Saskatchewan Research Council

Groundwater Resources of the Prelate (72K) area, Saskatchewan

Prepared for Saskatchewan Watershed Authority

by
Harm Maathuis
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SRC Publication No. 11975-1E07

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Saskatchewan Research Council
125 – 15 Innovation Blvd.
Saskatoon, SK   S7N 2X8
Tel: 306-933-5400
Fax: 306-933-7299

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LIST OF ABBREVIATIONS AND SYMBOLS

SRC	Saskatchewan Research Council
SWA	Saskatchewan Watershed Authority
DMR	Department of Mineral Resources
EMR	Energy, Mines and Resources Canada
AAFC	Agriculture and Agri-Food Canada
SIR	Saskatchewan Industry and Resources
PFRA	Prairie Farm Rehabilitation Administration
CDED	Canadian Digital Elevation Data
GIS	Geographic Information System
UTM	Universal Transverse Mercator
SE	Saskatchewan Environment
NTS	National Topographic System

1. INTRODUCTION

1.1 Background

The first inventory and characterization of the groundwater resources in the Prelate NTS map sheet area (72K) dates back to the mid 1930s when the Geological Survey of Canada conducted a rural municipality (RM)-based well inventory in response to the drought of the early 1930s (Mackay *et al.,* 1936). Groundwater resource reports were prepared for each RM which included maps showing surficial and bedrock geology and locations of wells, and water quality data.

David (1964) studied the surficial geology and groundwater resources of the Prelate area. David and Whitaker (1973) published the provincial geology and groundwater resources map for the Prelate area. This map, accompanied by four (4) cross sections, shows the bedrock aquifers but aquifers and aquitard within the drift were undifferentiated.

The 2nd generation geology and groundwater maps for the Prelate NTS map sheet area were published in 1990 (Millard, 1990a). The geological setting of the area is shown in the form of 17 cross sections and maps showing the extent and thickness of the Judith River Formation, Bearpaw Formation sands, Eastend to Cypress Hills formations and Quaternary aquifers.

This report represents the first report in the 3rd generation series of geology and groundwater maps. Building on the 2nd generation maps, the 3rd generation maps are Geographical Information System (GIS)-based and, if sufficient information is available, include descriptions of aquifers in terms of their extent, chemistry, ground water flow, hydraulic properties, well and aquifer yield, usage and vulnerability.

The report has been funded by the Canada-Saskatchewan Water Supply Expansion Program (CSWSEP) of Agriculture and Agri-Food Canada (AAFC), the Saskatchewan Watershed Authority (SWA) and the Saskatchewan Research Council (SRC).

1.2 Objectives

The main objective of the 3rd generation NTS map sheet geology and groundwater resources maps is to provide information on groundwater resources in a GIS environment, accompanied by a report describing the characteristics of aquifers and aquitards. The geology is shown in a set of maps showing bedrock geology and topography, drift thickness, surficial geology, and cross sections. The groundwater resources are shown in cross sections and on various maps showing the extent and thickness of bedrock and Quaternary aquifers. If sufficient information is available for a particular aquifer additional maps such as an aquifer vulnerability index map and maps related to water quality and yield have been be prepared.

1.3 Study area

The Prelate NTS map sheet area (72K) includes Ranges 15 to 30, Townships 12 to 23, West of the 3rd Meridian and covers an area of about 15,792 km^2 (Figure 1). The area is bounded by longitudes 108º 00' and 110º 00', and latitudes 50º 00'and 51º 00'. Figure 1 also shows the Rural Municipalities within the study area.

1.4 Climate

Based on the modified Kőppen classification, the study area has a Steppe climate (dry year-around, cold to warm) (Fung, 1999, p. 95). The climate stations within the study area are shown in Figure 2. This figure also shows the average annual precipitation for the period 1971 - 2000. The average annual precipitation ranges from 314 to 379 mm. Precipitation in the form of snow, as percentage of total annual precipitation, varies from 22% to 29%. Within a year, the highest precipitation occurs during the months May – July.

The annual average temperature varies from 5.4 ± 1.3 ºC (Maple Creek North) to 4.3 ± 1.9 ºC (Golden Prairie) (http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html). The month of January has the coldest temperatures, with an average daily temperature in the -13.1 to -10.4 ºC range. July is the warmest month. The average daily temperature in July ranges from 18.4 to 19.3 ºC.

The average annual lake evaporation is in the to 800 mm range (Phillips, 1990).

1.5 Drainage

Much of the Prelate area is part of the South Saskatchewan River basin except the utmost northeastern portion which is part of the North Saskatchewan river basin (Figure 3). However, large areas of the portion that is part of the South Saskatchewan river basin are internal basins, including the Great Sand Hills area.

1.6 Topography

The topographical setting of the Prelate area is shown in Figure 4, in the form of a digital elevation model. The topographical elevation in the study area ranges from 946 m asl in Range 19, Township 12 to 556 m asl in Range 15, Township 20 (bottom of the South Saskatchewan River Valley).

1.7 Land Use

The land use in the study area is shown in Figure 5. Most of the area is covered by crop land and grass land.

2.0 GEOLOGY AND GROUNDWATER DATA

2.1 Introduction

The principle geology and groundwater data used in this report are:

- stratigraphical and well testhole data
- groundwater level data
- groundwater quality data
- hydraulic properties
- groundwater and surface water allocation and actual use data

These sources of information are briefly discussed in the following sections.

2.2 Geological Data

Subsurface information used in the compilation of the groundwater resources of the Prelate map sheet area, was extracted from the SRC testhole/well database, referred to as "SRC Bores". SRC Bores is a Microsoft Access™ relational database composed of a number of tables linked by a common identification number. These tables include: UTM coordinates, land location description, surface elevation, data type (well, testhole, geotechnical etc.), water levels, water quality, stratigraphy, carbonate analysis, well completion data and others.

The SRC Bores database consists of water well records and testhole information compiled from a variety of sources. The largest number testhole/well records were obtained from the Saskatchewan Watershed Authority (SWA) testhole database. Only SWA records which include both a drillers log and electric log (spontaneous potential and single point resistance) are included in the SRC database. The database also includes subsurface information extracted from reports prepared by geotechnical and groundwater consultants as well as stratigraphic testholes drilled by SRC staff. These records provide an excellent source of subsurface information, collected under the supervision/direction of professional geoscientists.

Well and testhole data in the 72K area were extracted from SRC Bores database and imported into the Geographic Information System (GIS), ArcGIS version 9.1. In total, there were 1,514 individual sites in the Prelate area at which stratigraphic information has been determined. These sites include: 83 SRC testholes, 477 SWA testholes for which an E-log is available and 23 Department of Highway logs. In addition, stratigraphic information for 931 oil exploration holes was entered into the SRC Bores database.

The locations of the testholes are shown in Figure 6. Stratigraphical picks, made by SRC Quaternary geologists, consisted of readily recognized units and stratigraphic picks from previous studies. (*e.g.* sand units, bedrock formations, group breaks, surficial sand deposits, etc.) A total of 4,183 stratigraphic picks made on testholes/wells in the Prelate area were entered into SRC Bores.

2.3 Location Data

The geographic (map) location of a point can be described in terms of the Canada Dominion Land Survey System, Universal Transverse Mercator (UTM) grid coordinates and latitude and longitude. The Canada Dominion Land Survey System describes a location in terms of Quarter-Legal Sub Division- Section-Township-Range-West of Meridian (QTR-LSD-Sec-Tp-Rg-M). A schematic illustration of the Canada Dominion Land Survey System is shown in Figure 7.

The Universal Transverse Mercator (UTM) grid is a 1,000 x 1,000 m grid covering the earth. UTM coordinates can be determined from topographical maps and from land location descriptions, using a conversion program. In recent years, the UTM coordinates of a location can be accurately determined to within a few meters, using handheld Global Positioning System (GPS) equipment. Both UTM and latitude and longitude are used for plotting of locations.

Most of the SWA records were originally reported to the quarter section (accuracy ± 400m). These locations have been confirmed and upgraded by SRC to the quarter legal sub-division level (accuracy ±100m). Based on the quarter legal sub-division land location UTM (NAD83) coordinates were generated for each well/testhole by calculating the centroid of the land location (*i.e.* well locations reported to a legal sub-division (LSD) location, were assigned the UTM point coordinate located at the center of that LSD).

2.4 Maps and Cross Sections

A large number of maps have been prepared using the GIS, including maps showing: location of well/testholes and cross section lines, topography, bedrock geology and topography, surficial geology, drift thickness and various aquifer related maps (depth to, thickness, water level elevation, aquifer vulnerability and water quality). In this report, reduced maps are referred to as figures, to facilitate readability of the report. Different scale maps can be generated using the GIS. In this section an explanation is provides as to how the various maps were prepared.

Ground surface elevation data for the Prelate area (NTS map 72K) were downloaded from the Natural Resources Canada, Geobase website (www.geobase.ca). The Canadian Digital Elevation Data (CDED) consists of an ordered array of ground elevations at regularly spaced intervals. Grids covering the map area were mosaicked using ESRI ArcInfo, to produce a single ESRI grid for the entire map area with a grid cell size of 15 m. A second surface elevation grid with a cell size of 250 m was created from the 15 m ESRI grid. The topographical setting of the study area shown in Figure 4 is based on the 250 m cell size grid.

The bedrock geology map prepared is based on the extent of subcropping bedrock units as defined by earlier SRC bedrock mapping (Millard, 1990a). Millard's map was modified to reflect new stratigraphic information that has become available since 1990. The bedrock surface topography was created by updating the previously bedrock topography map (Millard, 1990a) with new data. The previous bedrock topography contours were combined with the point file of most current bedrock top information using ArcGIS "topo to raster" tool, which creates a correct surface (grid) from point and line data. The grid was generated with a cell size of 250 meters.

The surficial geology for the 72K area was taken from SRC's 1:250,000 scale map "Surficial Geology of the Prelate area (72K), Saskatchewan (Campbell, 1987).

A map showing the thickness of drift was prepared by subtracting the bedrock surface topography grid from the ground surface elevation grid resulting in a grid indicating the thickness of drift throughout the Prelate map area.

Separate maps were prepared for each stratigraphic level at which aquifers or potential aquifers (*i.e.* sands and gravels) occur. The extent of aquifers was determined from cross sections and adjacent testhole information. Aquifer extent maps were prepared for both bedrock and drift aquifers. Bedrock aquifers included Ribstone aquifer, Judith River aquifer, Bearpaw sand aquifers (Outlook, Matador, Demaine, Chruikshank, Ardkeneth, Belenger, Thelma, and Oxarat members), and finally a composite aquifer composed of formations ranging from the Eastend Formation of Late Cretaceous age up to the Cypress Hills Formation of Tertiary age. Due to the relatively consistent nature of the bedrock aquifers with regard to lithology and lateral extent over large areas, it was possible indicate depth to, and thickness, of the bedrock aquifers, with the use of elevation models of grids. The depth to the top of each of the three major bedrock aquifers (Ribstone, Judith River and Eastend – Cypress Hills aquifers) was calculated by preparing grids representing the depth to the aquifer from well/testhole data points. The grids were limited in extent to polygon indicating their spatial extent of the aquifers. Similar grids were also prepared indicating the thickness of these bedrock aquifers.

Drift aquifer maps were prepared differently due to the high degree of lateral and vertical variability of these aquifers. Polygons indicating the spatial extent of each of the aquifers were prepared from the data indicating the location of a particular stratigraphic aquifer. The information relevant to a particular map was extracted from the SRC Bores database and was posted adjacent to the data point. Aquifers maps showing extent, depth to and thickness were prepared for Empress Group, Sutherland Group, Saskatoon Group and "surficial aquifers".

Cross sections represent a quasi three dimensional representation of the geological setting of a particular area. Cross sections were created by selecting wells/testholes from the map showing well/testhole locations and importing this data into AutoCAD. The topography along the cross section was prepared from the Canadian Digital Elevation Data surface elevation grid. The elevations of the various stratigraphic units were plotted along the testhole traces and finally geological correlations connecting similar units were prepared. Stratigraphic correlations and picks were then refined and edited by interpreting and extrapolating stratigraphic data from one well to the next using AutoCAD software. A total of 14 stratigraphic cross sections were prepared (Figure 6, cross sections A-A' to N-N"). The cross sections run roughly parallel and were spaced approximately 15 km apart: seven (7) in a north-south orientation, and seven (7) traversing the study area in an east-west direction. The cross sections have a vertical exaggeration of 20 times. The cross sections are included in Appendix A. This Appendix also includes the cross section log index.

2.5 Groundwater Quality Data

Groundwater quality data were obtained from a variety of sources including:

- SRC's groundwater quality database, including the Rutherford data (Rutherford, 1967)
- SWA water well drillers record database
- groundwater quality records in the Saskatchewan Environment (SE) database
- groundwater quality data collected as part of SWA's Rural Water Quality Advisory Program (RWQAP)
- groundwater quality data contained in consultant reports
- other sources (*e.g.* Maathuis, 2006)

Within the Prelate map sheet area there are 573 water quality data are available for 526 well sites. Figure 8 shows the locations of the sites for which there are groundwater quality data. The distribution of the depth of wells for which water quality data are available is shown in Figure 9. The majority of wells (58%) for which water quality data are available are less than 30 m deep.

The term Total Dissolved Solids (TDS) is used throughout this report to denote the sum of the concentrations of the dissolved major ions. It is the sum of the following constituents: Ca, Mg, Na, K, Fe, Mn, CO_3, HCO_3, SO_4, Cl, and NO_3 (Saskatchewan Environment, 2006).

In as much as possible, a chemical analysis has been related to the formation and/or aquifer from which the water sample was taken. The database of the Geological Survey of Canada Open File report included information on the source of the water sample. No changes were made to this information.

2.6 Groundwater and Surface Water Withdrawal Data

Groundwater and surface water withdrawal allocation data were obtained from the Operations Division of the Saskatchewan Watershed Authority. The total volume of allocated withdrawals is 4,601.4 dam^3/a. Table 1 provides a breakdown of allocations by purpose and formation from which the water is withdrawn. The locations of groundwater withdrawals are shown in Figure 10.

Table 1 Groundwater allocations in the Prelate area

Purpose	Formation	Allocation (dam^3/a)
Water supply enhanced oil recovery	Judith	883
	Mannville	3,766
	Jurassic/Roseray	883
Municipal	Glacial	1,243
	Judith	43
Industrial (process water)	Glacial	80
	Judith	27
Intensive live stock	Bearpaw	33
	Judith	12
Irrigation	Glacial	198
TOTAL		**7,168**

In Table 2, a summary is provided of the surface allocations and diversions by purpose. Allocation refers to the allowable consumptive volume whereas diversion includes an assigned net annual evaporation loss. Wetland/wild life projects do not use water but are assigned a diversion volume.

Table 2 Surface water allocations and diversions in the Prelate area

Purpose	Allocation (dam^3/a)	Net evaporation loss (dam^3/a)	Diversion (dam^3/a)
Irrigation	34,292	451	34,743
municipal	793	136	929
Industrial (intensive livestock, oil recovery	323	4	327
Other (recreation, wild life)	0	12,008	12,008
Domestic	682	1,204	1,886
Totals	**36,090**	**13,803**	**49,893**

As is evident from Tables 1 and 2, the surface water allocations/diversions are significantly higher than the allocated groundwater withdrawals. Most of the surface water diversions are for irrigation purposes. The locations of surface water diversions are shown in Figure 11.

The Sedimentary Geodata Branch of Saskatchewan Industry and Resources maintains a database of groundwater withdrawals by the oil industry for enhanced oil recovery. For source wells, information is available for active, non-active and abandoned wells. The term active applied to wells used in the past or which are currently pumped. Non-active wells are wells from which pumping has been suspended but which can be taken in production again. Abandoned wells are decommissioned wells. The locations of the active wells are shown in Figure 12.

2.7 Well Yield and Hydraulic Properties

The yield of an individual well depends on a number of hydraulic parameters including hydraulic conductivity and transmissivity of the aquifer, the thickness and vertical hydraulic conductivity of aquitards, the storage coefficient (semi-confined aquifers) or specific yield (unconfined aquifers), the available drawdown and, to a limited extend, the well/screen diameter. Definitions of the hydraulic parameters can be found in Kruseman and de Ridder (1990).

The hydraulic properties are determined by conducting pumping test. However, tests conducted typically are short-duration tests (24 – 48 hrs), and at best, yield values for the transmissivity and storativity of the aquifer. Such tests do not yield any information on the hydraulic properties of aquitards.

The hydraulic properties of aquitards in the Prelate area can only be estimated based on published information. Tables 3 and 4 provide a listing of reported hydraulic conductivities for Cretaceous silts and clays and tills in Saskatchewan.

Table 3 Hydraulic conductivities of Cretaceous silts and clays

Unit	Hydraulic Conductivity m/s	Method	Reference
Bearpaw Formation (Saskatchewan)	3×10^{-8} - 3×10^{-12}	unknown	Peterson (1954)
Pierre Shale (Saskatchewan)	1.2×10^{-12} (K_h)	slug test	van der Kamp *et al.* (1986)
Lea Park Formation (Saskatchewan)	2.5×10^{-10} - 1.3×10^{-11} (K_v) 7.6×10^{-12} - 3.8×10^{-12} (K_h) 3.8×10^{-10} (K_v)	permeameter permeameter consolidation	Misfeldt (1988)

Source; Maathuis and Thorleifson, 2000

It is noted that all the values quoted above pertain to small-scale tests. Information on the bulk vertical hydraulic conductivity of the Cretaceous silts and clays is not available.

Information on the hydraulic conductivity of tills in the Prelate area is not available. Table 4 provides a summary of available information on the hydraulic conductivity of tills in Saskatchewan.

Table 4 Hydraulic conductivity of tills in Saskatchewan

Site	Formation	Hydraulic conductivity (m/s)	References
Warman	Sutherland till - unfractured	10^{-10} - 10^{-11}	Keller *et al.* (1987, 1988, 1989), Fortin *et al.* (1991), Remenda *et al.* (1996)
Dalmeny	Floral till, fractured	5×10^{-9}	
	Floral till, bulk	3.2×10^{-10}	
Birsay	Battleford till (?), unfractured	5.4×10^{-11} - 2.7×10^{-11}	Shaw and Hendry (1998)

Source: Maathuis and Thorleifson, 2000

The theoretical yield of a well completed in a semi-confined aquifer can by estimated by considering the steady-state drawdown model for an aquifer with leakage through an overlying aquitard (*e.g.* Kruseman and de Ridder, 1990):

$$s = \frac{Q}{2\pi T} K_0 (\frac{r}{L}) \qquad [1]$$

where:

s = drawdown (meters)
Q = pumping rate (m3/day)
r = distance from well (meters)
T = transmissivity of the aquifer (m2/day)
$L =$ $\sqrt{Tc}$ = leakage length (meters)
$c =$ b'/K_v = vertical resistance (days)
b' = thickness of the overlying aquitard (meters)
$K_v =$ vertical hydraulic conductivity of aquitard (m/day)
K0 = modified Bessel function of the second kind and zero order

It is noted that equation [1] assumes that the aquifer is homogeneous, infinite in extent over the distance to which the drawdown extends and that the well is screened across the entire thickness of the aquifer. For a given pumping rate, equation [1] can also be used to determine the extent of the drawdown cone. The extent of the drawdown cone can also be estimated using the leakage length: at a distance r = 3L the drawdown is negligible small compared to the drawdown at the well (*e.g.* Maathuis van der Kamp, 2006).

2.8 Water Level Data

Long-term water level records in the Prelate area are available for only one provincial ground water level observation well; SWA Verlo (Figure 13).

Details for this observation wells can be found in Maathuis *et al.* (2001) and on the SWA website. (http://www.swa.ca/WaterManagement/Groundwater.asp?type=ObservationWells)

A point-water level (depth to water) measurement was commonly obtained at the time of the construction of a well. These depths to water measurements are included in the SWA water well driller record database and can be converted into water level elevation by subtracting the depth to water from the surface elevation. For any particular aquifer, the reported point-water level elevation data may span a time period of decades and the reliability of the depth to water measurements can be highly variable. Nevertheless, the point-water level data may provide an insight in general groundwater flow directions.

2.9 Aquifer Vulnerability Mapping

2.9.1 Introduction

Protecting of the quality of groundwater from contamination is increasingly becoming a priority throughout the world as remediation of polluted groundwater and development of clean-up technologies is highly expensive.

Vulnerability can be defined as follows:

> *Intrinsic (or natural) vulnerability is the vulnerability solely dependent on the characteristics of an aquifer and the overlying soil and geological materials. It differs from the specific (or integrated) vulnerability in that the latter includes the potential impact(s) of specific land uses or contaminants (Vrba and Zaporozec, 1994).*

There are a number of aquifer vulnerability methods including DRASTIC (Aller *et al.*, 1987), GOD (Foster, 1987), DAT (Ross *et al.*, 2004) and AVI (Van Stempvoort *et al.*, 1992, 1993). These methods vary in the type and number of variables needed to derive at a vulnerability value and each method has its advantages and disadvantages. Consequently, interpretation of vulnerability maps requires an understanding of what they are based on. Typically, in terms of land use management, regional scale aquifer vulnerability maps are useful for initial screening of areas of interest. Local, and more detailed, studies are required to assess the potential impact on groundwater of a specific land use.

The **A**quifer **V**ulnerability **I**ndex (AVI) method (see section 2.9.2) was developed in Saskatchewan and has been used in this report. It has been applied to areas along the Alberta and Manitoba borders (Grove and Androsoff, 1994 and 1995), the Rosetown NTS map sheet area (Van Stempvoort, 1995), and in the Yorkton area (Maathuis and Simpson, 2006).

2.9.2 Aquifer Vulnerability Index (AVI)

The AVI method assumes that the contaminant source is placed at the ground surface and is based on two parameters:

- the thickness D of the confining layer above an aquifer
- the vertical hydraulic conductivity K_v of the confining layer

These two parameters can be combined into a single factor, referred to as the hydraulic resistance (*e.g.* Kruseman and de Ridder, 1990):

$$c = \frac{D}{K_v} \qquad [2]$$

where: c = vertical hydraulic resistance (time), D = thickness of aquitard overlying aquifer, Kv is the vertical hydraulic conductivity (length/time). The vertical resistance is commonly expressed in days or years.

The hydraulic resistance characterizes the resistance of an aquitard to vertical flow, either upward or downward. While it has the dimension of Time, it does not represent the travel time of water or contaminants. The time for water to flow through a confining layer further depends on the porosity and vertical hydraulic gradient. Additional factors such as diffusion, density, decay and sorption will have to be taken into account when considering migration of a contaminant.

For a sequence of layers, the total resistance to flow becomes the sum of the c values of individual layers:

$$c_T = \sum_{i=1}^{n} D_i / K_{v_i} \qquad [3]$$

where: c_T = total vertical resistance (time)
D_i = thickness of layer i (length)
K_{v_i} = vertical hydraulic conductivity of layer i
n = number of layers

For the purpose of calculating a c value Van Stempvoort et al. (1992) used approximate mean hydraulic conductivity values are listed in Table 5.

Table 5 Hydraulic conductivity estimates for various sediments in the Canadian Prairies

Sediment type	Standard Code	Hydraulic Conductivity (m/day)
Gravel	A	1000 *
Sand	B	10 *
Silty sand	C	1 *
Silt	D	10-1 *
Fractured till, clay or shale (0 to 5 m from ground surface)	E	10-3 **
Fractured till, clay or shale (10 to 15 m from ground surface)	F	10-4 *
Fractured till, clay or shale (10 m from ground surface, but weathered based on colour)	F	10-4 *
Massive till or mixed sand-silt-clay	G	10-5 *
Massive clay or shale	H	10-6 *

* estimate based on Freeze and Cherry (1979)
** estimate based on Keller *et al.,* 1988

To facilitate plotting and contouring of the hydraulic resistance data, the AVI has been defined as:

$$\text{AVI} = {}^{10}\text{Log}\,(c) \qquad [5]$$

The standard codes in Table 5 have no physical meaning and are used only in spreadsheets to facility calculation on the AVI value.

The relationship between the AVI and hydraulic resistance is shown in Table 6.

Table 6 Relationship between aquifer vulnerability index (AVI) and hydraulic resistance

Hydraulic Resistance (years)	Log (hydraulic resistance)	Vulnerability Index (AVI)
0 to 10	< 1	extremely high
10 to 100	1 to 2	high
100 to 1,000	2 to 3	moderate
1,000 to 10,000	2 to 4	low
> 10,000	> 4	extremely low

The AVI method as originally used considered the nearest-to surface aquifers and therefore, does not distinguish between surficial, intertill and bedrock aquifers. An aquifer was defined as any gravel, sand or silty sand greater than 0.6 m thick and deeper than 5 m below ground surface. When the upper 10 m of the aquitard consists of till, the AVI method assumes a decreasing fracture permeability: in the 0 - 5 and 5 - 10 m intervals. Tills below a depth of 10 m are assigned a vertical hydraulic conductivity of 10^{-5} m/d (about 1 x 10^{-10} m/s). This hydraulic conductivity may be an order of magnitude lower than the actual vertical hydraulic conductivity since fracture permeability may extend deeper than 10 m (e.g. Keller *et al.*, 1989). Consequently, this assumption may overestimate the hydraulic resistance and may result in higher than "real" AVI's.

Maps showing contoured AVI values based on the original concept of nearest-to surface aquifers are of no value with respect to determining the aquifer vulnerability of regional aquifers as they use AVI values for various, rather than specific, aquifers. Consequently, in this report an aquifer-based approach was used. Furthermore, AVI point values were calculated rather than grid-based values. The number of AVI values for a particular aquifer varies as it is dependent on the number of testholes available. However, based on the hydrogeological setting of the aquifer this report provides general comments on the susceptibility of individual aquifer to contamination from the ground surface.

3.0 DEFINITIONS

3.1 Aquifer and Aquitard

An aquifer is a saturated geologic unit that is permeable enough to transmit significant quantities of water under ordinary hydraulic gradients, or as the term is commonly used in the water-well industry: an aquifer is a saturated geologic unit that is permeable enough to yield economic quantities of water to wells (*e.g.* Freeze and Cherry, 1979; Kruseman and de Ridder, 1990). Aquifers can be part of a geological formation, the entire formation or group of formations.

An aquitard is a saturated geologic unit which is permeable enough to transmit water in significant quantities when viewed over large areas and long periods, but does not yield economic quantities of water to wells (Kruseman and de Ridder, 1990).

3.2 Unconfined and Semi-confined Aquifer

An unconfined aquifer, or water-table aquifer, is an aquifer bounded at the bottom by an aquitard and at the top by the water table. A semi-confined, or leaky aquifer, is an aquifer bounded at the top and bottom by aquitards. Typically, semi-confined aquifers occur at depth, whereas unconfined aquifers are near the ground surface. However, near discharge areas semi-confined aquifer may become unconfined, *i.e.* the water table can occur within the permeable formation below the overlying aquitard.

3.3 Base of Groundwater Exploration

The base of exploration is commonly defined as the depth below which it is uneconomical to explore for groundwater because of drilling cost and/or the water at that depth is too highly mineralized (TDS> 4,000 mg/L) for the intended use (*e.g.* David and Whitaker, 1973).

3.4 Recharge and Discharge

The term recharge refers commonly refers to recharge to the water table. It originates directly from precipitation, or surface water bodies, infiltrates into the ground surface and moves downward to become part of the saturated groundwater system. Groundwater discharge is the amount or rate of water that leaves the groundwater system, either by flow to surface water, discharge onto the ground surface in the form of springs or seeps, or by (evapo) transpiration. Recharge to, and discharge from, semi-confined aquifers is through the over- and underlying aquitards.

In the semi-arid Prairies, recharge to the water table and recharge to shallow semi-confined aquifers is limited by the amount of precipitation. The low hydraulic conductivity of thick aquitards is the factor limiting replenishment of deep semi-confined aquifers (Maathuis and van der Kamp, 1986; van der Kamp and Maathuis, 1991).

3.5 Groundwater Flow

Groundwater flow in aquifers is generally horizontal. In aquitards flow is either vertically upward or downward, provided that the thickness of the aquitard is small compared to its lateral extent. Flow in aquifers is controlled by gravity: it flows from areas with high water levels to area with lower water levels. The direction of groundwater flow in large-scale regional aquifers is controlled by the large-scale topographical setting and the flow in smaller scale aquifers is determined by the "local" topography.

3.6 Sustainable Well and Sustainable Aquifer Yield

Any groundwater development necessarily changes the pre-existing groundwater regime. As stated by Theis (1940): *"Under natural conditions, previous to development by wells, aquifers are in a state of approximate dynamic equilibrium. Discharge by wells is thus a new discharge superimposed upon a stable system, and it must be balanced by an increase in recharge of the aquifer, or by a decrease in the old discharge, or by loss of storage in the aquifer, or by a combination of these"*. Once a new steady-state has been reached, the discharge by wells comes from an increase in recharge and decrease in discharge.

A groundwater development can be considered sustainable if it does not result in unacceptable environmental, economic, or social consequences for the future (*e.g.* Alley *et al.*, 1999; Alley and Leaky, 2004). Unacceptable consequences are often a small number of specific constraints. A typical constraint is that the drawdown in the pumping well should not exceed 70% of the available drawdown; that the base flow to a stream needs to be maintained during a drought or that there are no undesirable changes in the quality of the water from the pumping well. The dynamic response of the groundwater system is important in arriving at a sustainable yield (Bredehoeft, 2002). Furthermore, the sustainable yield of a well or aquifer can not be determined without explicitly stating the constraints on which it is based, and a time component may have to be included. The sustainable well or aquifer yield is not a fixed value as physical parameters may change over time. For example: changes in land use activities, climate variability and climate change will over time impact the hydrologic cycle (Alley and Leake, 2004; Sophocleous, 2004). Furthermore, the way society views and values water and the environment are subject to change over time.

Prediction of the response of a well or aquifer development depends on the observed behavior of the groundwater flow system as a whole. As a result of the complexity of the hydrogeological settings, the limited availability, if at all, of only short-term pumping test data and absence of constraints it is not possible to determine sustainable well or aquifer yields.

4. GEOLOGY

4.1 Introduction

For mapping purposes the top of the Mannville Group was taken as the lowest stratigraphical unit to be considered in this study. The stratigraphy and lithology of the formations between the ground surface and the Mannville Group is shown in Figure 14. Because of its complexity, the nomenclature of the Cretaceous sediments in western Saskatchewan is also shown in Figure 15.

The term bedrock applies to pre-Quaternary sediments. All the materials between bedrock and the ground surface are collectively referred to as “drift”.

4.2 Bedrock Geology

4.2.1 Mannville Group

The Mannville Group occurs throughout the Western Sedimentary basin. The Mannville Group in southern Saskatchewan has been described by Christopher (1984). The Group consists of various sand, silts and clays units. The Mannville Group is too deep to be shown on the cross sections presented in this report.

4.2.2 Colorado Group, Milk River Formation, Lea Park Formation and Ribstone Creek Tongue

The Mannville Group is overlain by a sequence of overconsolidated marine clays and silts of the Colorado Group, Milk River Formation and the Lea Park Formation. The Colorado Group can only be differentiated from the Milk River Formation using the difference in gamma log characteristics between the two units. On cross sections these units are combined. The Eagle Shoulder is a regional marker bed, marking the top of the Milk River Formation. The silts and clays between the Eagle Creek Shoulder and bottom of the Judith River Formation form the Lea Park Formation. On older geology maps this unit is also referred to as the Claggett (Pakowki) Formation (Whitaker, 1976). Where present beneath the main body of the Judith River Formation, the Ribstone Creek Tongue is separated from the main body by the Grizzly Bear Tongue of the Lea Park Formation (see Figure 15). There are no testholes in the Prelate area which provide a description of the sediments of the Ribstone Creek Tongue. The Ribstone Creek Tongue elsewhere is described as consisting of non-calcareous, very fine to fine grained sand, friable to very hard, locally with a clayey matrix and non-calcareous clays and silts (Maathuis and Simpson, 2002). Within the Ribstone Creek Tongue the thickness of the sand unit(s) may vary locally. The Grizzly Bear Tongue is composed of non-calcareous marine silts and clays.

4.2.3 Judith River Formation

The Late Cretaceous Judith River Formation, also referred to as the Belly River Formation, is an eastward thinning sedimentary wedge.

The Judith River Formation is composed of non-marine and marine, multi-colored, sands (very fine to medium-grained), silts and clays, with carbonaceous and concretionary zones, deposited in a deltaic environment (McLean, 1971). The deltaic environment is a composite environment including alluvial, lacustrine, aeolian, lagoonal, swamp, beach and marine environments. The lower part of the Judith River Formation was deposited in a more marine environment whereas the upper portion represents a more continental depositional environment (Dawson *et al.*, 1994) Typically, individual units are heterogeneous, rarely are greater than 3 to 5 m thick and laterally can only be followed over a few kilometers (McLean, 1971).

Tongues splitting of from the top of the main body of the Judith River Formation are included in the Bearpaw Formation (see section 4.2.4), whereas the tongues splitting from the bottom of the main body are part of the Judith River Formation (see Figure 15).

4.2.4 Bearpaw Formation

In central Saskatchewan the sand tongues splitting off from the top of the main body of the Judith River Formations have been named and described by Caldwell (1968). The sand members are, in ascending order, named: Outlook Member, Matador Member, Demaine Member, Ardkenneth Member and Cruikshank Member. These sand members are separated by silt and clay members of the Bearpaw Formation (see Figure 14).

Within the Prelate area, additional sand members have been identified. These are stratigraphically higher than the Cruikshank Member and have been named the Oxarart, Belanger and Thelma units (Lomenda, 1973). Whitaker (1976) and Millard (1990b) identified these units in cross sections but spelled them differently than Lomenda (1973).

The thickness of the Bearpaw Formation ranges from zero (0) m where absent to 410 m in the southeastern part of the Prelate area.

4.2.5 Eastend to Ravenscrag Formations

When the sea retreated from Saskatchewan during the Late Cretaceous, non-marine sands and silts were deposited in an advancing delta and in the following alluvial deltaic plain (Whitaker *et al.*, 1978).

The Eastend Formation is composed of grayish and greenish sand, silt and clay, with thin coal seams in the upper part. The Whitemud is composed of kaolinitized, white sand and clay, separated by a carbonaceous zone and overlain by purplish shale of the Battle Formation. The Frenchman Formation is composed of sand and clays. Since the Eastend, Whitemud and Frenchman formations can not be separated in geophysical logs Whitaker *et al.* (1978, p. 24) combined these units in the Frenchman Formation. The Ravenscrag Formation is comprised of sands, silts, clays and coals. As there is no credible mappable contact between the Frenchman Formation and the overlying Ravenscrag Formation, Christiansen (1983) lumped all formations between the top of the Bearpaw Formation and the top of the Ravenscrag Formation into a single unit, referred to as the Eastend to Ravenscrag formations unit.

4.2.6 Swift Current Creek Beds and Cypress Hills Formation

The Eastend to Ravenscrag formations are overlain by a sequence of Tertiary sediments including, in ascending order: the Swift Current Creek Beds and the Cypress Hills Formation.

Whether or not the Swift Current Creek beds are present in the study area is not known as this unit is only known from a few outcrops southeast of Swift Current. The unit consists of sands and gravels which locally are clayey and silty. The unit is indistinguishable lithologically from the overlying sediments of the Cypress Hills Formation and therefore, is included in the latter Formation (Vonhof, 1965a; Whitaker *et al.*, 1978).

The Tertiary Cypress Hills Formation is composed of conglomerate, gravel, sand and silt (Vonhof, 1965a, b; Vonhof, 1969). Leckie and Cheel (1989) interpreted the Formation as a braidplain deposit and provided a history of the deposition. It unconformably overlies the Ravenscrag Formation (or Eastend to Ravenscrag formations), or directly overlies the Bearpaw Formation.

Since it is difficult to separate the Swift Current Creek Beds and Cypress Hills Formation from the underlying Eastend to Ravenscrag unit, the entire sequence of Eastend to Cypress Hills formations has been mapped as a single unit. For simplicity, this unit is referred to as the Eastend –Cypress Hills unit.

4.2.7 Bedrock Surface Geology and Topography

The distribution of bedrock units outcropping at the bedrock surface is shown in Figure 16. The distribution is a function of the bedrock units in the Western Sedimentary basin gently sloping upward from south to north and preglacial, glacial and fluvial erosion.

The bedrock topography is shown in Figure 17. The highest bedrock elevation (920 m asl) is found in the southeastern part of the Prelate area where the Cypress Hills Formation is present. The lowest bedrock elevation 470 m asl) occurs in the northern part of the area and is associated with the Tyner Valley aquifer.

4.3 Quaternary Geology

4.3.1 Quaternary Stratigraphy

The "drift" can be separated into the Empress Group, Sutherland and Saskatoon groups and their formations and subdivisions (Figure 18). Drift consists of till and stratified deposits. Till is an unsorted and unstratified material deposited directly by the glaciers and is comprised of a mixture of clay, silt, sand, gravel and boulders. Stratified drift consists of sand, gravel, silt and clay deposited by water. Tills can be differentiated on the basis of carbonate content, weathering zones, single-point electrical resistance, preconsolidation pressures and stratigraphic position.

The Empress Group is composed of sand, gravel, silt and clay of fluvial, lacustrine and colluvial origin that overlies Cretaceous bedrock and non-marine Tertiary bedrock and underlies till of Quaternary age (Whitaker and Christiansen, 1972). In preglacial valleys, the Empress Group may include a preglacial unit identified by the presence of quartzite and chert gravel and the absence of carbonate and shield-derived material. The upper sands and gravels are of glacial origin and contain igneous, metamorphic and carbonate fragments (Christiansen, 1992).

The Sutherland Group, originally described by Christiansen (1968a), is defined as the drift between the Empress Group and Saskatoon Group or the drift between bedrock and the Saskatoon Group Christiansen, 1992). The Sutherland Group has been further subdivided, in ascending order, into the Mennon, Dundurn and Warman formations (Christiansen, 1992).

The Saskatoon Group includes, in ascending order: Floral and Battleford formations and surficial stratified deposits. The Floral and Battleford formations were initially described by Christiansen (1968a, b). Christiansen (1992) subdivided the Floral Formation into a lower and upper till, separated by the Riddell Member (stratified sands). The term surficial stratified deposits are an informal name for deglacial lacustrine, outwash, ice-content and post glacial alluvium and eolian sediments between the Battleford Formation and the present land surface Christiansen (1992).

Although throughout much of the Prelate area the Sutherland and Saskatoon groups can be identified, there is insufficient information to identify the formations within these groups.

The history of deglaciation of the Prelate area was described by Christiansen (1979). The area was ice free about 14,000 years ago (Christiansen, 1979; Fig. 13).

4.3.2 Drift Thickness

In Figure 19, the thickness of the drift is shown. The drift ranges in thickness from zero (0) meters in the southeast to 251 m in Tp 23, Rg 22 (Sec 28).

4.4 Identification of Principal Aquifers and Aquitards

The major bedrock aquifers in the Prelate area are, in ascending order: Mannville aquifer, Milk River aquifer, Ribstone Creek aquifer, Judith River aquifer, Bearpaw sand aquifers and the Eastend – Cypress Hills aquifer. Major aquitards are the silts and clays of the Lea Park and Bearpaw formations (Figure 14). Empress Group sediments, stratified deposits within the Sutherland and Saskatoon groups and surficial sands form Quaternary aquifers. Quaternary aquitards are formed by till units (Figure 18).

