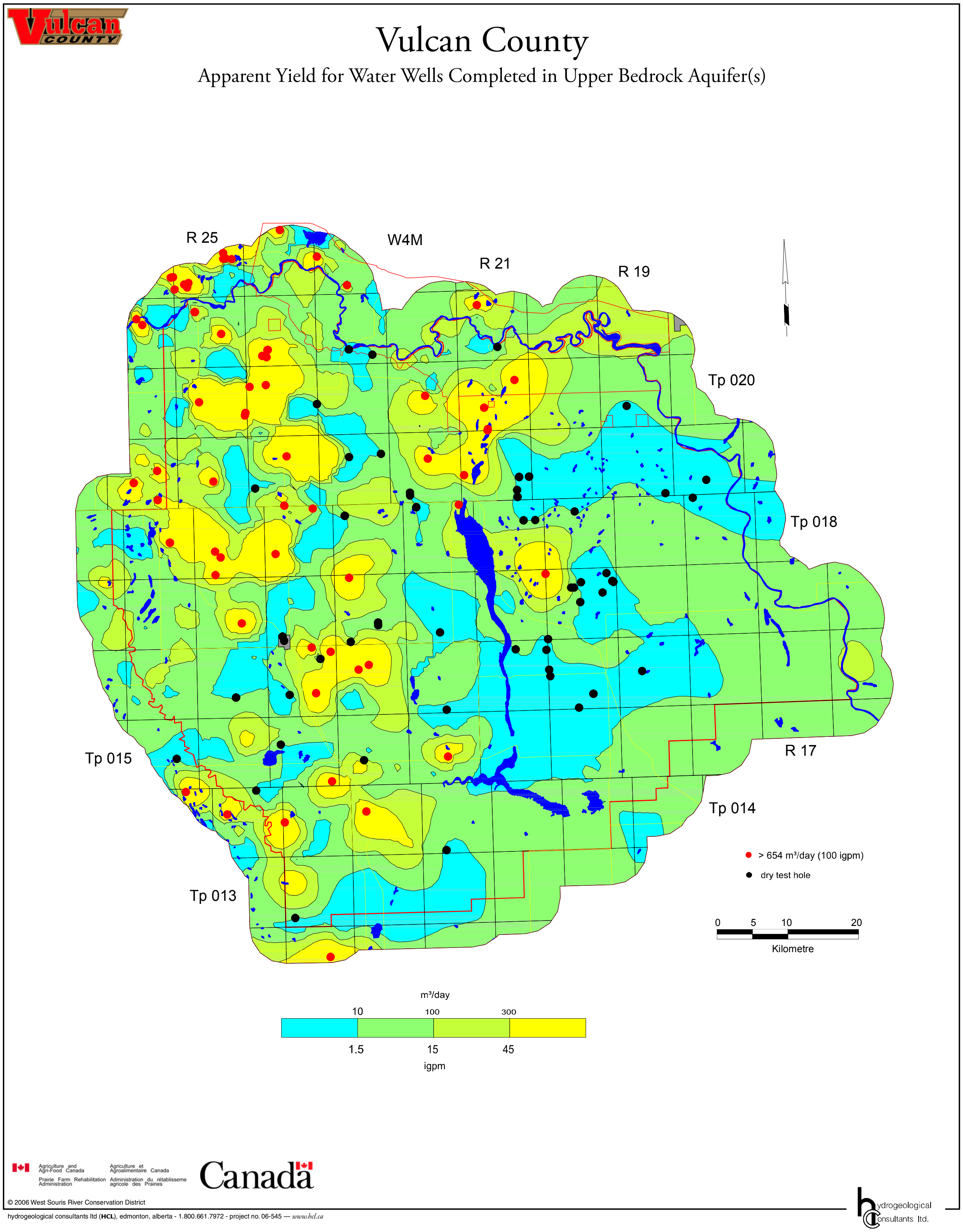
Apparent Yield for Water Wells Completed in Sand and Gravel Aquifer(s)



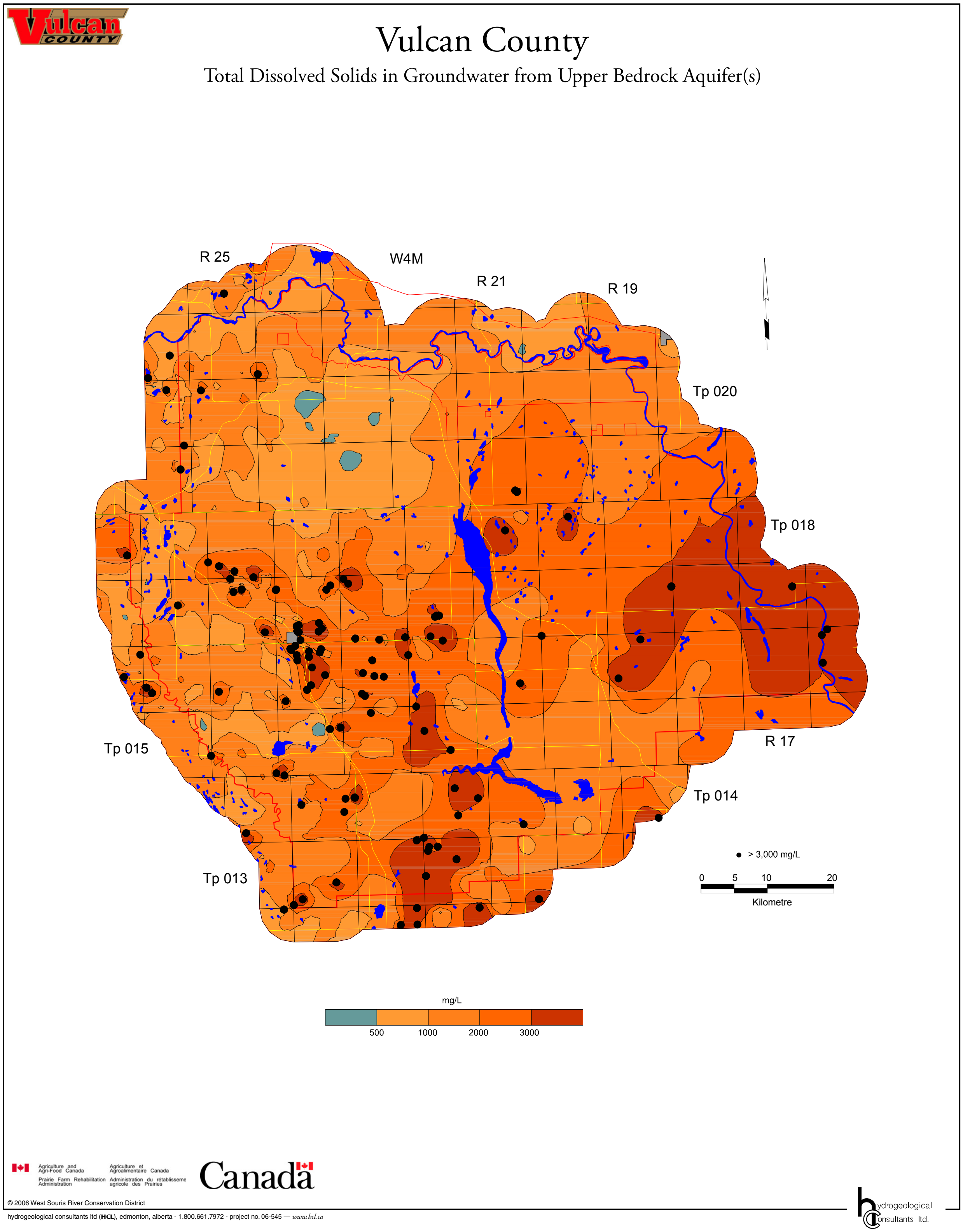
Total Dissolved Solids in Groundwater from Surficial Deposits



