Saskatchewan Research Council

Groundwater Resources of the Cypress Lake (72F) area, Saskatchewan

Prepared for Saskatchewan Watershed Authority

By
Harm Maathuis
and
Mark Simpson
Saskatchewan Research Council
Environment and Forestry

SRC Publication No. 11974-1E07

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APPENDICES

Appendix A: Cross Section Log Index and Cross sections

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
WWDR	SWA Water Well Driller Record

1. INTRODUCTION

1.1 Background

The first inventory and characterization of the groundwater resources in the Cypress Lake NTS mapsheet area (72F) 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.

Whitaker (1976) published the first provincial geology and groundwater resources map for the Cypress Lake 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 Cypress Lake NTS mapsheet area were published in 1990 (Millard, 1990). 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 Cypress Lake NTS mapsheet area, map 72F, encompasses Ranges 15 to 30, Townships 1 to 12, West of the 3rd Meridian and covers an area of about 16,128 km^2 (Figure 1). The area is bounded by longitudes 108º 00’ and 110º 00’, and latitudes 49º 00’ and 50º 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), except the Cypress Hills area which has a Continental climate (cool summers) (Fung, 1999, p. 95). The climate stations within the study area are shown in Figure 2.

This figure also shows the average annual precipitation. The average annual precipitation ranges from 328 (Treelon) to 592 mm (Cypress Hills). Due to its higher elevation, the Cypress Hills receives a larger amount of precipitation than the surrounding lower area. Precipitation in the form of snow, as percentage of total annual precipitation, varies from 21% (Treelon) to 45.2% (Cypress Hills). 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 ± 1.3 ºC (Claydon) 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 -11.6 to -9.5 ºC range. July is the warmest month. The average daily temperature in July ranges from 15.4 to 18.9 ºC.

The average annual lake evaporation is in the 800 to 1,000 mm range (Phillips, 1990).

1.5 Drainage

The Cypress Hills form the divide between the South Saskatchewan River basin and the Missouri River basin (Figure 3). The South Saskatchewan river ultimately discharges into the Hudson Bay whereas the Missouri river discharges into the Gulf of Mexico. The northwestern part of the area, between the Alberta border and the Swift Current Creek watershed is an internal drainage basin referred to as the "Cypress Hills North Slope Basin" by the Saskatchewan Watershed Authority. A portion of the northeastern area of the map sheet is also part of an internal drainage basin, the Old Wives Lake basin.

The Frenchman River valley was formed during the final deglaciation of the Cypress Lake area as an ice-marginal meltwater channel receiving meltwater from the glacier to the north and an ice lobe to the south (Christiansen, 1979; Christiansen and Sauer, 1988). The current Frenchman River is small compared to the river that formed the valley. Several creeks draining the southern part of the Cypress Hills discharge into the Frenchman river as are a few tributaries from the plains to the south. The Cypress Hills are drained by a large number of streams. This large number is due in part to the higher precipitation that this area receives.

1.6 Topography

The topographical setting of the Cypress Lake area is shown in Figure 4, in the form of a digital elevation model. The Cypress Hills are the most prominent topographical feature in the study area. The topographical elevation in the study area ranges from 1390 m asl in Range 30, Township 7 (Cypress Hills) to 724 m asl in Range 29, Township 12.

1.7 Land Use

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

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 Cypress Lake 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. However, 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 72F area were extracted from SRC Bores database and imported into the Geographic Information System (GIS), ArcGIS version 9.1. In total there were 1,676 individual sites in the Cypress Lake area at which stratigraphic information has been determined. These sites include: 90 SRC testholes, 270 SWA testholes for which an E-log is available and 132 DMR-SRC-EMR stratigraphic testholes. In addition, stratigraphic information for 1,044 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 2,732 stratigraphic picks made on testholes/wells in the Cypress area were entered into SRC Bores.