5.0 HYDROGEOLOGY OF BEDROCK AQUIFERS

5.1 Introduction

The major bedrock aquifers in the Prelate area are, in ascending order: Mannville aquifer, River, Ribstone Creek aquifer, Judith River aquifer, Bearpaw sand aquifers and the Eastend – Cypress Hills aquifer.

5.2 Mannville Group and Milk River Aquifers

5.2.1 Mannville Group Aquifer

Sediments of the Mannville Group form a major bedrock aquifer through most of the Western Sedimentary basin (Maathuis and Thorleifson, 2000). Within the Prelate area it occurs at great depths and only has been used by the oil industry for enhanced oil recovery (Table 7).

Table 7 Groundwater withdrawals from the Mannville Group aquifer for enhanced oil recovery

Land location	Period of withdrawals	Annual volume withdrawn		Total volume withdrawn	Highest annual withdrawal rate	
		Min (m^3)	Max (m^3)	m^3	m^3/day	L/s
Active						
02-10-17-16-W3	1964 - 1999	3,160	243,056	3,622,078	666	7.71
02-34-16-19-W3	1970 - 1997	8,910	298,353	4,419,449	817	9.46
03-14-15-19-W3	1967 - 1996	8,512	157,408	2,721,260	431	4.99
03-17-15-18-W3	2004 - 2005	10,497	10,966	21,463	30	0.35
03-20-15-15-W3	1984 - 1993	307	7,327	28,877	20	0.23
03-24-15-19-W3	1967 - 1978	217	60,340	160,022	165	1.91
04-23-16-17-W3	1996 - 1999	9	224,809	398,629	616	7.13
04-26-17-16-W3	1984 - 2005	9,155	91,285	714,647	250	2.89
05-10-17-18-W3	1967 - 1996	19	40,372	405,986	111	1.28
05-21-18-17-W3	2003 - 2005	11,441	198,866	383,304	545	6.31
07-12-17-18-W3	1963 - 1984	8,225	291,756	3,015,989	799	9.25
07-15-17-18-W3	2000 - 2001	13,741	35,644	71,119	98	1.13
07-21-18-17-W3	2000 - 2005	6,790	326,357	1,155,292	894	10.35
08-21-18-17-W3	2001 - 2005	17,764	281,903	924,508	772	8.94
08-26-18-17-W3	1978 - 2005	7,913	119,475	1,042,020	327	3.79
09-12-15-19-W3	1966 - 2005	4,406	147,206	999,227	403	4.67
09-28-16-16-W3	1990 - 2005	8,009	57,593	585,500	158	1.83
10-03-17-19-W3	1987 - 2005	2,783	169,037	1,154,334	463	5.36
10-31-15-18-W3	1998 - 1999	1,978	36,410	38,388	100	1.15
11-09-16-16-W3	1975 - 2001	7,262	146,408	2,317,042	401	4.64
11-33-14-19-W3	1994 - 2005	699	52,680	284,816	144	1.67
12-02-17-18-W3	2005		43,814	43,814	120	1.39
12-25-18-17-W3	1966 - 2005	170	125,850	2,166,851	345	3.99
13-09-15-18-W3	1996 - 1998	3,977	20,554	45,084	56	0.65
15-34-14-19-W3	1973 - 2002	2,071	20,292	206,783	56	0.64
16-24-18-17-W3	1988 - 2005	817	75,538	361,051	207	2.40

Land location	Period of withdrawals	Annual volume withdrawn		Total volume withdrawn	Highest annual withdrawal rate	
		Min (m^3)	Max (m^3)	m^3	m^3/day	L/s
Non-Active						
07-29-18-17-W3	1973 - 1978	921	15,743	58,625	43	0.50
13-29-14-18-W3	1996 - 1998	10,233	52,044	94,041	143	1.65
16-02-17-18-W3	1965 - 1970	11,330	128,862	424,875	353	4.09
15-03-17-18-W3	1959 - 1966	13,381	83,611	430,546	229	2.65
Total	**1959 - 2005**			**24,673,541**		

Based on the maximum reported annual withdrawals, well yields varied between 20 and 894 m^3/day (0.235 – 10.35 L/s). The reported maximum pumping rate from a source well is 45,150 m^3 (about 1,600 m^3/day). Since 1959, a total volume of about 24,674 dam^3 has been withdrawn from the aquifer. The impact of this pumping on water levels in the Mannville cannot be assessed as there are no long-term water level records available. The Mannville aquifer is a semi-confined aquifer, overlain by a thick sequence of presumably low permeable silts and clays of the Colorado Group and the Lea Park Formation. Therefore, pumping from this aquifer will result in drawdowns extending over large distances.

5.3 Ribstone Creek Aquifer

The extent of the Ribstone Creek Tongue in Saskatchewan and Alberta is shown in Figure 20.

The Ribstone Creek aquifer is defined as the aquifer formed by the sand/sandstone units of the Ribstone Creek Tongue (Maathuis and Simpson, 2002). In the Prelate area the Ribstone Creek Tongue occurs at depths ranging from 65 (T23, Rg 29) to 557 m (Tp 12, Rg 18) below the ground surface (Figure 21).

The thickness of the Tongue ranges between zero (0) and 52 m but typically is between 10 and 20 meters thick (Figure 22). The thickness of the Ribstone Creek aquifer will be less of that of the Tongue since the sands and sandstones only comprise part of the sediments of the Tongue. The Ribstone Creek aquifer is separated from the overlying Judith River aquifer by 20 to 60 meters of silts and clays of the Grizzly Bear Tongue (Lea Park Formation). The Ribstone Creek aquifer is a semi-confined aquifer. Under steady-state pumping conditions the yield of a well completed in the aquifer will come from the overlying Judith River aquifer, through the aquitard formed by the Grizzly Bear Tongue. Maathuis and Simpson (2002) summarized reported transmissivities and hydraulic conductivities for the aquifer. The hydraulic conductivity ranges from less than one to several meters/day, resulting in low transmissivities of the aquifer. Pumping from this aquifer will result in drawdowns extending over tens of kilometers.

There are no reported withdrawals from the Ribstone Creek aquifer in the Prelate area.

The four (4) available water quality data for the Ribstone Creek aquifer are provided in Table 8. The data, all obtained from drill stem tests, indicate a sodium-chloride (Na-Cl) type of water with a TDS in the 1,875 – 10,625 mg/L range at three (3) sites. A drill stem test conducted at 14-21-21-28-W3 yielded a calcium-sulfate type of water with a TDS of 2,075 mg/L.

5.4 Judith River Aquifer

5.4.1 Definition and Extent of the Judith River Aquifer

The extent of the Judith River Formation (and its equivalents in Alberta) is shown in Figure 23. The Formation extends southwards into the United States where it outcrops at the ground surface in Montana.

It also extends westward and outcrops at the ground surface in southern Alberta. The aquifer formed by sediments of the Judith River Formation is referred to as the Judith River aquifer. The groundwater resources of the Judith River Formation in southwestern Saskatchewan were discussed by Whitaker (1980; 1982a, b).

The extent and depth to the top of the Judith River Formation is shown in Figure 24. In the northern part of the Prelate area and in Range 25 the Judith River Formation is absent. In these areas it was removed by preglacial fluvial erosion. The Judith River Formation occurs at depths below ground surface ranging from 34 m to 418 m. The depth to the top is the greatest in the southeast (Tp 12, Rg 16 -18). The depth to the top of the formation is also an indication of the thickness of the aquitard confining the Judith River aquifer. As is shown in the cross sections, the overlying aquitard is either entirely composed of drift, mainly till, or also includes the silts and clays of the Bearpaw Formation.

The thickness of the Judith River Formation is shown in Figure 25. The point thickness ranges from zero (0) along the erosional edge to 136 m in the south-central portion of the Prelate area (Tp 15, Rg 21).

The Judith River Formation is a highly complex geological unit which for one-half of it thickness is composed of silts and clays. Sand units within the Formation are not thicker than 15 m and commonly are only a few meters. It is difficult to trace individual sand layers, and silt and clay beds, over distance more than a few kilometers. However, under pumping conditions the entire formation will, in complex ways, act as a single hydrogeological (hydrostratigraphical) unit because of interactions between sand units. Therefore, it is justified to consider the entire formation as the Judith River aquifer. Whitaker (1982) combined the Judith River aquifer the aquifers formed by the Outlook and Matador members of the Bearpaw Formation into one hydrogeological unit as these two units are hydraulically connected to the Judith River aquifer. In the Prelate area only the Outlook member appears to be hydraulically connected to the Judith River aquifer (see cross sections D – D’, E – E’ and F – F’).

5.4.2 Hydraulic properties of the Judith River Aquifer

Short term pumping tests conducted on a well at SW-02-04-18-21-W3 yielded a hydraulic conductivity ranging from (5.4×10^{-6} to 6.5×10^{-6} m/s) (Whitaker, 1982).

Whitaker (1982) suggests that the maximum hydraulic conductivity of a Judith River aquifer sand bed could be 15 m/day ($\approx 1.7 \times 10^{-4}$ m/s), but that the average hydraulic conductivity for the fine to medium-grained sands would likely be no more than 5 m/day ($\approx 5.8 \times 10^{-5}$ m/s). Kewen and Schneider (1979) documented hydraulic conductivity data for the Judith River aquifer in the Kindersley map sheet area (72N). They reported hydraulic conductivities in the 0.16 – 1.5 m/day (1.9×10^{-6} to 1.7×10^{-5} m/s) range, with an average of 0. 6 m/day (7.1×10^{-6} m/s).

The currently available data for the Judith River aquifer sands indicate that a hydraulic conductivity in the 0.1 to 5 m/day ($\approx 1.2 \times 10^{-6}$ to 5.8×10^{-5}) range can be taken as representative values.

5.4.3 Groundwater Withdrawals from the Judith River Aquifer

Water from the Judith River aquifer is produced mainly by the oil industry. Records regarding the withdrawals from the Judith River aquifer by the oil industry date back to 1959 and are summarized in Table 9.

Table 9 **Groundwater withdrawals from the Judith River aquifer for enhanced oil recovery**

Land location	Period of withdrawals	Annual volume withdrawn		Total volume withdrawn	Highest annual withdrawal rate	
		Min (m3)	Max (m3)	m3	m3/day	L/s
Active						
03-05-12-17-W3	1966 - 2002	19	146,954	1,601,813	403	4.66
04-20-14-19-W3	1970 - 2003	6,892	105,940	1,065,497	290	3.36
06-11-13-19-W3	1972 - 2005	8,471	154,432	1,369,932	423	4.90
06-12-12-19-W3	1997 - 2005	8,191	50,372	243,755	138	1.60
07-20-15-19-W3	1966 - 2005	6,244	161,291	2,552,211	442	5.11
07-29-12-19-W3	1992 - 1997	2,847	16,512	62,899	45	0.52
09-18-16-16-W3	1999 - 2005	11,613	57,205	243,832	157	1.81
10-17-14-19-W3	1973 - 2005	9,633	105,463	732,779	289	3.34
11-21-18-17-W3	1965		7,141	7,141	20	0.23
12-12-18-17-W3	1988 - 2005	80	36,004	229,479	99	1.14
12-16-15-19-W3	1968 - 1974	715	66,620	173,942	183	2.11
12-17-14-19-W3	1971 - 2005	3,435	139,357	2,506,705	382	4.42
12-17-15-19-W3	1967 - 1973	11,631	114,592	286,525	314	3.63
16-04-17-18-W3	1967 - 2005	1,801	29,066	205,067	80	0.92
16-18-14-19-W3	1966 - 1990	162	142,626	1,182,925	391	4.52
16-20-15-19-W3	1966 - 1972	24,491	212,220	917,087	581	6.73
Non Active						
02-10-17-18-W3	1959 - 1967	21,993	65,933	438,005	181	2.09
06-10-17-18-W3	1959 - 1966	4,059	47,847	228,645	131	1.52
07-10-17-18-W3	1959 - 1967	35,821	58,403	424,153	160	1.85
08-10-17-18-W3	1959 - 1967	31,131	62,841	437,978	172	1.99
10-10-17-18-W3	1959 - 1964	8,627	14,700	42,820	40	0.47
Total				**14,953,187**		

Based on the reported highest annual volumes withdrawn, Table 9 shows that well yields varied between 20 and 442 m^3/day (0.23 to 5.1 L/s). The reported maximum monthly volume pumped from a source well is 74,750 m^3 (2,490 m^3/day).

Although the Judith River aquifer is an important water supply source for domestic/farm use, the total annual volumes withdrawn from domestic/farm is small.

5.4.4 Groundwater Regime and Groundwater Levels

The Judith River aquifer, on a large regional scale, is recharged directly by infiltrating precipitation and surface water in the areas where the aquifer outcrops at the ground surface. In areas where the aquifer is covered by an aquitard and a downward gradient exists, the aquifer is recharged by vertical downward movement through the overlying aquitard.

Based on reported depth to water data in the SWA WWDR database, Figure 26 shows the distribution of water level elevations in the Judith River aquifer. The general flow direction is from the south-southwest to the north-northwest. Virtually throughout the entire area where the aquifer is present the water table is higher than the water level in the aquifer. Consequently, there is downward flow into the aquifer over much of its extent. Based on reported water level data, Figure 27 shows the available drawdown in wells completed in the Judith River aquifer. Throughout most of the area where the aquifer occurs the available drawdown is in the 60 to 80 m range.

Along its northern extent the aquifer discharges through the Empress Group sediments of the Tyner Valley aquifer (see section 6.2) and the alluvium of the South Saskatchewan river valley into the bottom of this river (see cross sections G – G' to K – K'). Along cross section L – L' the northern extent of the Judith aquifer is truncated by till and in this area there does not appear to be a hydraulic connection with the Tyner Valley aquifer. This is the likely explanation for the flowing wells reported in Tp 22 and 23, Rg 21 (see Figure 26).

Cross section N – N' shows that the alluvium of the South Saskatchewan River is hydraulically connected to the Judith River aquifer. Prior to the creation of Lake Diefenbaker there likely was discharge from the aquifer into the South Saskatchewan River valley from both the south and north of the valley. The creation of Lake Diefenbaker may have impacted the discharge from the aquifer in this area. It either may have lead to a reduction of the volume of discharge into the valley or to a reversal of flow (*i.e.* recharge from the Lake Diefenbaker into the aquifer). However, there are no water level data available to confirm the impact of Lake Diefenbaker on the water level in the aquifer.

As is shown in cross sections B – B', C – C' and D – D', the preglacial tributary to the South Saskatchewan river valley in Range 25 is incised into the Judith River aquifer and is partly filled with sediments of the Empress Group. It is possible that the aquifer formed by these Empress Group sediments act as a "drain" for the Judith River aquifer. However, there are no water level data to confirm if this indeed the case and how effective this drain would be.

There are no long-term water level records for the Judith River aquifer in the Prelate area.

5.4.5 Groundwater Quality in the Judith River Aquifer

The available water quality data for the Judith River aquifer are listed in Table 10. The locations of wells for which there are water quality data are shown in Figure 28. Based on the most recent water quality data, Figure 29 shows a Piper-plot of the water quality data for the Judith River aquifer. Both Table 10 and Figure 29 show that sodium is the dominant cation in water from the aquifer but that the anion content is highly variable. Waters may be of the Na-SO_4, Na-Cl or Na-HCO_3 type (Figure 29). The TDS (sum ions) ranges from 820 to 12,200 mg/L but typically is in the 1,500 to 3,000 mg/l range.

5.4.6 Theoretical Yield of Wells Completed in the Judith River Aquifer

Based on Figure 25, a representative range for the thickness of the Judith River Formation is between 50 and 100 m. Assuming that 50% of the formation consists of sands, this corresponds to the aquifer sands being 25 – 50 m thick. The hydraulic conductivity of the aquifer sands is taken to be in the 0.1 to 5 m/day ($\approx 1.2 \times 10^{-6}$ to 5.8×10^{-5} m/s). The aquifer is overlain by 100 to 200 meters of aquitard, which has an assumed vertical conductivity in the 8.64×10^{-6} - 8.64×10^{-8} m/day (1×10^{-10} – 1×10^{-12} m/s) range. The available drawdown is in the 60 to 80 m range (Figure 27). It is further assumed that the well has a diameter of 0.15 m. Based on these assumptions, Table 11 summarizes the theoretical yields.

Table 11 Theoretical yields for wells completed in the Judith River aquifer and leakage length for various aquifer and aquitard thicknesses, hydraulic properties and available drawdowns

Vertical conductivity of aquitard (m/day)	**Aquitard thickness (m)**	**Effective thickness Judith aquifer (m)**	**Transmissivity Judith River aquifer (m^2/day)**	**Theoretical well yield (m^3/day)**	**Leakage length L (km)**
8.64 x 10^{-6}	100	25	2.5 - 125	85 – 4,750	5 - 38
8.64 x 10^{-6}	100	50	5 - 250	160 – 9,250	8 - 54
8.64 x 10^{-6}	200	25	2.5 - 125	80 – 4,600	8 - 54
8.64 x 10^{-6}	200	50	5 - 250	157 – 9,000	11 - 76
8.64 x 10^{-8}	100	25	2.5 - 125	70 – 4,050	54 - 380
8.64 x 10^{-8}	100	50	5 - 250	135 – 7,900	76 - 538
8.64 x 10^{-8}	200	25	2.5 - 125	68 – 3,950	76 - 538
8.64 x 10^{-8}	200	50	5 - 250	175 – 7,750	108 - 760

The values in Table 10 show that the theoretical yield for a well completed in the Judith River aquifer is highly dependent on the transmissivity of the aquifer. For a particular transmissivity of the aquifer, the theoretical yield is less dependent on the vertical hydraulic conductivity and the thickness of the overlying aquitard. The transmissivity range used in calculating the theoretical yield is extreme in that it assumes that all the sands of the aquifer have the same hydraulic conductivity. In reality, this will not be the case.

Table 11 illustrates a very important characteristic of the impact of major withdrawals from the Judith River aquifer in the Prelate, namely; the very large values for the leakage length L. The L values may range from several kilometers to potentially hundreds of kilometers. The high L values mean that major withdrawals will only be possible if wells are being spaced far apart because of significant drawdown interference. It also means that large withdrawals near the Alberta – Saskatchewan may cause interprovincial transboundary issues.

It is not possible to determine the safe yield of the Judith aquifer in the Prelate area as the aquifer extends well beyond the borders of the Prelate area and as shown above, well interference is a major issue. A numerical model could perhaps provide additional insight in what the safe yield of the aquifer could be. However, the area to be modeled would have to be much greater than the study area because of the potentially very large L values and the results would be hypothetical since there are no firm data on the vertical hydraulic conductivity of the Bearpaw silts and clays and tills.

It is not possible to determine the safe yield of the Judith aquifer in the Prelate area as the aquifer extends well beyond the borders of the Prelate area and as shown above, well interference is a major issue. A numerical model could perhaps provide additional insight in what the safe yield of the aquifer could be. However, the area to be modeled would have to be much greater than the study area because of the potentially very large L values and the results would be hypothetical since there are no firm data on the vertical hydraulic conductivity of the Bearpaw silts and clays and on the aerial distribution of the available drawdown.

5.4.7 Susceptibility of the Judith River Aquifer to Contamination

Point aquifer vulnerability index (AVI) values for the Judith River aquifer are shown in Figure 30. Considering the depth of the aquifer and the thickness of overlying aquitards formed by Bearpaw Formation silts and clays and tills, it is not surprising that all calculated values indicate an extremely low vulnerability. In fact, over its entire extent in the Prelate area the aquifer is very well protected against contamination from the ground surface. Only improper well location and/or well construction could lead to local contamination of the aquifer.

5.5 Aquifers within Bearpaw Formation

5.5.1 Definition and Extent of Bearpaw Formation Aquifers

The Bearpaw Formation includes a number of sand and silt and clay members (see Figure 14). The sand members in ascending order are named: Outlook, Matador, Demaine, Ardkenneth, Cruikshank and Oxarart, Belanger, Thelma. The latter three units have been mapped as a single unit. Although the silts and clays between the sand members have been named (Figure 14), they have not been separated on the cross sections.

Figure 31 shows the extent of the aquifers formed by sand members of the Bearpaw Formation. The extent of the Ardkenneth, Cruikshank and Oxarart, Belanger, Thelma sand members is limited to the utmost southeastern part of the Prelate area (see cross sections F – F’, M – M’ and N – N’). The aquifers formed by the Outlook, Matador, Demaine and Ardkenneth members occur in the southwestern part of the Prelate area.

As is evident from the cross sections aquifers formed by the Bearpaw sand members occur at different depths. The thickness of the sand members ranges from zero (0) to 50 m but typically is between 5 and 20 m. The thickest aquifers are formed by the Outlook and Matador members.

5.5.2 Hydraulic Properties of Bearpaw Formation Aquifers

The Bearpaw sand members are composed of fine to medium-grained sands. Based on the lithology, the hydraulic conductivity of the sands likely will be in the 1 to 5 m/day range (1.2×10^{-5} to 5.8×10^{-5} m/s).

5.5.3 Groundwater Withdrawals from Bearpaw Formation Aquifers

Pumping from the Bearpaw sand members is limited to domestic/farm wells as there are no major withdrawals from the Bearpaw sand members.

5.5.4 Groundwater Levels and Groundwater Regime

There are few wells completed in Bearpaw sands and therefore, information on water levels is very limited. The aquifers formed by the Bearpaw sands are recharged by vertical downward flow through overlying aquitards formed by Bearpaw silt and clay members and till. Because of the low vertical hydraulic conductivity of these aquitards, recharge to the Bearpaw aquifers will be small. The direction of groundwater flow in the aquifers is controlled by the large-scale regional topographical setting.

5.5.5 Groundwater Quality in the Bearpaw Formation Aquifers

A listing of available water quality data for Bearpaw Formation sands is provided in Table 12. Concentrations exceeding the Saskatchewan drinking water quality standards and objectives (Saskatchewan Environment, 2006) are highlighted in Table 12. The locations of the sample points are shown in Figure 32. In Figure 33, the groundwater quality data are presented in the form of a Piper-plot.

The TDS (sum of ions) ranges from 200 to 5,600 mg/L but typically is in the 500 to 2,500 mg/L range. As is evident from Figure 33, either sulfate or bicarbonate is the dominant anion and only at a few locations is chloride the dominant anion. As the cation concentrations are highly variable, various water types can be found in the Bearpaw sands.

5.5.6 Yield of Wells Completed in Bearpaw Formation Aquifers

The aquifers formed by the Bearpaw sand members are semi-confined but insufficient information exits to provide realistic estimates of yields. In general terms, yields will be limited by the fact that the aquifers are relatively thin and have a low transmissivity. Because of the low transmissivity drawdowns cones can be expected to be steep.

5.5.7 Susceptibility of Bearpaw Formation Aquifers to Contamination

Point aquifer vulnerability index (AVI) values for the Bearpaw sand members are shown in Figure 34. As is evident from the cross sections, the individual aquifers formed by the Bearpaw sand members occur at variable depths and are confined by either Bearpaw silt and clay and/or by till. It is not surprising that, considering the hydrogeological settings of the Bearpaw sand members, all point AVI values are greater than 4, indication a very low vulnerability. In fact, throughout their extents, all Bearpaw sand member aquifers are very well protected from contamination originating at the ground surface.

5.6 Eastend to Cypress Hills Aquifer System

5.6.1 Definition and Extent of Eastend to Cypress Hills Aquifer

The Eastend – Cypress Hills aquifer is defined as the aquifer formed by the sediments of, in ascending order, the Eastend, Whitemud, Battle, Frenchman, Ravenscrag and Cypress Hills formations. The aquifer consists of sands, silts, clays and coals. Within the Prelate area the unit only occurs in the utmost southeastern part (Figure 35) and not all sub-units are present (see cross sections F – F', M – M' and N – N'). The aquifer ranges in thickness from zero (0) to 118 m (Figure 36).

5.6.2 Hydraulic Properties of Eastend - Cypress Hills Aquifer

Based on a review of available data in the Cypress Lake area, Maathuis and Simpson (2007) suggest that the hydraulic conductivity of the Eastend – Ravenscrag sands likely is in the 1 – 10 m/day (1.1×10^{-5} – 1.1×10^{-4} m/s) range, typical for the fine to medium-grained sands of the aquifer. There is no information on the hydraulic conductivity of the gravels of the Cypress Hills Formation. Literature suggest that the hydraulic conductivity of gravels can range from hundreds to thousands meters per day (*e.g.* Freeze and Cherry, 1979).

5.6.3 Groundwater Withdrawals from the Eastend - Cypress Hills Aquifer

Withdrawals from the Eastend - Cypress Hills aquifer in the Prelate area are limited to domestic/farm use and therefore, are small.

5.6.4 Groundwater Levels and Groundwater Regime

The water level in the aquifer commonly is below the top of the aquifer and therefore, the aquifer is unconfined. Recharge to the aquifer takes places over virtually the entire extent of the aquifer. As is evident from cross section N – N', the Swift Current Creek valley is a discharge area for the Cypress Hills aquifer.

5.6.5 Groundwater Quality in the Eastend - Cypress Hills Aquifer

A listing of available water quality data for the Eastend – Cypress Hills aquifer is provided in Table 13. Concentrations exceeding the Saskatchewan drinking water quality standards and objectives (Saskatchewan Environment, 2006) are highlighted in Table 13. The locations of the sample points are shown in Figure 37. In Figure 38, the groundwater quality data are presented in the form of a Piper-plot.

Water from the Eastend – Cypress Hills aquifer has a TDS in the 300 to 2,400 mg/L range (Table 13). The aquifer yields water of the Ca/Mg-SO_4, Ca/Mg-HCO_3 and Na-HCO_3 type.

5.6.6 Yield of Wells Completed in Eastend to Cypress Hills

There is insufficient information to establish the possible yield from wells completed in the Eastend - Cypress Hills aquifer.

5.6.7 Susceptibility of the Eastend - Cypress Hills Aquifer to Contamination

Point aquifer vulnerability index (AVI) values for the Eastend – Cypress Hills aquifer are shown in Figure 39. The vulnerability of the Eastend – Cypress Hills aquifer to contamination from the ground surface is highly variable, ranging from extremely vulnerable in areas where the overlying drift is absent or very thin to low where the drift is thicker.

6.0 HYDROGEOLOGY OF QUATERNARY AQUIFERS

6.1 Definition of Extent of Quaternary Aquifers

Quaternary aquifers in the Prelate area are formed by sand and gravels of the Empress, Sutherland and Saskatoon groups and the surficial stratified deposits. Except for the Tyner Valley aquifer, none of the Quaternary aquifers have been named.

6.1.1 Definition and Extent of Empress Group Aquifers

The extent, depth to and thickness of aquifers formed by sediments of the Empress Group are shown in Figure 40.

The major aquifer formed by sediments of the Empress Group is the Tyner Valley aquifer. The Tyner Valley aquifer is one of the major buried valley aquifer systems in Saskatchewan (Figure 41). It enters the province from Alberta and traverses mid-central Saskatchewan to a short distance north of Saskatoon where the aquifer discharges into the North Saskatchewan River. As is evident from Figure 41, the Tyner Valley aquifer in the Prelate area covers only a portion of the Tyner Valley in southwestern Saskatchewan.

The hydrogeological setting of the Tyner Valley aquifer is shown in cross sections A – A’ and sections G – G’ to I – I’. In Tp 23, Ranges 27 – 30, the Tyner Valley aquifer directly underlies the alluvium of the South Saskatchewan River (cross section A – A’). Cross sections J – J’ and K – K’ do not extend far enough north to determine the relationship between the Tyner Valley aquifer and the South Saskatchewan River valley. East of Range 20 the Tyner Valley aquifer is not present beneath the South Saskatchewan River valley (cross section L – L’ to N – N’).

The Tyner Valley aquifer is overlain by either South Saskatchewan alluvium or drift. Where there is a direct connection between the Tyner Valley aquifer and the South Saskatchewan River valley the aquifer is overlain by 20 to 35 m of alluvium. Elsewhere the aquifer is confined by 60 – 150 m of drift, mainly till. The aquifer ranges in thickness between 10 and 60 m (Figure 40).

In the eastern half of the Prelate area sediments of the Empress Group form small isolated, unnamed, aquifers. The depth at which these aquifers occur varies. In Tp 14, Rg 19 the aquifer is between 20 – 55 m deep, 45 – 60 m deep in Tp 19, Rg 18 – 19 and 90 -130 m deep in Tp 19, Rg 15 – 17. The thickness of the Empress Group sediments in these areas typically is in the 10 – 20 m range.

6.1.2 Definition and Extent of Sutherland Group Aquifers

The extent, depth to and thickness of aquifers formed by stratified sediments of the Sutherland Group are shown in Figure 42. As there is insufficient information to separate the formations of the Sutherland Group, the stratified drift forming the aquifers within the Sutherland Group are referred to as Sutherland Group aquifers.

Figure 42 shows that there are several Sutherland Group aquifers in the Prelate area, mainly in the northern part of the area. None of these aquifers have been named. The hydrogeological setting of these aquifers is shown in the cross sections.

As shown in Figure 42, there are two Sutherland Group aquifers with a significant extent and several smaller aquifers. The main Sutherland aquifers are located in Tp 16 – 21, Rg 24 - 25 and Tp 19 – 23, Rg 18 – 26. Both these aquifers are long but narrow features. The aquifer in Tp 16 – 21, Rg 24 – 25 occurs at a depth ranging from 60 to 90 m. Its thickness is variable, ranging from 2 to 50 m. The aquifer in Tp 19 – 23, Rg 18 – 26 is found at depths in the 50 to 85 m range. The thickness of the aquifer is also variable, ranging from 5 to maximum of 75 m. The smaller aquifers occur at depths in the 35 to 55 m and are typically between 5 and 25 m thick.

6.1.3 Definition and Extent of Saskatoon Group Aquifers

The extent, depth to and thickness of Saskatoon Group aquifers is shown in Figure 43. As there is insufficient information to define the units within the Saskatoon Group, all aquifers within the Saskatoon Group have been referred to as Saskatoon Group aquifers. As is evident from Figure 43 there are numerous Saskatoon Group aquifers in the Prelate area but none of these aquifers have been named. The hydrogeological settings of these aquifers are shown in the cross sections. The Saskatoon Group aquifers occur at depth ranging from 20 to 50 meters and are between 5 and 20 m thick.

6.1.4 Definition and Extent of Surficial Aquifers

The surficial aquifers are composed of alluvial, eolian, and fluvial material deposited after the recession of the Wisconsinan glacier. The surficial geology map (Figure 44) provides an indication of surficial sand deposits. It is noted that the extents of surficial deposits do not indicate the extent of surficial aquifers as many of the surficial deposits are thin and may be unsaturated (*i.e.* dry). The surficial aquifers identified are shown in Figure 45.

The most prominent surficial sand feature in the Prelate area is the Great Sand Hills area. Epp and Townley-Smith (1980) divided the Great Sand Hills are into a northern and southern part. The division between the northern and southern part is Tp 16. The combined Great Sand Hills area is 1,910 km^2 in size. The sediments of the Great Sand Hills are glaciofluvial and glacialacustrine in origin (Muhs and Wolfe, 1999), and likely were deposited in glacial Lake Bigstick during the final deglaciation of the area about 15,500 to 14,000 year ago (Christiansen, 1979, Fig. 12). The deposits that form the Great Sand Hills are mainly fine to medium-grained sands but also include silt(y) layers. The Great Sand Hills area is characterized by dunes up to 15 m high. The sands of the Great Sand Hills area are shown in cross sections C – C', D – D' and K – K'. The Great Sand Hills deposits are between zero (0) and 52 m thick (Figure 45).

The alluvium of the South Saskatchewan River forms an alluvial aquifer. The aquifer is between 20 and 35 m thick.

6.2 Hydraulic Properties

Little information is available on the hydraulic properties of the Quaternary aquifers. Aquifers formed by sediments of the Empress, Sutherland and Saskatoon groups commonly are composed of medium to coarse-grained sands with gravel layers. The hydraulic conductivity of these sediments may ranges from several meters/day to several tens of meters per day (*e.g.* Freeze and Cherry, 1979).

A short-duration pumping test conducted at the SWA Verlo site, located in the Great Sand Hills and completed in a silty clay at a depth of 12.8 m, yielded a hydraulic conductivity of 1 m/day (1.2×10^{-5} m/s). A response test yielded a value of 7.5×10^{-2} m/day (8.7×10^{-7}m/s).

6.3 Groundwater Withdrawals

There are no major withdrawals from the Quaternary aquifers. Water from these aquifers is used for farm/domestic and municipal water supply purposes.

6.4 Groundwater Levels and Groundwater Regimes

6.4.1 Empress Group Aquifers

The Tyner Valley aquifer is recharged by both downward vertical flow and lateral flow the Judith River aquifer. The South Saskatchewan River valley is a major discharge area for the Tyner Valley aquifer. The available point-water level data for the Tyner Valley aquifer are shown in Figure 46 but do not allow for a detailed description of the groundwater flow in the aquifer.

As shown in cross sections G – G' to I – I' the Tyner Valley aquifer is hydraulically connected to the Judith River aquifer. The Tyner Valley aquifer in this area acts as a drain for the Judith River aquifer and discharges through the alluvium of the South Saskatchewan River into the bottom of the river valley. Cross sections J – J' and K – K' also show a hydraulic connection between the Judith River aquifer and the Tyner Valley aquifer. However, the Prelate area does not extend north enough to show the relationship between the Tyner Valley aquifer and the South Saskatchewan River valley.

6.4.2 Sutherland Group Aquifers

The Sutherland aquifers identified are recharged by vertical downward groundwater flow from the water table. Considering that, the aquifers occur at depth ranging from 50 to 90 m, recharge to the aquifers will be small, a few millimeters per year at best. There is insufficient information to describe direction of groundwater flow within the aquifers and to identify the discharge areas.

6.4.3 Saskatoon Group Aquifers

The Saskatoon Group aquifers are recharged by vertical downward flow from the water table. Considering that, the aquifers occur at depth ranging from 20 to 50 m, recharge to the aquifers will be small, a few millimeters per year. There is insufficient information to describe direction of groundwater flow within the aquifers and to identify the discharge areas.

6.4.4 Surficial Aquifers

Surficial aquifers per definition are unconfined aquifers, which are recharged by infiltrating precipitation that reaches the water table. The thickness of the Great Sand Hills aquifers is unknown as there is insufficient information to establish the saturated thickness of the deposits.

While recharge might be more or less uniform over the area, the groundwater flow systems will be complex because of the topographic relief in the area.

Provincial groundwater level observation well SWA Verlo has been completed at shallow depth (12.8 m) in a silty clay of the Great Sand Hills surficial aquifer. The hydrograph for this well is shown in Figure 47. The water level trend is characterized by an increasing water level during the period 1964 – 1971 but since 1971, the level has declined by about 3 m. The hydrograph shows seasonal fluctuations but during the period, 1972 – 2006 there was no recharge during the spring in many years. The long-term trend of the water level in the Verlo well is in sharp contrast to the behavior in two wells, located about 74 – 80 km south of the Verlo well, which were completed at shallow depth in a semi- confined bedrock aquifer (SWA Garden Head and Shaunavon). The water levels in both the SWA Garden Head and Shaunavon wells have been increasing since recording started. There is no obvious explanation for the difference in behavior of the long-term water level trends over such a short distance. The significant of the observed water level decline in the SWA Verlo well may only become apparent if long-term records will become available for other groundwater level observation wells completed in the Great Sand Hills aquifer.

6.5 Groundwater Quality in Quaternary Aquifers

A listing of available water quality data for the Quaternary aquifers is provided in Table 14. Concentrations exceeding the Saskatchewan drinking water quality standards and objectives (Saskatchewan Environment, 2006) are highlighted in Table 14. The locations of the sample points are shown in Figure 48. In Figure 49, the groundwater quality data are presented in the form of a Piper-plot.

Water from the Quaternary aquifers has a TDS in the 225 to 151,000 mg/L range (Table 14). The majority of the water has a TDS in the 500 to 2,000 mg/L range. Saline waters (TDS 4,000 – 151,000 mg/L) are related to groundwater discharges areas. As is evident from Figure 49, either sulfate or bicarbonate is the dominant anion. As the cation concentrations are highly variable, various water types can be found in the Quaternary aquifers.

6.6 Yield of Wells completed in Quaternary Aquifers

6.6.1 Yield of Wells Completed in the Empress Group Aquifers

The complexity of the hydrogeological setting of the Tyner Valley aquifer only allows for a qualitative assessment of the potential yield of wells completed in this aquifer.

Considering the thickness (10 – 60 m thick) and the hydraulic conductivity of the Empress Group sediments, it will be possible to construct high yield wells in the Tyner Valley aquifer.

The yield of production wells completed in the Tyner Valley aquifer under the alluvium of the South Saskatchewan River will come from interception of the discharge of the Judith River aquifer into the Tyner Valley aquifer and from induced vertical recharge through the alluvium. The pumping from such wells will result in a decrease of the discharge into the South Saskatchewan River and may result in a reduction of flow the South Saskatchewan River. Production wells in the aquifer away from the South Saskatchewan River valley will mainly come from interception of discharge from the Judith River aquifer and will result in a decrease in discharge to the South Saskatchewan River valley.

It may also be possible to construct high yield wells in the south – north “tributaries” of the Tyner Valley aquifer. These” tributaries” are incised into the Judith River aquifer, which has a lower hydraulic conductivity and therefore, will act as buried-valley aquifers. Withdrawals from the Empress Group sediments in these ‘tributaries’ will result in drawdowns extending over significant distances along these valleys.

The potential yield of wells in the unnamed Empress Group aquifer will be small because of the limited extent of these aquifers.

6.6.2 Yield of Wells Completed in the Sutherland and Saskatoon Group Aquifers

The potential yield of wells completed in the Sutherland and Saskatoon group aquifers is limited because the aquifers are confined by thick till units and are of limited extent. Any significant withdrawals will result in drawdowns throughout the entire extent of the aquifers and well interference will be an issue limiting the aquifer yield.

6.6.3 Yield of Wells Completed in the Surficial Aquifers

The potential yield of wells completed in the surficial aquifers will be small because the saturated thickness of the aquifers likely is limited and therefore, the available drawdown is limited. Wells completed in the South Saskatchewan River valley alluvium may have higher yields, in particular if located close to the river. However, much of the yield of such wells will be induced recharge from the river and thus merely represent diverted surface water.

6.7 Susceptibility of Quaternary Aquifers to Contamination

6.7.1 Susceptibility of the Empress Group Aquifers to Contamination

Point aquifer vulnerability index (AVI) values for the Empress Group aquifers are shown in Figure 50. The point AVI values show a low to extremely low vulnerability. Considering the hydrogeological settings of the Empress Group aquifers much of the Tyner Valley aquifer and all the unnamed Empress Group aquifers can be considered very well protected against contamination. However, in the area where the Tyner Valley aquifer is directly overlain by the alluvium of the South Saskatchewan River the aquifer will be susceptible to contamination from the ground surface.

6.7.2 Susceptibility of the Sutherland Group Aquifers to Contamination

Point aquifer vulnerability index (AVI) values for the Sutherland Group aquifers are shown in Figure 51.

The AVI value at testhole/well sites typically is greater than four (*i.e.* extremely low aquifer vulnerability).
Considering the depth at which the Sutherland aquifers occur, the aquifers over their entire extent are well protected against contamination from the ground surface.

6.7.3 Susceptibility of the Saskatoon Group Aquifers to Contamination

Point aquifer vulnerability index (AVI) values for the Saskatoon Group aquifers are shown in Figure 52.
The AVI value at testhole/well sites typically is greater than three (*i.e.* low aquifer vulnerability). Considering the depth at which the Saskatoon aquifers occur, the aquifers over their entire extent are well protected against contamination from the ground surface.