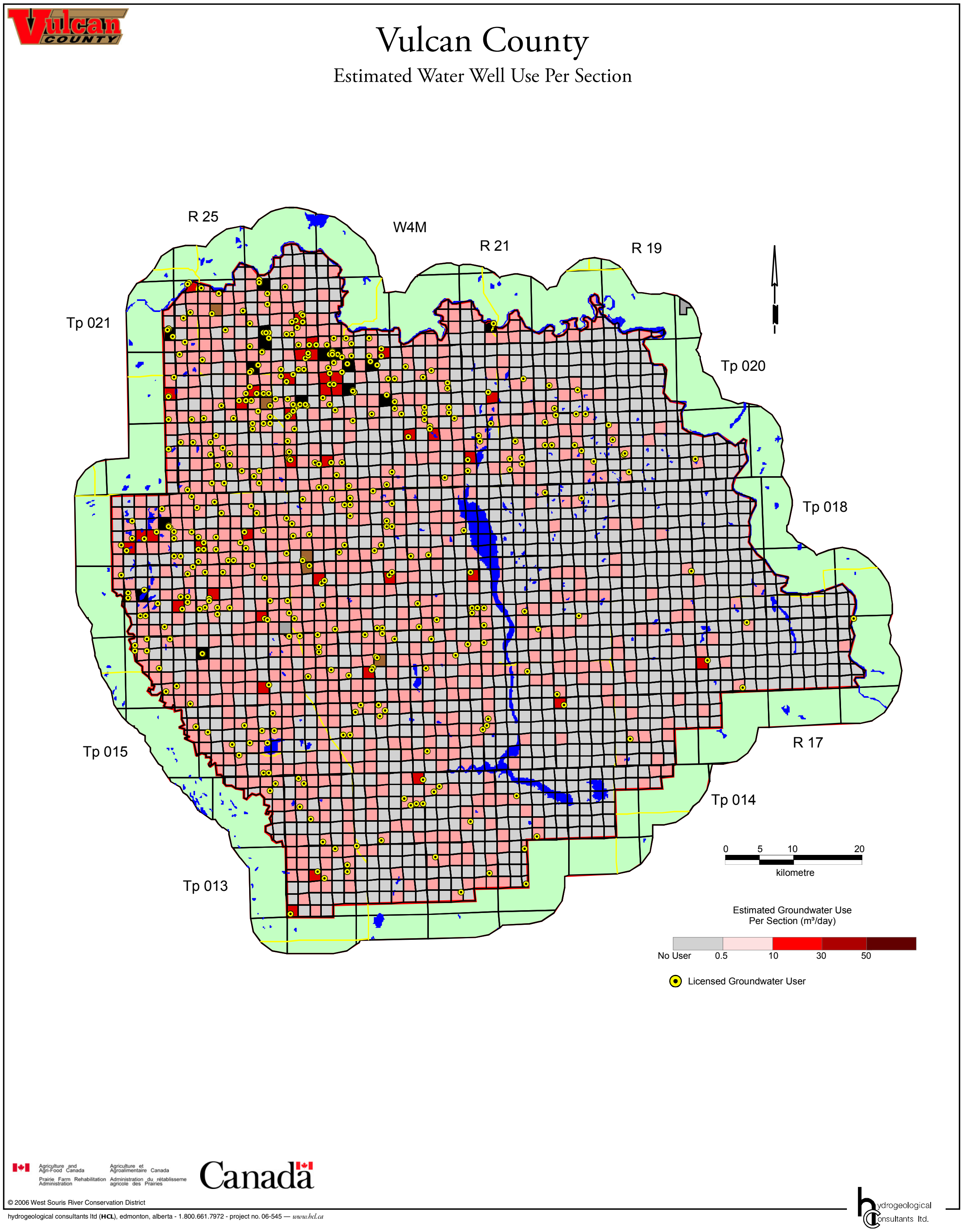
Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)



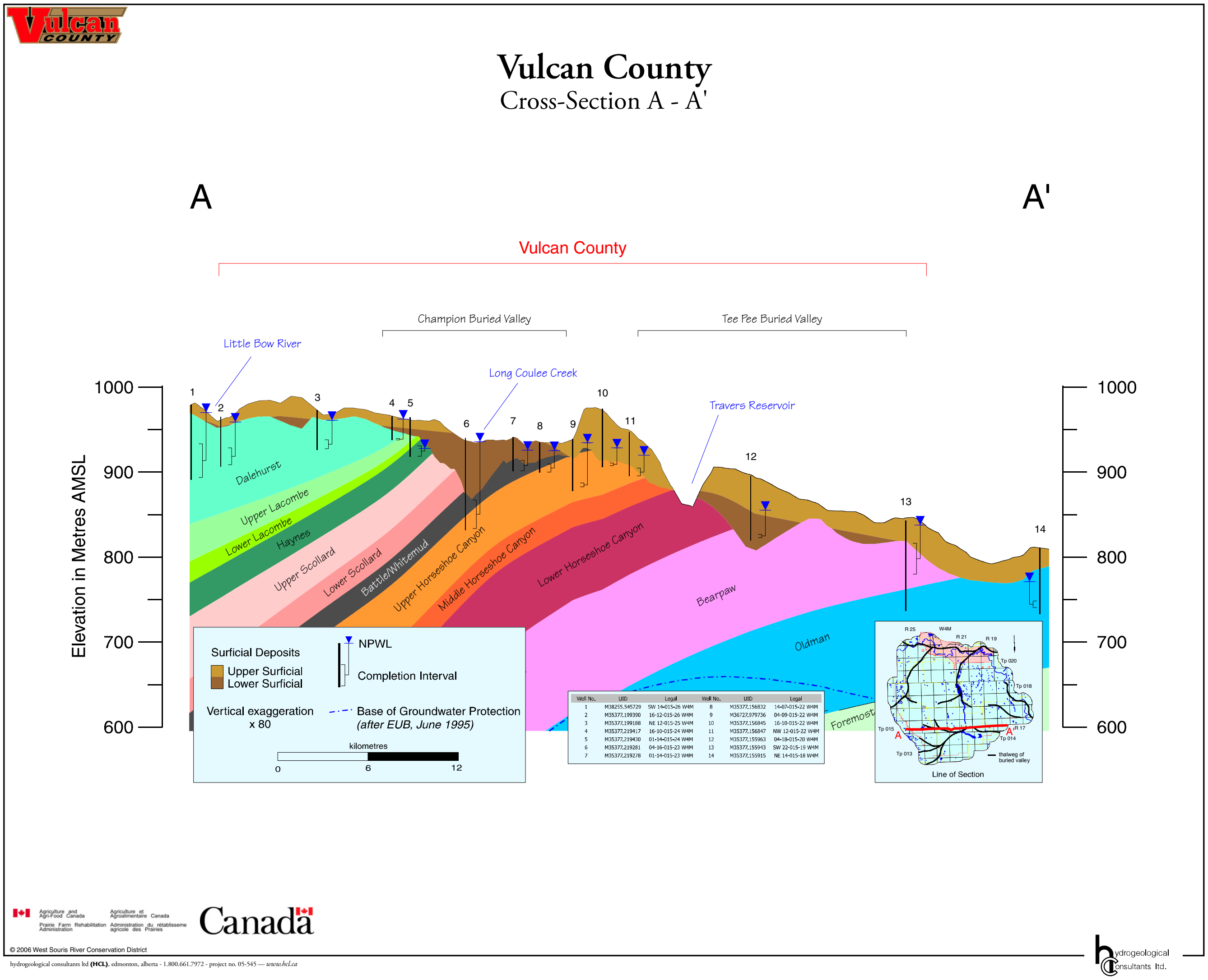
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)



Estimated Water Well Use Per Section



Cross-Section A - A'



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6	M35377.219281	04-16-015-23 W4M	13	M35377.155943	SW 22-015-19 W4M
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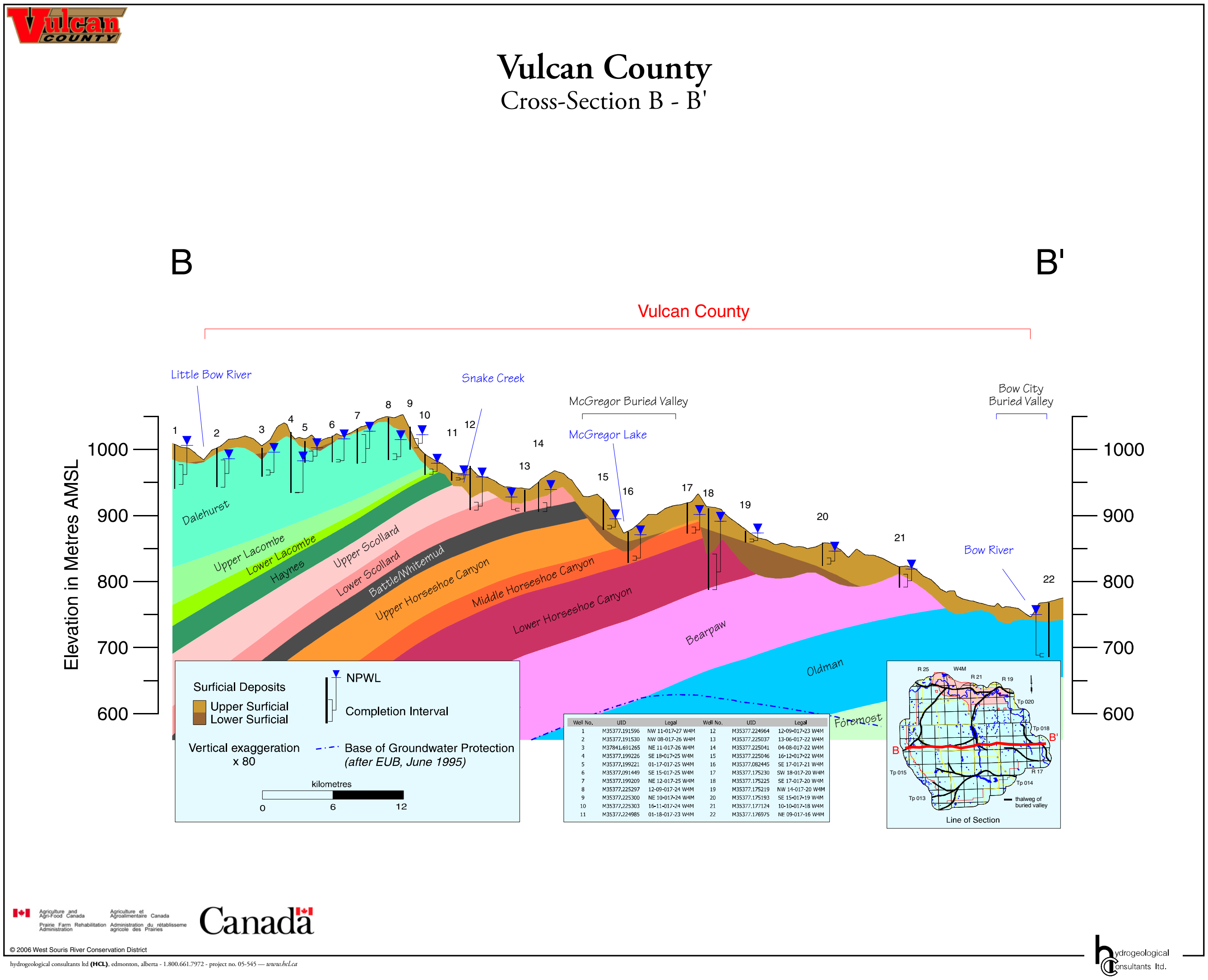
Cross-Section B - B’