2.3 Location and Elevation 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. All UTM coordinates used in this report are NAD83 coordinates. 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). If a GPS'ed location was available for a well/testhole site, the GSP UTM's were entered into the database.

For most testholes/well sites used in this study a surface elevation was available. Typically, surface elevations were determined by plotting locations on 1: 50,000 topographical maps. If a surface elevation for a site was not available, it was obtained by plotting the reported location on the 1: 50,000 scale Canadian Digital Elevation Data (CDED) grid.

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 Cypress Lake area (NTS map 72F) 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 is based on the extent of subcropping bedrock units as defined by earlier SRC bedrock mapping (Millard, 1990). 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, 1990) 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 72F area was taken from SRC's 1:250,000 scale "Surficial Geology of the Cypress Area (72F), Saskatchewan (Simpson, 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 Cypress Lake 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 are the 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 (WWDR)
- groundwater quality records in the Saskatchewan Environment (SE) database
- groundwater quality collected in the RM’s of Piapot, Carmichael and Webb as part of SWA’s Rural Water Quality Advisory Program (RWQAP)
- groundwater quality data contained in consultant reports
- other sources (*e.g.* Dyck, 1980; Maathuis, 2006)

Within the Cypress Lake map sheet area there are 1,259 water quality data available for 1,027 individual well sites. The large number of groundwater quality analyses is due in particular to a groundwater quality survey conducted in 1976 in the map sheet areas 72F, 72K/1 and 72K/2 by the Geological Survey of Canada as part of an uranium reconnaissance program. The sampling procedures, analytical methods and results were published in the form of a Geological Survey of Canada Open File report (Dyck, 1980). The samples were analyzed in a field laboratory. An electronic copy of the results was obtained through the library of the Geological Survey of Canada.

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. This figure shows that the majority of the groundwater quality data (about 55%) are for wells 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 Cypress Lake mapsheet area

Purpose	**Formation**	**Allocation (dam^3/a)**
Water supply enhanced oil recovery	Ravenscrag Fm.	13
	Judith River Fm	1,196.9
	Mannville Gr/Mississipian	529
Municipal	Glacial	1,207.3
	Cypress Hills Fm	61.5
	Ravenscrag Fm.	437.5
	Bearpaw Fm	25.6
	Judith River Fm	83
Industrial (process water, ILO)		983.1
Irrigation		64.5
TOTAL		**4,601.4**

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 Cypress Lake map sheet area

Purpose	**Allocation (dam^3/a)**	**Net evaporation loss (dam^3/a)**	**Diversion (dam^3/a)**
Irrigation	67,353	6,532	73,885
municipal	236	28	264
Industrial	192	0	192
Other (wild life)	138	8,126	8,264
Domestic	3,338	4,246	7,584
Totals	**71,257**	**18,932**	**90,189**

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 is for irrigation purposes (67,353 dam^3/a). 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 hydraul**ic** 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 Cypress Lake 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 Cypress Hills area is not available. Table 3 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 x 10^{-9}	
	Floral till, bulk	3.2 x 10^{-10}	
Birsay	Battleford till (?), unfractured	5.4 x 10-11 - 2.7 x 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 L: 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 are available for the following SWA provincial groundwater level observation wells in the Cypress Lake map sheet area: SWA Garden Head, SWA Shaunavon and SWA Instow (Figure 13).

Details on these 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 2.7.2) 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, K_v 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:

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

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:

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

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.*, 1986). 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 Cypress Lake 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). Coals within the Formation are a potential source of NGC (Natural Gas in Coal, also known as coal bed methane) (Saskatchewan Industry and Resources, 2005).

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).

Beneath the Cypress Hills 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 (1990a) 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 (see Figure 16; cross section A – A') to 400 m beneath the Cypress Hills.

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. The Ravenscrag Formation is comprised of sands, silts, clays and coals. Since these formations can not be separated in the subsurface they have been lumped together into one unit (*e.g.* Whitaker *et al*., 1978; Christiansen, 1983).