6.7.4 Susceptibility of the Surficial Aquifers to Contamination

Point aquifer vulnerability index (AVI) values for the surficial aquifers are shown in Figure 53. By definition, because of the absence of a confining layer, all surficial aquifers in the Prelate area are highly susceptible to contamination from the ground surface (AVI less than 1: extremely high).

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"The water quality tables in this report contain personal information within the meaning of *The Freedom of Information and Protection of Privacy Act* (Saskatchewan) and therefore have been intentionally removed."

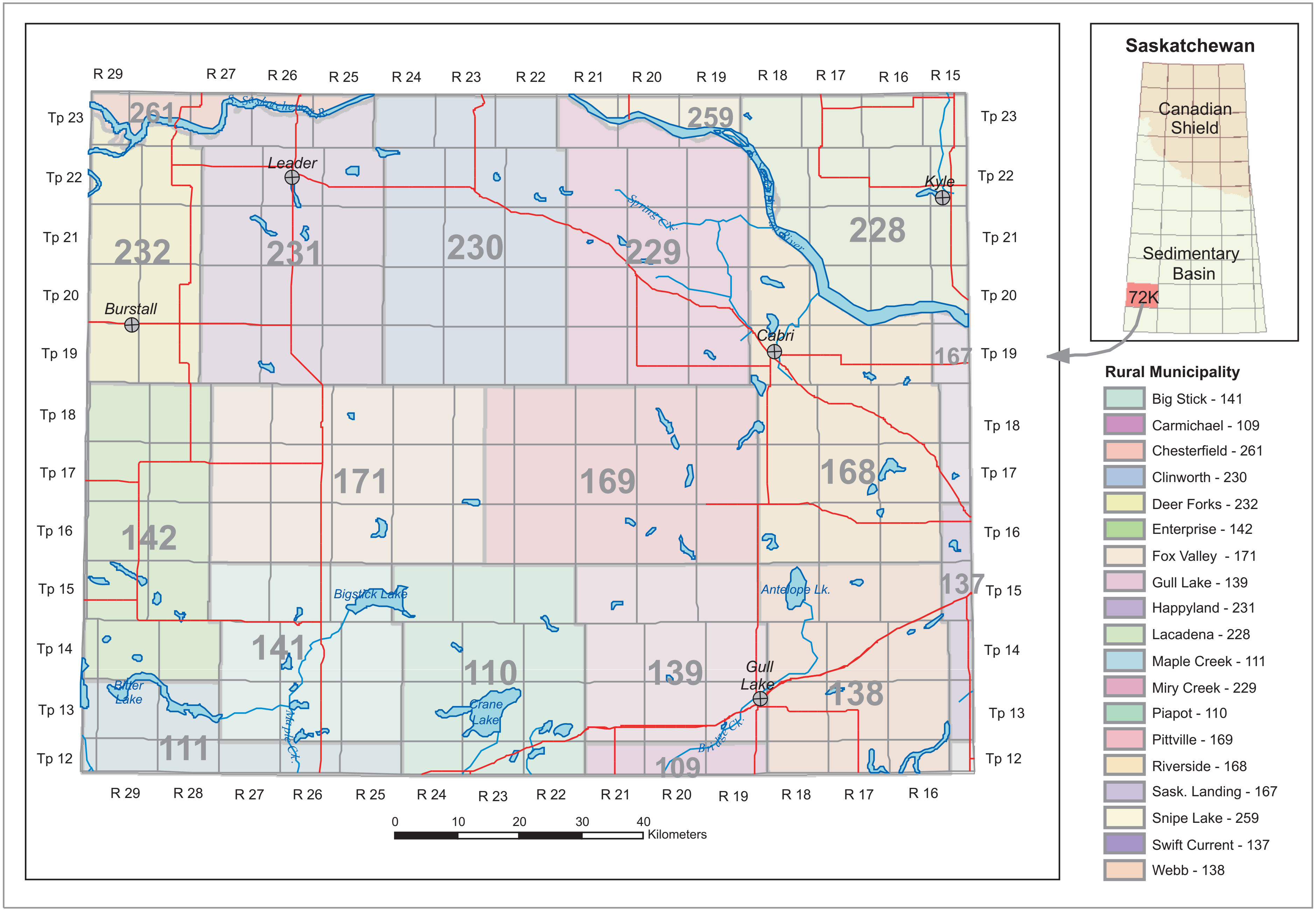
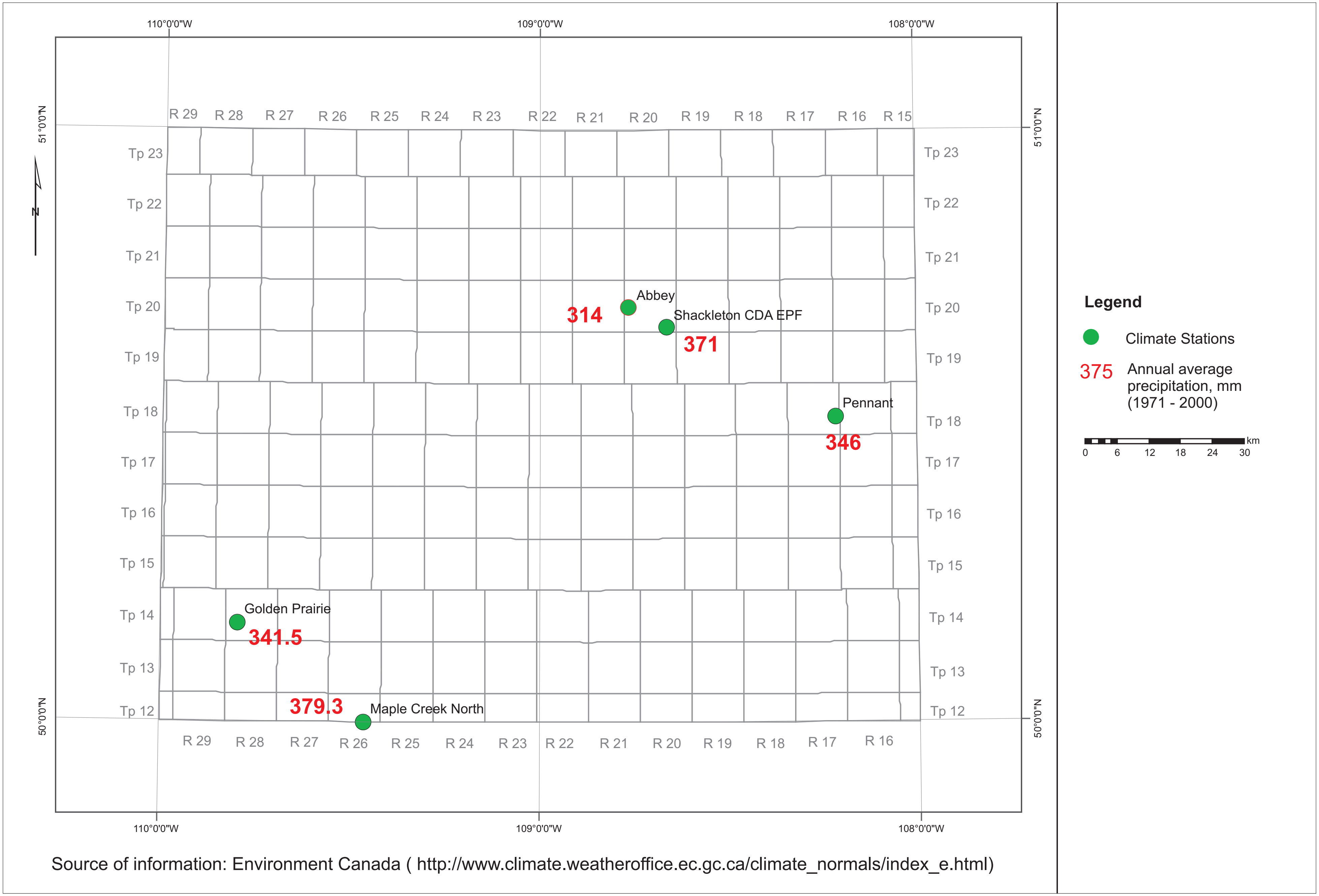


Figure 1 Location of Prelate area



Source of information: Environment Canada (http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html)

Figure 2 Locations of climate stations in the Prelate area and average annual precipitation

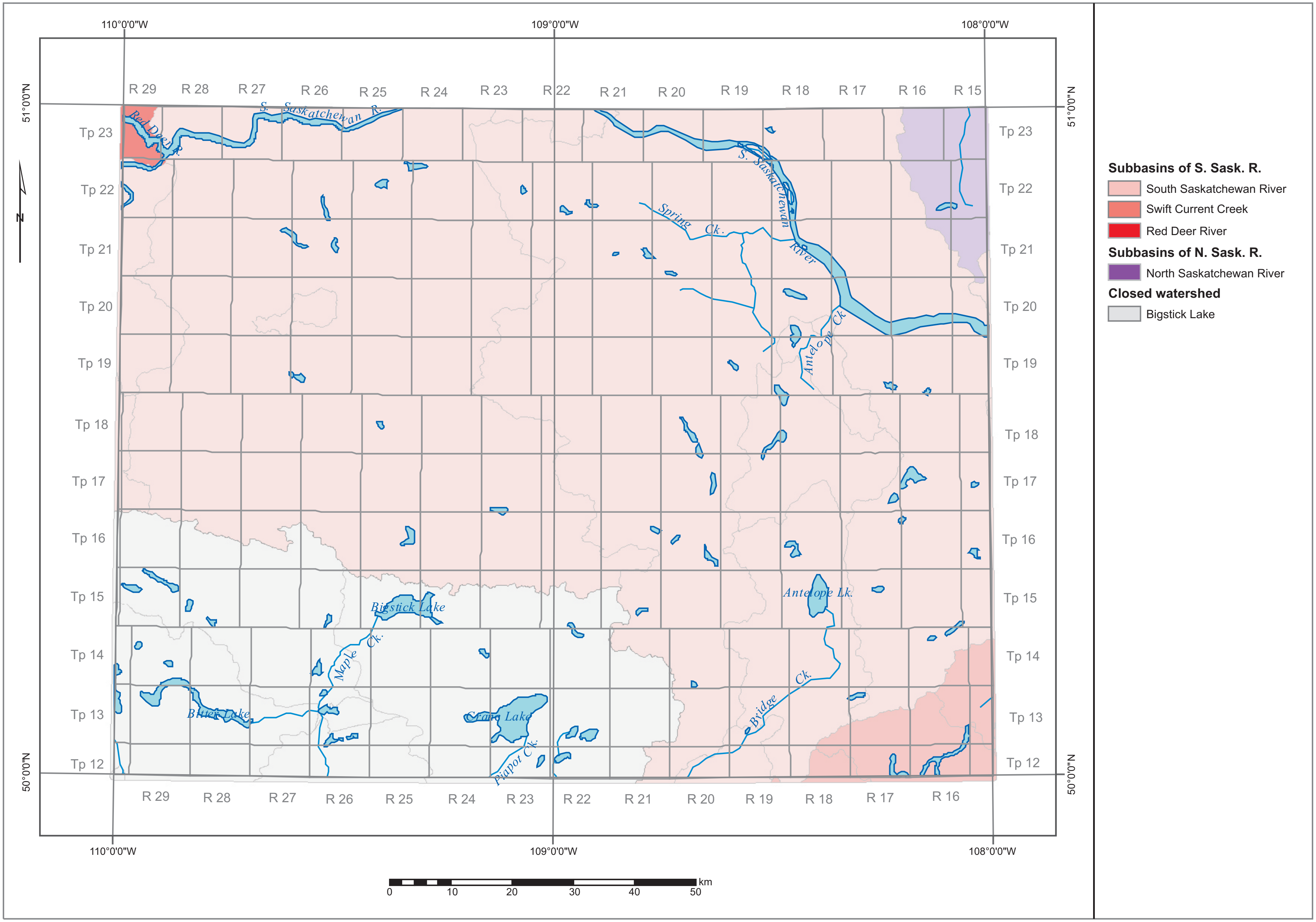


Figure 3 Drainage basins in the Prelate area

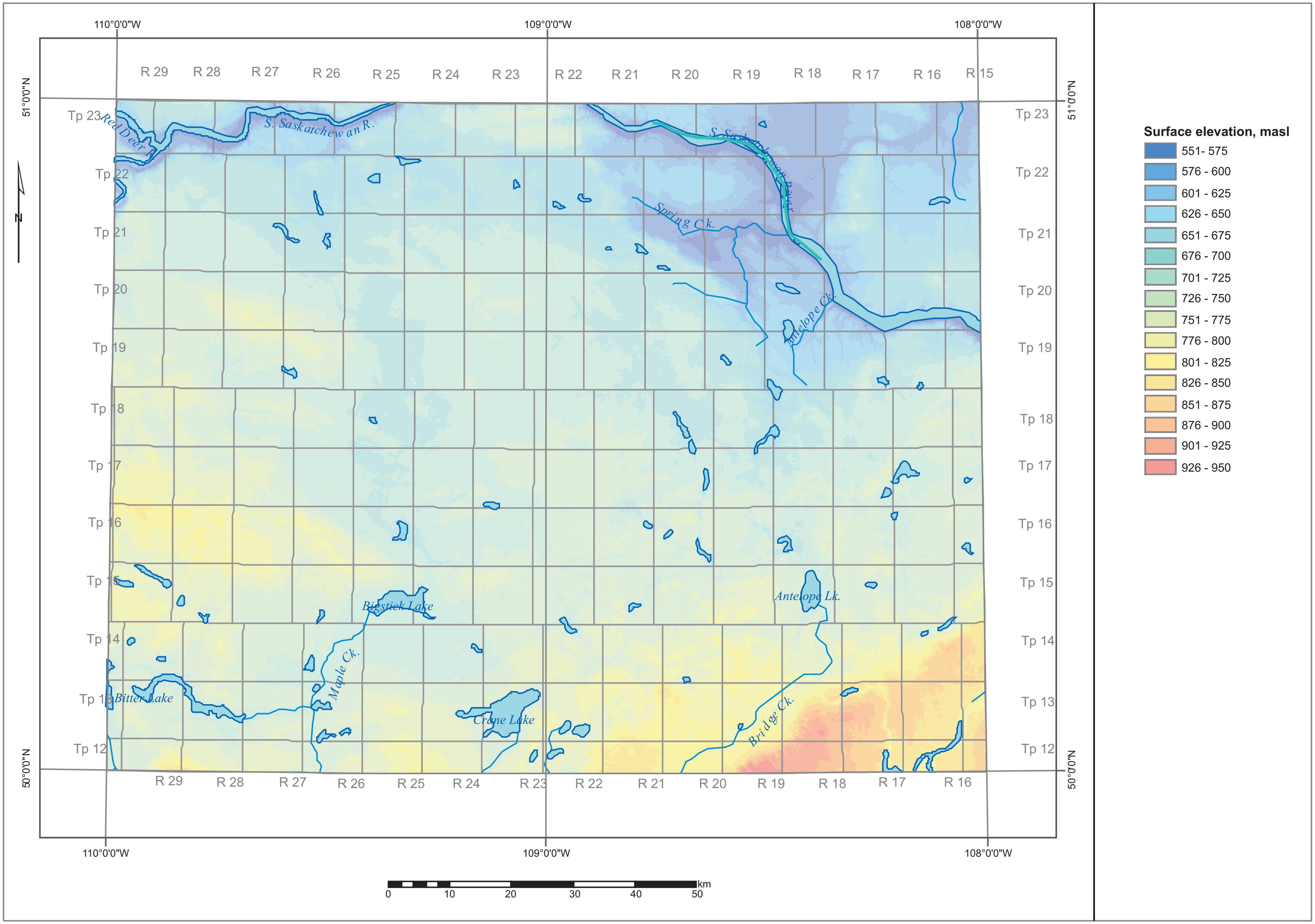


Figure 4 Topography of the Prelate area

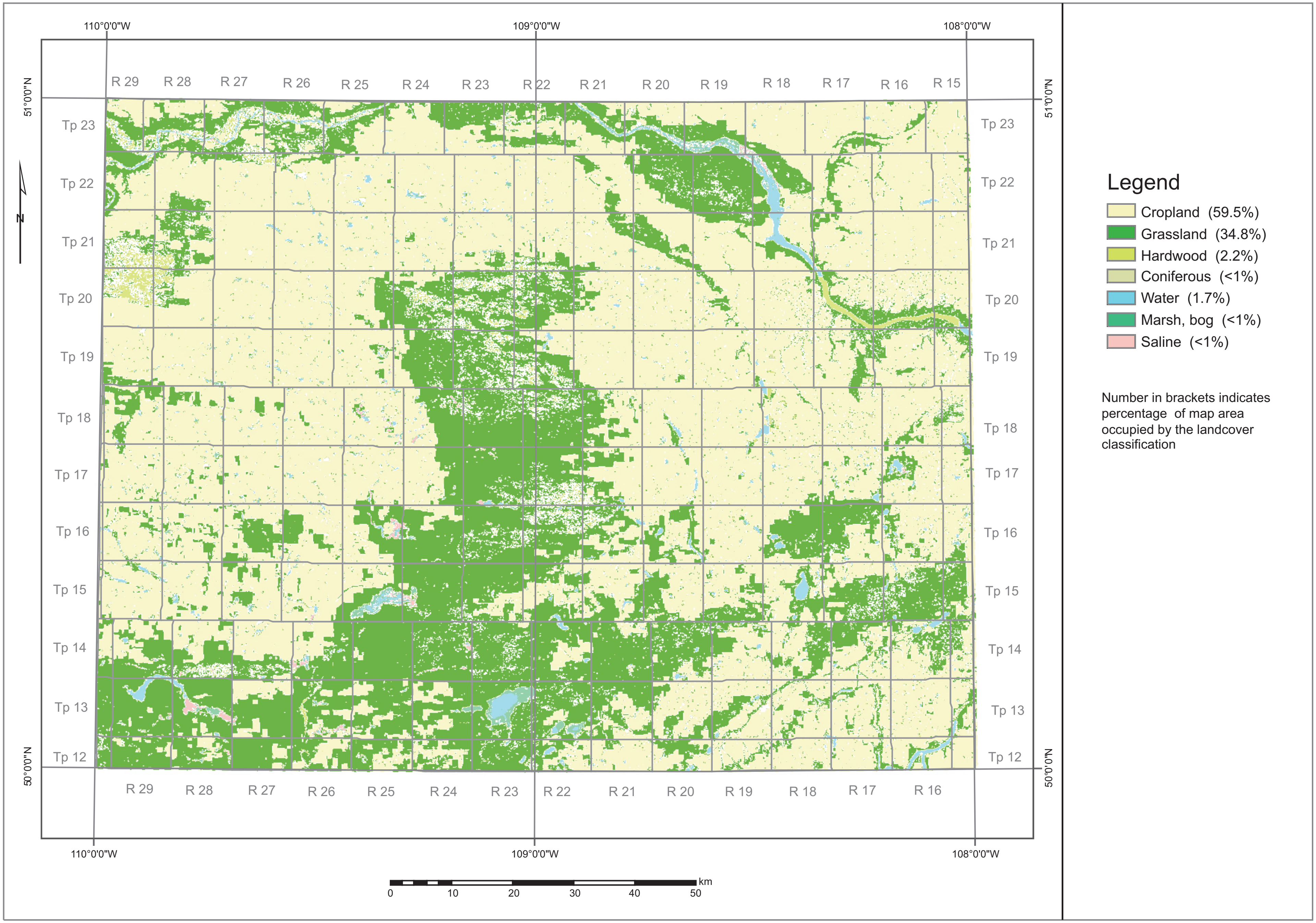


Figure 5 Land use in the Prelate area

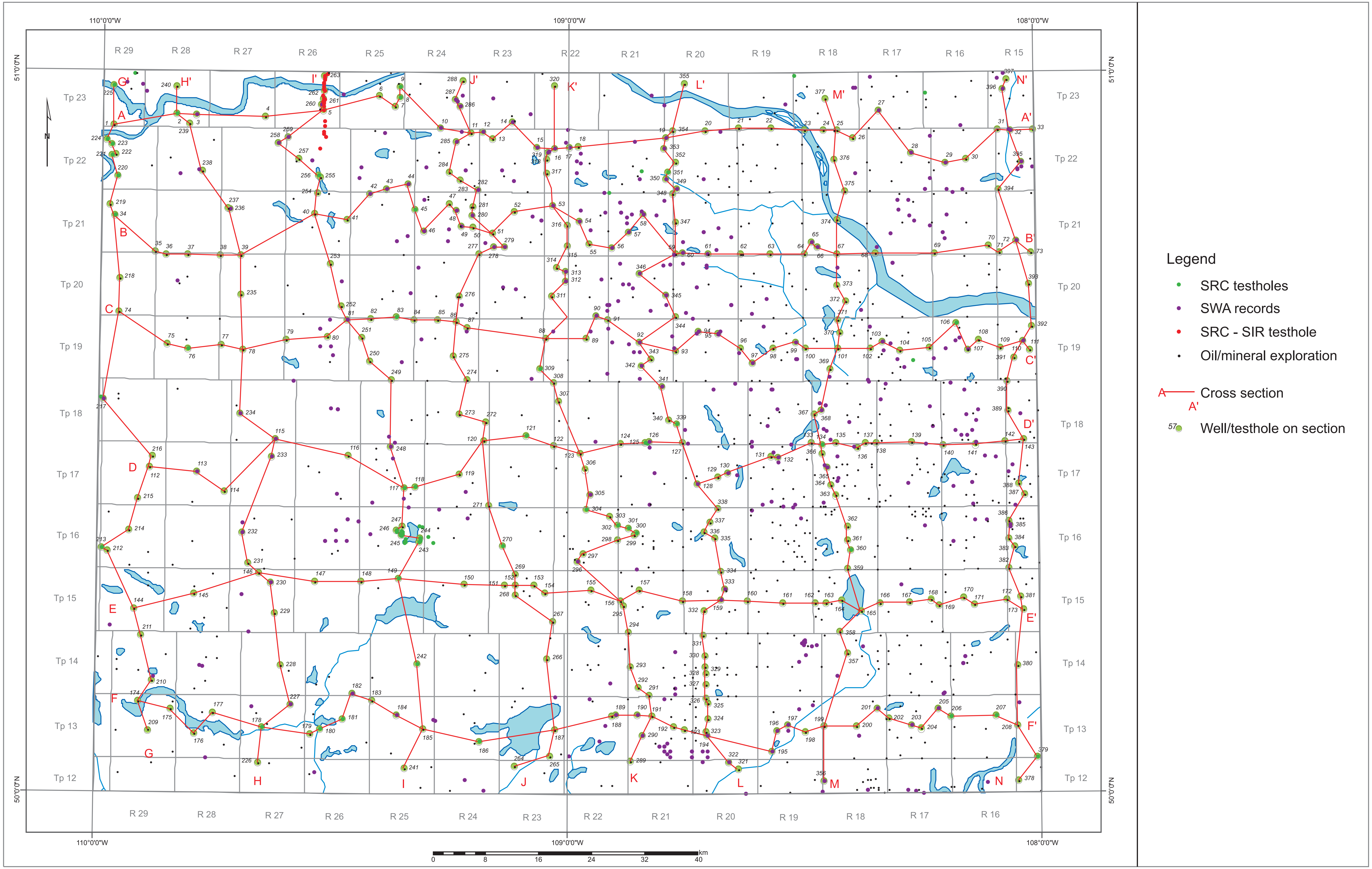
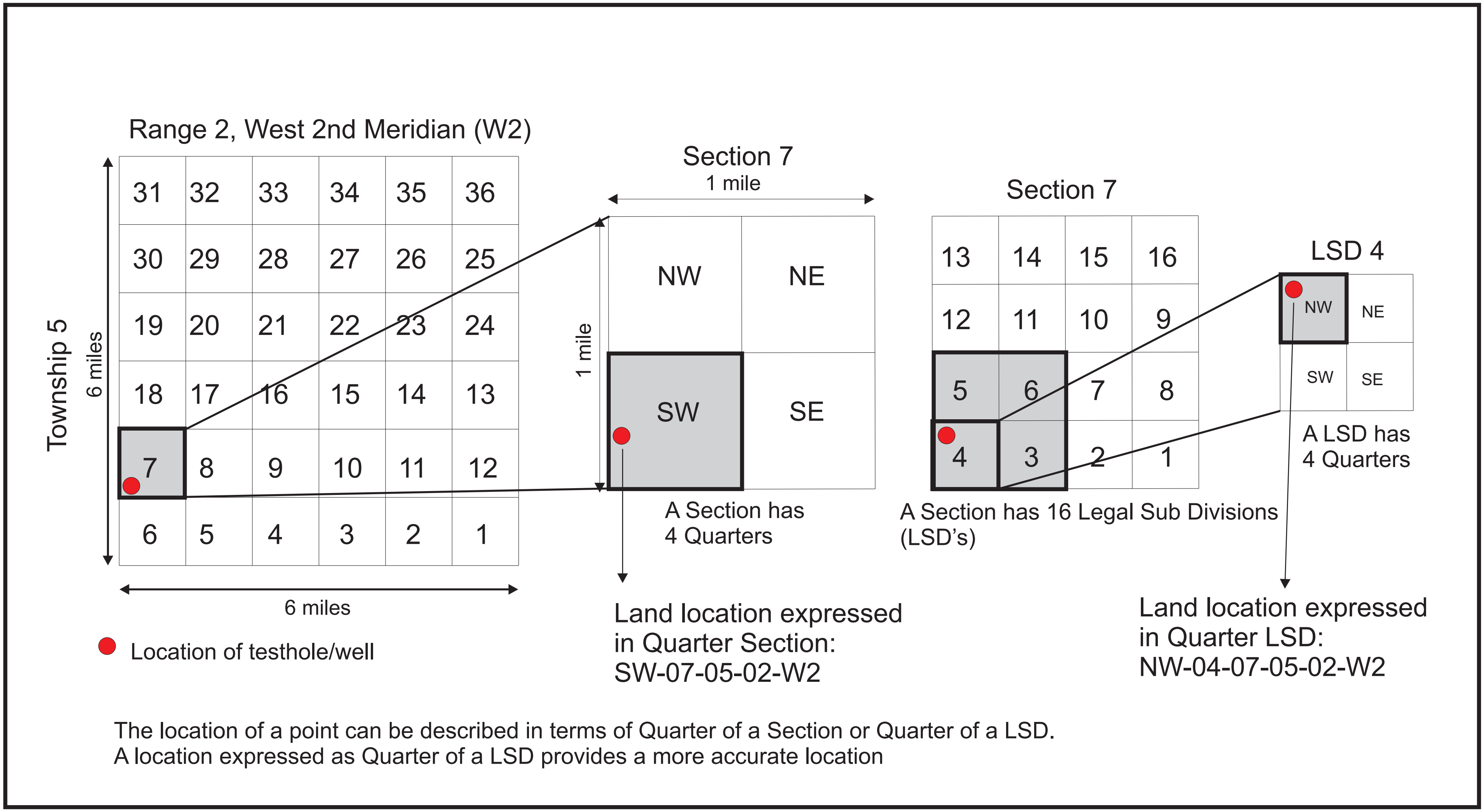


Figure 6 Locations of testholes and cross sections in the Prelate area



Land location expressed in Quarter Section: SW-07-05-02-W2

Land location expressed in Quarter LSD: NW-04-07-05-02-W2

The location of a point can be described in terms of Quarter of a Section or Quarter of a LSD. A location expressed as Quarter of a LSD provides a more accurate location