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4	M35377.199226	SE 18-017-25 W4M	15	M35377.225046	16-12-017-22 W4M
5	M35377.199221	01-17-017-25 W4M	16	M35377.082445	SE 17-017-21 W4M
6	M35377.091449	SE 15-017-25 W4M	17	M35377.175230	SW 18-017-20 W4M
7	M35377.199209	NE 12-017-25 W4M	18	M35377.175225	SE 17-017-20 W4M
8	M35377.225297	12-09-017-24 W4M	19	M35377.175219	NW 14-017-20 W4M
9	M35377.225300	NE 10-017-24 W4M	20	M35377.175193	SE 15-017-19 W4M
10	M35377.225303	16-11-017-24 W4M	21	M35377.177124	10-10-017-18 W4M
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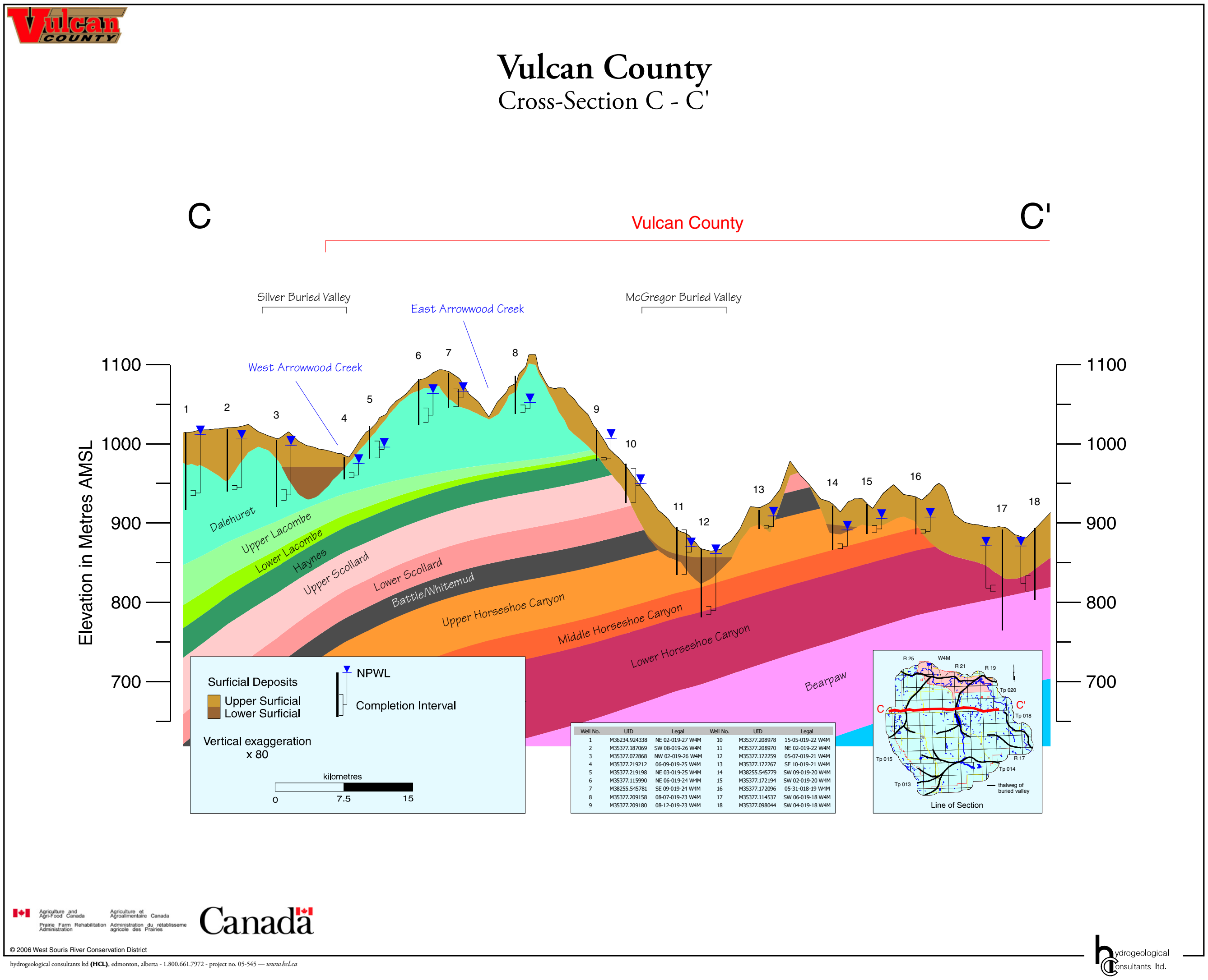
Cross-Section C - C'



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3	M35377.072868	NW 02-019-26 W4M	12	M35377.172259	05-07-019-21 W4M
4	M35377.219212	06-09-019-25 W4M	13	M35377.172267	SE 10-019-21 W4M
5	M35377.219198	NE 03-019-25 W4M	14	M38255.545779	SW 09-019-20 W4M
6	M35377.115990	NE 06-019-24 W4M	15	M35377.172194	SW 02-019-20 W4M
7	M38255.545781	SE 09-019-24 W4M	16	M35377.172096	05-31-018-19 W4M
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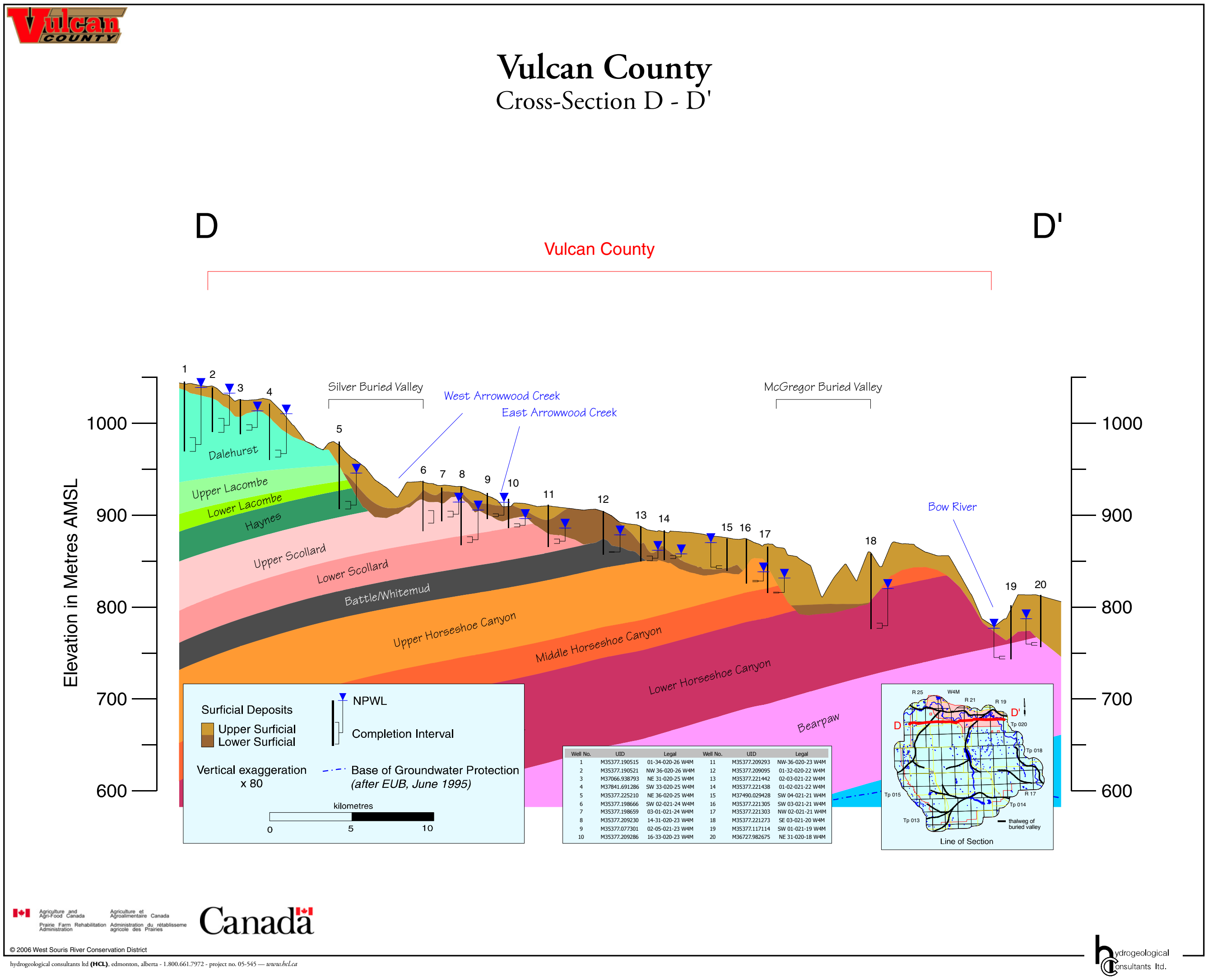