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.

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 and glacial erosion.

The bedrock topography is shown in Figure 17. The bedrock topography ranges from a high of 1385 m in the Cypress Hills upland (Rg 30, Tp 7) to a low of 630 m in the northern portion of the map sheet (Rg 25, Tp 12).

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).

In the Cypress Lake area there is insufficient information to separate the groups and formations. Consequently, the Quaternary deposits on cross sections are shown as “drift, undifferentiated”. Only in a few occasions it was possible to differentiate between the Sutherland and Saskatoon groups (see cross sections).

4.3.2 Drift Thickness

In Figure 19, the thickness of the drift is shown. The drift thickness ranges from zero meters where bedrock units outcrop at the ground surface to about 156 m. The thickest drift is found in Rg 24, Tp 12.

4.4 Identification of Principal Aquifers and Aquitards

The major bedrock aquifers in the Cypress Lake 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 formed by the silts and clays of the Lea Park and Bearpaw formations (Figure 14).

Empress Group sediments, stratified deposits within the Saskatoon Group and surficial sands form Quaternary aquifers. No aquifers have been identified within the Sutherland Group. Quaternary aquitards are formed by till units (Figure 18).

5.0 HYDROGEOLOGY OF BEDROCK AQUIFERS

5.1 Introduction

The major bedrock aquifers in the Cypress Lake 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.

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 Cypress Lake 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

Mannville - Active	**Period of withdrawals**	**Range of annual withdrawals m^3**	**Total volume withdrawn m^3**	**Highest annual withdrawal rate m^3/day**
08-08-11-18-W3	1996-1998	10,467 - 41,336	67,773	113
13-24-06-19-W3	1997-2005	6,221 - 30,005	121,485	82
07-33-11-19-W3	1996-1998	24,470 - 33,257	89,940	91
04-09-04-20-W3	1995-1996	4,548 - 4,853	9,403	13
08-29-05-20-W3	1995-1998	2,269 - 11,918	28,413	33
09-36-11-20-W3	1995-1998	28,785 - 68,614	25,141	188
		Total	**342,155**	
Mannville - Non-active				
07-29-18-17-W3	1973-1978	4,814 - 15,743	57,704	43
12-26-09-18-W3	1958-1963	15,634 - 72,724	255,265	199
13-29-14-18-W3	1996-1998	10,233 - 52,044	94,041	143
16-02-17-18-W3	1965-1970	35,794 - 128,862	424,875	353
15-03-17-18-W3	1959-1966	13,381 - 83,611	430,546	229
13-01-07-20-W3	1957-1980	94 - 186,615	1,559,500	511
05-11-07-20-W3	1956-1966	86,722 - 197,404	1,735,855	541
05-14-07-20-W3	1956-1971	27,238 - 194,183	1,859,730	532
13-23-07-20-W3	1958-1964	3,590 - 186,512	755,875	511
		Total	**7,173,390**	
Total withdrawals	**1956-2005**		**7,515,545**	

Based on the maximum reported annual withdrawals, well yields varied between 13 and 541 m^3/day (0.15 – 6.25 L/s). Since 1956, a total volume of 7.515 dam^3 has been withdrawn from the aquifer. The impact of this pumping on water levels in the Mannville can not be assessed as there are no long-term water level records available.

There are no water quality data available for the Mannville aquifer in the Cypress Lake area.

5.2.1 Milk River Aquifer

The Milk River aquifer is an important bedrock aquifer in southeastern Alberta but in southwestern Saskatchewan the Formation is mainly composed of silts and clays. However, in the utmost southwestern part of the province a well has been completed in the Milk River aquifer. This well yields a Na-Cl type of water with a TDS of 4,070 mg/L.