Figure 7 Schematic illustration of the Canada Dominion Land Survey System

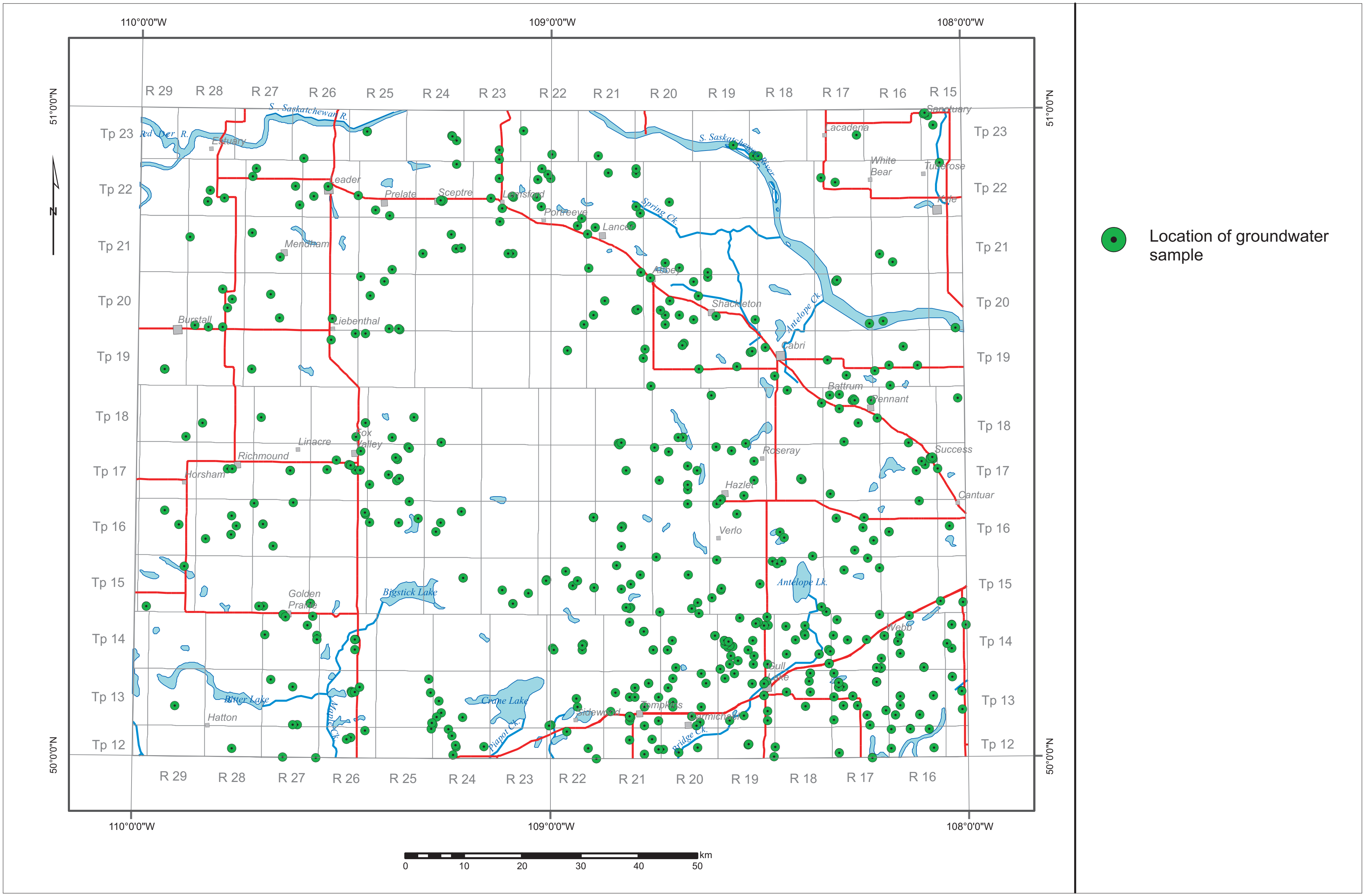


Figure 8 Locations of groundwater quality sample points in the Prelate area

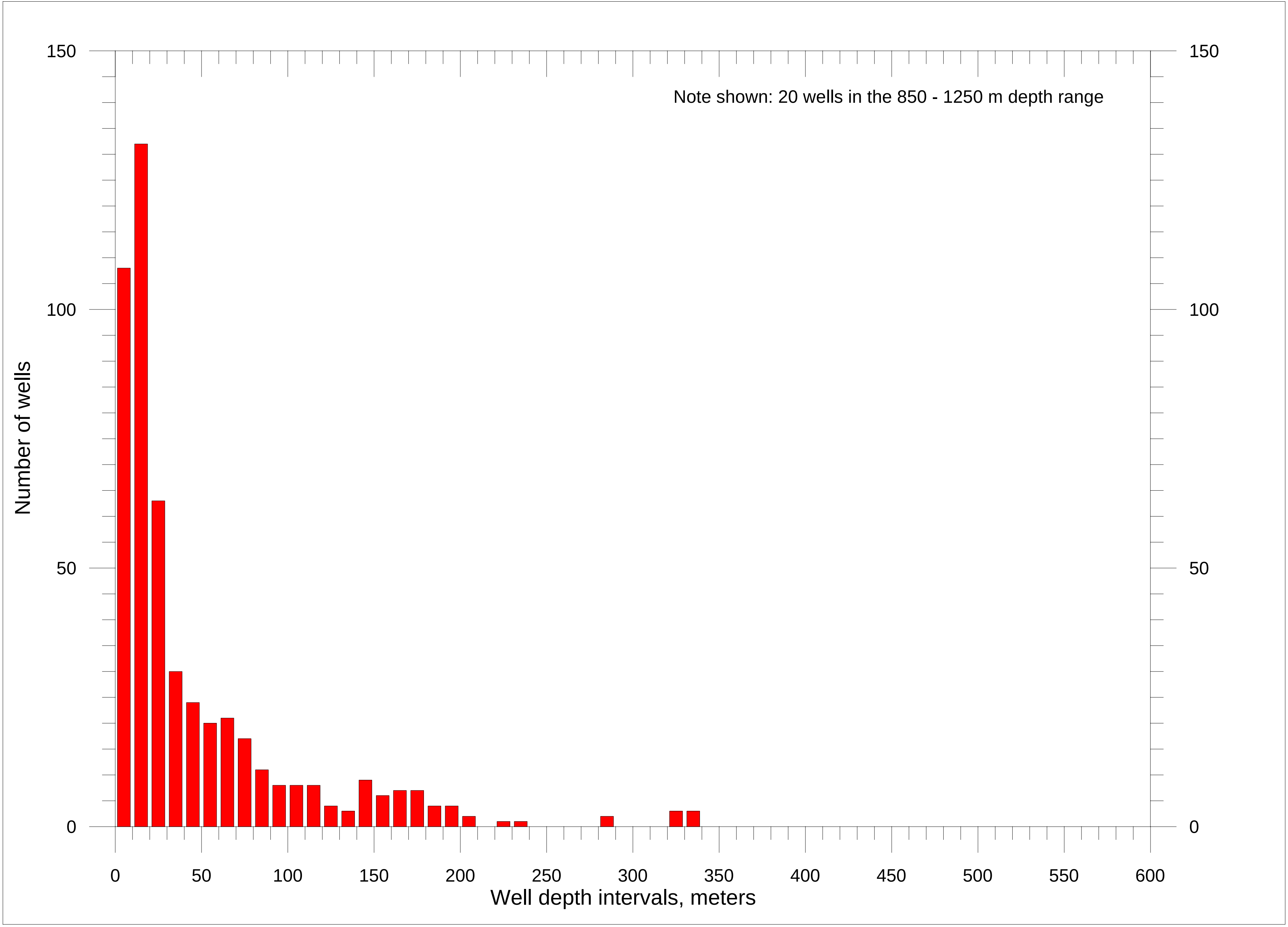


Figure 9 Depth distribution of groundwater quality samples in the Prelate area

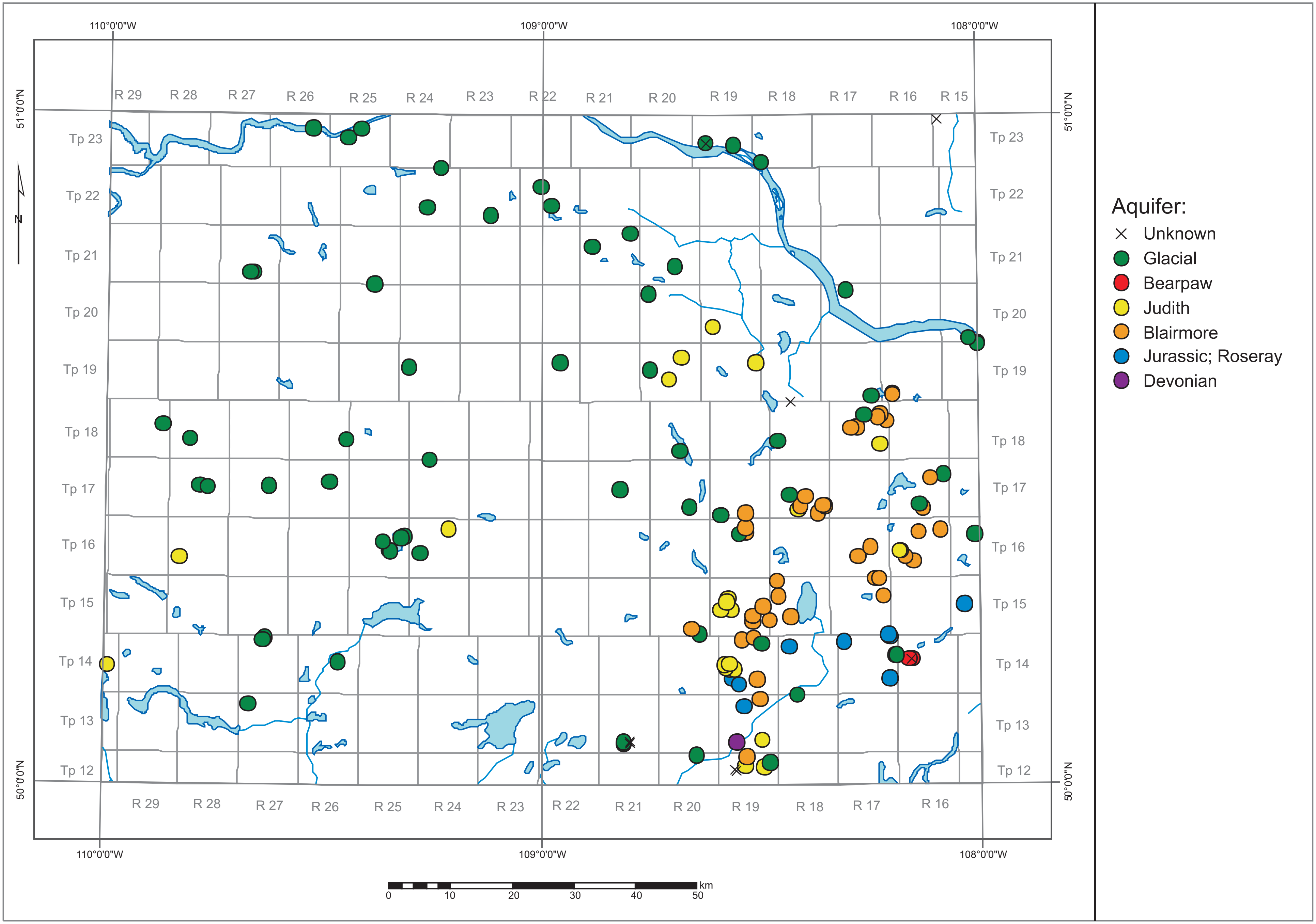


Figure 10 Locations of groundwater allocations in the Prelate area, by aquifer

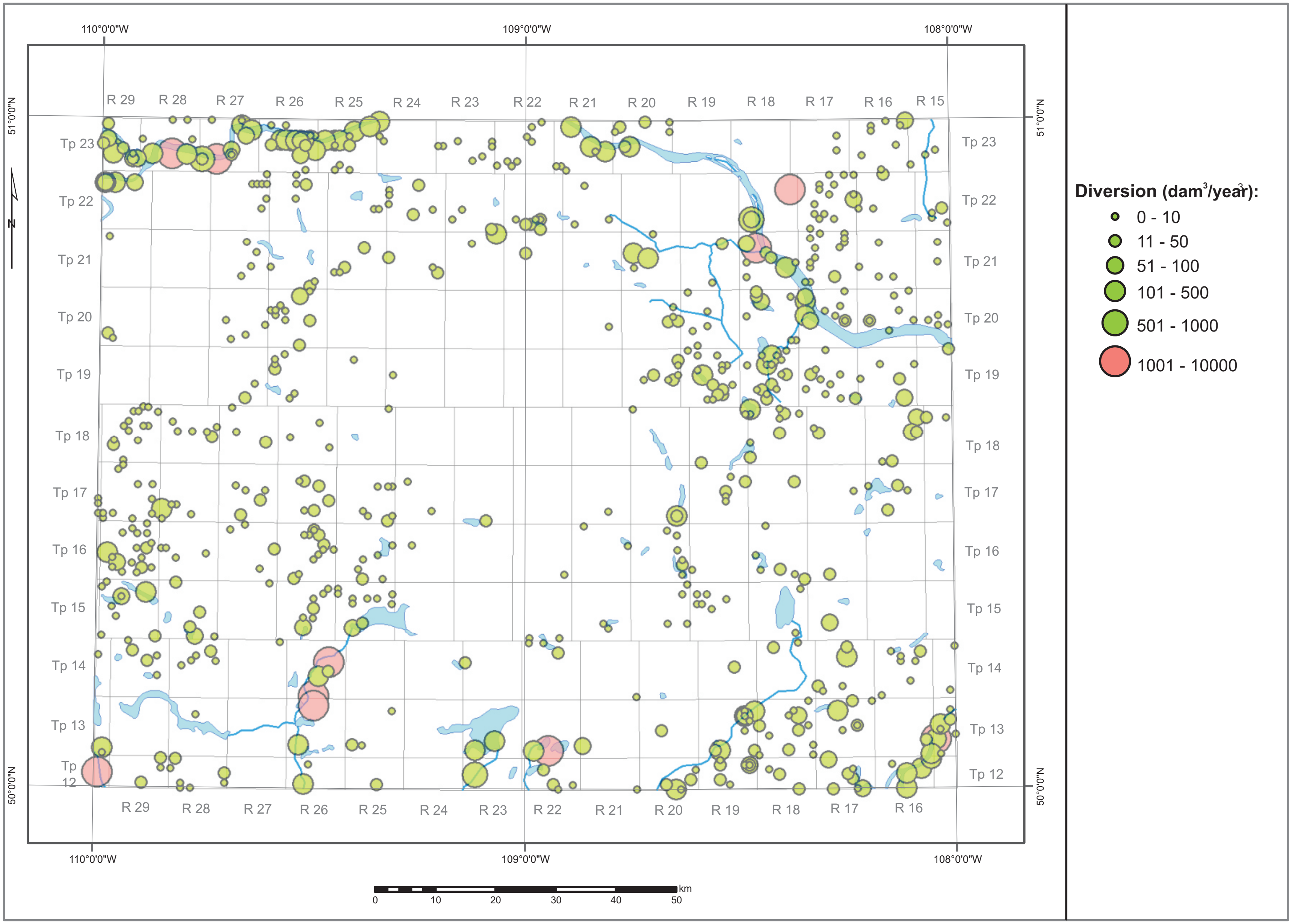


Figure 11 Locations of surface water diversions in the Prelate area

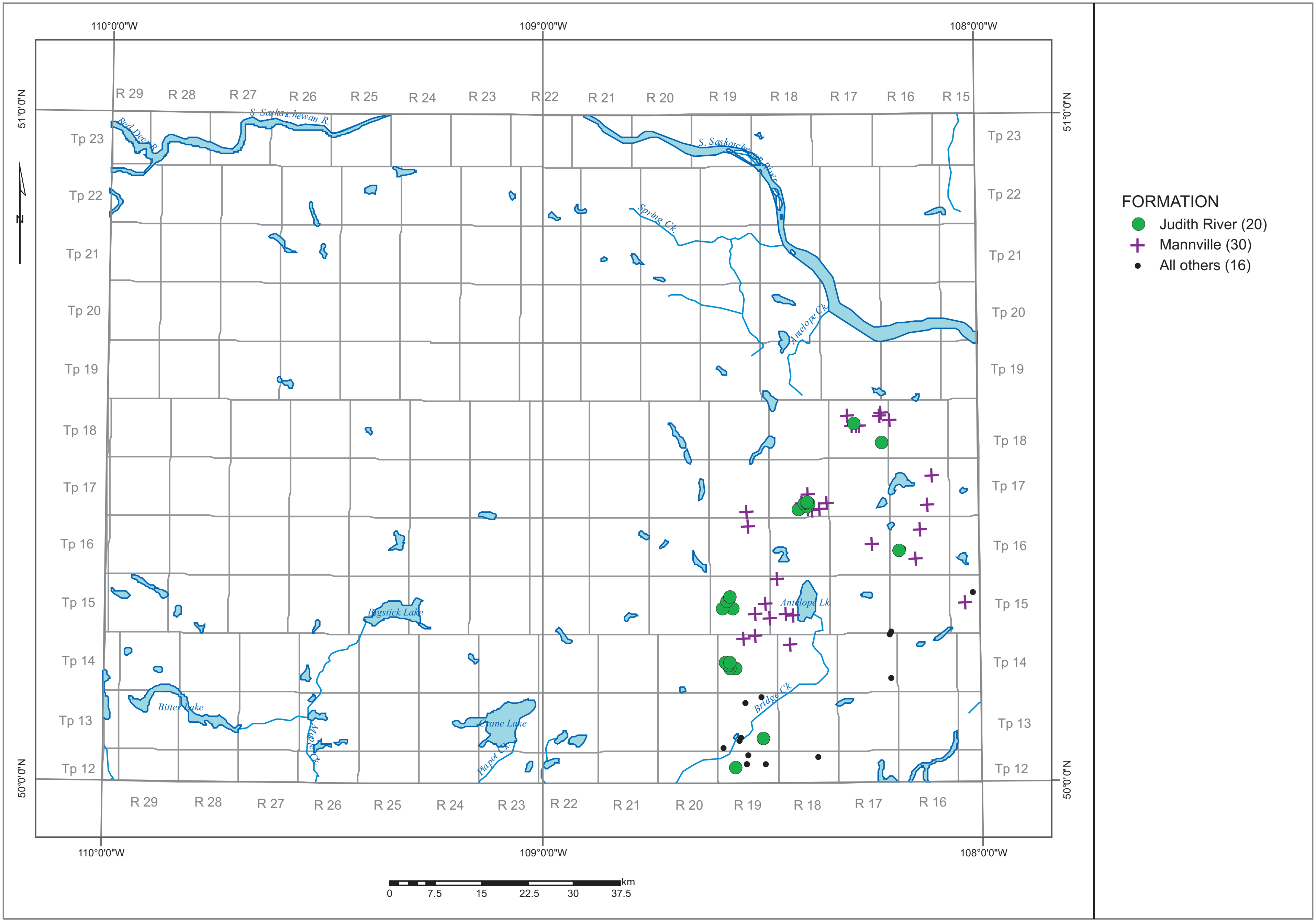


Figure 12 Locations of active source wells in the Prelate for enhanced oil recovery

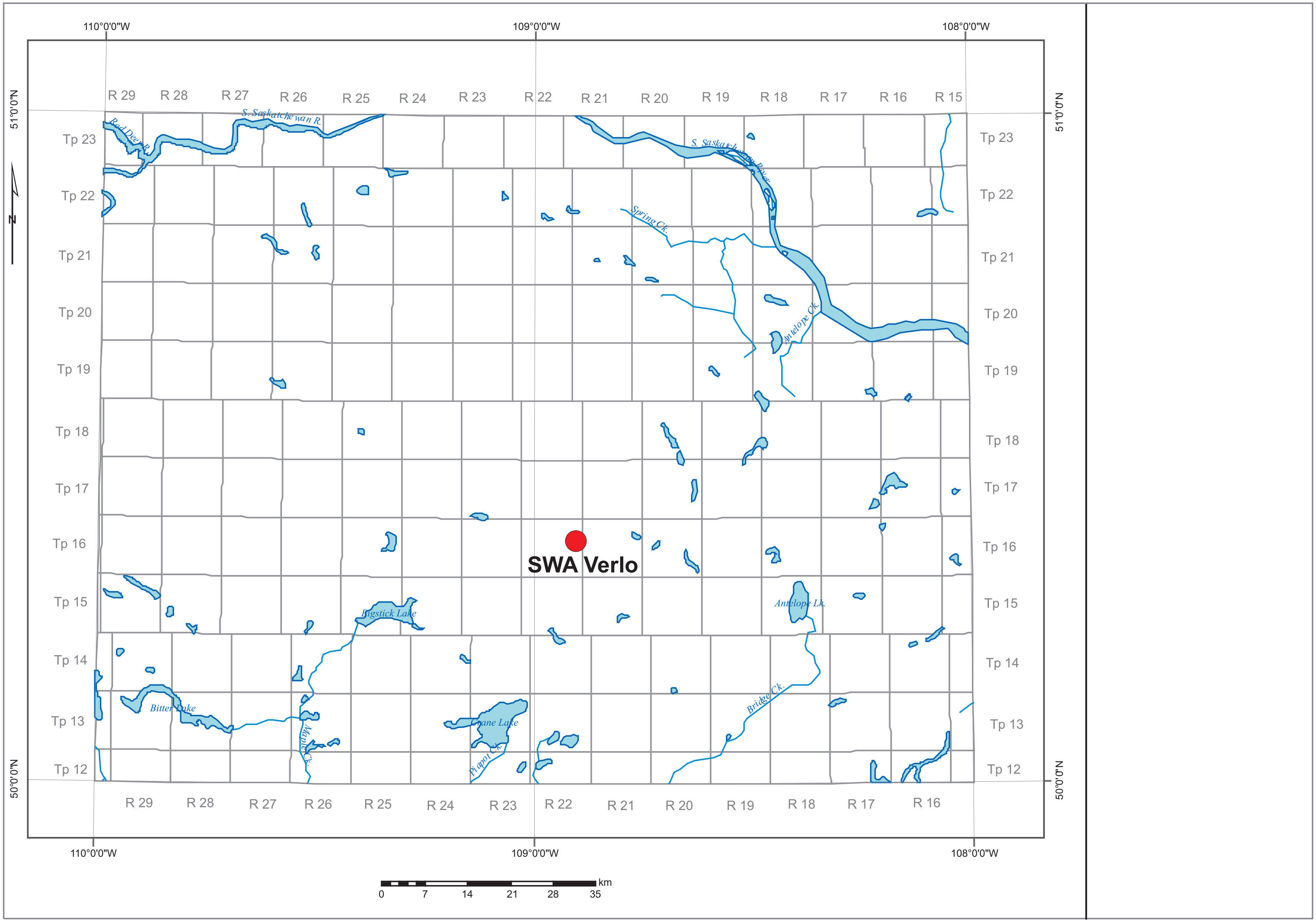
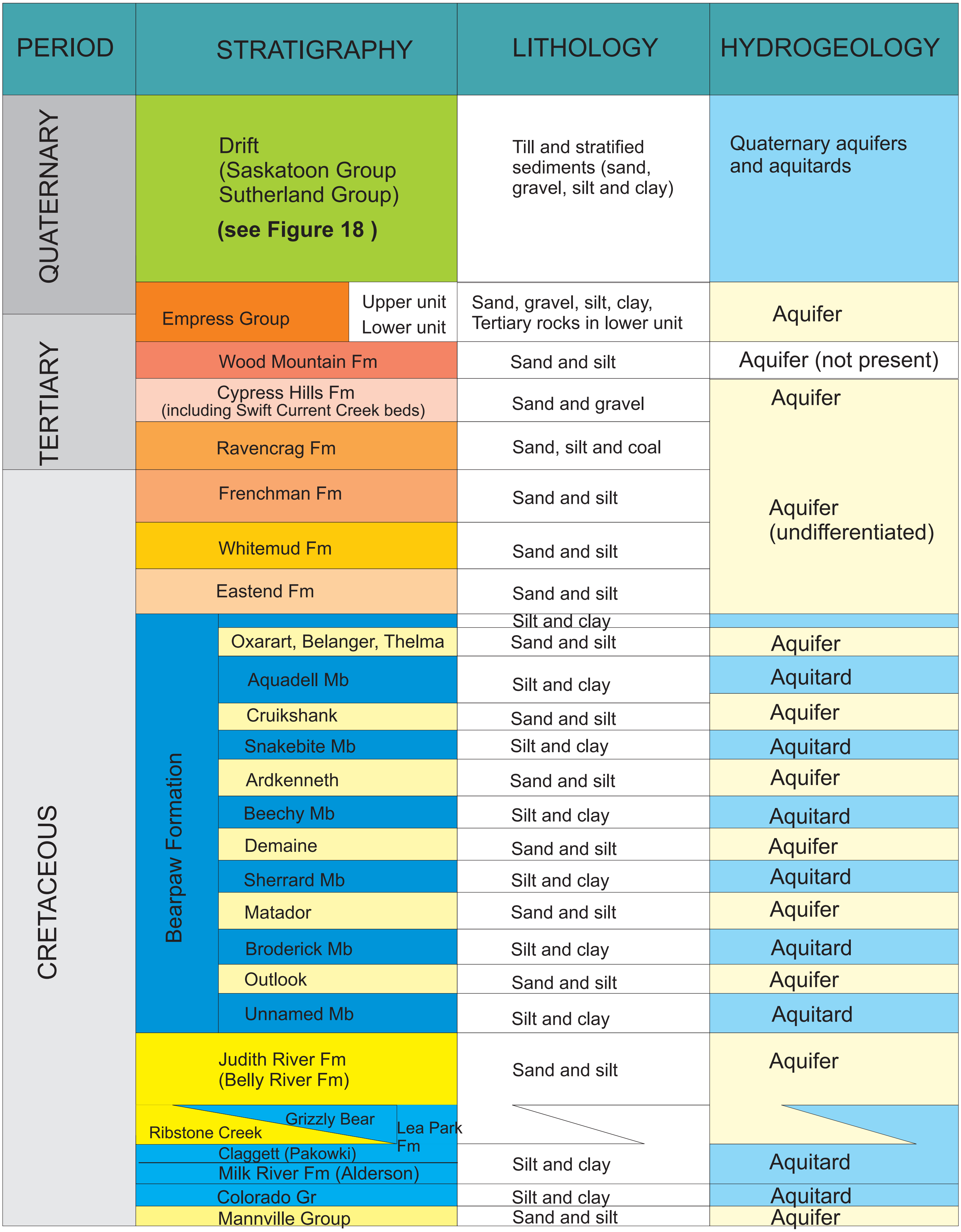


Figure 13 Location of provincial groundwater level observation well in the Prelate area



PERIOD	STRATIGRAPHY		LITHOLOGY	HYDROGEOLOGY
QUATERNARY	Drift (Saskatoon Group Sutherland Group) **(see Figure 18)**		Till and stratified sediments (sand, gravel, silt and clay)	Quaternary aquifers and aquitards
TERTIARY	Empress Group	Upper unit Lower unit	Sand, gravel, silt, clay, Tertiary rocks in lower unit	Aquifer
	Wood Mountain Fm		Sand and silt	Aquifer (not present)
	Cypress Hills Fm (including Swift Current Creek beds)		Sand and gravel	Aquifer
	Ravencrag Fm		Sand, silt and coal	
CRETACEOUS	Frenchman Fm		Sand and silt	Aquifer (undifferentiated)
	Whitemud Fm		Sand and silt	
	Eastend Fm		Sand and silt	
	Bearpaw Formation		Silt and clay	
		Oxarart, Belanger, Thelma	Sand and silt	Aquifer
		Aquadell Mb	Silt and clay	Aquitard
		Cruikshank	Sand and silt	Aquifer
		Snakebite Mb	Silt and clay	Aquitard
		Ardkenneth	Sand and silt	Aquifer
		Beechy Mb	Silt and clay	Aquitard
		Demaine	Sand and silt	Aquifer
		Sherrard Mb	Silt and clay	Aquitard
		Matador	Sand and silt	Aquifer
		Broderick Mb	Silt and clay	Aquitard
		Outlook	Sand and silt	Aquifer
		Unnamed Mb	Silt and clay	Aquitard
	Judith River Fm (Belly River Fm)		Sand and silt	Aquifer
	Ribstone Creek Grizzly Bear	Lea Park Fm		
	Claggett (Pakowki)		Silt and clay	Aquitard
	Milk River Fm (Alderson)			
	Colorado Gr		Silt and clay	Aquitard
	Mannville Group		Sand and silt	Aquifer

Figure 14 Schematic stratigraphical, lithological and hydrogeological settings of southwestern Saskatchewan (after Caldwell, 1968; Lomenda, 1973; Christiansen, 1992)

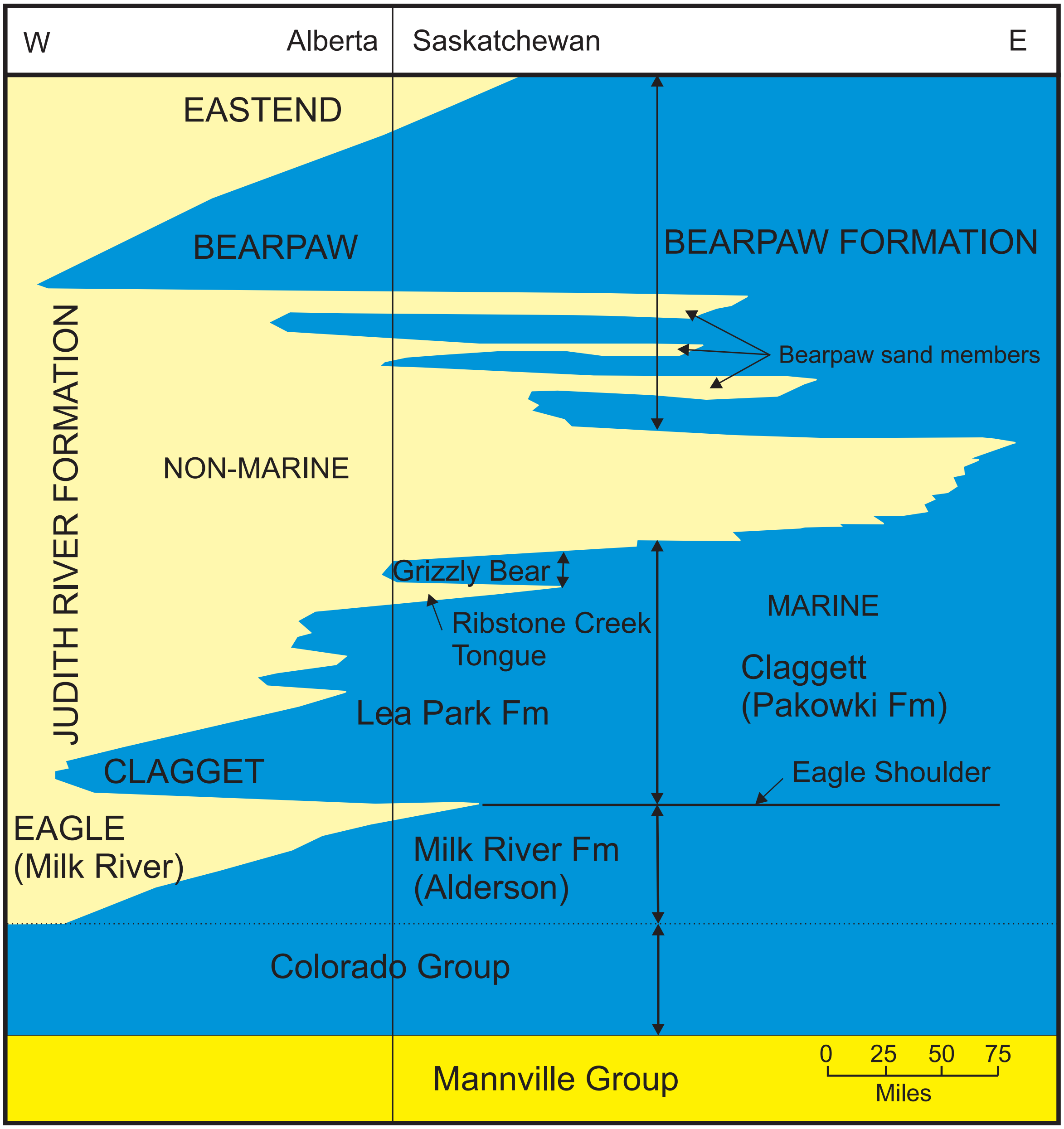


Figure 15 Schematic cross section through Late Cretaceous sediments in eastern Alberta and western Saskatchewan (after McLean, 1971)

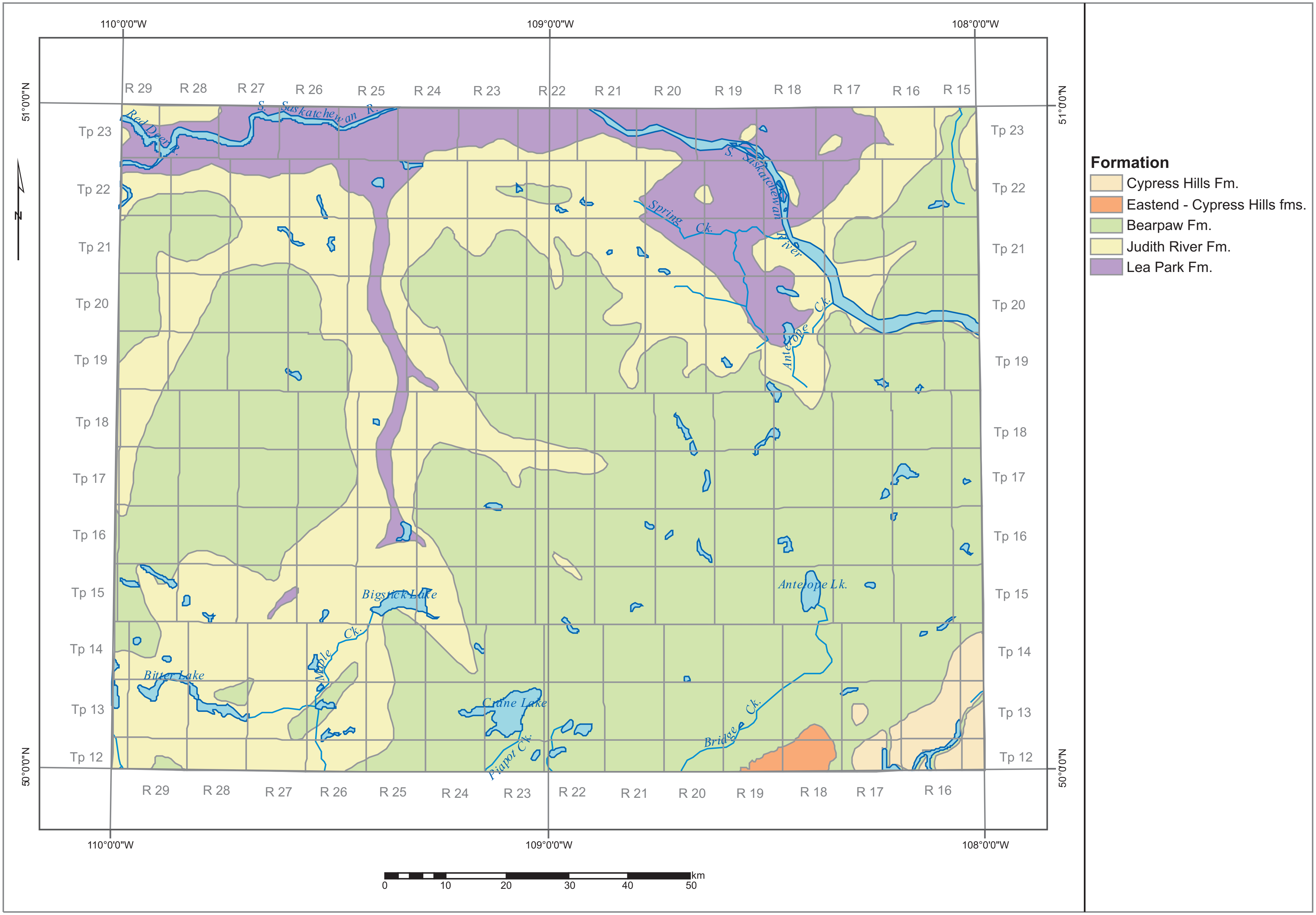


Figure 16 Bedrock geology of the Prelate area

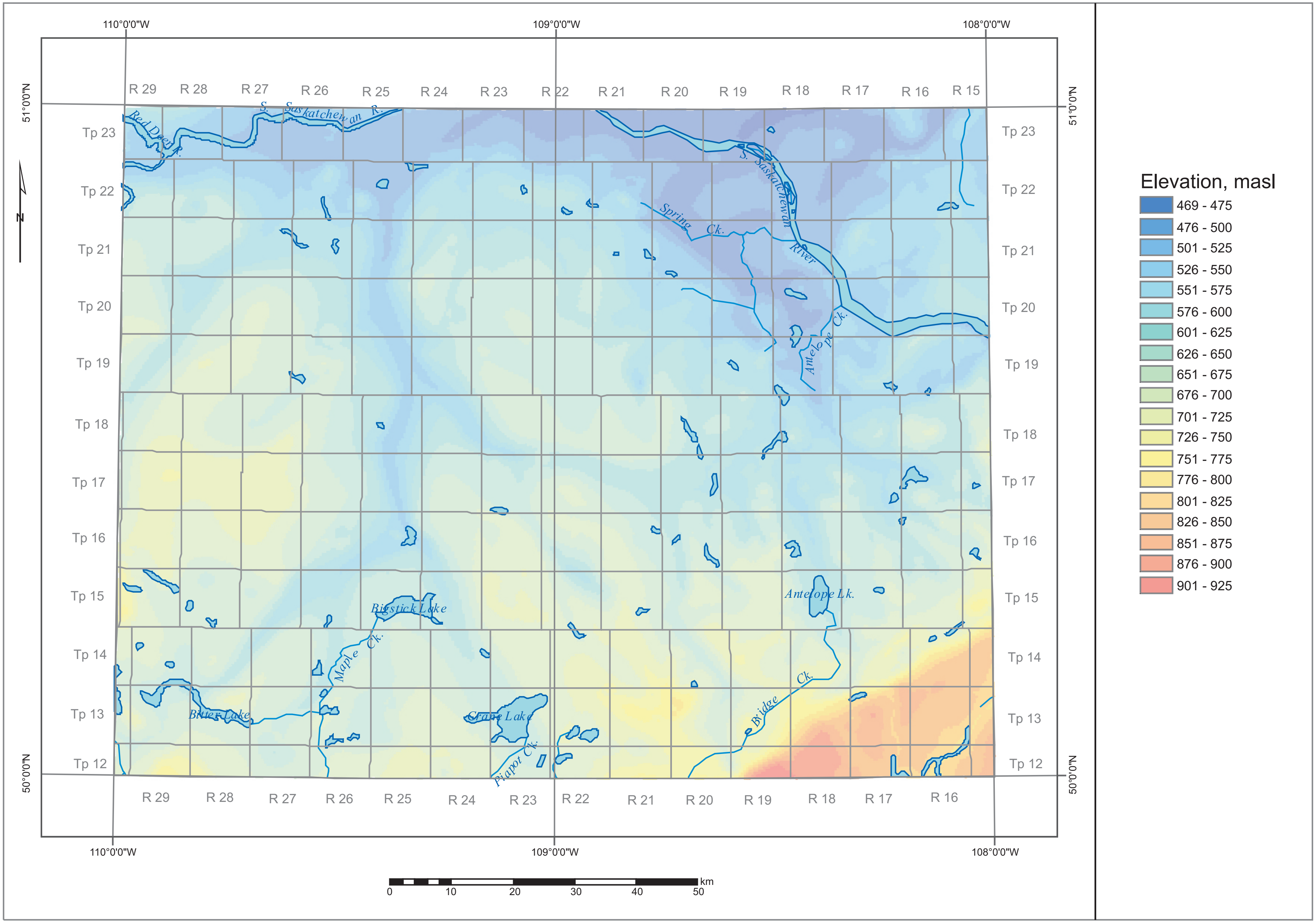
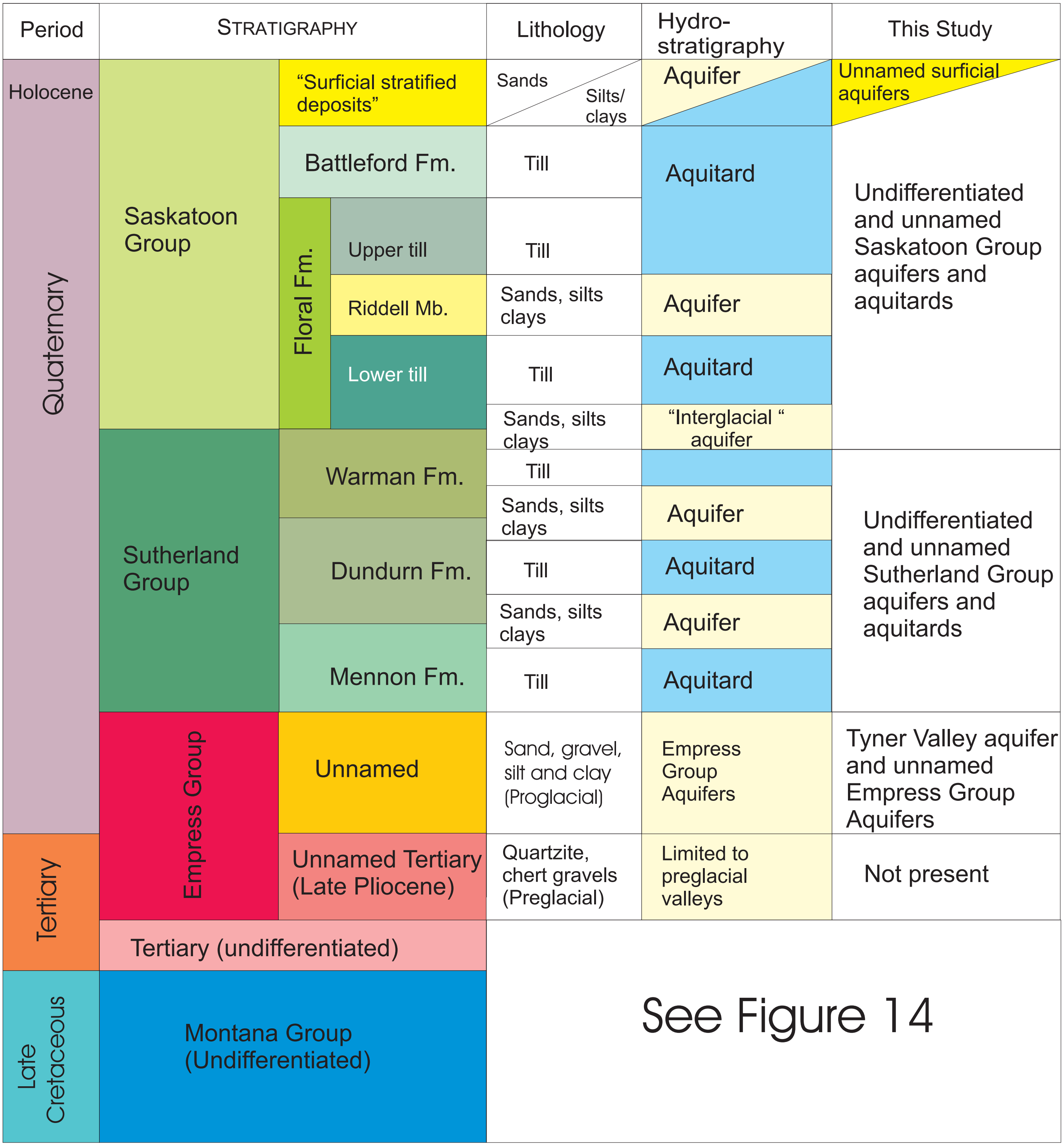


Figure 17 Bedrock surface topography in the Prelate area



Period	STRATIGRAPHY			Lithology	Hydro-stratigraphy	This Study
Holocene	Saskatoon Group	“Surficial stratified deposits”		Sands Silts/ clays	Aquifer	Unnamed surficial aquifers
Quaternary		Battleford Fm.		Till	Aquitard	Undifferentiated and unnamed Saskatoon Group aquifers and aquitards
		Floral Fm.	Upper till	Till		
			Riddell Mb.	Sands, silts clays	Aquifer	
			Lower till	Till	Aquitard	
				Sands, silts clays	“Interglacial “ aquifer	
	Sutherland Group	Warman Fm.		Till		Undifferentiated and unnamed Sutherland Group aquifers and aquitards
				Sands, silts clays	Aquifer	
		Dundurn Fm.		Till	Aquitard	
				Sands, silts clays	Aquifer	
		Mennon Fm.		Till	Aquitard	
	Empress Group	Unnamed		Sand, gravel, silt and clay (Proglacial)	Empress Group Aquifers	Tyner Valley aquifer and unnamed Empress Group Aquifers
Tertiary		Unnamed Tertiary (Late Pliocene)		Quartzite, chert gravels (Preglacial)	Limited to preglacial valleys	Not present
	Tertiary (undifferentiated)			See Figure 14		
Late Cretaceous	Montana Group (Undifferentiated)					

Figure 18 Schematic stratigraphic, lithologic, and hydrogeologic settings of the Quaternary deposits. (Stratigraphy after Christiansen, 1992)

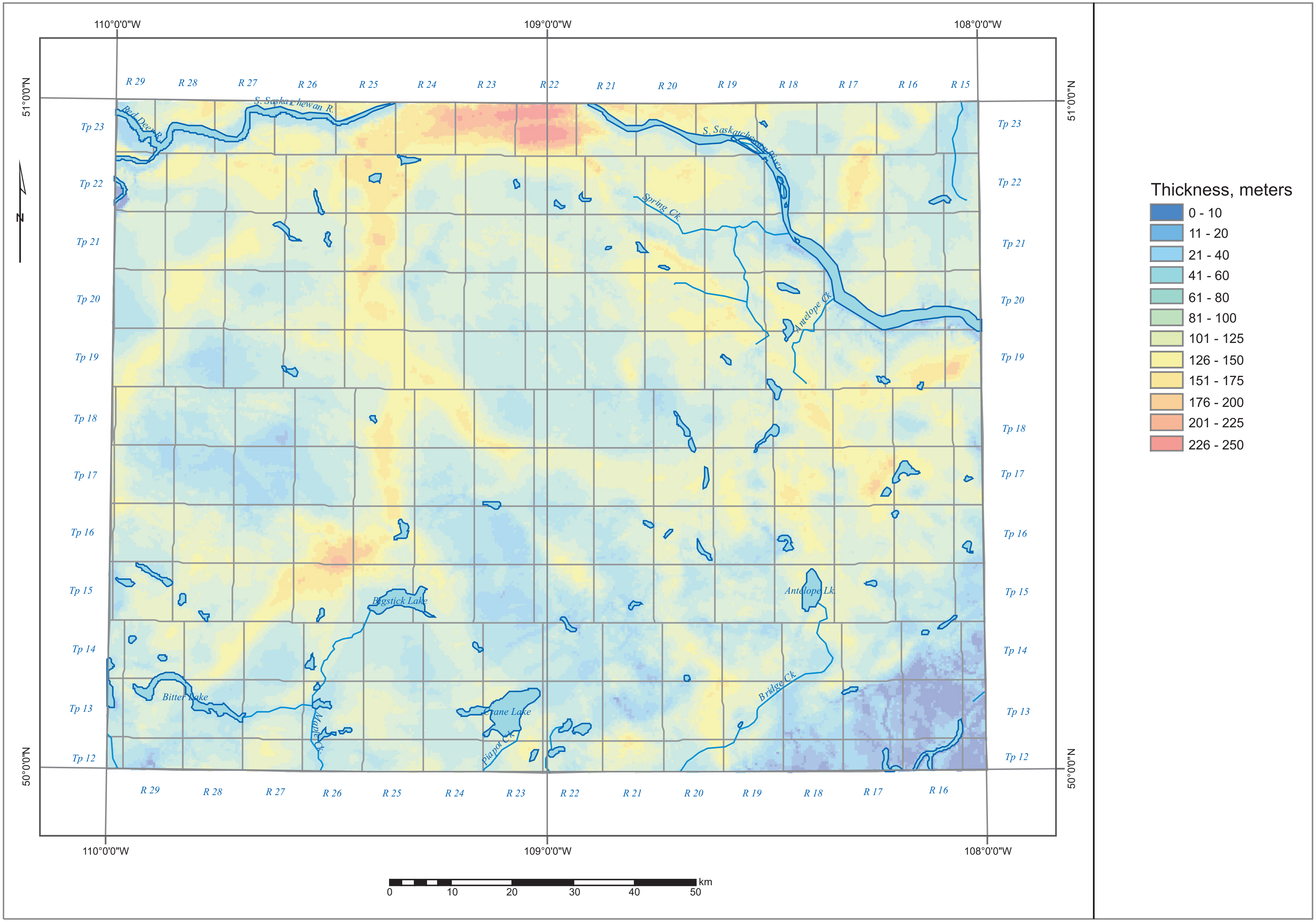


Figure 19 Thickness of the drift in the Prelate area

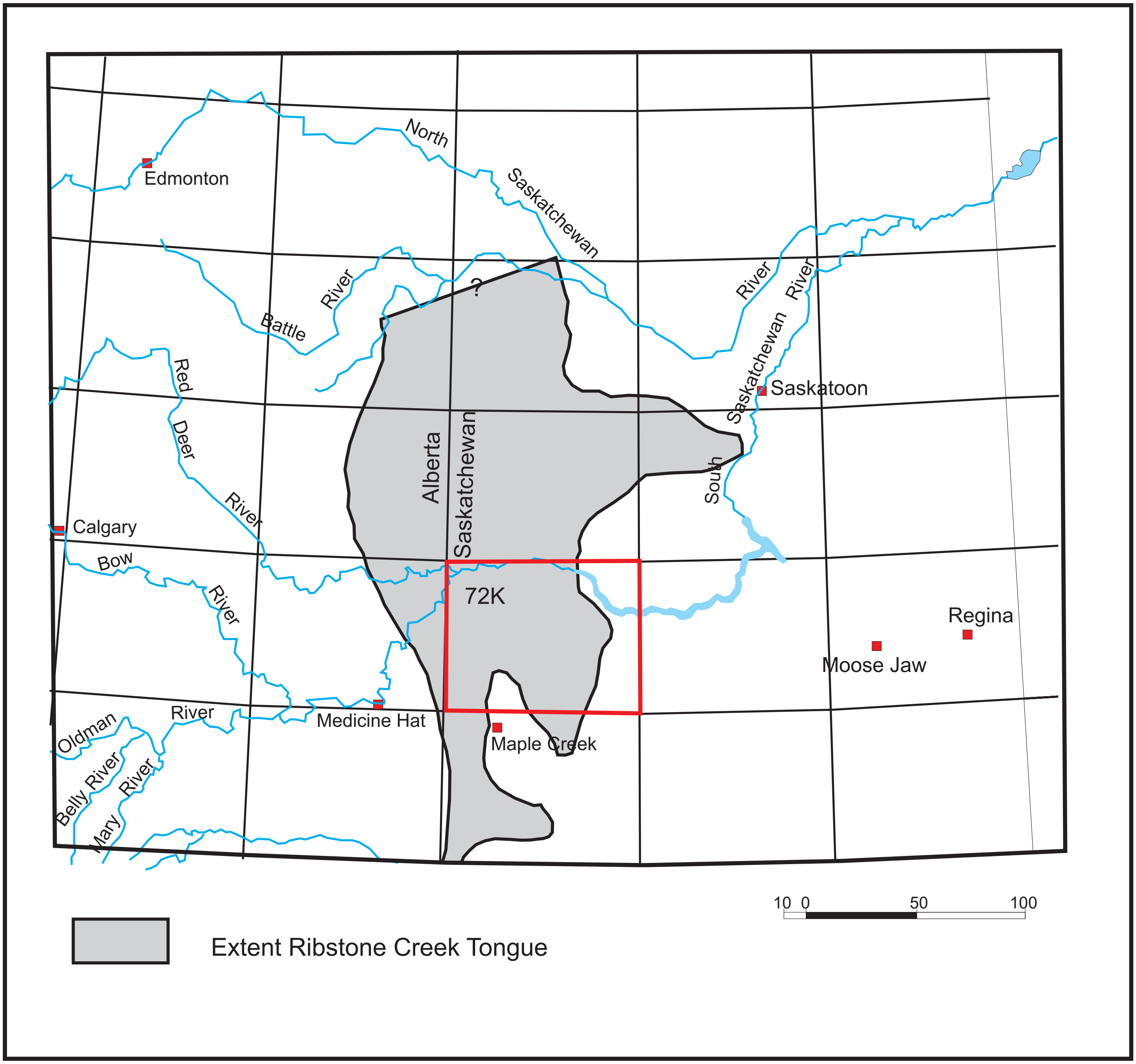


Figure 20 Extent of the Ribstone Creek aquifer in Saskatchewan and Alberta

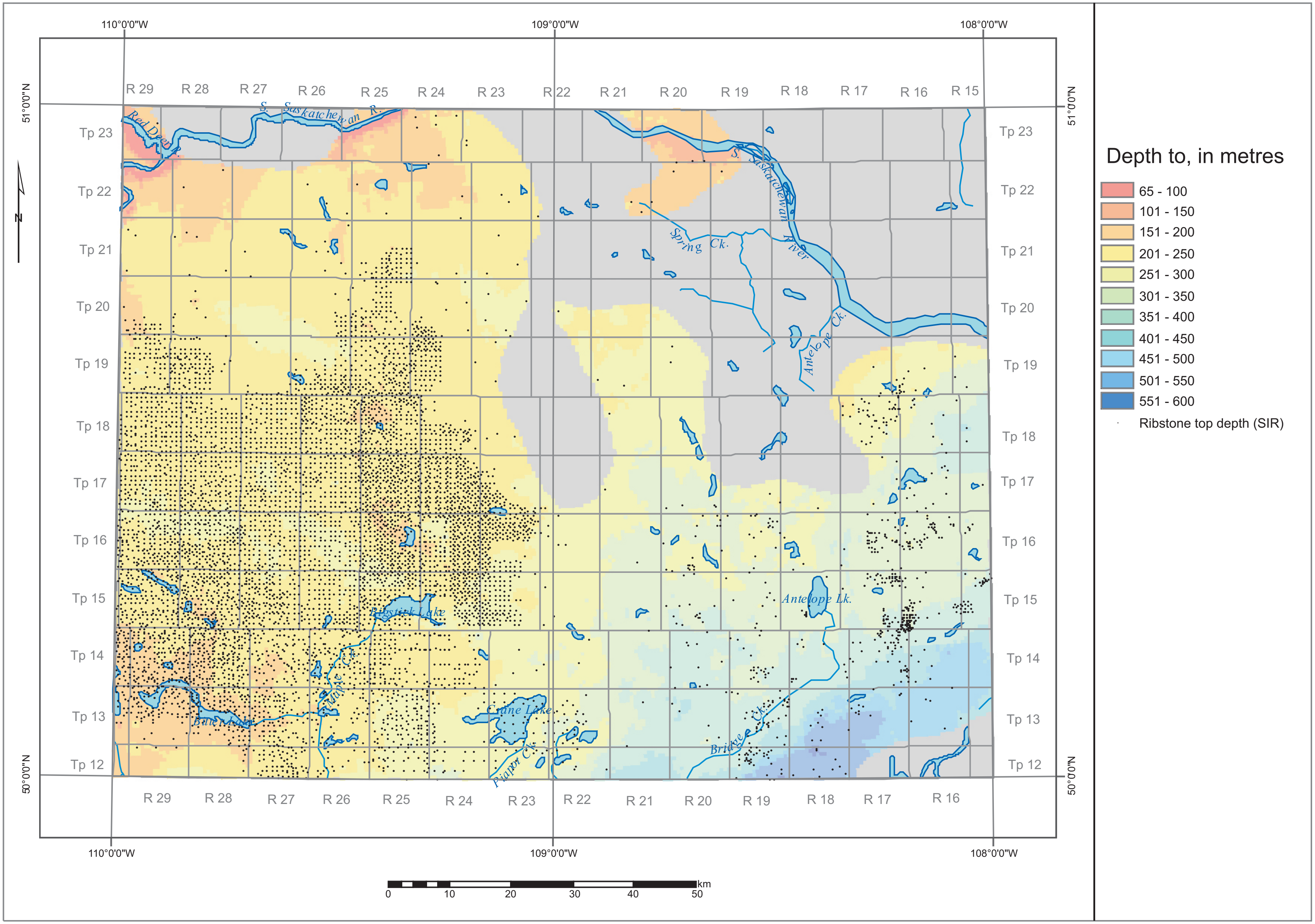


Figure 21 Extent of and depth to the top of the Ribstone Creek Tongue in the Prelate area