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3	M37066.938793	NE 31-020-25 W4M	13	M35377.221442	02-03-021-22 W4M
4	M37841.691286	SW 33-020-25 W4M	14	M35377.221438	01-02-021-22 W4M
5	M35377.225210	NE 36-020-25 W4M	15	M37490.029428	SW 04-021-21 W4M
6	M35377.198666	SW 02-021-24 W4M	16	M35377.221305	SW 03-021-21 W4M
7	M35377.198659	03-01-021-24 W4M	17	M35377.221303	NW 02-021-21 W4M
8	M35377.209230	14-31-020-23 W4M	18	M35377.221273	SE 03-021-20 W4M
9	M35377.077301	02-05-021-23 W4M	19	M35377.117114	SW 01-021-19 W4M
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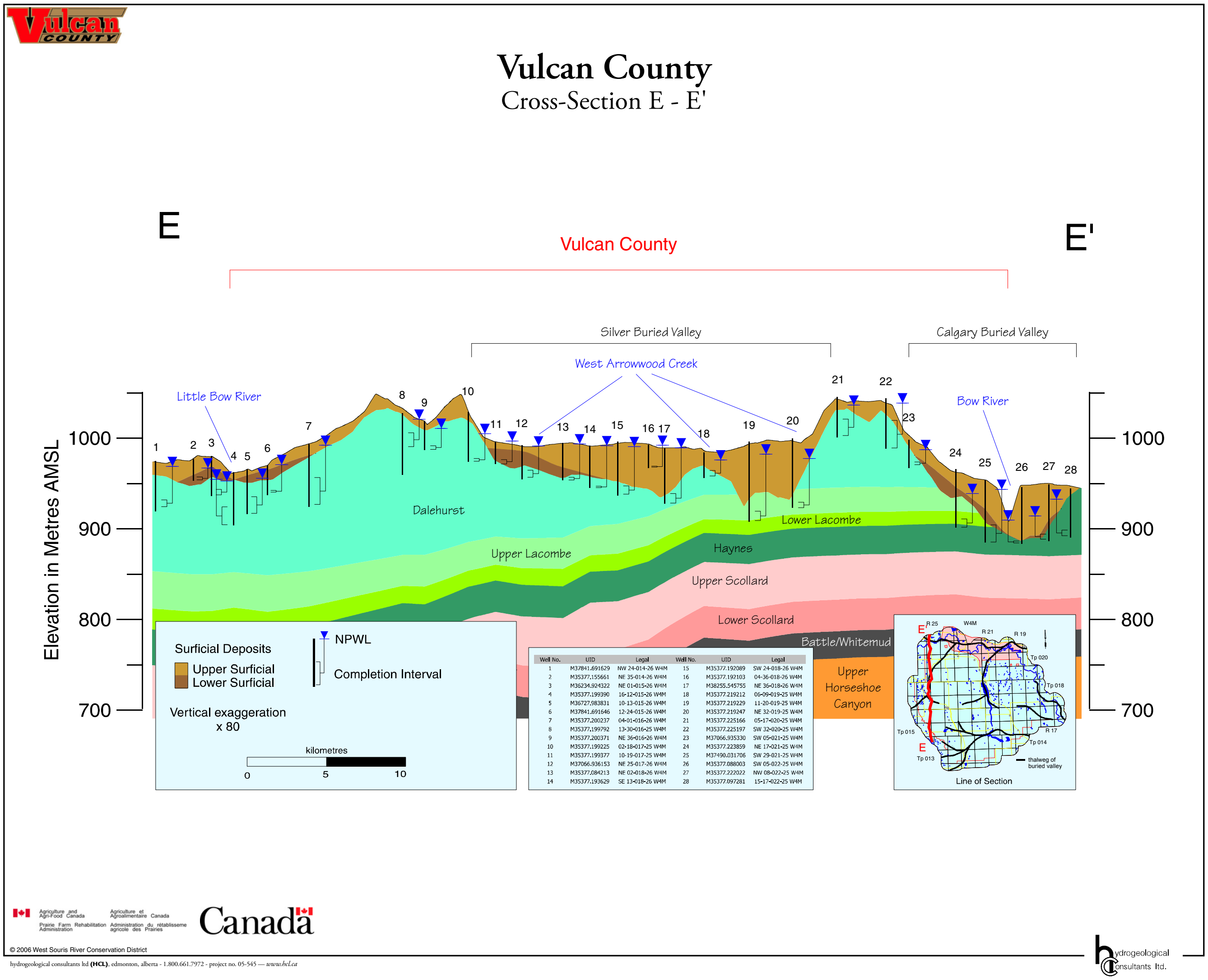
Cross-Section E - E'



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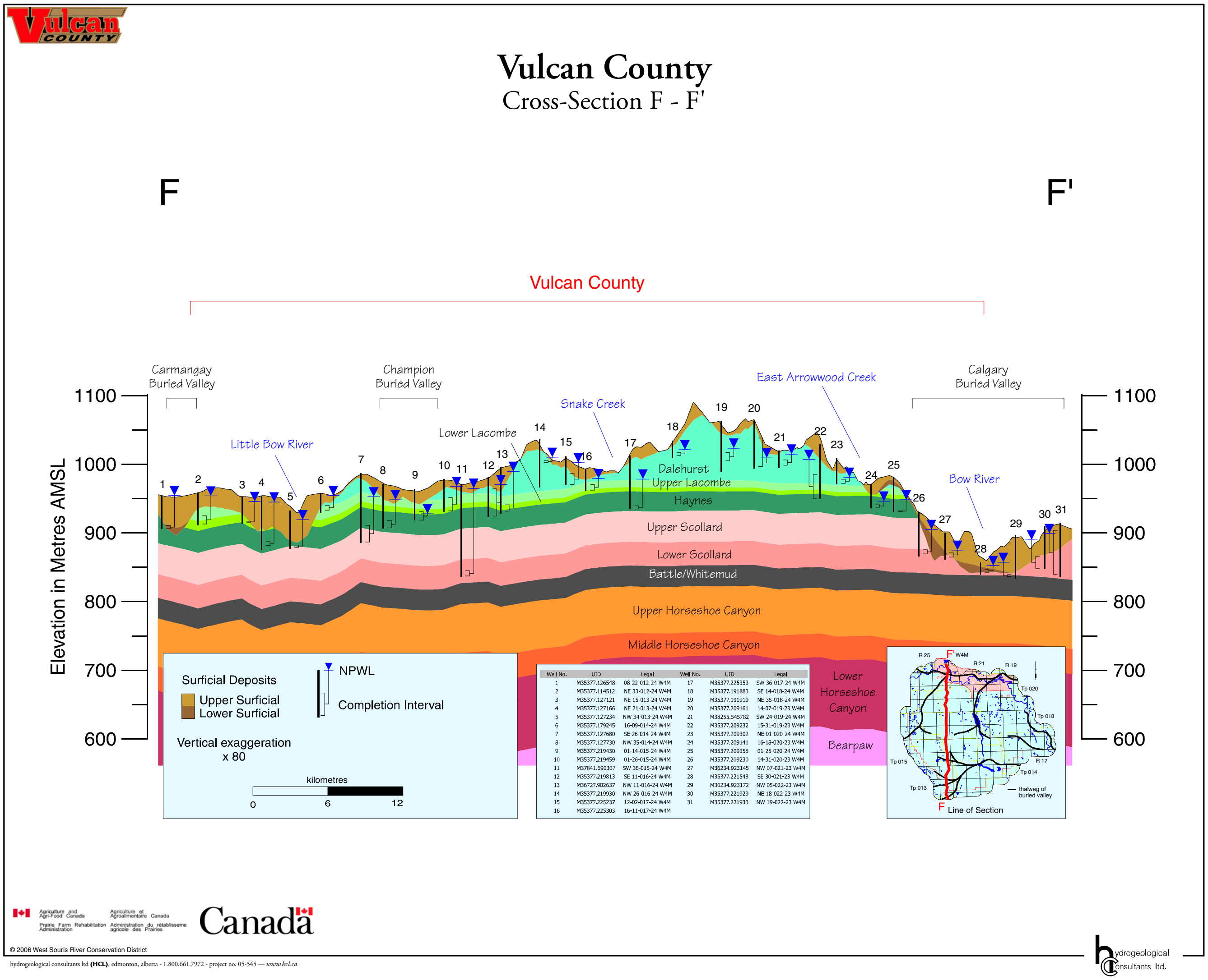
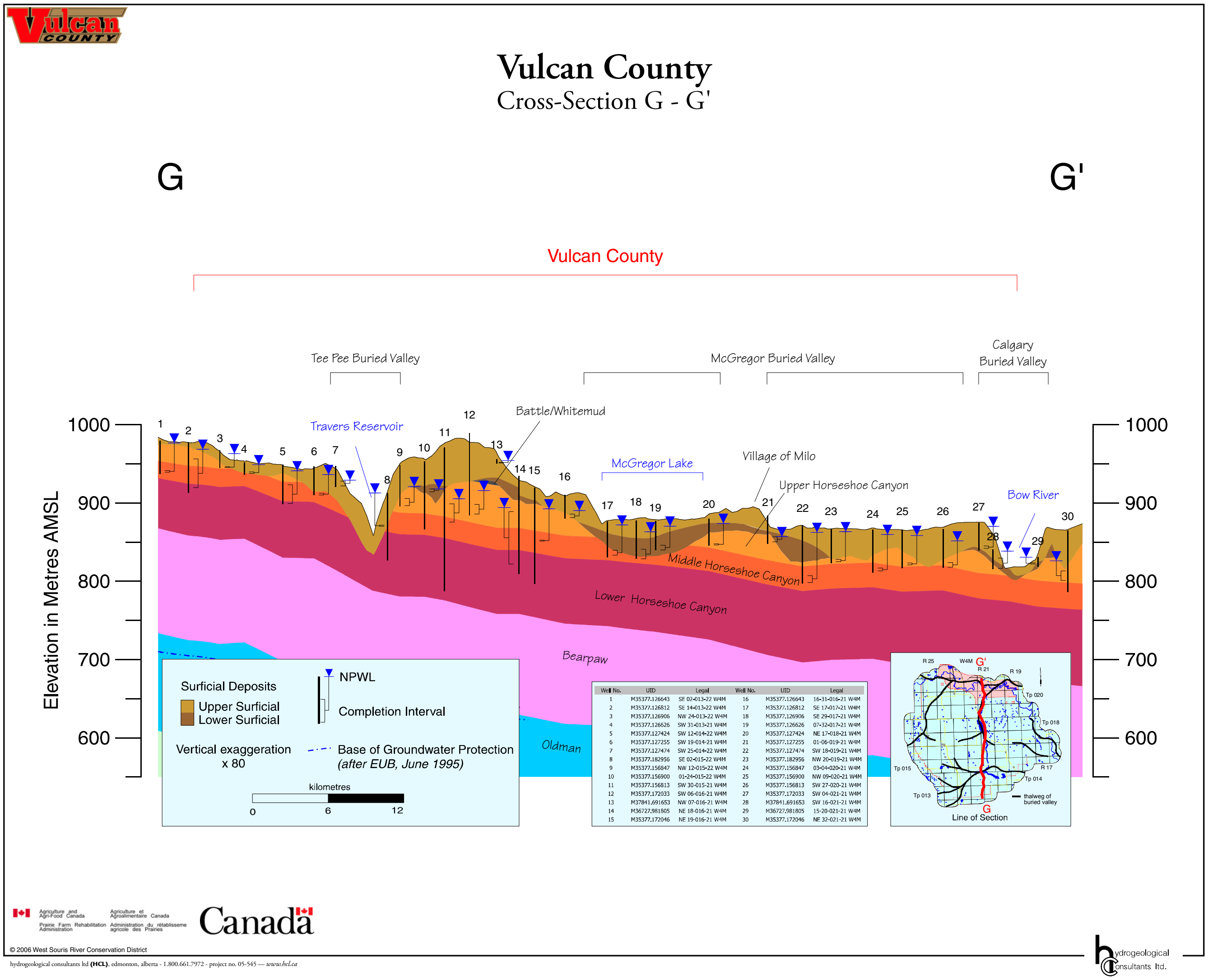
1	M37841.691629	NW 24-014-26 W4M	15	M35377.192089	SW 24-018-26 W4M
2	M35377.155661	NE 35-014-26 W4M	16	M35377.192103	04-36-018-26 W4M
3	M36234.924322	NE 01-015-26 W4M	17	M38255.545755	NE 36-018-26 W4M
4	M35377.199390	16-12-015-26 W4M	18	M35377.219212	06-09-019-25 W4M
5	M36727.983831	10-13-015-26 W4M	19	M35377.219229	11-20-019-25 W4M
6	M37841.691646	12-24-015-26 W4M	20	M35377.219247	NE 32-019-25 W4M
7	M35377.200237	04-01-016-26 W4M	21	M35377.225166	05-17-020-25 W4M
8	M35377.199792	13-30-016-25 W4M	22	M35377.225197	SW 32-020-25 W4M
9	M35377.200371	NE 36-016-26 W4M	23	M37066.935330	SW 05-021-25 W4M
10	M35377.199225	02-18-017-25 W4M	24	M35377.223859	NE 17-021-25 W4M
11	M35377.199377	10-19-017-25 W4M	25	M37490.031706	SW 29-021-25 W4M
12	M37066.936153	NE 25-017-26 W4M	26	M35377.088003	SW 05-022-25 W4M
13	M35377.084213	NE 02-018-26 W4M	27	M35377.222022	NW 08-022-25 W4M
14	M35377.193629	SE 13-018-26 W4M	28	M35377.097281	15-17-022-25 W4M

Cross-Section F - F'



Well No.	UID	Legal	Well No.	UID	Legal
1	M35377.126548	08-22-012-24 W4M	17	M35377.225353	SW 36-017-24 W4M
2	M35377.114512	NE 33-012-24 W4M	18	M35377.191883	SE 14-018-24 W4M
3	M35377.127121	NE 15-013-24 W4M	19	M35377.191919	NE 35-018-24 W4M
4	M35377.127166	NE 21-013-24 W4M	20	M35377.209161	14-07-019-23 W4M
5	M35377.127234	NW 34-013-24 W4M	21	M38255.545782	SW 24-019-24 W4M
6	M35377.179245	16-09-014-24 W4M	22	M35377.209232	15-31-019-23 W4M
7	M35377.127680	SE 26-014-24 W4M	23	M35377.209302	NE 01-020-24 W4M
8	M35377.127730	NW 35-014-24 W4M	24	M35377.209141	16-18-020-23 W4M
9	M35377.219430	01-14-015-24 W4M	25	M35377.209358	01-25-020-24 W4M
10	M35377.219459	01-26-015-24 W4M	26	M35377.209230	14-31-020-23 W4M
11	M37841.690307	SW 36-015-24 W4M	27	M36234.923145	NW 07-021-23 W4M
12	M35377.219813	SE 11-016-24 W4M	28	M35377.221548	SE 30-021-23 W4M
13	M36727.982637	NW 11-016-24 W4M	29	M36234.923172	NW 05-022-23 W4M
14	M35377.219930	NW 26-016-24 W4M	30	M35377.221929	NE 18-022-23 W4M
15	M35377.225237	12-02-017-24 W4M	31	M35377.221933	NW 19-022-23 W4M
16	M35377.225303	16-11-017-24 W4M			

Cross-Section G - G'