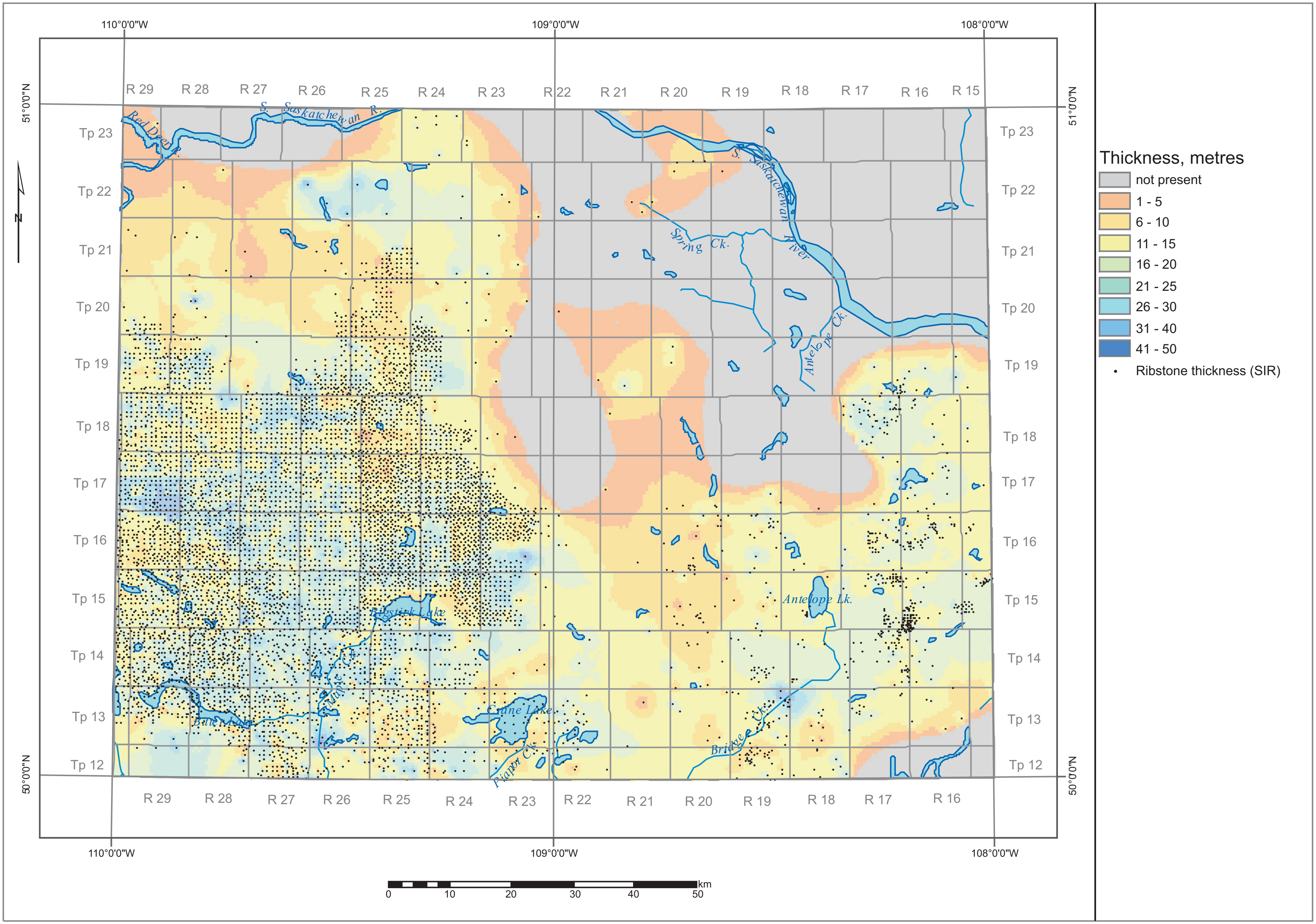


Figure 22 Thickness of the Ribstone Creek Tongue in the Prelate area

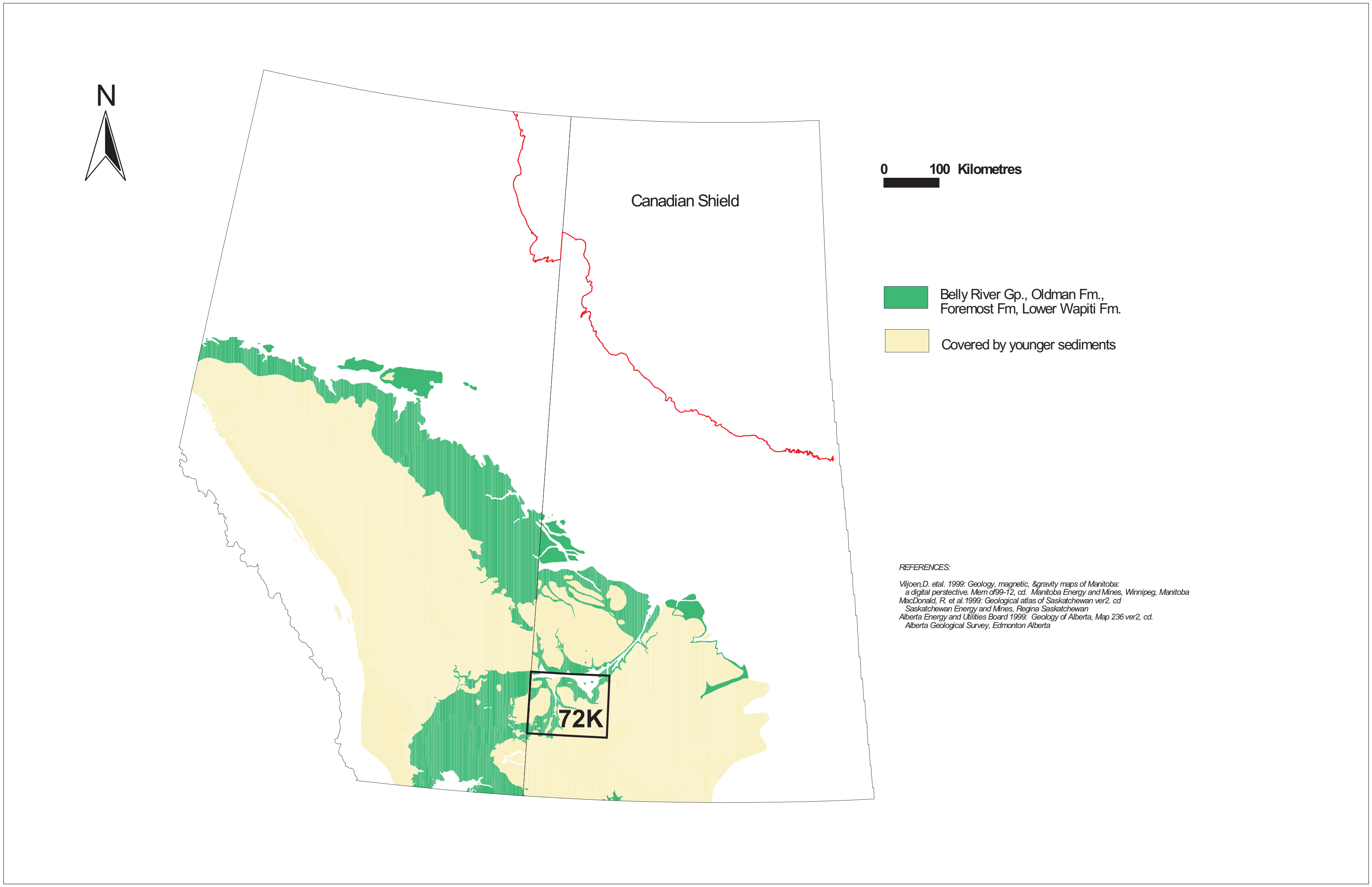


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Figure 23 Extent of the Judith River Formation in Saskatchewan and Alberta

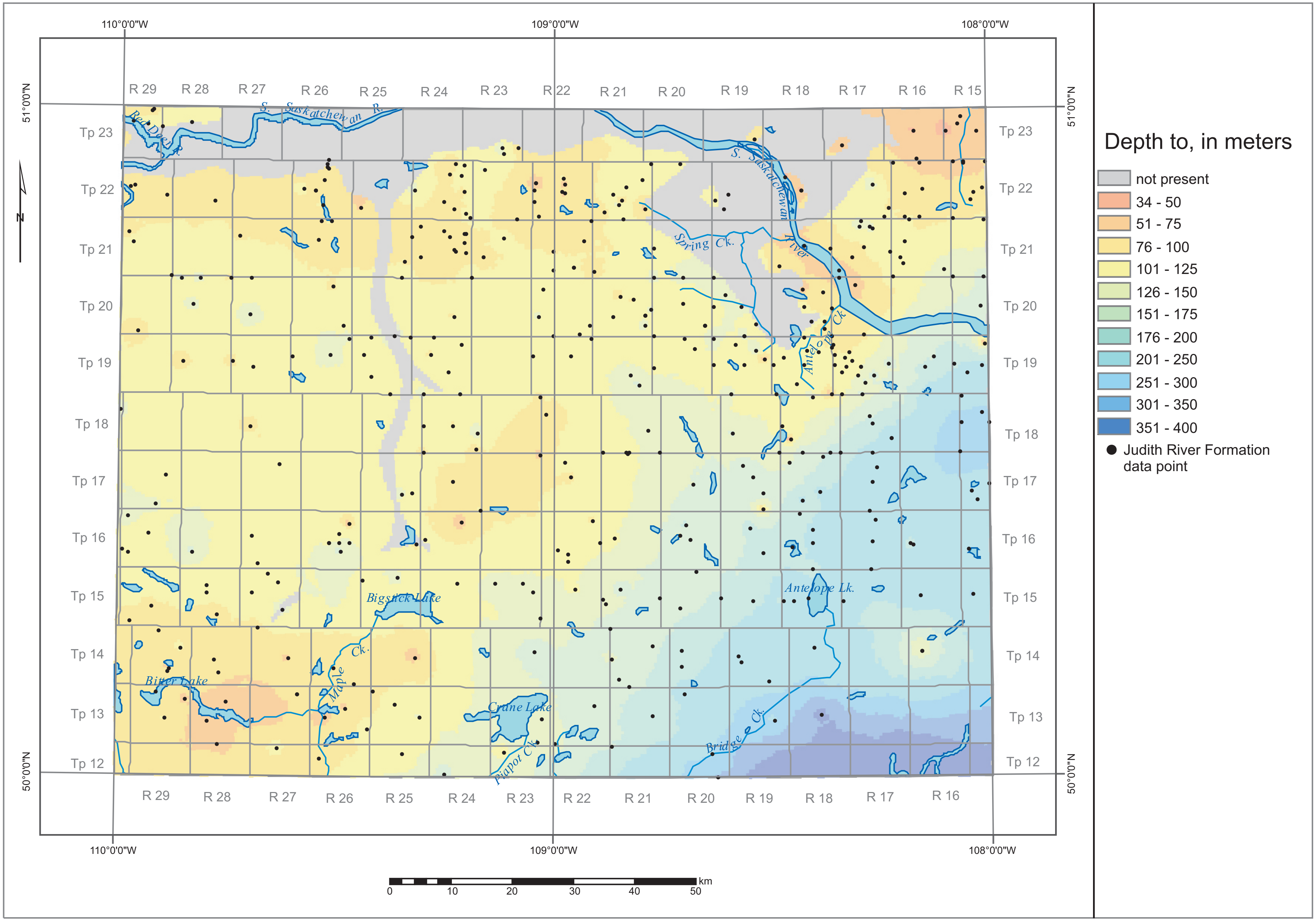


Figure 24 Extent and depth to the top of the Judith River Formation in the Prelate area

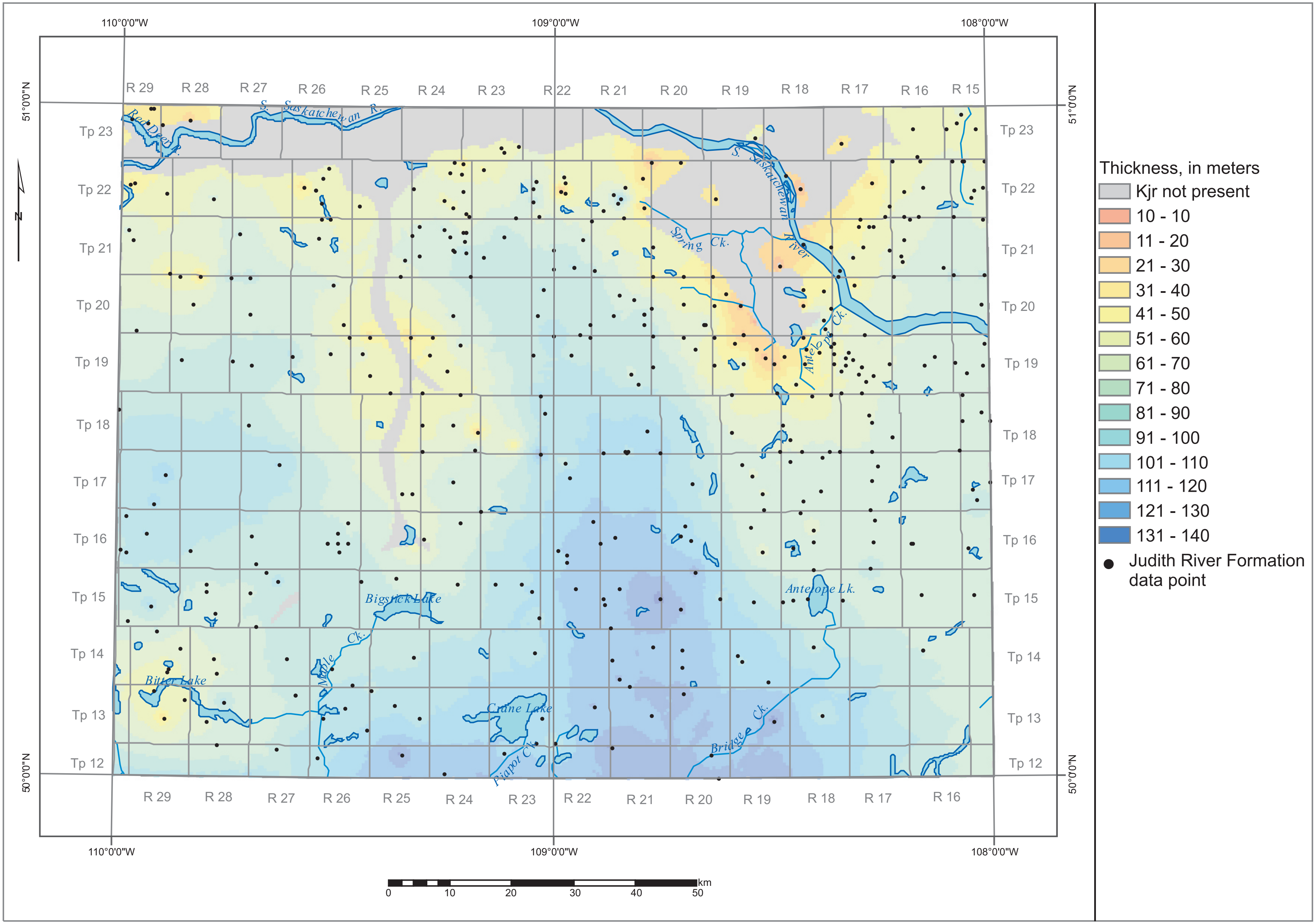


Figure 25 Thickness of the Judith River Formation in the Prelate area

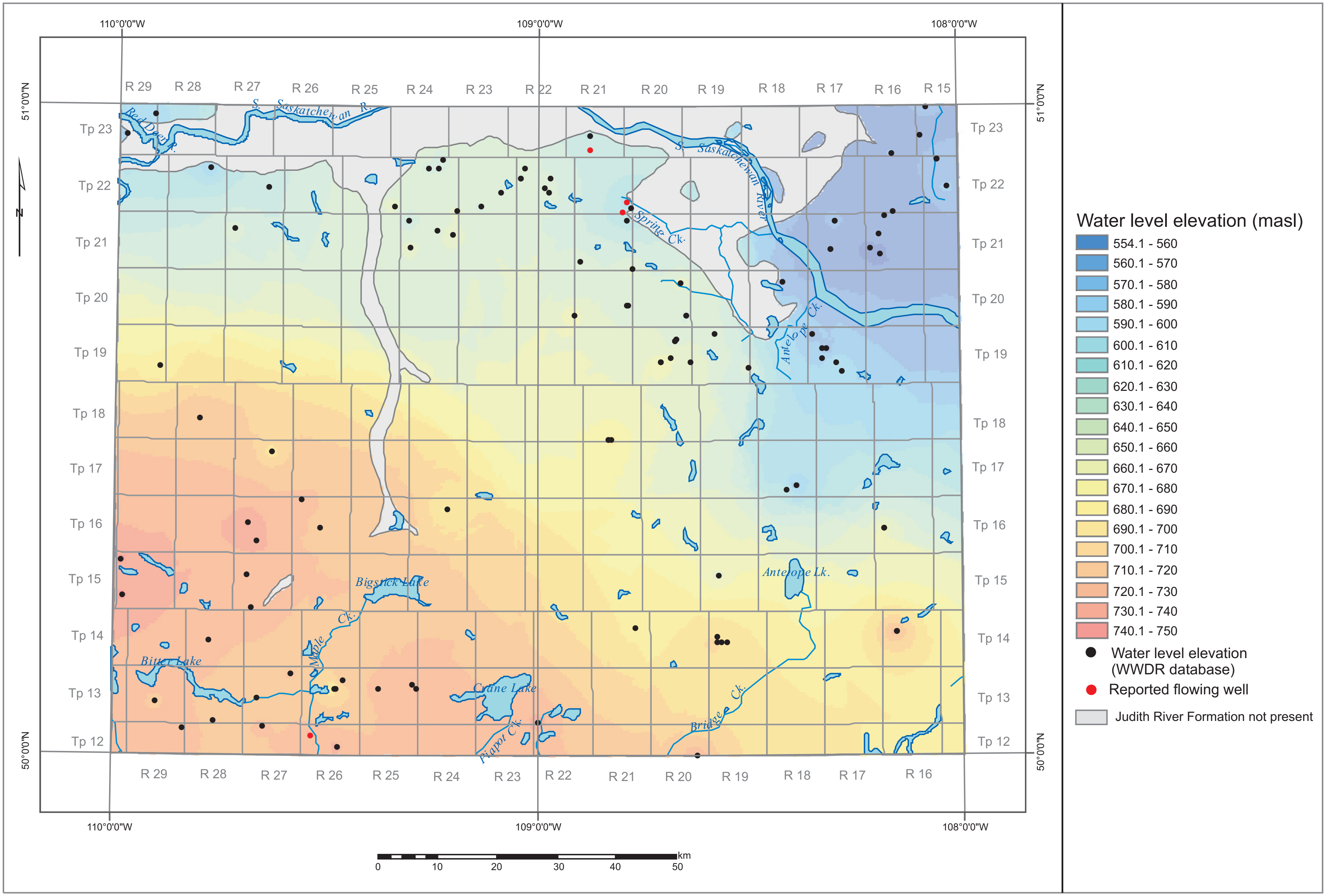
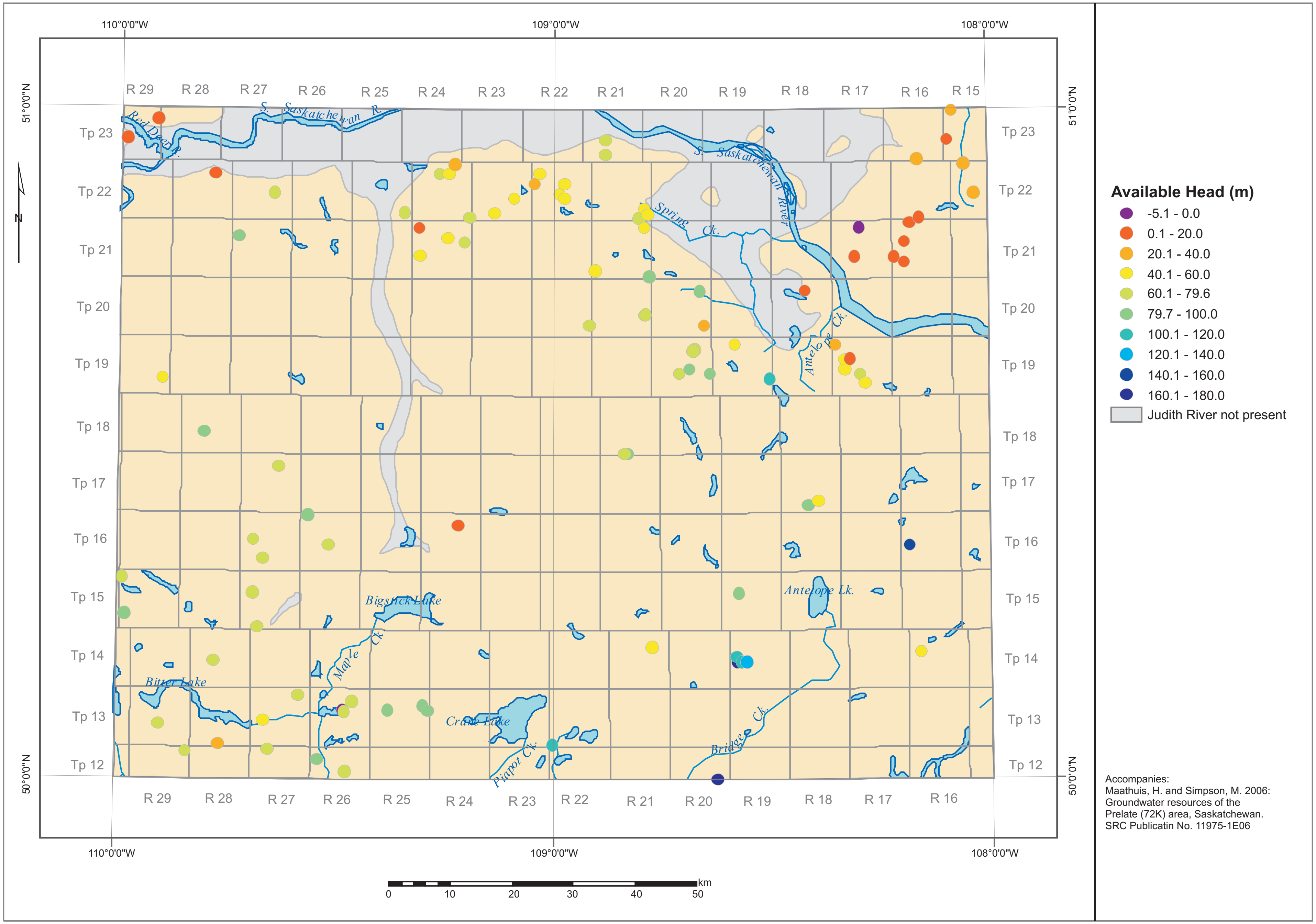


Figure 26 Distribution of water level elevations in the Judith River aquifer in the Prelate area



Accompanies:
Maathuis, H. and Simpson, M. 2006:
Groundwater resources of the
Prelate (72K) area, Saskatchewan.
SRC Publicatin No. 11975-1E06

Figure 27 Available drawdown in wells completed in the Judith River aquifer in the Prelate area

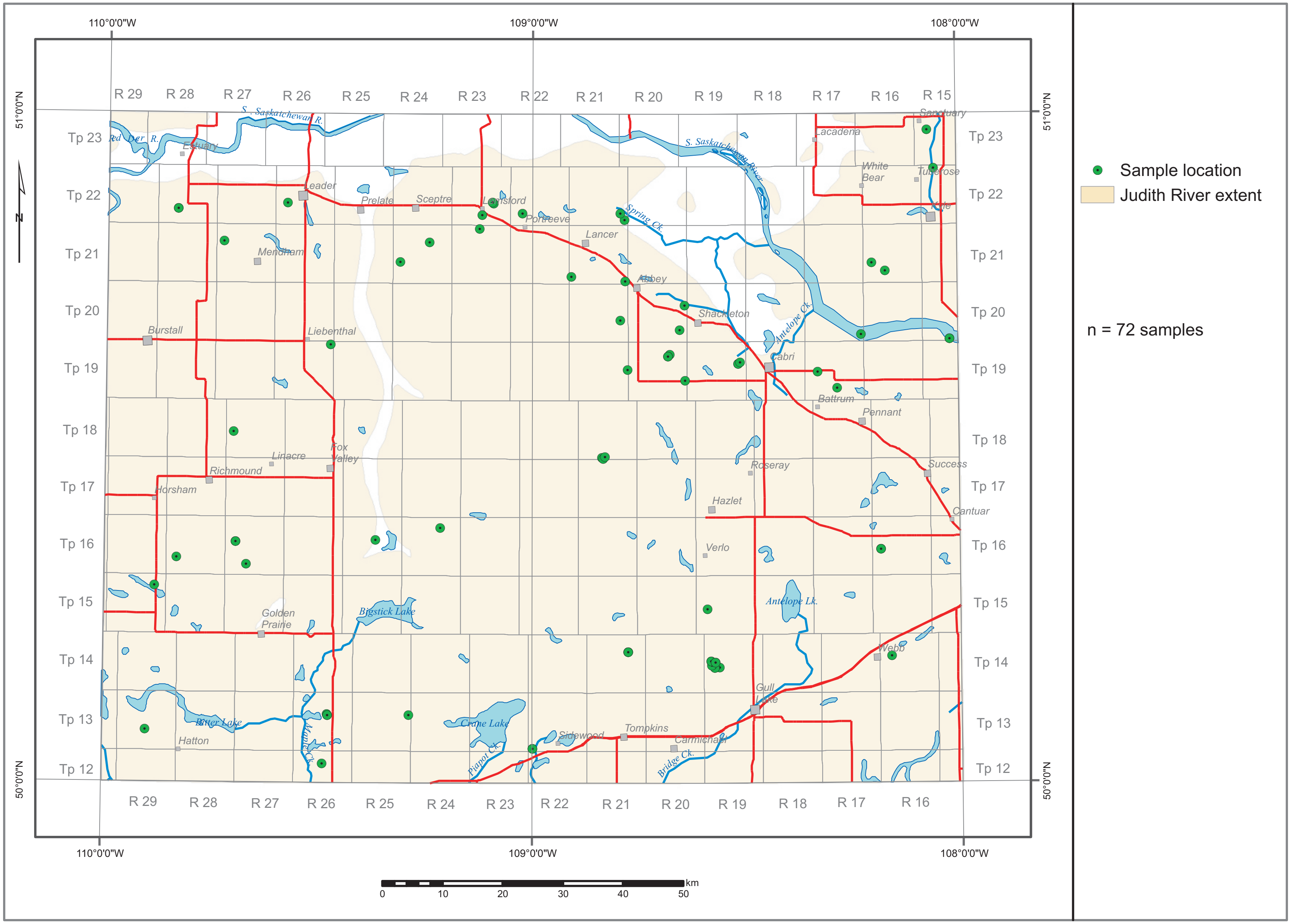


Figure 28 Locations of groundwater samples from the Judith River aquifer

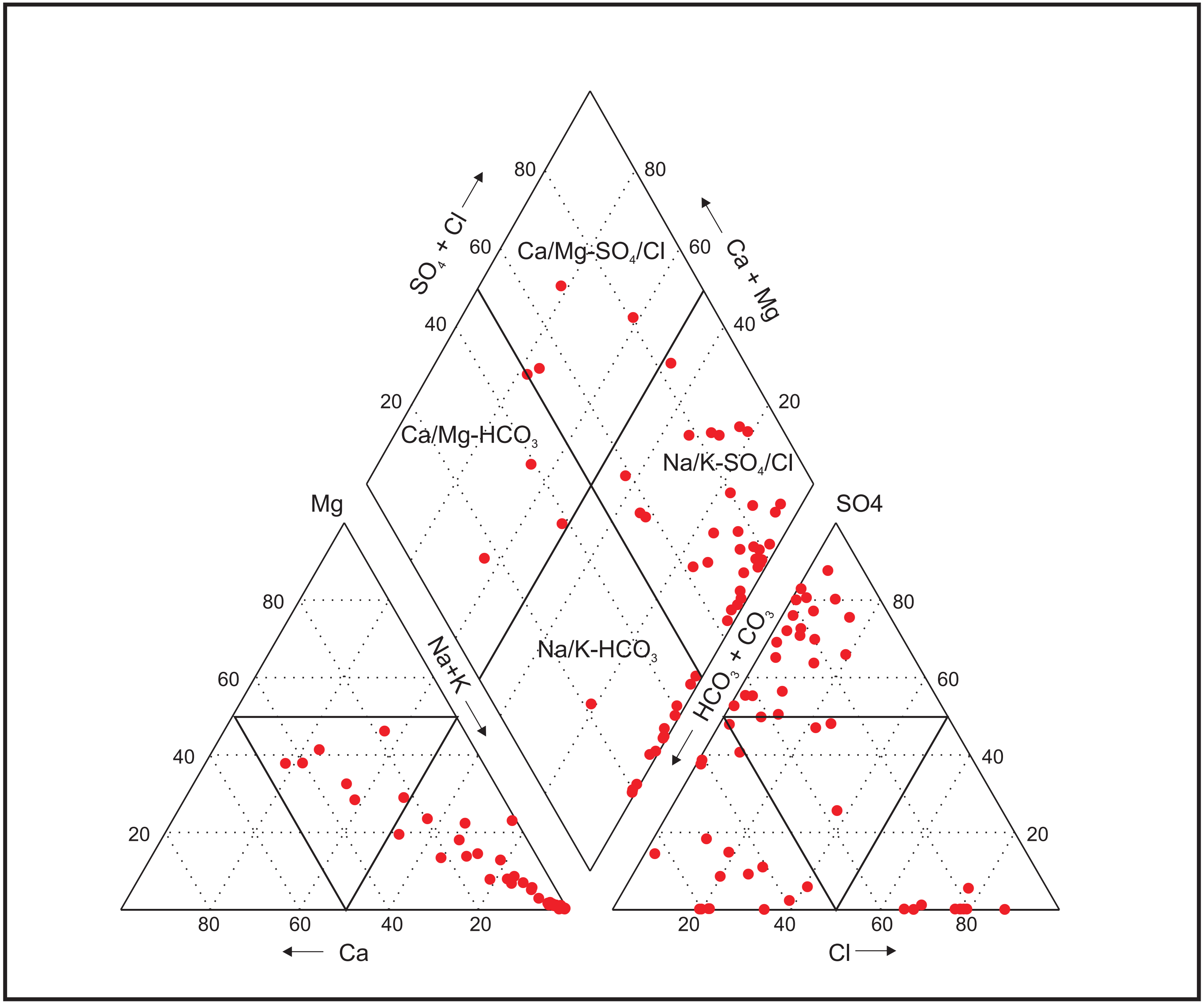


Figure 29 Piper-plot of water quality data for the Judith River aquifer in the Prelate area

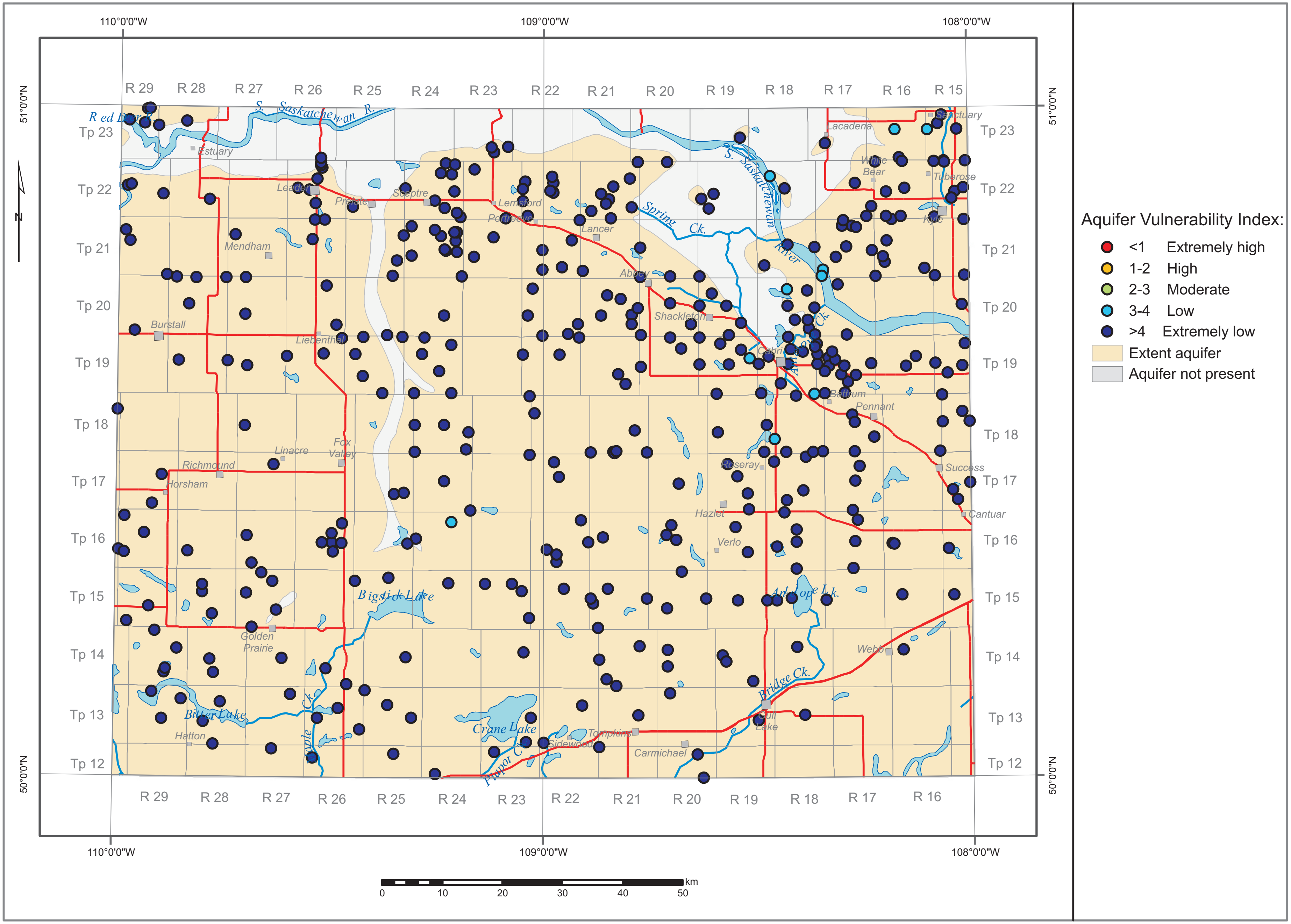


Figure 30 Aquifer vulnerability index (AVI) for the Judith River aquifer in the Prelate area