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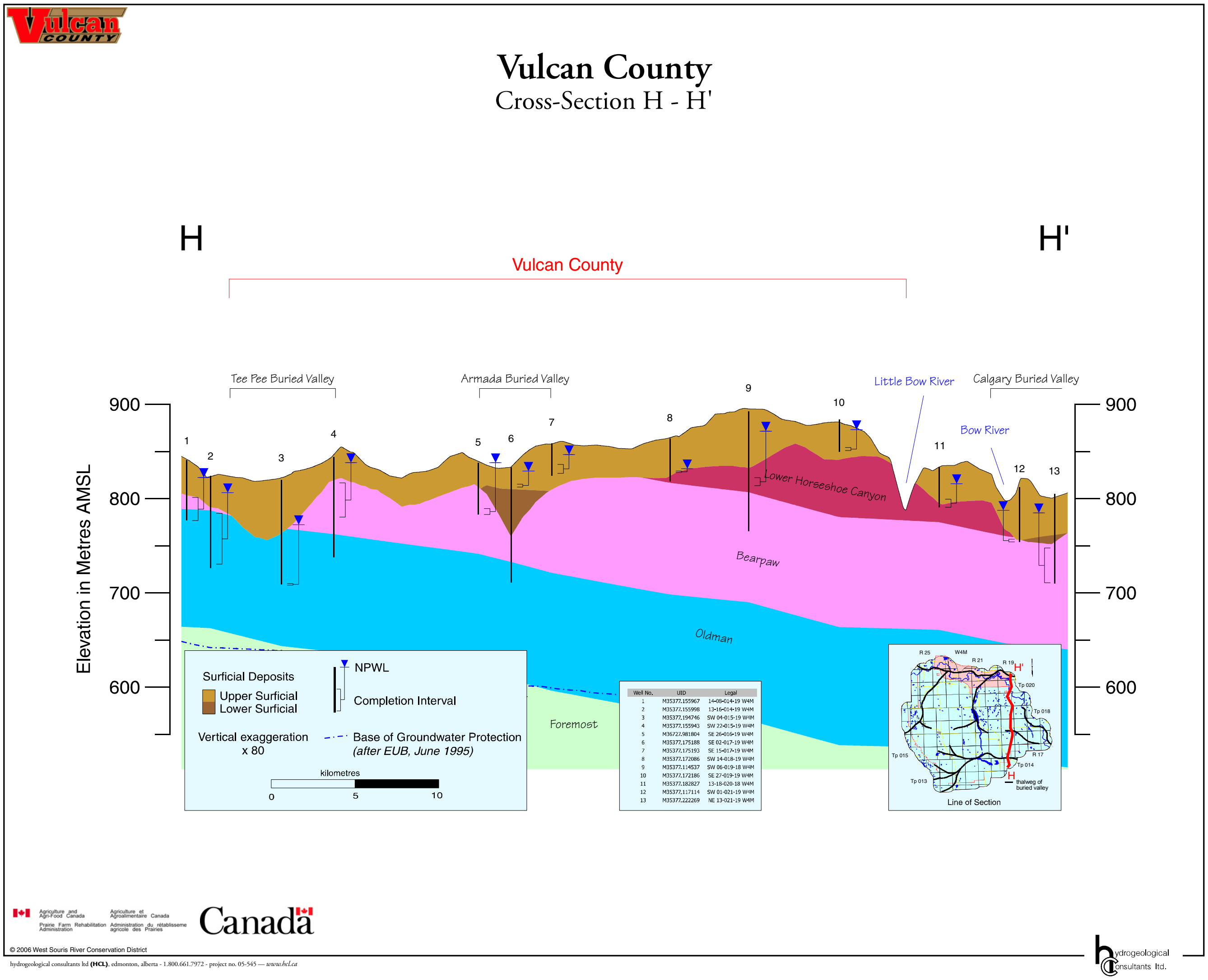
1	M35377.126643	SE 02-013-22 W4M	16	M35377.126643	16-31-016-21 W4M
2	M35377.126812	SE 14-013-22 W4M	17	M35377.126812	SE 17-017-21 W4M
3	M35377.126906	NW 24-013-22 W4M	18	M35377.126906	SE 29-017-21 W4M
4	M35377.126626	SW 31-013-21 W4M	19	M35377.126626	07-32-017-21 W4M
5	M35377.127424	SW 12-014-22 W4M	20	M35377.127424	NE 17-018-21 W4M
6	M35377.127255	SW 19-014-21 W4M	21	M35377.127255	01-06-019-21 W4M
7	M35377.127474	SW 25-014-22 W4M	22	M35377.127474	SW 18-019-21 W4M
8	M35377.182956	SE 02-015-22 W4M	23	M35377.182956	NW 20-019-21 W4M
9	M35377.156847	NW 12-015-22 W4M	24	M35377.156847	03-04-020-21 W4M
10	M35377.156900	01-24-015-22 W4M	25	M35377.156900	NW 09-020-21 W4M
11	M35377.156813	SW 30-015-21 W4M	26	M35377.156813	SW 27-020-21 W4M
12	M35377.172033	SW 06-016-21 W4M	27	M35377.172033	SW 04-021-21 W4M
13	M37841.691653	NW 07-016-21 W4M	28	M37841.691653	SW 16-021-21 W4M
14	M36727.981805	NE 18-016-21 W4M	29	M36727.981805	15-20-021-21 W4M
15	M35377.172046	NE 19-016-21 W4M	30	M35377.172046	NE 32-021-21 W4M

Cross-Section H - H'



Well No.	UID	Legal
1	M35377.155967	14-08-014-19 W4M
2	M35377.155998	13-16-014-19 W4M
3	M35377.194746	SW 04-015-19 W4M
4	M35377.155943	SW 22-015-19 W4M
5	M36727.981804	SE 26-016-19 W4M
6	M35377.175188	SE 02-017-19 W4M
7	M35377.175193	SE 15-017-19 W4M
8	M35377.172086	SW 14-018-19 W4M
9	M35377.114537	SW 06-019-18 W4M
10	M35377.172186	SE 27-019-19 W4M
11	M35377.182827	13-18-020-18 W4M
12	M35377.117114	SW 01-021-19 W4M
13	M35377.222269	NE 13-021-19 W4M

VULCAN COUNTY

Appendix E

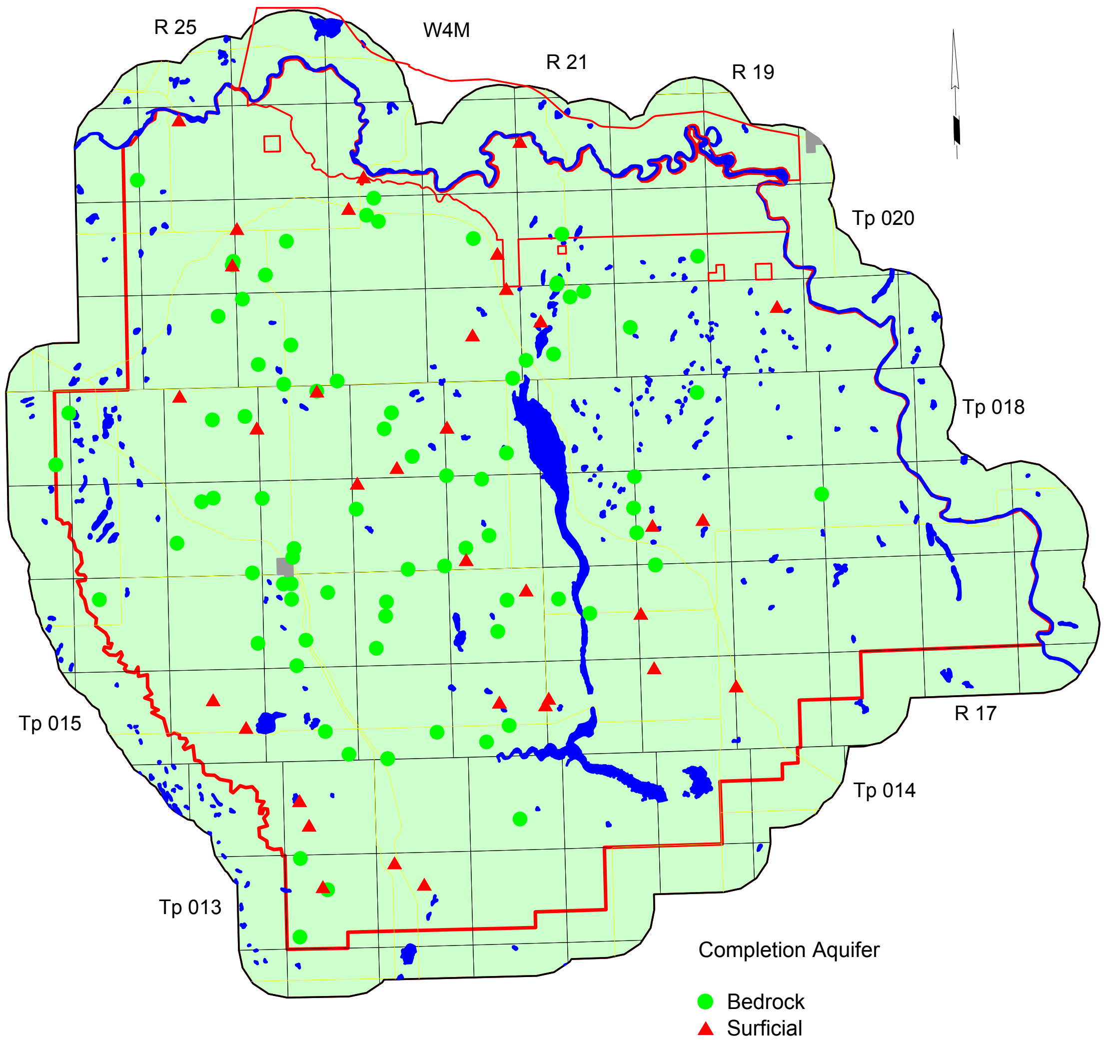
Water Wells That Are Recommended for Field-Verification

including

County-Operated Water Wells

Water Wells That Are Recommended For Field-Verification

(details on following pages)



WATER WELLS RECOMMENDED FOR FIELD-VERIFICATION THAT MEET CRITERIA

Owner	Location	Aquifer Name	Date Water Well Drilled	Completed Depth Metres	Completed Depth Feet	NPWL Metres	NPWL Feet	UID
Androsoff, John	SE 13-020-25 W4M	Haynes	21611.0	42.7	140.0	-2.1	-7.0	M35377.225155
Androsoff, W.	NE 12-020-25 W4M	Haynes	21298.0	30.5	100.0	3.7	12.0	M35377.225152
Androsoff, W.	NE 12-020-25 W4M	Upper Surficial	21300.0	14.6	48.0	-1.1	-3.5	M35377.225151
Auestad, R.	NW 09-019-21 W4M	Upper Horseshoe Canyon	24412.0	25.9	85.0	10.7	35.0	M35377.172262
Axe, Jessie	SW 09-021-23 W4M	Surficial	30859.0	9.1	30.0	3.1	10.0	M35377.221499
Bach, Don	SW 20-014-24 W4M	Upper Surficial	29259.0	7.6	25.0	1.4	4.7	M35377.127583
Barr, Allen	SW 22-020-24 W4M	Haynes	32311.0	54.9	180.0	38.1	125.0	M35377.209356
Bateman, Brian	SW 12-018-27 W4M	Dalehurst Member	29140.0	79.2	260.0	9.1	30.0	M35377.192114
Budd	09-04-018-23 W4M	Surficial	24412.0	13.1	43.0	0.3	1.0	M35377.191793
Bushell, Eugene	NE 16-019-22 W4M	Surficial	29339.0	53.3	175.0	51.5	169.0	M35377.156884
Carrington, C. H.	SE 25-017-19 W4M	Bearpaw	25174.0	48.2	158.0	18.9	62.0	M35377.175194
Craine, Herb	SW 18-017-20 W4M	Middle Horseshoe Canyon	23743.0	46.3	152.0	12.8	42.0	M35377.175230
De Clerq, Paul	SE 14-015-25 W4M	Surficial	29152.0	59.4	195.0	21.3	70.0	M35377.199191
Deal, Allan	SW 28-016-23 W4M	Haynes	31006.0	21.9	72.0	7.0	23.0	M35377.225492
Delta Project	01-24-015-22 W4M	Surficial	28004.0	38.7	127.0	35.1	115.0	M35377.156900
Denbigh, Joe	NW 26-016-24 W4M	Dalehurst Member	30526.0	33.5	110.0	25.8	84.6	M35377.219930
Department of Parks & Wildlife	SE 33-021-25 W4M	Lower Surficial	28160.0	13.7	45.0	3.3	10.8	M35377.077405
Douglas, S.	SE 10-018-23 W4M	Upper Scollard	24096.0	39.6	130.0	3.1	10.0	M35377.191799
Ensign, Ralph	NE 21-013-24 W4M	Haynes	29095.0	72.5	238.0	9.1	30.0	M35377.127166
Ensign, Ralph	NW 21-013-24 W4M	Upper Surficial	26846.0	30.2	99.0	9.1	30.0	M35377.127161
Fawn Hills Simmentals	NW 12-020-20 W4M	Upper Horseshoe Canyon	30119.0	22.9	75.0	16.2	53.0	M35377.208655
Fetkenker, Ron	03-01-019-22 W4M	Upper Horseshoe Canyon	27556.0	22.9	75.0	6.1	20.0	M35377.208957
Fleetwood, Alf	NW 04-015-22 W4M	Upper Horseshoe Canyon	28611.0	41.2	135.0	15.2	50.0	M35377.156828
Fleming, F. J.	01-05-015-23 W4M	Lower Scollard	30567.0	54.9	180.0	4.9	16.0	M35377.219256
Fleming, J.	01-05-015-23 W4M	Upper Scollard	24229.0	23.8	78.0	9.1	30.0	M35377.219254
Gateman, B.E.	01-08-020-24 W4M	Dalehurst Member	23418.0	36.6	120.0	29.0	95.0	M35377.209309
Gerschwindt, F.	NW 10-016-22 W4M	Lower Scollard		39.6	130.0	13.7	45.0	M35377.225369
Goldthorpe, Merv	01-04-019-24 W4M	Dalehurst Member	28174.0	36.6	120.0	13.7	45.0	M35377.209329
Gooch, Dennis	SW 06-019-23 W4M	Dalehurst Member	26724.0	33.5	110.0	30.5	100.0	M35377.209154
Good Eagle, Harry	SE 21-020-21 W4M	Middle Horseshoe Canyon	26481.0	54.9	180.0	13.7	45.0	M35377.172498
Gottenberg Brothers	05-08-017-22 W4M	Lower Scollard	28936.0	58.5	192.0	12.2	40.0	M35377.225038
Graham, D.C.	12-09-017-24 W4M	Dalehurst Member	30089.0	64.0	210.0	33.5	110.0	M35377.225297
Graham, Glen	SW 09-017-24 W4M	Dalehurst Member	27416.0	62.5	205.0	27.4	90.0	M35377.225294
Graham, John & Doug	NW 31-017-23 W4M	Lower Surficial	25560.0	13.7	45.0	0.3	1.0	M35377.225011
Graham, Russell M.	13-30-017-24 W4M	Dalehurst Member	22241.0	13.7	45.0	3.7	12.0	M35377.225340
Groves, K.	12-12-015-23 W4M	Upper Horseshoe Canyon	21864.0	56.4	185.0	16.8	55.0	M35377.219270
Haga Farms	03-01-017-25 W4M	Dalehurst Member	31002.0	31.7	104.0	9.1	30.0	M35377.199140
Hagg, Alex	SW 26-019-19 W4M	Upper Surficial		29.0	95.0	10.7	35.0	M35377.172184
Hagg, Howard	04-04-016-24 W4M	Dalehurst Member	29699.0	59.7	196.0	17.7	58.0	M35377.219329
Hanna, Max	NW 32-016-20 W4M	Lower Horseshoe Canyon	22285.0	51.8	170.0	18.3	60.0	M35377.172029
Hartung, David	NE 10-015-22 W4M	Upper Horseshoe Canyon	26196.0	68.6	225.0	64.0	210.0	M35377.156841
Hartung, Ferdinand	NE 19-016-21 W4M	Middle Horseshoe Canyon	27360.0	68.6	225.0	27.4	90.0	M35377.172046
Helland, Earl	08-31-015-20 W4M	Surficial	23436.0	45.7	150.0	16.5	54.0	M35377.155966
Henrickson, H.	SW 17-017-20 W4M	Lower Surficial	24689.0	74.4	244.0	41.2	135.0	M35377.175227
Henrickson, Maurice	NW 14-017-20 W4M	Surficial	22572.0	16.8	55.0	3.1	10.0	M35377.175219
Hill, Duane	11-15-019-24 W4M	Dalehurst Member	27631.0	18.3	60.0	7.9	26.0	M35377.209376
Hilz, A.	SW 30-017-23 W4M	Haynes	23743.0	52.4	172.0	40.2	132.0	M35377.225006
Holoboff, Joe	02-14-020-22 W4M	Upper Surficial	27606.0	18.3	60.0	2.1	7.0	M35377.209056
Howerton, R.H.	SE 20-016-23 W4M	Haynes	22763.0	34.1	112.0	7.6	25.0	M35377.225458
Hummel, George	NE 08-014-24 W4M	Upper Surficial	26855.0	17.4	57.0	13.7	45.0	M35377.121512
Irwin, Dave	10-29-016-26 W4M	Dalehurst Member	27303.0	21.3	70.0	3.1	10.0	M35377.200277
Jacobson, Norman	16-33-020-23 W4M	Lower Scollard	24813.0	30.5	100.0	21.3	70.0	M35377.209286
Johnson, Cliff	NW 20-019-21 W4M	Surficial	28195.0	45.4	149.0	3.4	11.0	M35377.172304
Johnson, H	08-29-016-24 W4M	Dalehurst Member	27354.0	50.9	167.0	18.3	60.0	M35377.219949
Jones, Jim	04-30-015-19 W4M	Upper Surficial	30979.0	6.7	22.0	2.4	8.0	M35377.155946

WATER WELLS RECOMMENDED FOR FIELD-VERIFICATION THAT MEET CRITERIA (cont.)