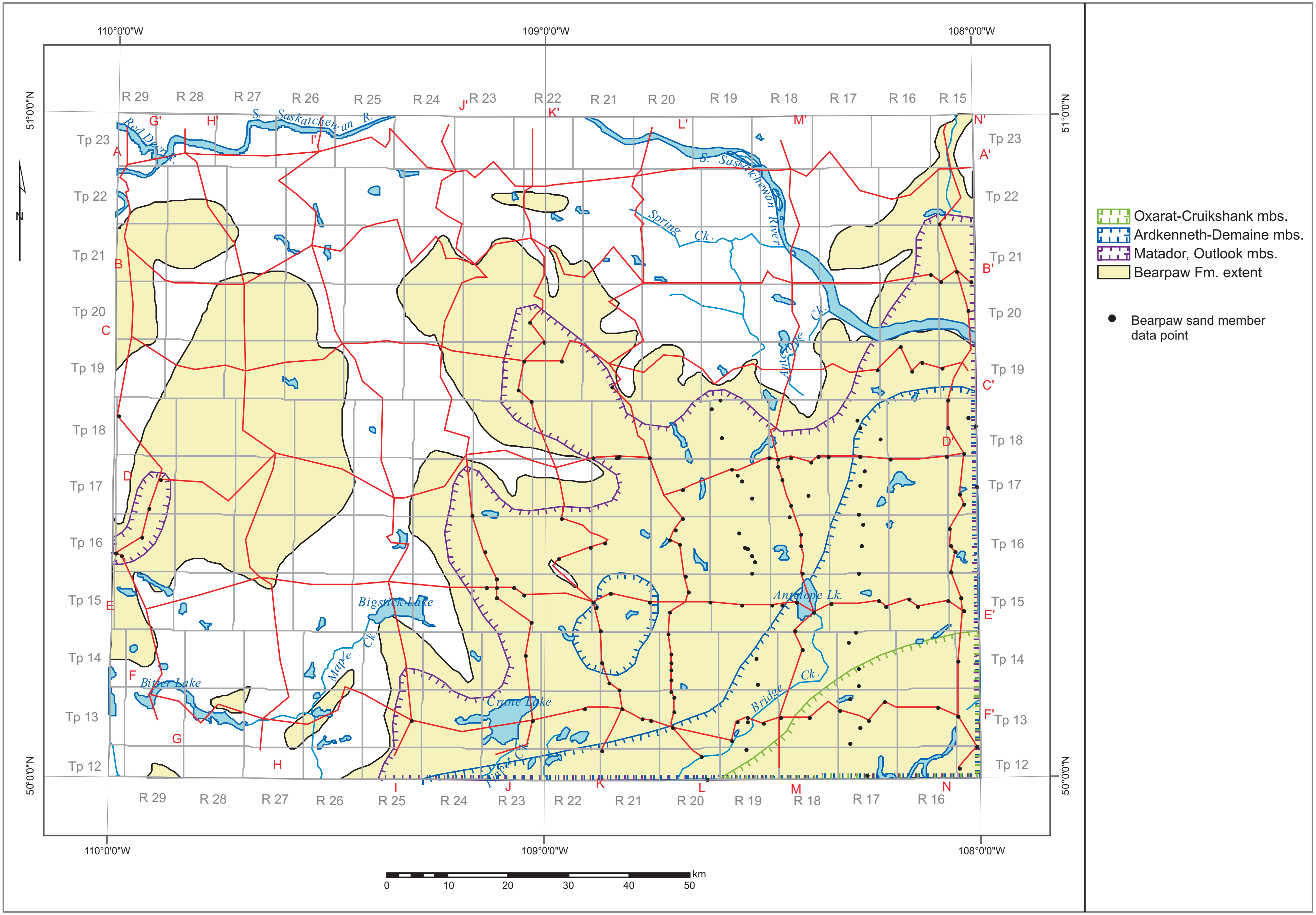


Figure 31 Extent of aquifers formed by Bearpaw Formation sand members in the Prelate area

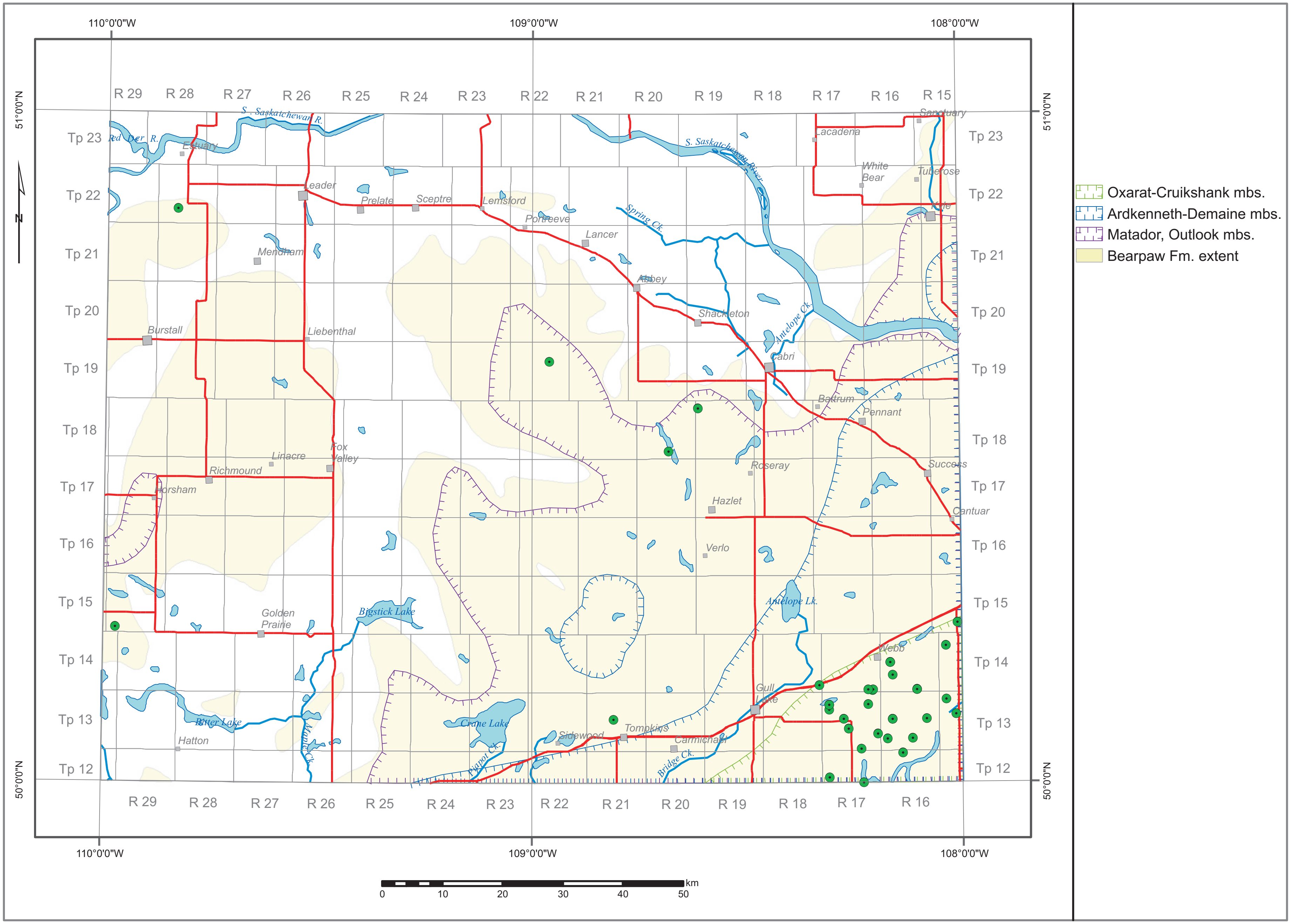


Figure 32 Locations of groundwater samples from Bearpaw Formation sands in the Prelate area

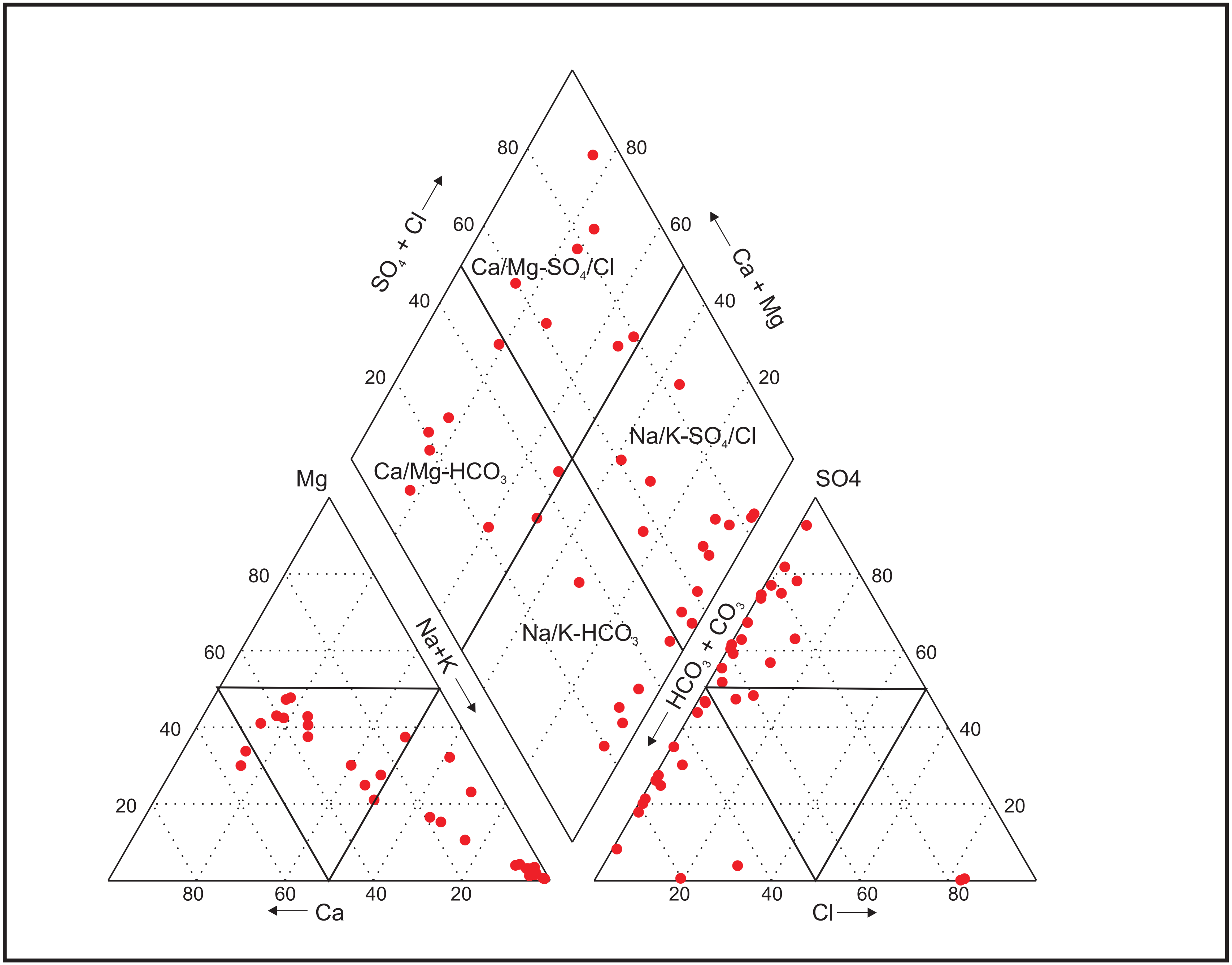


Figure 33 Piper-plot of groundwater quality data for Bearpaw sands in the Prelate area

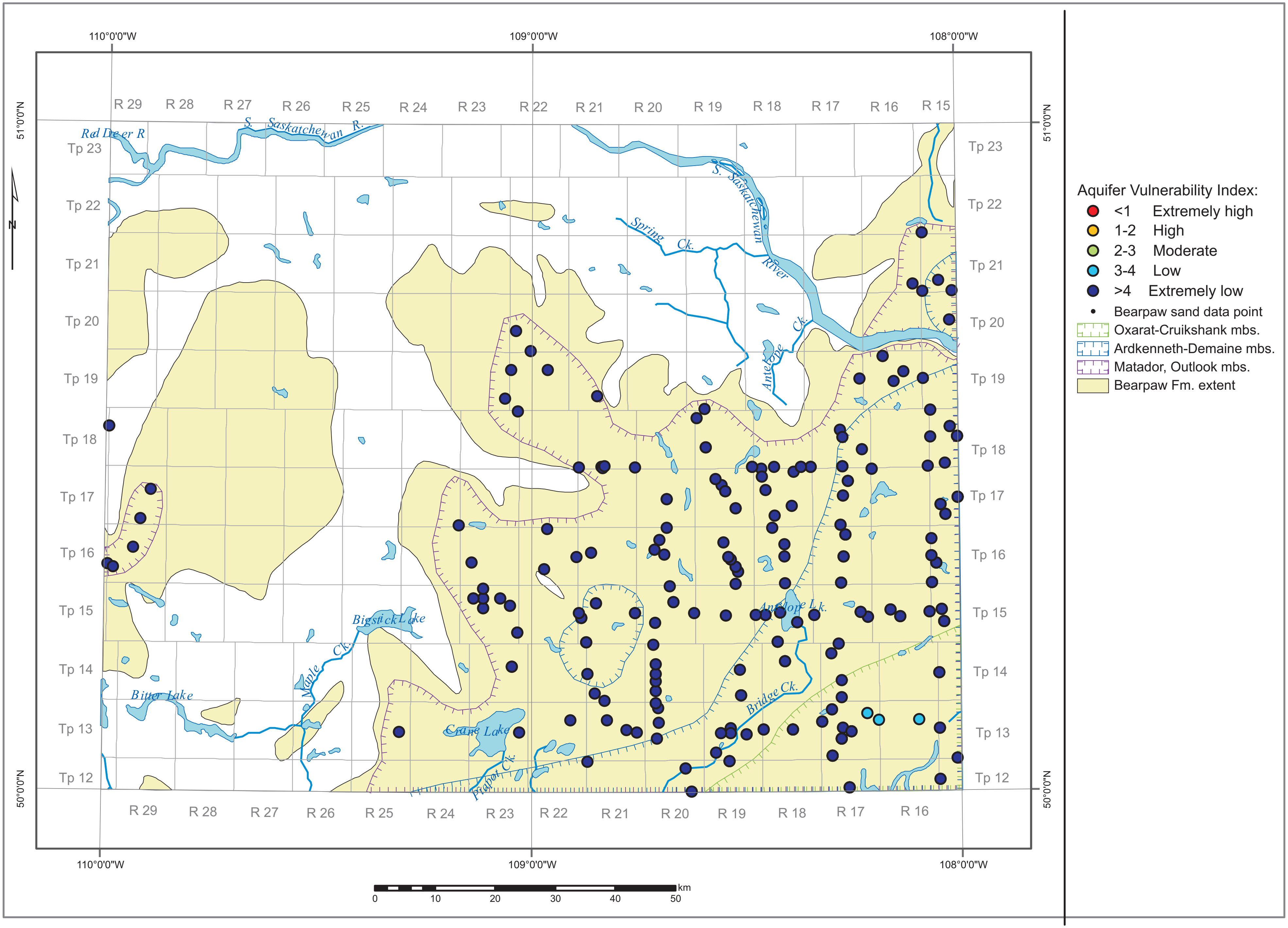


Figure 34 Aquifer vulnerability index (AVI) for the Bearpaw sand members aquifer in the Prelate area

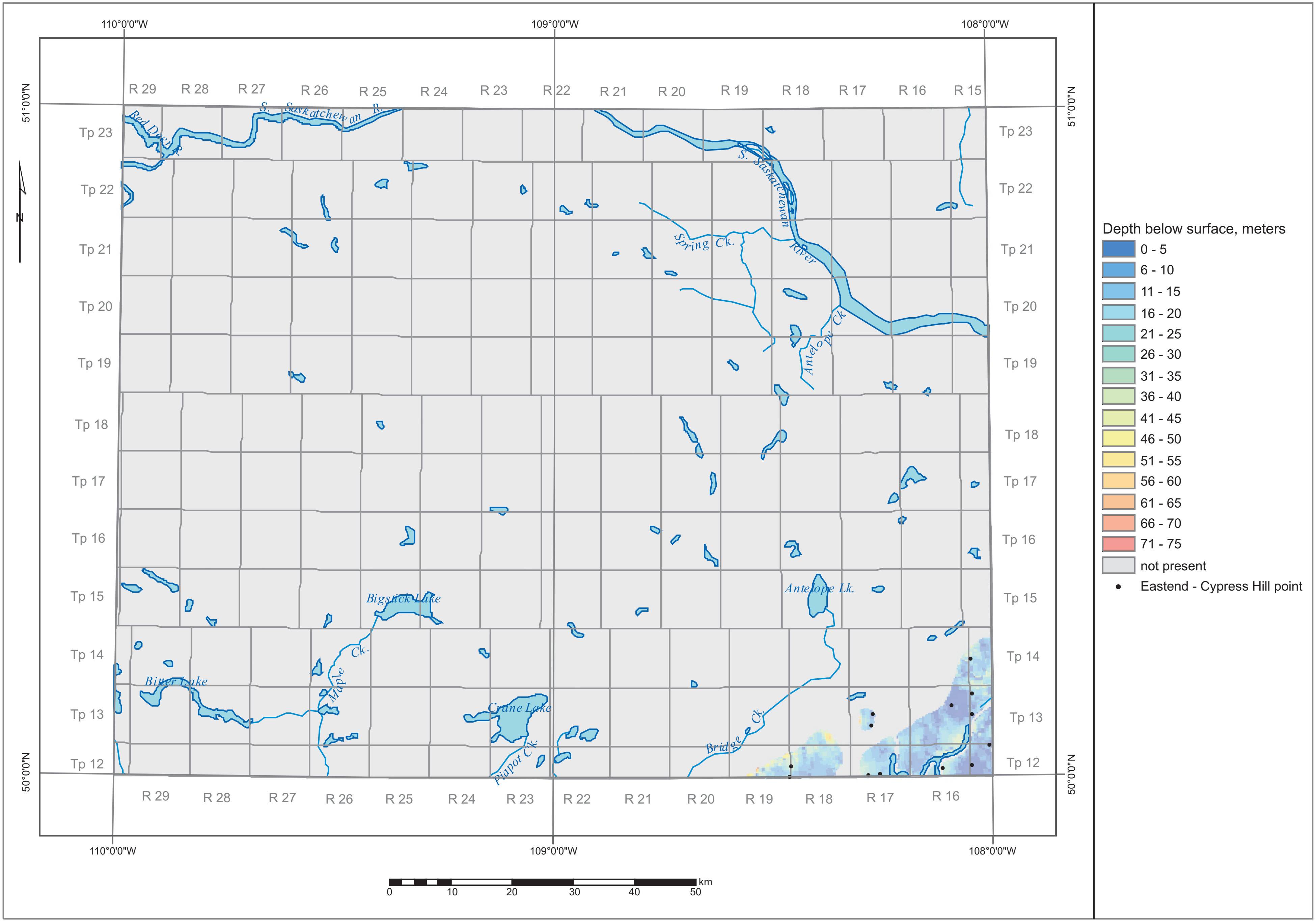


Figure 35 Extent of and depth to Eastend - Cypress Hills aquifer in the Prelate area

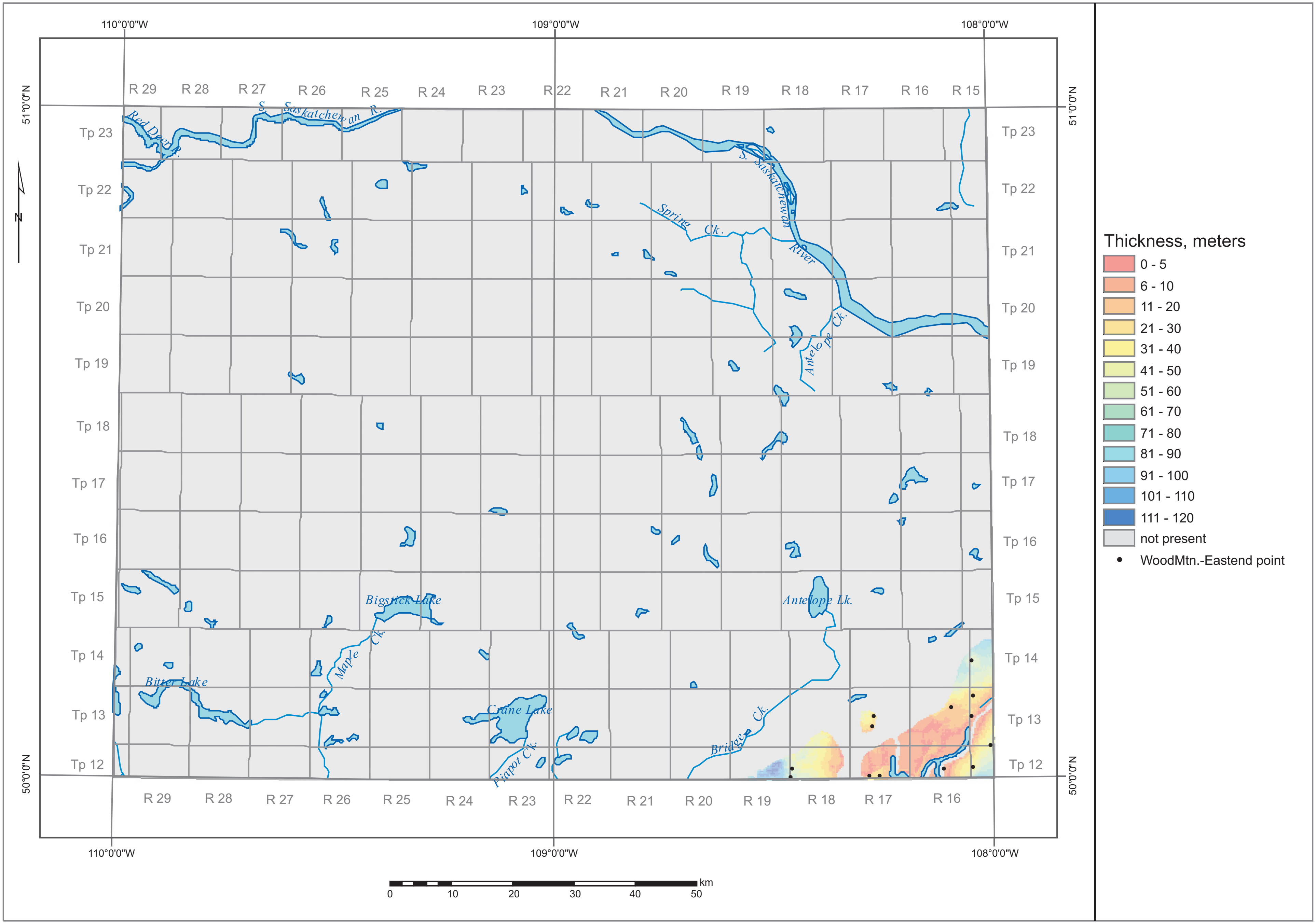


Figure 36 Thickness of the Eastend - Cypress Hills aquifer in the Prelate area

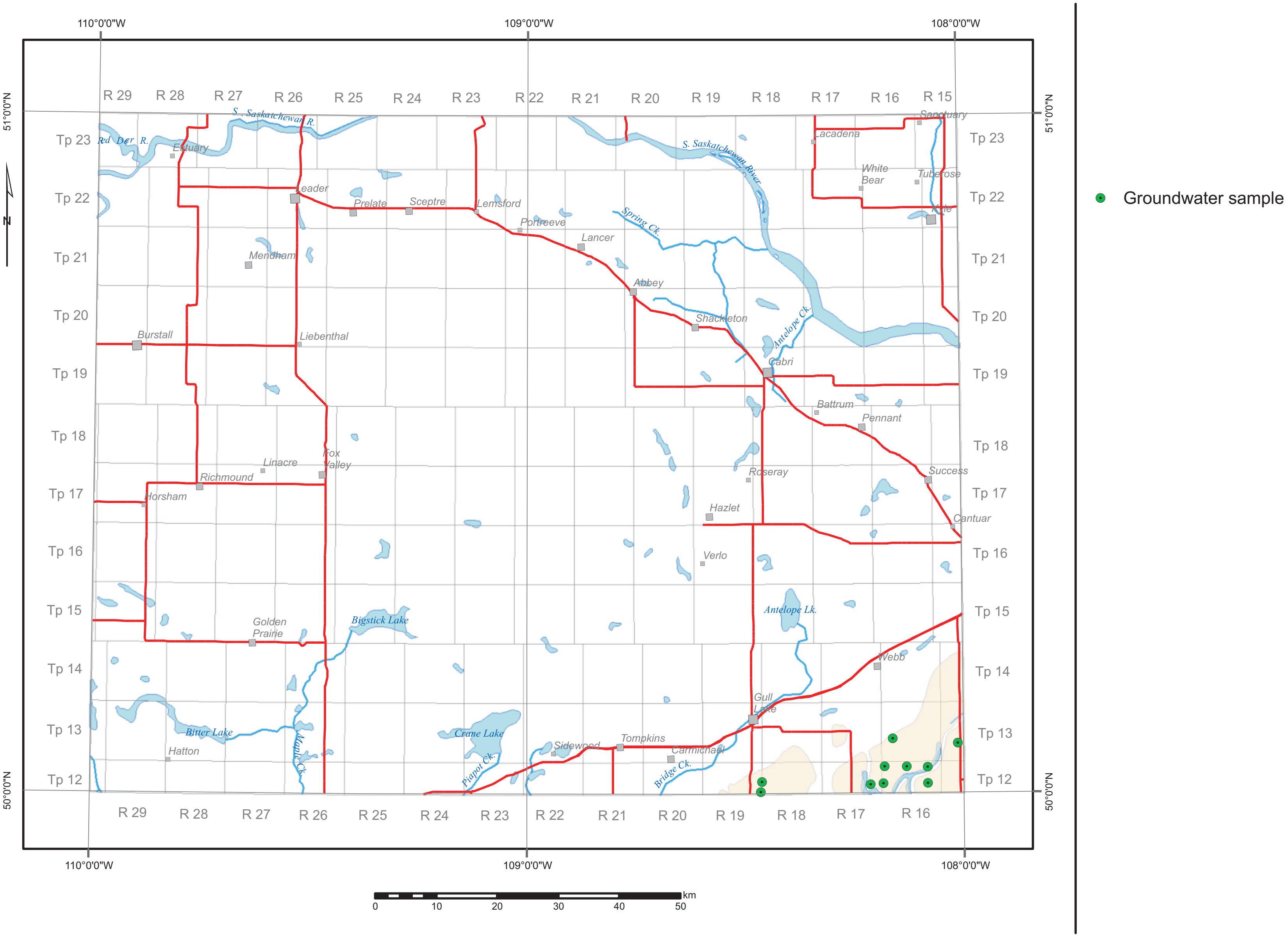


Figure 37 Locations of groundwater samples from the Eastend – Cypress Hills aquifer in the Prelate area

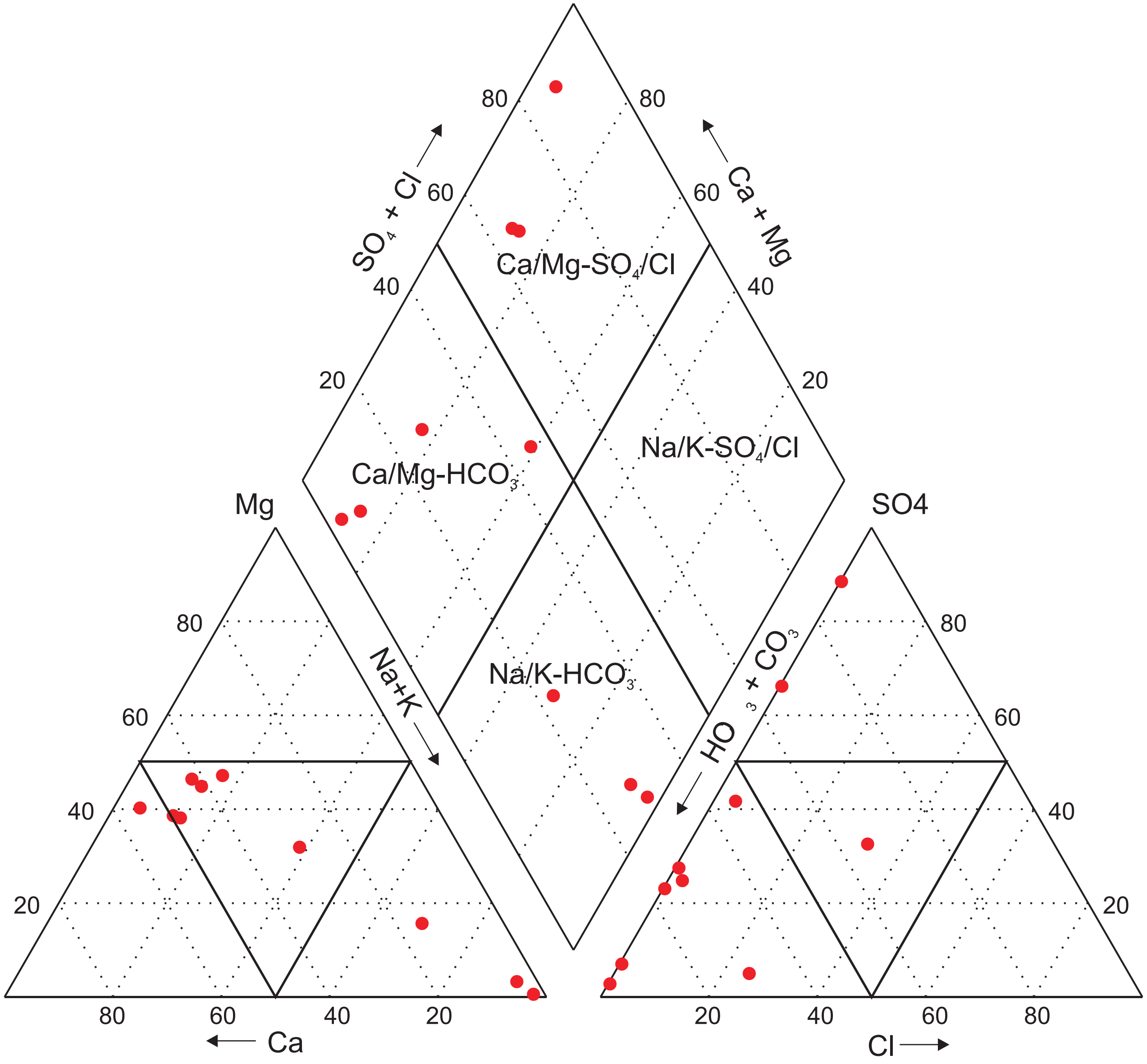


Figure 38 Piper-plot of water quality data for the Eastend - Cypress Hills aquifer in the Prelate area

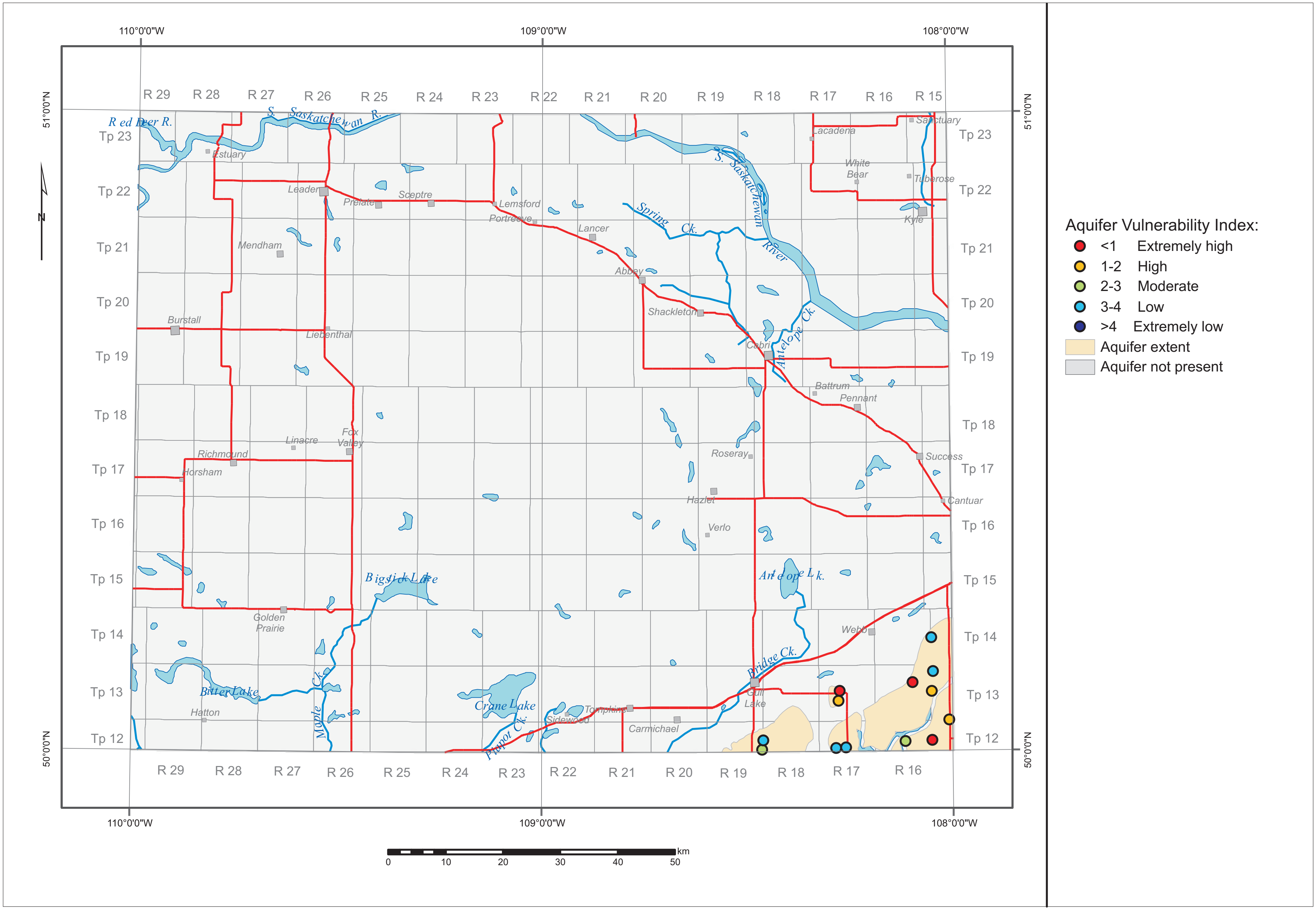


Figure 39 Aquifer vulnerability index (AVI) for the Eastend - Cypress Hills aquifer in the Prelate area

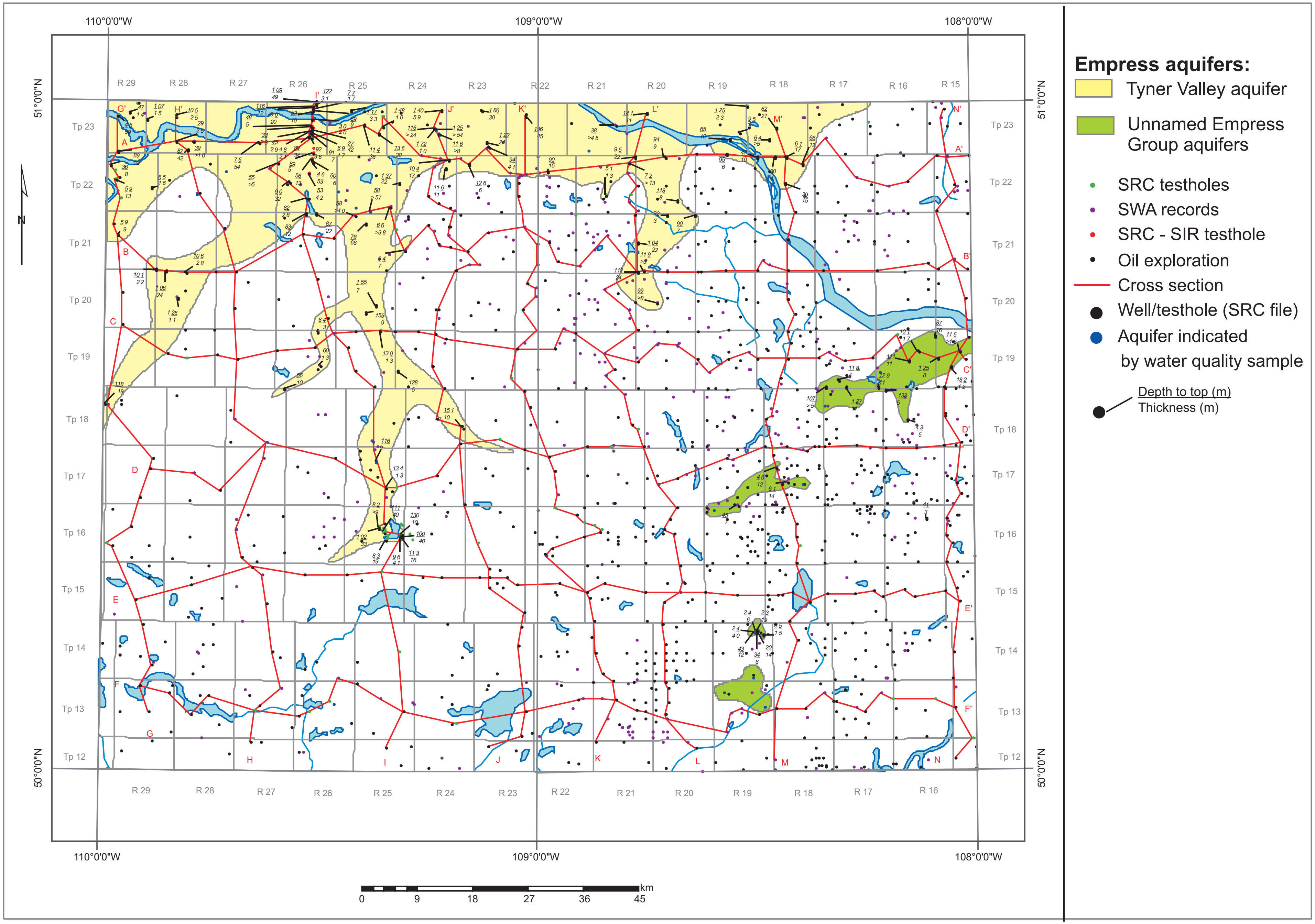


Figure 40 Extent, depth to and thickness of aquifers formed by Empress Group sediments in the Prelate area