Owner	Location	Aquifer Name	Date Water Well Drilled	Completed Depth Metres	Completed Depth Feet	NPWL Metres	NPWL Feet	UID
Junnila, Steve	06-32-016-24 W4M	Dalehurst Member	27-Jun-81	45.11	148.0	30.48	100.0	M35377.219959
Kindree, C.	08-12-021-26 W4M	Dalehurst Member	23-Sep-78	45.72	150.0	4.57	15.0	M35377.180267
Knive, A.J.	NE 34-018-24 W4M	Surficial	01-Dec-61	12.19	40.0	3.35	11.0	M35377.191917
Knive, Roy	NE 34-018-24 W4M	Dalehurst Member	22-May-81	21.33	70.0	7.62	25.0	M35377.191918
Kunkel, Bob	13-18-016-20 W4M	Surficial	16-May-80	50.59	166.0	44.19	145.0	M35377.172003
Ladd, J	13-36-019-22 W4M	Surficial	01-Mar-72	27.43	90.0	7.62	25.0	M35377.209096
Larkins, Alvin L.	NE 26-016-22 W4M	Surficial	05-Jul-67	24.99	82.0	14.32	47.0	M35377.225393
Lebsack, Richard	NW 27-017-25 W4M	Dalehurst Member	15-Apr-75	32	105.0	18.29	60.0	M35377.199402
Love, Frank	04-21-018-23 W4M	Dalehurst Member	26-May-65	27.43	90.0	38.1	125.0	M35377.191818
Maclean, Murray	SE 28-018-23 W4M	Haynes	15-Nov-74	53.34	175.0	41.15	135.0	M35377.191845
Manybears, Julius	SW 19-021-21 W4M	Surficial	27-Jun-84	12.19	40.0	5.91	19.4	M35377.221358
Manybears, Lois	SW 19-021-21 W4M	Surficial	29-Jun-82	9.14	30.0	4.88	16.0	M35377.221359
Marks, John	09-24-017-21 W4M	Upper Horseshoe Canyon	20-Oct-64	34.75	114.0	27.43	90.0	M35377.175276
Matlock Farms	SW 22-015-22 W4M	Surficial	28-Apr-82	64.92	213.0	11.28	37.0	M35377.156882
Mcfadden, Jim	02-18-017-25 W4M	Dalehurst Member	03-Apr-78	54.86	180.0	24.38	80.0	M35377.199225
Mcfarland, Glen	NW 22-013-23 W4M	Upper Surficial	01-Jun-74	13.72	45.0	5.79	19.0	M35377.127047
Mckay, Gordon	02-16-017-22 W4M	Lower Scollard	14-May-77	51.2	168.0	16.46	54.0	M35377.225053
Mcleod, Mel	NW 32-013-24 W4M	Upper Lacombe Member	16-Nov-57	45.72	150.0	19.81	65.0	M35377.127218
Mcleod, Roy	NW 10-014-22 W4M	Upper Horseshoe Canyon	09-Mar-85	25.6	84.0	12.19	40.0	M35377.127415
Mcniven, Dan	NW 32-018-25 W4M	Upper Surficial	05-Jan-58	10.36	34.0	6.1	20.0	M35377.192019
Mcniven, Don	SW 08-019-24 W4M	Dalehurst Member	25-Aug-70	28.35	93.0	7.31	24.0	M35377.209344
Mcniven, J.	08-24-018-25 W4M	Surficial	02-Oct-80	62.79	206.0	44.5	146.0	M35377.191988
Mcniven, J.H.	08-24-018-25 W4M	Surficial	01-Jan-68	42.06	138.0	8.23	27.0	M35377.191987
Middleton, Blaine	10-12-016-25 W4M	Dalehurst Member	21-Mar-78	73.15	240.0	4.57	15.0	M35377.199678
Mix, Duane	15-22-016-22 W4M	Upper Horseshoe Canyon	10-Feb-86	48.77	160.0	11.58	38.0	M35377.225388
Muckalt, H.G.	NE 09-016-24 W4M	Dalehurst Member	21-Sep-76	45.72	150.0	4.88	16.0	M35377.219778
Munton, Stan	12-19-015-21 W4M	Lower Surficial	27-Apr-77	42.67	140.0	40.48	132.8	M35377.156806
Myers, Stuart	SE 01-017-23 W4M	Lower Scollard	14-Jun-71	30.78	101.0	26.82	88.0	M35377.224942
Nelson, Aurthur	SW 07-019-21 W4M	Middle Horseshoe Canyon	19-Aug-65	59.43	195.0	3.66	12.0	M35377.172251
Nelson, Chris	04-22-020-22 W4M	Lower Scollard	28-Oct-76	40.84	134.0	28.95	95.0	M35377.209007
Northcott, J.H.	NW 35-019-21 W4M	Middle Horseshoe Canyon	07-Nov-84	70.1	230.0	29.56	97.0	M35377.172351
Northcott, N.	08-10-018-22 W4M	Upper Horseshoe Canyon	29-Jun-83	33.53	110.0	18.29	60.0	M35377.225091
Papp, John	SW 34-019-21 W4M	Upper Horseshoe Canyon	01-Aug-58	28.35	93.0	12.19	40.0	M35377.172335
Pasolli Brothers	SW 08-016-23 W4M	Haynes	22-Nov-73	24.38	80.0	2.44	8.0	M35377.225433
Paton, Bill	NW 28-017-25 W4M	Dalehurst Member	09-Jul-76	45.72	150.0	16.76	55.0	M35377.229454
Perry, Brian	NE 26-019-25 W4M	Dalehurst Member	22-Oct-65	18.29	60.0	7.62	25.0	M35377.219244
Plytka, S	01-28-015-25 W4M	Surficial	21-Apr-82	16.76	55.0	3.66	12.0	M35377.199267
Pobst, Arnold	05-27-020-23 W4M	Upper Scollard	21-Dec-76	51.81	170.0	41.45	136.0	M35377.209218
Printice, Jim	SE 19-019-20 W4M	Upper Horseshoe Canyon	09-Apr-76	68.58	225.0	27.43	90.0	M35377.172206
Robinson, A.E.	04-30-020-24 W4M	Lower Surficial	12-Nov-77	62.48	205.0	8.26	27.1	M35377.209374
Ruark, Dave	NW 22-018-25 W4M	Upper Lacombe Member	08-Nov-74	73.15	240.0	5.49	18.0	M35377.191982
Ryrie, W.	NE 06-013-24 W4M	Dalehurst Member	17-Feb-88	21.33	70.0	7.62	25.0	M35377.127106
Samaroden, Peter	11-31-019-24 W4M	Dalehurst Member	28-Aug-75	73.15	240.0	24.08	79.0	M35377.209397
Schmidt, Cleo	12-05-017-22 W4M	Surficial	25-Oct-76	35.05	115.0	10.67	35.0	M35377.225033
Sealock, Ken	NW 31-017-20 W4M	Upper Horseshoe Canyon	01-Oct-71	42.67	140.0	19.81	65.0	M35377.175261
Sharp, F.W.	04-19-018-22 W4M	Upper Surficial	01-Jan-64	27.43	90.0	10.67	35.0	M35377.225097
Silbernagel, P.W.	NW 33-017-22 W4M	Upper Horseshoe Canyon	25-Apr-67	44.8	147.0	35.05	115.0	M35377.225069
Steiner, G.D.	04-25-018-25 W4M	Dalehurst Member	24-Jun-83	18.59	61.0	2.13	7.0	M35377.191999
Stokes, Chuck	NW 32-016-20 W4M	Lower Horseshoe Canyon	06-Feb-75	52.73	173.0	19.81	65.0	M35377.172028
Thompson, Arvid	03-04-020-21 W4M	Middle Horseshoe Canyon	20-Nov-85	52.73	173.0	6.1	20.0	M35377.172485
Thompson, Elmer	SW 04-020-21 W4M	Middle Horseshoe Canyon	30-Oct-74	54.86	180.0	6.1	20.0	M35377.172483
Tompkins, Dr. A.D.	08-32-016-24 W4M	Dalehurst Member	20-Nov-74	50.59	166.0	24.38	80.0	M35377.095381
Vaile, Alan	16-16-016-21 W4M	Lower Horseshoe Canyon	31-Jan-81	65.83	216.0	41.45	136.0	M35377.172041
Village of Arrowwood	SW 32-020-23 W4M	Lower Surficial	15-Jul-77	29.56	97.0	15.24	50.0	M35377.209254
Village of Carmangay	05-32-013-23 W4M	Surficial	01-Feb-63	60.96	200.0	-4.27	-14.0	M35377.127069
Visser, Andrew	06-01-015-24 W4M	Haynes		43.89	144.0	10.67	35.0	M35377.219309
Vooys, Leonard	13-26-018-20 W4M	Upper Horseshoe Canyon		31.39	103.0	12.19	40.0	M35377.172108
Ward, G.A.	NW 28-020-23 W4M	Upper Surficial	15-Mar-69	24.38	80.0	7.62	25.0	M35377.209221
White, Terry	SW 03-017-23 W4M	Upper Scollard	29-Oct-62	27.43	90.0	7.62	25.0	M35377.229453
Wickerstrom, Stan	SW 06-018-22 W4M	Upper Scollard	16-Jun-74	50.29	165.0	27.43	90.0	M35377.225088
Wilderman, Wayne	NE 25-018-27 W4M	Dalehurst Member	23-Oct-74	83.82	275.0	8.53	28.0	M35377.192490
Wolfe, Grant	16-10-015-24 W4M	Dalehurst Member	01-Apr-79	27.43	90.0	3.05	10.0	M35377.219417

VULCAN COUNTY-OPERATED WATER WELLS

Owner	Location	Aquifer Name	Date Water Well Drilled	Completed Depth Metres	Completed Depth Feet	NPWL Metres	NPWL Feet	UID
County of Vulcan	SW 30-020-24 W4M	Upper Scollard	08-May-57	65.53	215.0	7.62	25.0	M35377.209369
County of Vulcan	NW 20-019-25 W4M	Lower Lacombe Member		92.65	304.0	10.67	35.0	M35377.219226
County of Vulcan	16-21-015-25 W4M	Lower Surficial	23-Nov-84	19.51	64.0			M35377.199227