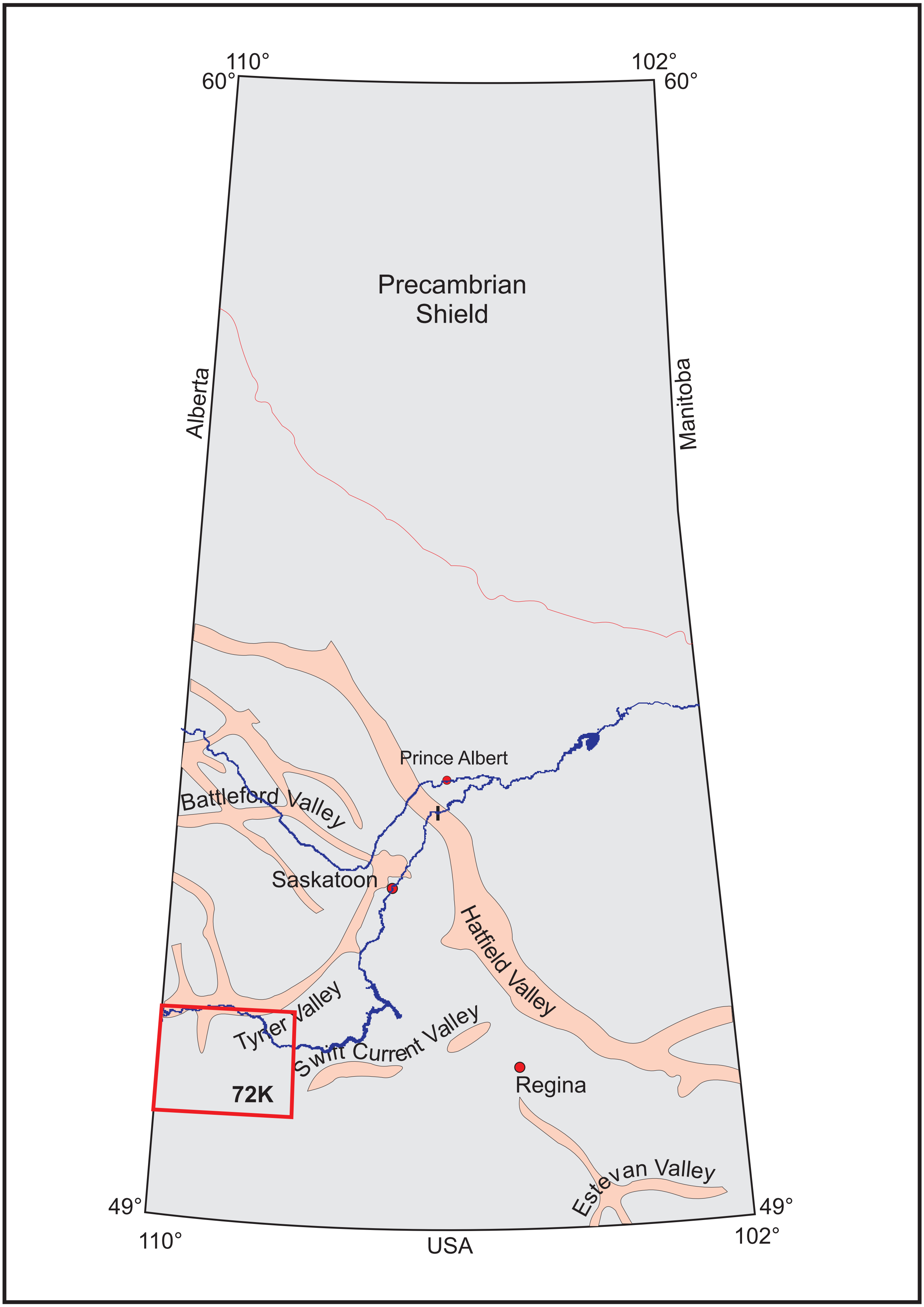


Figure 41 Extent of major buried valley aquifers in Saskatchewan

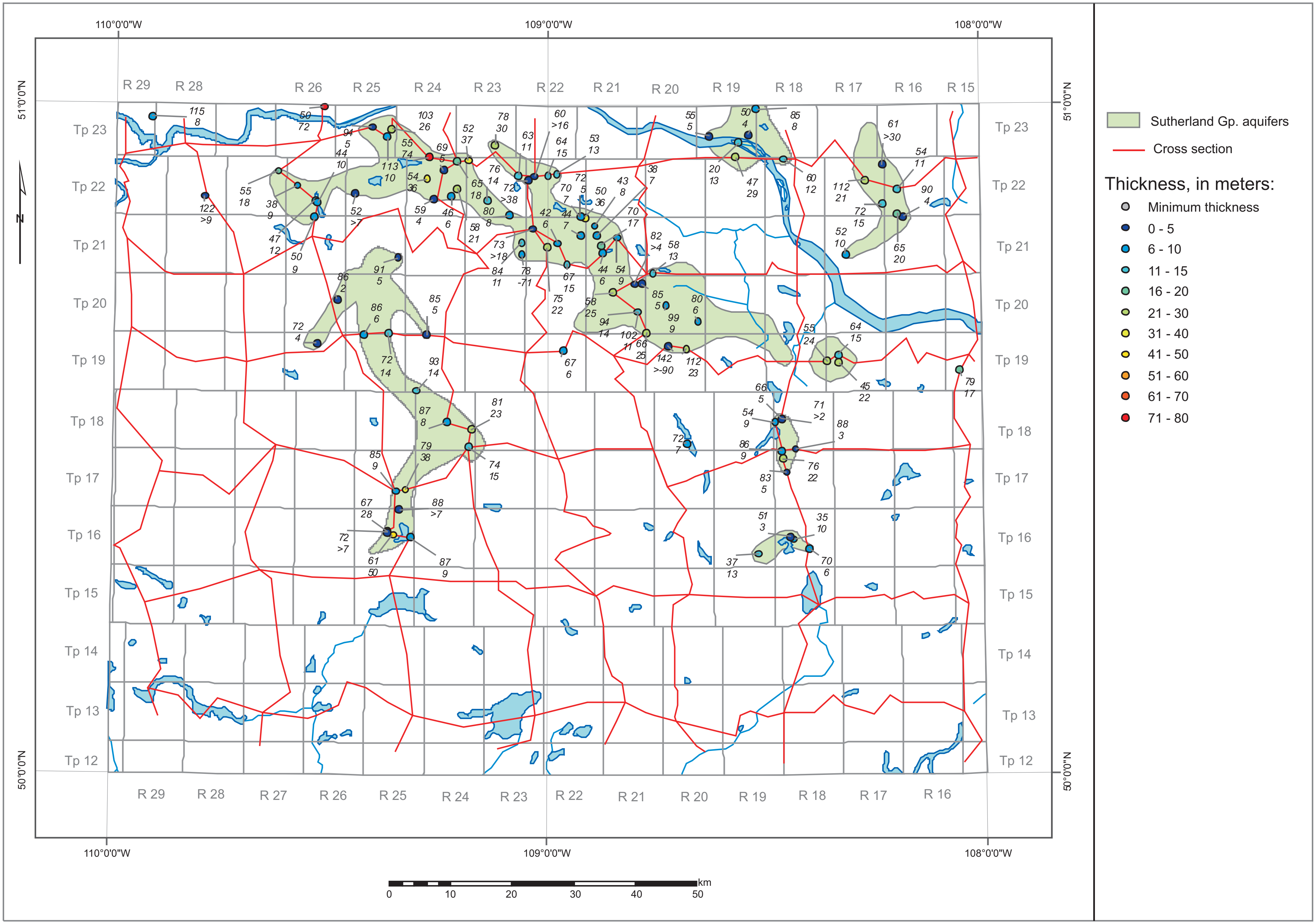


Figure 42 Extent, depth to and thickness of Sutherland Group aquifers in the Prelate area

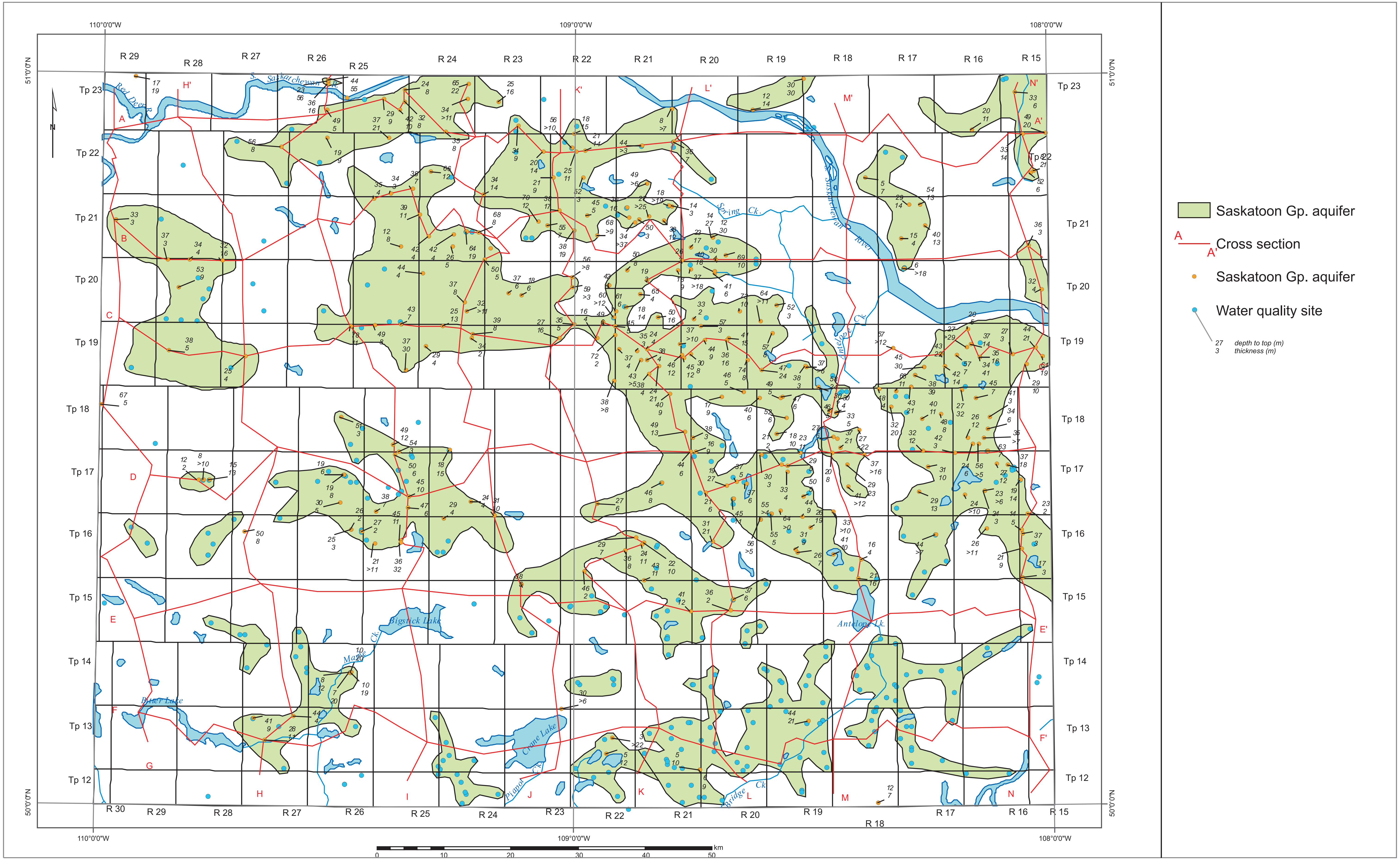


Figure 43 Extent, depth to and thickness of Saskatoon Group aquifers

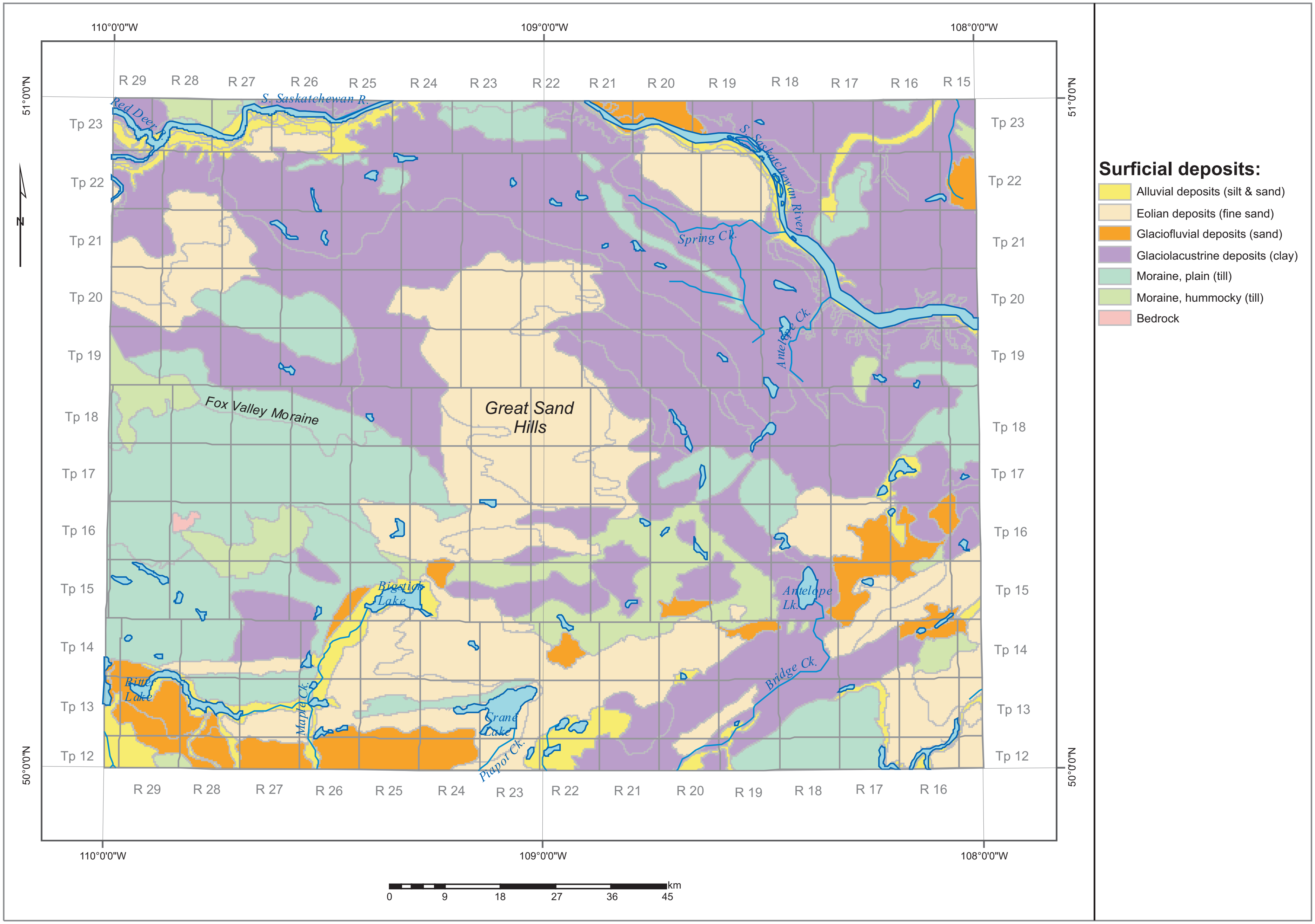


Figure 44 Surficial geology of the Prelate area

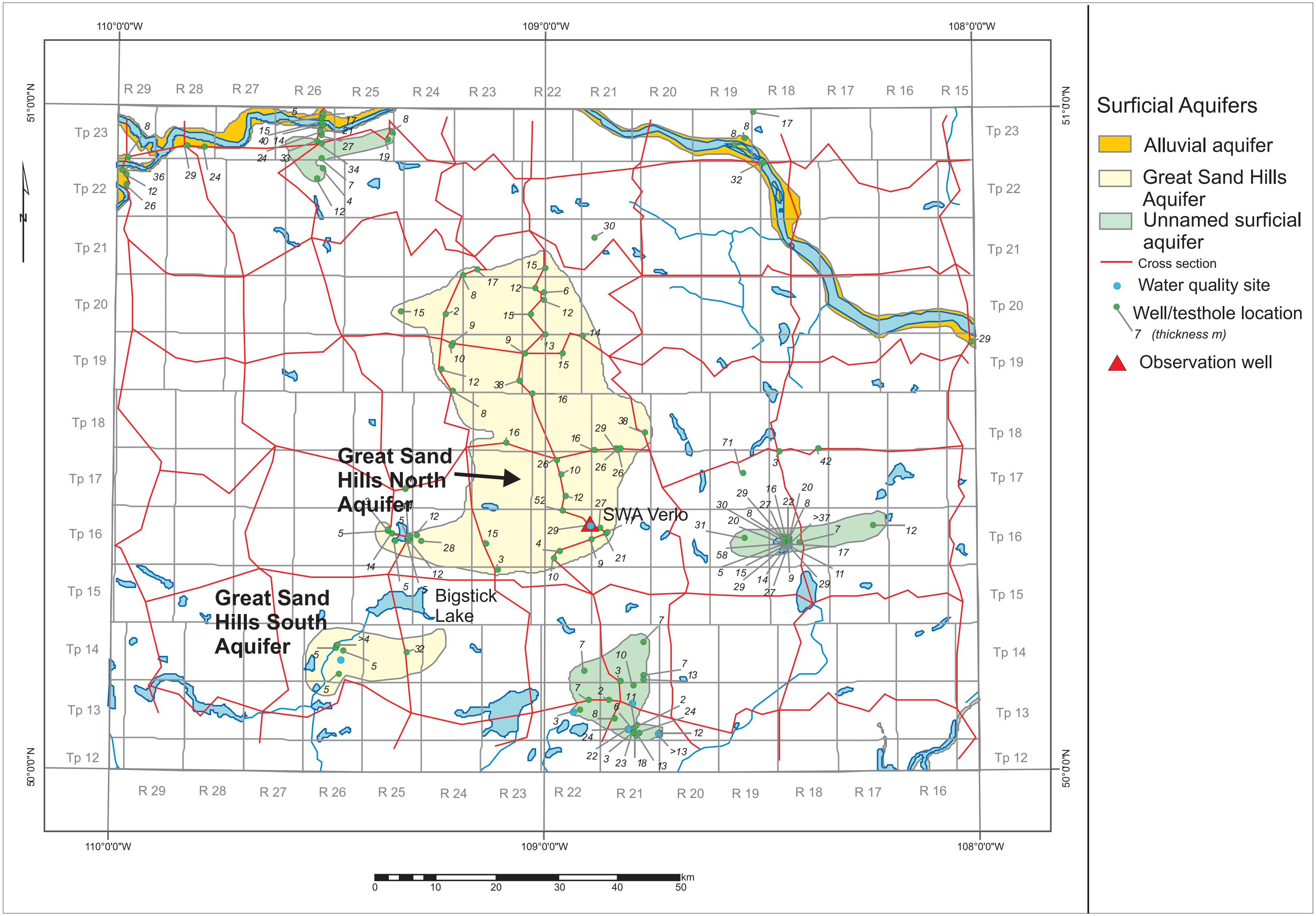


Figure 45 Extent and thickness of surficial aquifers in the Prelate area

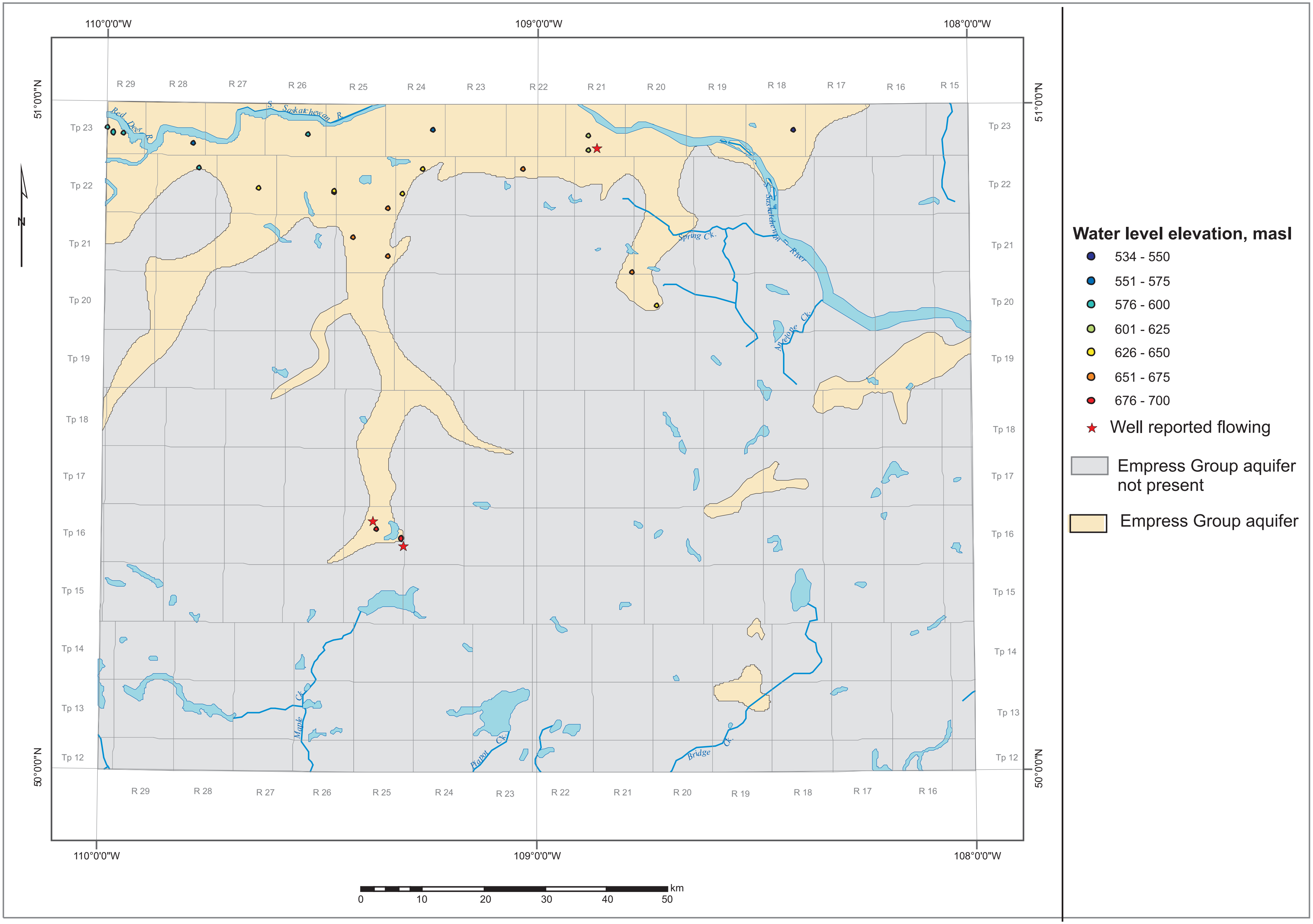


Figure 46 Point-water level elevations for wells completed in Empress Group aquifers in the Prelate area

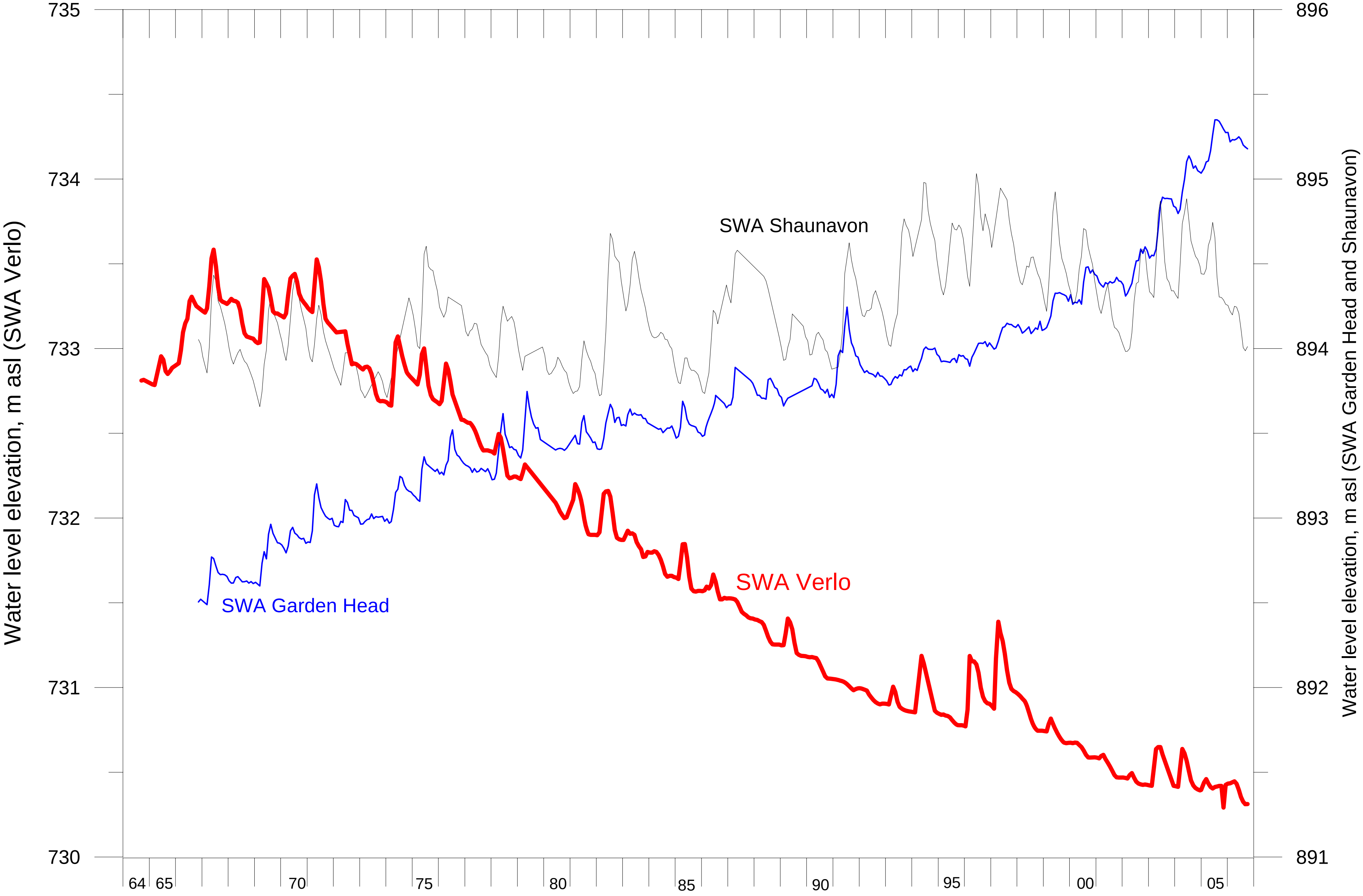


Figure 47 Hydrograhps for SWA Verlo and SWA Shaunavon and Garden Head

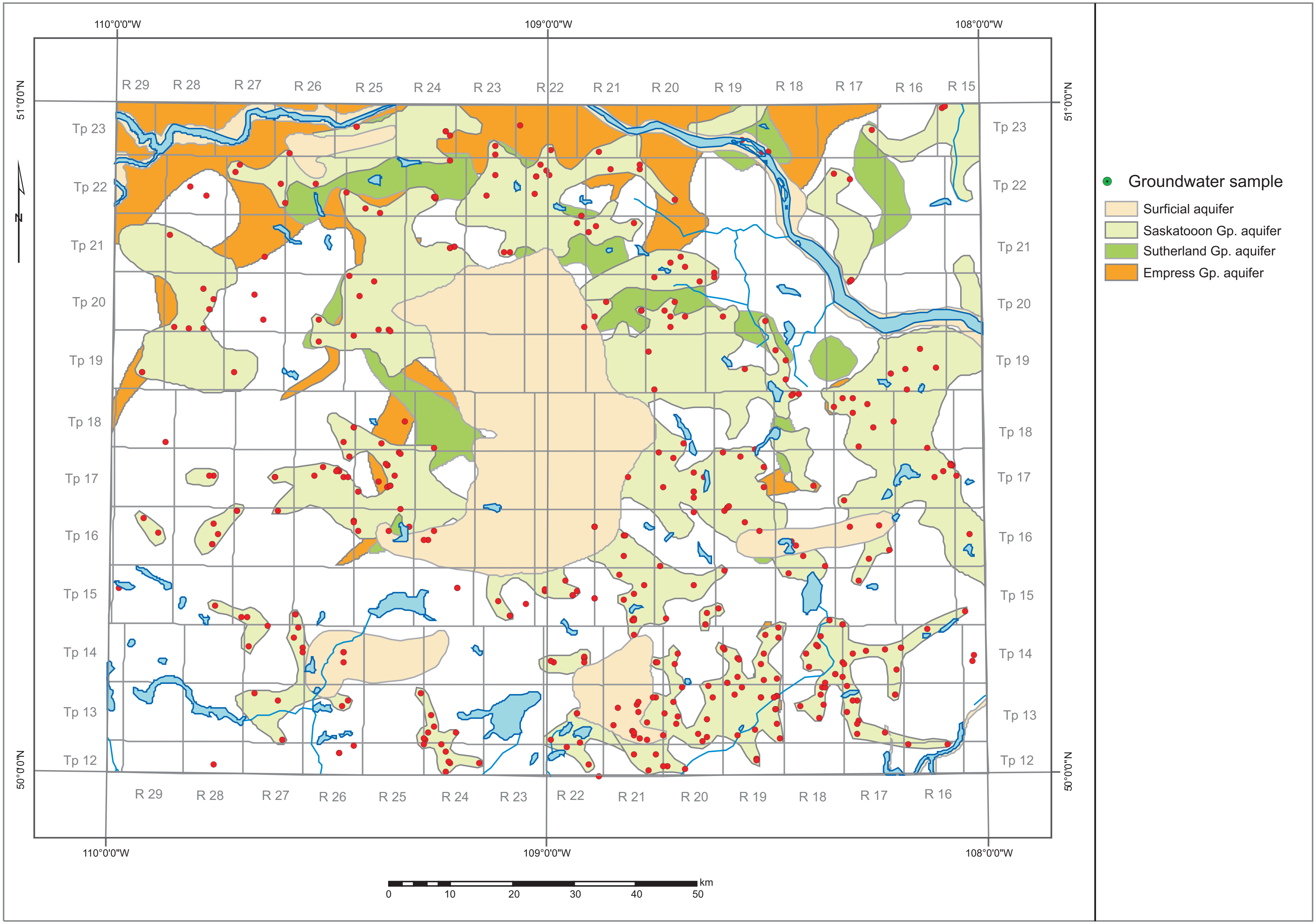


Figure 48 Locations of groundwater samples from Quaternary aquifers in the Prelate area

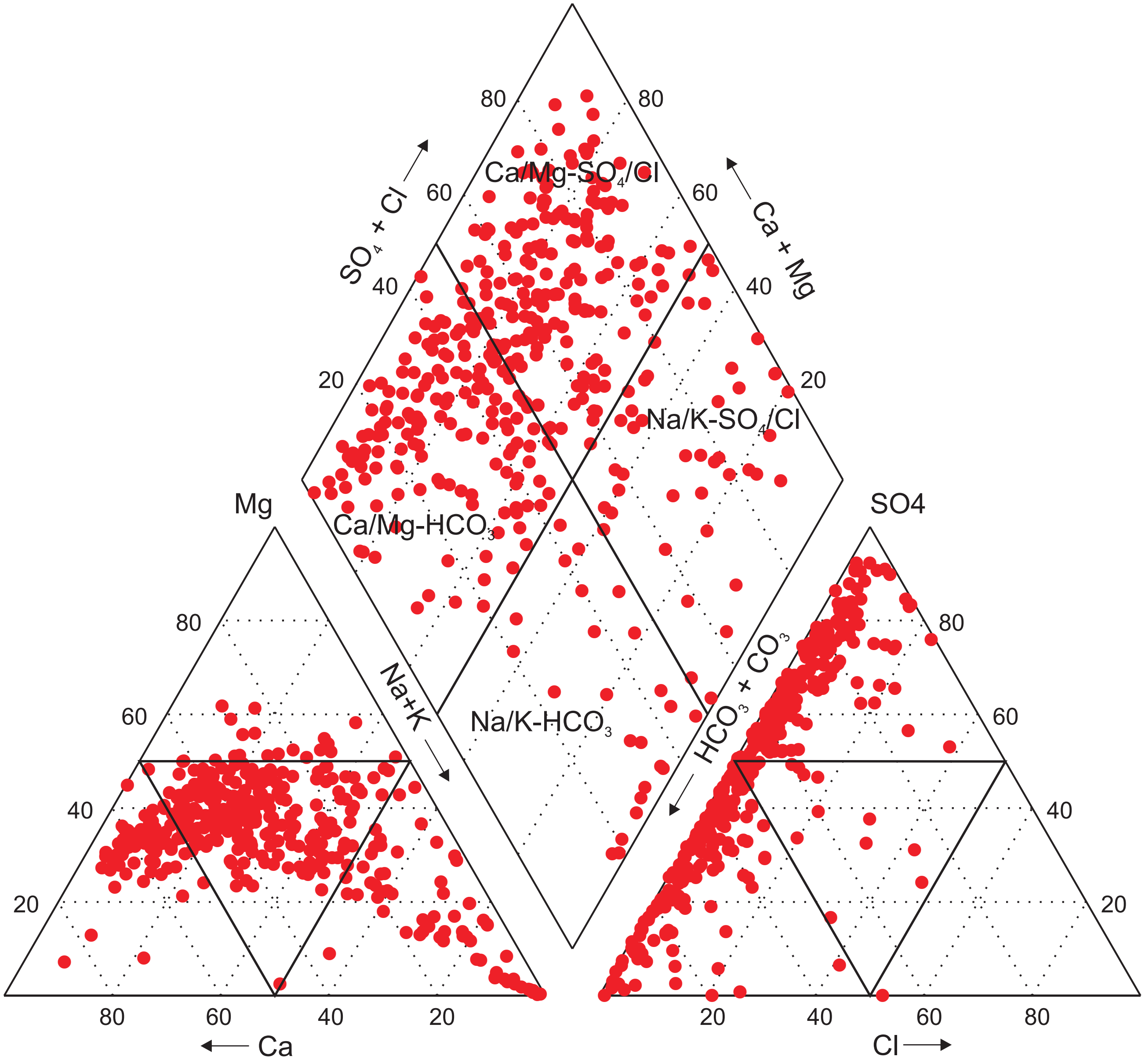


Figure 49 Piper-plot of groundwater quality data for the Quaternary aquifers in the Prelate area

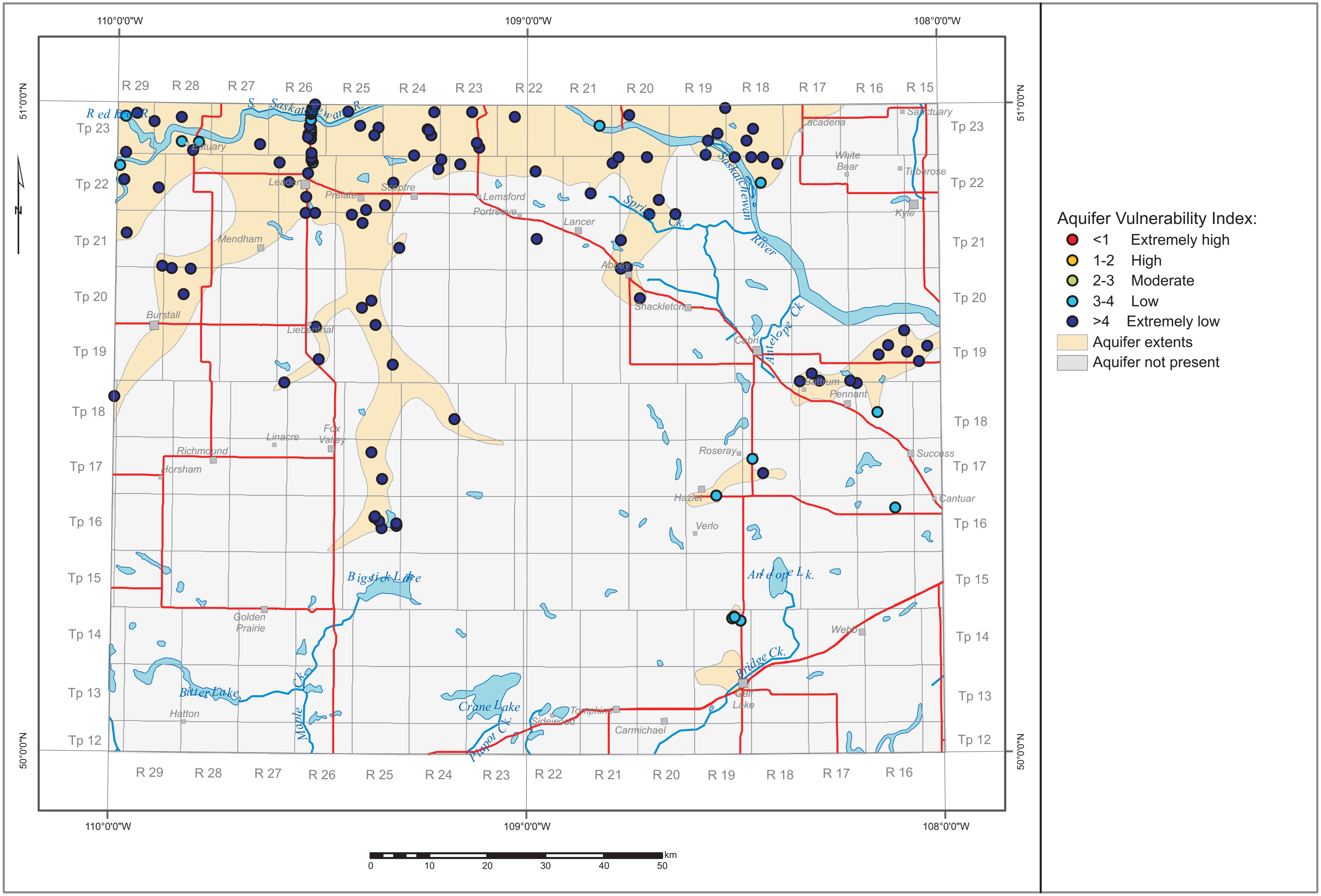


Figure 50 Aquifer vulnerability index (AVI) for the Empress Group aquifers in the Prelate area

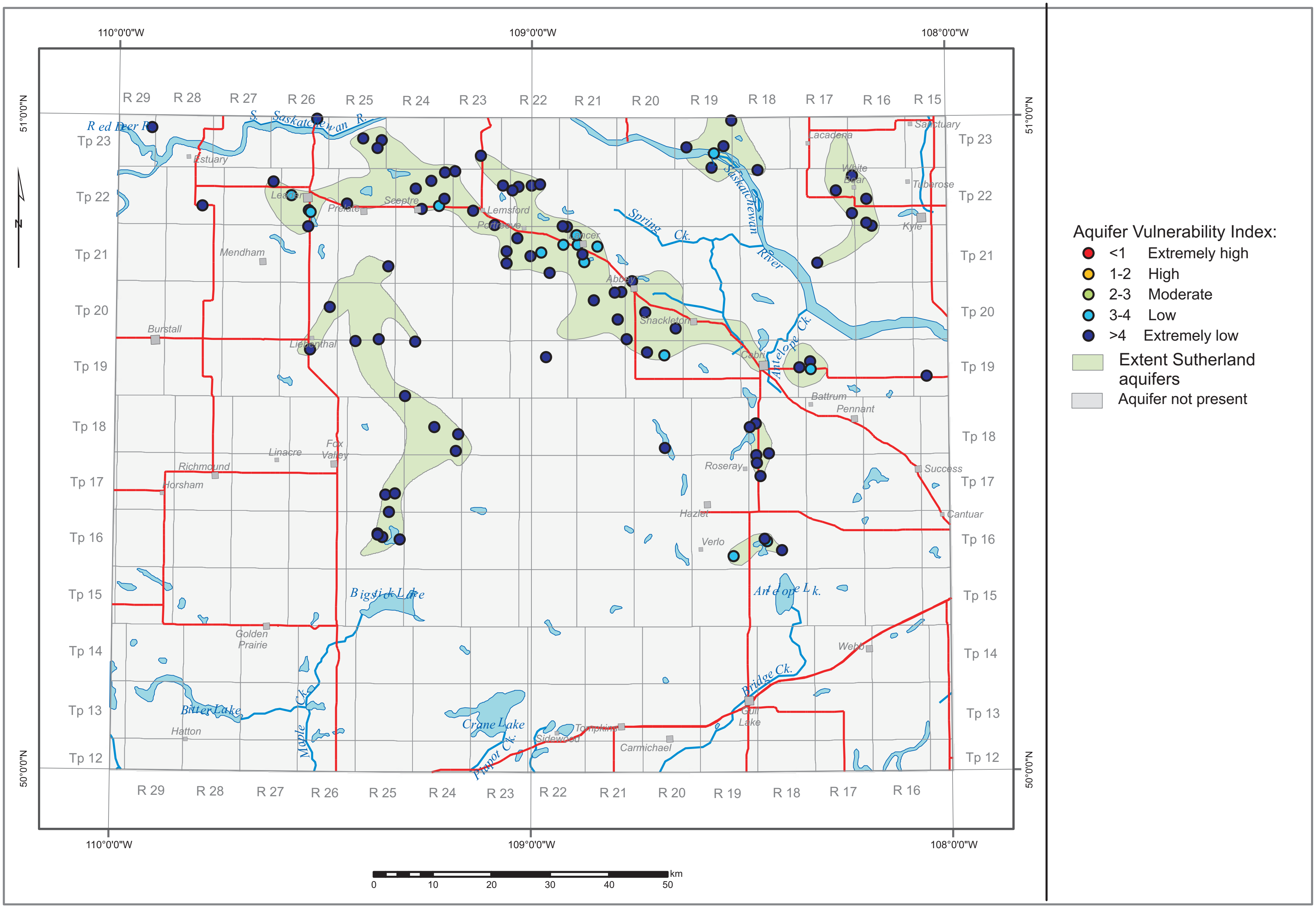


Figure 51 Aquifer vulnerability index (AVI) for the Sutherland Group aquifers in the Prelate area

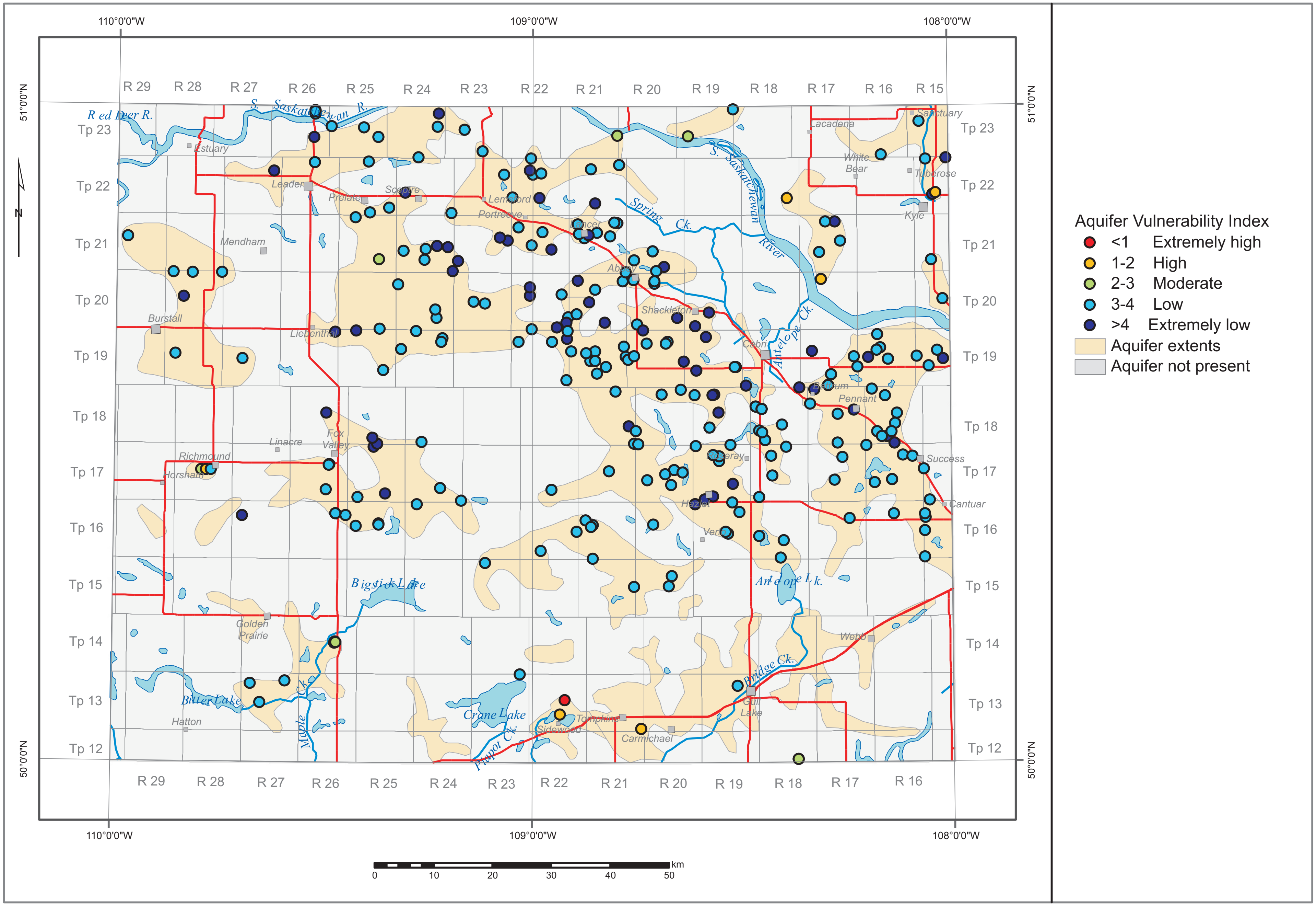
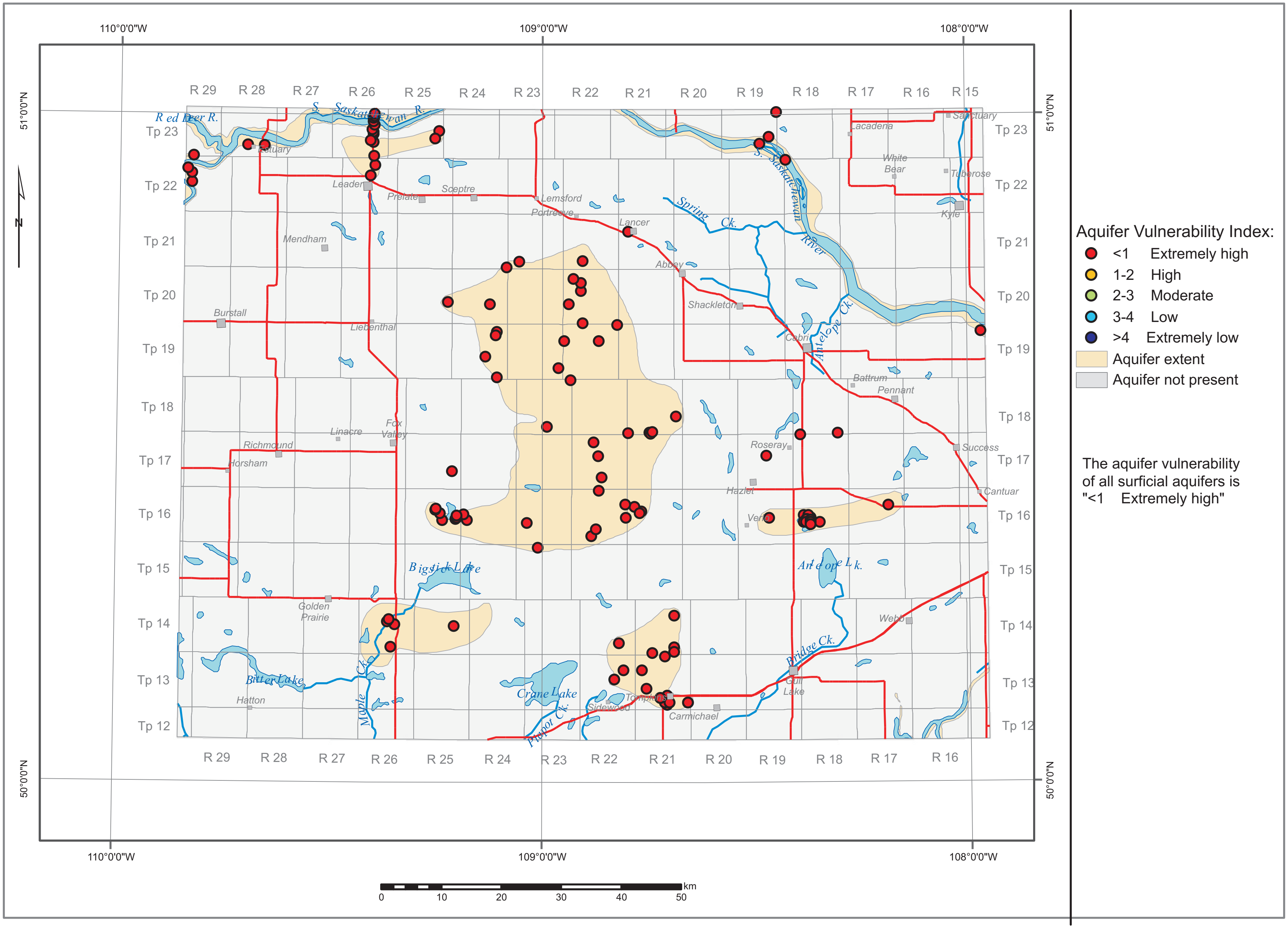


Figure 52 Aquifer vulnerability index (AVI) for the Saskatoon Group aquifers in the Prelate area



The aquifer vulnerability of all surficial aquifers is "<1 Extremely high"

Figure 53 Aquifer vulnerability index (AVI) for the surficial aquifers in the Prelate area

Appendix A:

Cross Section Log Index and Cross sections

Log Index	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
1	AMERICAN CLIMAX STH S-8		4		3	23	29	3
2	ESTUARY	SE	8		9	23	28	3
3	ELSASSER HILMER	SW	4		11	23	28	3
4	PHILLIPS HUSKY WESTERHAM		4		12	23	27	3
5	SDH Leader No.12	NE	11		11	23	26	3
6	PHILLIPS HUSKY PRELATE 2		2		22	23	25	3
7	PHILLIPS HUSKY PRELATE		4		13	23	25	3
8	PRELATE	NW	15		13	23	25	3
9	PRELATE FERRY	SW	2		25	23	25	3
10	SCEPTRE FARMS LTD	SW	3		3	23	24	3
11	FRONTIER SCEPTRE STH 174-6		12		36	22	24	3
12	KALES FARMS LTD	NE	13		31	22	23	3
13	BOSSORT PORTREEVE STH 11		4		32	22	23	3
14	BISCHOFF JOE	NE	9		3	23	23	3
15	ROWBOTHAM RON	NW	5		25	22	23	3
16	ERICKSON DWIGHT		1		30	22	22	3
17	R.M. OF CLINTWORTH	NW	4		28	22	22	3
18	BOSSORT PORTREEVE STH 20		5		27	22	22	3
19	HALE KEN	SW	4		36	22	21	3
20	TW CABRI STH 102		16		33	22	20	3
21	TW CABRI STH 103		1		6	23	19	3
22	TW CABRI STH 104		1		3	23	19	3
23	TW KYLE STH 90		13		31	22	18	3
24	TW ELROSE STH 301		16		32	22	18	3
25	TW KYLE STH 57		13		34	22	18	3
26	TW ELROSE STH 305		2		35	22	18	3
27	TURNER WAYNE	NE	16		8	23	17	3
28	FIGLEY FARM LTD	NW	12		23	22	17	3
29	CLARK RAYMOND	SW	13		17	22	16	3
30	TW KYLE STH 74		4		22	22	16	3
31	TW KYLE STH 72		13		31	22	15	3
32	LEWIS JIM		13		32	22	15	3
33	TW KYLE STH 73		14		34	22	15	3
34	GASCOIGNE	SW	12		21	21	29	3
35	INTER-CITY GAS BURSTALL 2		1		1	21	29	3
36	BEARD LEADER TH 20		16		31	20	28	3
37	BEARD LEADER TH 22		16		33	20	28	3
38	BEARD LEADER TH 31		16		36	20	28	3
39	IMPERIAL KEYNOTE R/A		16		32	20	27	3
40	IMPERIAL SPEYER R/A		15		21	21	26	3
41	SASKOIL LEADER 2		7		24	21	26	3
42	BONOGOFSKI JOE	NE	16		32	21	25	3
43	LASALLE JAMES	NW	13		3	22	25	3
44	ST JACQUES ROCH		13		1	22	25	3
45	SCEPTRE	SE	8		25	21	25	3
46	CHRISTOPHER HERMAN	NE	8		18	21	24	3
47	BOSSORT PORTREEVE STH 13		13		27	21	24	3
48	FARRER KEN	SW	2		27	21	24	3
49	GROPP DONALD	NW	13		14	21	24	3
50	BOSSORT PORTREEVE STH 25		11		13	21	24	3
51	RIO PRADO LEMSFORD		4		17	21	23	3

Log Index	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
52	BOSSORT PORTREEVE STH 10		4		27	21	23	3
53	MASTEL GEORGE	NW	9		30	21	22	3
54	TUCHSCHERER SAM	SW	5		22	21	22	3
55	BOSSORT PORTREEVE STH 8		4		11	21	22	3
56	MURCH KEITH	SW	14		6	21	21	3
57	ANDREAS ERNEST	NE	8		17	21	21	3
58	WAGNER KASPER		13		22	21	21	3
59	TW CABRI STH 120		4		6	21	20	3
60	PRENTICE HAROLD B			SE	6	21	20	3
61	TW CABRI STH 121		4		3	21	20	3
62	TW CABRI STH 122		4		6	21	19	3
63	TW CABRI STH 123		1		4	21	19	3
64	TW KYLE STH 124		4		6	21	18	3
65	DAVIDSON LEE	SE	1		7	21	18	3
66	GREER GORDON HUGH	SW	12		5	21	18	3
67	TW CABRI STH 125		4		3	21	18	3
68	TW KYLE STH 50		2		6	21	17	3
69	TW KYLE STH 52		4		6	21	16	3
70	TW KYLE STH 366		13		1	21	16	3
71	TW KYLE STH 360		4		6	21	15	3
72	VANBUSKIRK LYLE		8		8	21	15	3
73	TW KYLE STH 361		4		3	21	15	3
74	INTER-CITY GAS BURSTALL 5		7		4	20	29	3
75	IMPERIAL RICHVILLE R/A		5		20	19	28	3
76	BURSTALL	NW	13		15	19	28	3
77	IMPERIAL KRUPP R/A		5		19	19	27	3
78	FARMERS MUTUAL STH 2		13		16	19	27	3
79	FARMERS MUTUAL STH 9		13		19	19	26	3
80	FARMERS MUTUAL STH 12		1		27	19	26	3
81	DOUBLE E FARMS LTD	SW	10		36	19	26	3
82	STANOLIND STH 24		16		32	19	25	3
83	JOHNSBOROUGH	SW	3		2	20	25	3
84	STANOLIND STH 23		16		36	19	25	3
85	STANOLIND STH 32		13		33	19	24	3
86	STANOLIND PRELATE CROWN 1		9		34	19	24	3
87	STANOLIND STH 13		1		35	19	24	3
88	FED PETRO ABBEY STH 10		4		30	19	22	3
89	FED PETRO ABBEY STH 15		1		27	19	22	3
90	HUBERT KARL	SE	1		2	20	22	3
91	FED PETRO ABBEY STH 5		16		36	19	22	3
92	ANDREAS MARTIN	SW	9		21	19	21	3
93	TW CABRI STH 150		13		18	19	20	3
94	SMITH DAWSON	SW	12		28	19	20	3
95	MILNICE FARMS	SW	12		26	19	20	3
96	TW CABRI STH 152		4		19	19	19	3
97	SHAW WAYNE	NW	13		8	19	19	3
98	TW CABRI STH 153		4		22	19	19	3
99	R M OF MIRY CREEK	NE	14		24	19	19	3
100	TW CABRI STH 154		4		19	19	18	3
101	TW CABRI STH 155		4		22	19	18	3
102	TW CABRI STH 156		4		19	19	17	3

Log Index	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
103	RIVER BUTTE STOCK FARM (FRASER McLEOD)	SW	12		20	19	17	3
104	TW CABRI STH 157		16		16	19	17	3
105	TW CABRI STH 158		2		24	19	17	3
106	PENNANT	NW	5		33	19	16	3
107	TW CABRI STH 159		13		15	19	16	3
108	BA OIL ZELLER		13		23	19	16	3
109	TW CABRI STH 187		4		19	19	15	3
110	BLANKE JERRY	NW	12		21	19	15	3
111	TW CABRI STH 188		16		16	19	15	3
112	UNITED CANSO HORSHAM		11		23	17	29	3
113	KAMBEITZ BEN			SE	21	17	28	3
114	CAN EXP FOX VALLEY		6		12	17	28	3
115	ALBRECHT EDWIN	NW	5		2	18	27	3
116	CYPRESS FOX VALLEY 1		16		26	17	26	3
117	FOX VALLEY	SW	13		11	17	25	3
118	FOX VALLEY	NW	13		12	17	25	3
119	SOC WEST CH 123-36		4		22	17	24	3
120	SOC WEST CH 123-29		6		1	18	24	3
121	FREEFIGHT LAKE	SW	14		3	18	23	3
122	SOC WEST CH 123-23		16		36	17	23	3
123	SOCONY WOODLEY SOUTHERN BESTVI		3		33	17	22	3
124	SOC WEST CH 123-17		4		6	18	21	3
125	SE HAZLET JR.1	NE	3		4	18	21	3
126	SHIELS IRENE	NW	2		4	18	21	3
127	SOC WEST CH 123-11		1		1	18	21	3
128	SLETTEN STUART	NW	5		17	17	20	3
129	SOCONY WESTERN CH 124-50		13		15	17	20	3
130	SLETTEN LYLE	SW	5		23	17	20	3
131	SOCONY WESTERN CH 124-122		13		28	17	19	3
132	S W C - GREAT SAND HILLS			NE	28	17	19	3
133	SOCONY WESTERN CH 124-20		1		1	18	19	3
134	ROSERAY	NW	16		31	17	18	3
135	SOCONY WESTERN STH 124-24		4		4	18	18	3
136	SOCONY WESTERN CH 124-16		12		35	17	18	3
137	SOCONY WESTERN STH 124-80		1		2	18	18	3
138	SOCONY WESTERN STH 124-62		1		1	18	18	3
139	SOCONY WESTERN CH 124-63		4		3	18	17	3
140	SOCONY WESTERN CH 124-64		13		31	17	16	3
141	SOCONY WESTERN CH 124-78		13		34	17	16	3
142	SOCONY WESTERN CH 124-79		1		1	18	16	3
143	GARVEY STH 1		7		5	18	15	3
144	INTER-CITY GAS 4 GOLDEN PRAIRI		4		15	15	29	3
145	AMUREX CANSO HERTER		10		21	15	28	3
146	AMUREX CAN SOUTHERN COUTTS		10		33	15	27	3
147	SPRIG PURE INGLEBRIGHT		16		29	15	26	3
148	AMUREX CAN SOUTHERN WINKLER		13		30	15	25	3
149	BIGSTICK NORTH	NW	2		34	15	25	3
150	AMUREX ALBERCAN STICK LAKE		10		27	15	24	3
151	CAN SUP BESTVILLE S STH		11		29	15	23	3
152	CAN SUP BESTVILLE S STH		11		28	15	23	3
153	CAN SUP BESTVILLE S STH 6		12		26	15	23	3

Log Index	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
154	CAN SUP BESTVILLE S STH 5		13		24	15	23	3
155	SOCONY WOODLEY SOUTHERN N CRAN		3		27	15	22	3
156	SOC WEST CH 123-57		4		19	15	21	3
157	CAN SUP BESTVILLE S STH		1		29	15	21	3
158	SOC WEST CH 126-31		1		24	15	21	3
159	CROOK ANDREW L	NE	3		22	15	20	3
160	SOCONY WESTERN CH 126-23		1		24	15	20	3
161	SOCONY WESTERN CH 126-41		13		15	15	19	3
162	SOCONY WESTERN CH 126-42		13		18	15	18	3
163	SEDCO BASS STH 51		13		17	15	18	3
164	SOCONY WESTERN CH 126-43		2		21	15	18	3
165	SEDCO ALCAN PETRO		3		14	15	18	3
166	SOCONY WESTERN CH 126-44		13		18	15	17	3
167	SOCONY WESTERN CH 124-93		16		16	15	17	3
168	SOCONY WESTERN CH 124-111		1		23	15	17	3
169	SOCONY WESTERN CH 124-92		10		13	15	17	3
170	SOCONY WESTERN PRAIRIE BEVERLE		8		20	15	16	3
171	SOCONY WESTERN CH 124-91		9		16	15	16	3
172	SOCONY WESTERN CH 124-90		1		24	15	16	3
173	TW STEWART VALLEY STH 337		3		17	15	15	3
174	AMUREX HATTON UNIT		6		33	13	29	3
175	AMUREX CANSO BITTER LAKE		11		25	13	29	3
176	AMUREX CANSO BITTER LAKE		7		17	13	28	3
177	AMUREX CAN SOUTHERN RUDD		6		27	13	28	3
178	BITTER LAKE	NE	16		17	13	27	3
179	PBOG HATTON		6		18	13	26	3
180	TENAILLE LAKE	SW	14		17	13	26	3
181	SE MAPLE CREEK JR.2	SE	14		22	13	26	3
182	MARTIN ROSS	SE	3		2	14	26	3
183	AMUREX SMITH		12		31	13	25	3
184	KRUCZKO STEVE	NE	3		28	13	25	3
185	AMUREX CAN SOUTHERN ENGLISH		16		14	13	25	3
186	CRANE LAKE	NW	12		11	13	24	3
187	AMUREX CAN SOUTHERN SANCTUARY		13		13	13	23	3
188	SOCONY WOODLEY SOUTHERN N SIDE		3		26	13	22	3
189	VILLAGE OF TOMPKINS	NE	1		26	13	22	3
190	VILLAGE OF TOMPKINS			SE	30	13	21	3
191	SOCONY WESTERN STH 126-19		4		28	13	21	3
192	SOCONY WESTERN STH 126-12		4		23	13	21	3
193	SOC WEST GULL LAKE CH 7		13		13	13	21	3
194	CARLSON WAYNE			SW	17	13	20	3
195	RETZLAFF ED		13		5	13	19	3
196	RM OF GULL LAKE NO. 139	NW	9		17	13	19	3
197	PIECHOTTA JIM	SE	1		21	13	19	3
198	ANGLO AM GRIDOIL GULL LAKE		11		14	13	19	3
199	SOCONY WESTERN CH 125-52		4		19	13	18	3
200	SOCONY WESTERN CH 125-51A		4		22	13	18	3
201	SAWATSKY HENRY	SW	13		25	13	18	3
202	SEDCO CLARK WEBB STH 1A		13		19	13	17	3
203	KERR PATRICK	SW	3		21	13	17	3
204	SOCONY WESTERN CH 125-48		13		15	13	17	3

Log Index	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
205	MARTINS JOHN	SE	16		26	13	17	3
206	WEBB	SE	1		25	13	17	3
207	DUNCAIRN	SW	4		26	13	16	3
208	SOCONY WESTERN 125-11		4		19	13	15	3
209	AMUREX CANSO HATTON		11		15	13	29	3
210	AMUREX CANSO BITTER LAKE		7		10	14	29	3
211	AMUREX CANSO HAGEL		10		33	14	29	3
212	NCO HATTON		10		7	16	29	3
213	SURPRISE	NW	13		7	16	29	3
214	AMUREX CANSO KUEST		10		21	16	29	3
215	NCO HORSHAM		11		3	17	29	3
216	BOUNDARY HORSHAM 1		10		26	17	29	3
217	GOMKE GORDON	SW	4		30	18	29	3
218	INTER-CITY GAS BURSTALL 1		10		21	20	29	3
219	INTERCITY BURSTALL 3		10		29	21	29	3
220	EMPRESS	SW	6		9	22	29	3
221	EMPRESS	NE	2		20	22	29	3
222	CHARTER CAN DEV		5		21	22	29	3
223	EMPRESS	SW	7		29	22	29	3
224	EMPRESS	SE	12		29	22	29	3
225	EMPRESS	NW	13		22	23	29	3
226	CAN HOMESTEAD HATTON		10		32	12	27	3
227	HUCULAK WALTER	NW	2		35	13	27	3
228	BA OIL ARNDT		15		15	14	27	3
229	SPRIG BIGSTICK		13		11	15	27	3
230	COAKES JOHN EVELYN GRACE	NE	15		27	15	27	3
231	AMUREX CAN SOUTHERN MURRAY 1		10		5	16	27	3
232	FOLK TOM	NW	5		20	16	27	3
233	GOLDEN PRAIRIE			NE	27	17	27	3
234	HELLMAN ROBERT	NE	9		18	18	27	3
235	FARMERS MUTUAL STH 4		1		17	20	27	3
236	AUSMUS LARRY		7		30	21	27	3
237	BAILEY MOBIL OKALTA		7		30	21	27	3
238	MOBIL SOUTH ESTUARY		13		11	22	28	3
239	AMERICAN CLIMAX EMPRESS STH S-		5		2	23	28	3
240	PHILLIPS HUSKY COMBE 1		16		21	23	28	3
241	AMUREX ALBERCAN RUSSEL		4		34	12	25	3
242	BIGSTICK SOUTH	SW	3		23	14	25	3
243	SASK MIN. INGEBRIGHT L. 5	NE	11		13	16	25	3
244	SASK MIN. INGEBRIGHT L. 6	SW	2		24	16	25	3
245	SASK MIN. INGEBRIGHT L. 44	SW	8		22	16	25	3
246	SASK MIN. INGEBRIGHT L. 31	SW	14		22	16	25	3
247	ASTRAL ARCADIAN 1		1		27	16	25	3
248	REINBOLDT DON	SW	15		33	17	25	3
249	STANOLIND STH 28		1		3	19	25	3
250	STANOLIND STH 27		16		8	19	25	3
251	IMPERIAL ELARDEE		4		29	19	25	3
252	FARMERS MUTUAL STH 10		4		12	20	26	3
253	FARMERS MUTUAL STH 5		4		35	20	26	3
254	BEARD LEADER 11		16		33	21	26	3
255	SASKOIL LEADER 3		5		10	22	26	3

Log Index	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
256	LEADER	SE	9		9	22	26	3
257	IMPERIAL PRUSSIA R/A		4		20	22	26	3
258	NAGEL CHRIS	SE	12		25	22	27	3
259	GILL SAM F	NW	4		31	22	26	3
260	FENRICH JOHN			SW	14	23	26	3
261	SDH Leader No.16	SE	14		14	23	26	3
262	SDH Leader No.24	SW	10		23	23	26	3
263	SDH Leader No. 2	NW	15		26	23	26	3
264	ANGLO AM GRIDOIL CRANE LAKE		6		32	12	23	3
265	JEFF LAKE SANDHILLS		7		2	13	23	3
266	AMUREX CAN SOUTHERN LAKE		11		23	14	23	3
267	SOC WEST CH 123-59		1		12	15	23	3
268	CAN SUP BESTVILLE S STH		11		21	15	23	3
269	CAN SUP BESTVILLE S STH		11		33	15	23	3
270	PARKLAND	SE	5		17	16	23	3
271	SOC WEST CH 123-65		1		1	17	24	3
272	SOC WEST CH 123-28		2		13	18	24	3
273	SOC WEST CH 123-31		13		15	18	24	3
274	STANOLIND STH 17		1		2	19	24	3
275	STANOLIND STH 19		7		15	19	24	3
276	BOSSORT PORTREEVE STH 14		4		14	20	24	3
277	STANOLIND STH 5		1		1	21	24	3
278	ROWBOTHAM CLARENCE			NW	5	21	23	3
279	HELMAN GEORGE	SW	13		4	21	23	3
280	BUSCHOLL JAMES J	NW	15		24	21	24	3
281	BOSSORT PORTREEVE STH 22		11		25	21	24	3
282	WILKINS BRIAN	SW	2		1	22	24	3
283	BOSSORT PORTREEVE STH 12		4		11	22	24	3
284	CALSTAN STH 5 LEADER		13		10	22	24	3
285	GIZEN DENNIS		9		27	22	24	3
286	STAPLE LILA	NW	4		13	23	24	3
287	ARMSTRONG JOHN	SE	15		14	23	24	3
288	IMPERIAL FAIRBANKS		11		25	23	24	3
289	SOCONY WESTERN CH 126-62		13		31	12	21	3
290	VILLAGE OF TOMPKINS			SW	17	13	21	3
291	SOC WEST TOMPKINS CH 126-16		1		5	14	21	3
292	SOCONY WOODLEY N TOMPKINS		16		6	14	21	3
293	SOC WEST CH 126-54		13		18	14	21	3
294	SOC WEST CH 126-50		1		6	15	21	3
295	CAN SUP BESTVILLE S STH 2		11		18	15	21	3
296	MCLEOD GRANT		13		4	16	22	3
297	CAN SUP BESTVILLE S STH 12		10		9	16	22	3
298	SOC WEST CH 123-53		16		13	16	22	3
299	CAN SUP BESTVILLE S STH 9		6		20	16	21	3
300	HAZLET	SW	10		20	16	21	3
301	FREEFIGHT LAKE	SW	1		30	16	21	3
302	SRC VERLO OBSERVATION	SW	8		25	16	22	3
303	SOCONY SOUTHERN S BESTVILLE		4		36	16	22	3
304	BOYERS LAKE	SE	16		33	16	22	3
305	ELKINK RANCH			SW	10	17	22	3
306	SOC WEST CH 123-44		9		21	17	22	3

Log Index	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
307	SOC WOODLEY N BESTVILLE		3		30	18	22	3
308	SOC WEST CH 123-21		16		36	18	23	3
309	MINOR	NW	2		12	19	23	3
311	FED PETRO ABBEY STH 12		2		18	20	22	3
312	WATSON BROS	SE	9		20	20	22	3
313	WATSON BROS	NE	8		29	20	22	3
314	FED PETRO ABBEY STH 11		13		29	20	22	3
315	BOSSORT PORTREEVE STH 19		13		4	21	22	3
316	BOSSORT PORTREEVE STH 4		13		16	21	22	3
317	BOSSORT PORTREEVE STH 16		13		7	22	22	3
318	CALSTAN LEADER 1&3		4		19	22	22	3
319	ERICKSON DEL		14		19	22	22	3
320	PHILLIPS HUSKY RIVERFRONT		1		29	23	22	3
321	CAN DEV CARMICHAEL 1		4		35	12	20	3
322	VILLAGE OF TOMPKINS	SW	12		34	12	20	3
323	SOCONY WESTERN CH 126-14		12		17	13	20	3
324	SOCONY WESTERN GULL LAKE CH 8		14		20	13	20	3
325	RIDGEWAY REALITY TOMPKINS		6		32	13	20	3
326	SOCONY WESTERN GULL LAKE CH 3		13		32	13	20	3
327	LIBERTY WEST MIDWAY STH 9		4		8	14	20	3
328	LIBERTY WEST MIDWAY STH 3		4		17	14	20	3
329	SOCONY WESTERN CH 126-20		13		17	14	20	3
330	LIBERTY WEST MIDWAY STH 13		13		20	14	20	3
331	SOCONY WESTERN CH 126-21		16		31	14	20	3
332	SOCONY WESTERN CH 126-32		1		17	15	20	3
333	STEELE ALBERT	NE	2		27	15	20	3
334	SOCONY WESTERN CH 124-46		14		34	15	20	3
335	SOCONY WESTERN CH 124-42		1		21	16	20	3
336	CE VERLO STH		9		20	16	20	3
337	PETCAL HOMESTEAD MOBIL WEST VE		11		28	16	20	3
338	SOCONY WESTERN CH 124-43		13		34	16	20	3
339	HAZLET	NW	14		12	18	21	3
340	MOBIL WOODLEY SOUTHERN W ROADE		7		14	18	21	3
341	HUGHES RUSSEL	SE	9		34	18	21	3
342	HEARD CYRIL	NE	8		9	19	21	3
343	FED PETRO ABBEY STH 18		1		15	19	21	3
344	TW CABRI STH 140		4		6	20	20	3
345	ABBEY COLONY HUTTERIAN BRETHREN #2		6		13	20	21	3
346	HUBERT PETER			SE	28	20	21	3
347	TW CABRI STH 115		4		19	21	20	3
348	TW CABRI STH 110		16		36	21	21	3
349	ANDERSON ROBERT	SE	5		6	22	20	3
350	DENKER HERMAN	NW	4		12	22	21	3
351	CRAMERSBURG	NE	14		12	22	21	3
352	TW CABRI STH 105		13		18	22	20	3
353	BRADFORD STAN	NW	4		25	22	21	3
354	TW CABRI STH 101		16		36	22	21	3
355	PHILLIPS HUSKY FAIRDALE 1		8		29	23	20	3
356	CONNICK DALE	NW	13		19	12	18	3
357	SOCONY WOODLEY SOUTHERN PREMIE		3		28	14	18	3
358	SOCONY WESTERN CH 126-40		3		4	15	18	3

Log Index	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
359	SOCONY WESTERN CH 126-46		4		3	16	18	3
360	LAKE ANTELOPE	NE	14		10	16	18	3
361	SOCONY WESTERN CH 124-52		13		15	16	18	3
362	MOBIL WOODLEY SOUTHERN ANTELOP		4		27	16	18	3
363	SOCONY WESTERN CH 124-4		4		9	17	18	3
364	SOCONY WESTERN CH 124-10		2		17	17	18	3
365	PELTIER PETE	NE	13		20	17	18	3
366	SOCONY WESTERN CH 124-19		1		31	17	18	3
367	SOCONY WESTERN STH 124-33		13		18	18	18	3
368	MCGUIGAN EARL	SE	8		19	18	18	3
369	SEABOARD TW CABRI CROWN		3		9	19	18	3
370	TW CABRI STH 226		11		27	19	18	3
371	TW CABRI STH 145		13		34	19	18	3
372	TW CABRI STH 229		9		10	20	18	3
373	TW CABRI STH 131		4		22	20	18	3
374	TW KYLE STH 45		5		22	21	18	3
375	TW KYLE STH 43		1		3	22	18	3
376	TW KYLE STH 53		1		21	22	18	3
377	TW KYLE STH 86		16		16	23	18	3
378	TW VESPER STH 375		13		19	12	15	3
379	VESPER	SE	1		5	13	15	3
380	SOCONY WESTERN 125-6		13		18	14	15	3
381	TW JAVA CROWN		5		20	15	15	3
382	SOCONY WESTERN CH 124-89		4		6	16	15	3
383	MCALESTER GOLDSTON SOUTH SUCCE		2		18	16	15	3
384	SOCONY WESTERN CH 124-86		13		18	16	15	3
385	SCHLAMP JACK	SE	4		30	16	15	3
386	SOCONY WESTERN CH 124-116		12		30	16	15	3
387	BA OIL LINES		2		8	17	15	3
388	TW WILDCAT STH 320		4		17	17	15	3
389	TW WILDCAT STH 197		4		19	18	15	3
390	SOCONY WESTERN CH 124-76		13		31	18	15	3
391	TW STEWART VALLEY STH 310		3		17	19	15	3
392	TW CABRI STH 183		4		34	19	15	3
393	TW KYLE STH 365		1		21	20	15	3
394	TW KYLE STH 23		4		6	22	15	3
395	KNOX CLARA		12		16	22	15	3
396	SMITH HERSCHEL M	NW	13		20	23	15	3
397	TW ELROSE STH 296		10		29	23	15	3

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LIMITATIONS:
Except at testhole sites where geologicall logs are available the geologic contacts are inferred and represent geologic models that are believed to best fit the information.

0 2 4
kilometres

Prelate Area
72K
CROSS SECTION
A-A'

Testhole or Well

🟨 Drift- aquifer
🟩 Drift- aquitard
🟧 Bedrock- aquifer
🟦 Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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LIMITATIONS:
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Prelate Area
72K
CROSS SECTION
B-B'

|	Testhole or Well
🟨	Drift- aquifer
🟩	Drift- aquitard
🟧	Bedrock- aquifer
🟦	Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
C-C'

Testhole or Well

🟨 Drift- aquifer
🟩 Drift- aquitard
🟧 Bedrock- aquifer
🟦 Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
D-D'

Testhole or Well

🟨 Drift- aquifer
🟩 Drift- aquitard
🟧 Bedrock- aquifer
🟦 Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
E-E'

❘	Testhole or Well
🟨	Drift- aquifer
🟩	Drift- aquitard
🟧	Bedrock- aquifer
🟦	Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
F-F'

|	Testhole or Well
🟨	Drift- aquifer
🟩	Drift- aquitard
🟧	Bedrock- aquifer
🟦	Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

LIMITATIONS:
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Prelate Area
72K
CROSS SECTION
G-G'

| Testhole or Well

🟨 Drift- aquifer
🟩 Drift- aquitard
🟧 Bedrock- aquifer
🟦 Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
H-H'

|	Testhole or Well
🟨	Drift- aquifer
🟩	Drift- aquitard
🟧	Bedrock- aquifer
🟦	Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
I-I'

|	Testhole or Well
🟨	Drift- aquifer
🟩	Drift- aquitard
🟧	Bedrock- aquifer
🟦	Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
J-J'

|	Testhole or Well
🟨	Drift- aquifer
🟩	Drift- aquitard
🟧	Bedrock- aquifer
🟦	Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
K-K'

Testhole or Well

🟨 Drift- aquifer
🟩 Drift- aquitard
🟧 Bedrock- aquifer
🟦 Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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LIMITATIONS:
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Prelate Area
72K
CROSS SECTION
L-L'

|	Testhole or Well
🟨	Drift- aquifer
🟩	Drift- aquitard
🟧	Bedrock- aquifer
🟦	Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

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Prelate Area
72K
CROSS SECTION
M-M'

🟥	Testhole or Well
🟨	Drift- aquifer
🟩	Drift- aquitard
🟧	Bedrock- aquifer
🟦	Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.

LIMITATIONS:
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Prelate Area
72K
CROSS SECTION
N-N'

Testhole or Well

🟨 Drift- aquifer
🟩 Drift- aquitard
🟧 Bedrock- aquifer
🟦 Bedrock- aquitard

Accompanies:
Maathuis, H. and Simpson. M., 2007.
Groundwater Resources of the Prelate
Area (72K), Saskatchewan.
SRC Report No.11975-1E07.