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). The depth to and thickness of the Ribstone Creek aquifer is solely based on oil logs and stratigraphical picks provided by the Saskatchewan Geological Survey. In the Cypress Lake area the Ribstone Creek Tongue occurs at depths ranging from 143 m (Tp 12, Rg 29) to 762 m (Tp 7, Rg 30) below the ground surface (Figure 21). The thickness of the Tongue ranges between zero (0) and 36 m (Figure 22). The Tongue is the thickest in Tp 9, Rg 26. 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 40 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 in the aquifer will come from the overlying Judith River aquifer, through the aquitard formed by the Grizzly Bear Tongue.

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

Water quality data for the Ribstone Creek aquifer are shown in Table 8. The water quality data are based on drillstem tests. Table 8 shows that the aquifer yields saline water with a TDS in the 4,950 to 30,160 mg/L range.

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. The Formation outcrops in Alberta and Montana. 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 depth to the top of the Judith River Formation is shown in Figure 24 and its thickness in Figure 25. Both the depth to and thickness are based on oil log and water well testhole information. The Judith River Formation is encountered at depths below ground surface ranging from 28 to 564 m. The depth to the top is the greatest where the surface elevation is the highest (Tp7, Rg 30). The point thickness ranges from 67 m (Tp 12. Rg 15) to 215 m (Tp 1, Rg 30).

The Judith River Formation is a highly complex geological unit which for one-half of it thickness is composed of silts and clays. In southwestern Saskatchewan the basal portion of the Judith River Formation (up to 85 m thick) consists predominantly of sands with relatively thin silts and clay interbeds (Whitaker, 1982). 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 (see cross sections A –A', C – C').

5.4.2 Hydraulic properties of the Judith River Aquifer

Only a few reliable pumping tests have been conducted on wells completed in the Judith River aquifer in the Cypress Lake area. Typically the tests are single-well pumping tests (*i.e.* the production well only was tested and there were no observation wells). The results of these tests are summarized in Table 9.

Table 9 Summary of results of pumping tests conducted on wells completed the Judith River aquifer

Land Location	Well name	Transmissivity m^2/day (m^2/s)	Hydraulic Conductivity m/day (m/s)	Reference
13-23-07-20-W3	Dollard 13-23	7.78 (9.0 x 10^{-5})	0.085 (9.84 x 10^{-7})	Beckie, 1979
		8.42 (9.75 x $10^{-5)}$	0.092 (1.06 x 10^{-6})	Beckie, 1979
		9.1 (1.05 x 10^{-4})	0.1 (1.16 x 10^{-6})	Beckie, 1979
06-09-04-20-W3	Page Rapdan	11.6 (1.34 x 10^{-4})	0.1 (1.16 x 10^{-6})	Whitaker, 1982
SE-08-13-03-20-W3	Frontier well #6	4.2 (4.9 x 10^{-5})	0.36 (4 x 10^{-6})	Meneley, 1974
01-13-03-19-W3	Frontier well #7	3.1 (3.6 x 10^{-5})	0.16 (1.9 x 10^{-6})	Beckie and Famulak, 1982
	Frontier well #7	3.5 (4.0 x 10^{-5})	0.18 (2.1 x 10^{-6})	Meneley, 1985
	Frontier well #7	3.6 (4.2 x 10^{-5})	0.19 (2.2 x 10^{-6})	Meneley and Allen, 1995
SW-02-02-03-26-W3	Supreme JR06	2.9 (3.4 x 10^{-5})	3.4 (4.0 x 10^{-6})	Whitaker, 1982a
SW-02-02-03-26-W3	Supreme JR03	1.1 (1.3 x 10^{-6})	0.18 (2.1 x 10^{-6})	Whitaker, 1982a

Beckie Hydrogeologists Ltd. (1979) conducted a pumping test on a well completed in the Judith River Formation (completion interval 505.1 – 413.6 m) which was used as a water source well for enhance oil recovery (Dollard 13-23-07-20-W3). A source well which was located at a distance of 38.6 m was converted into a Judith River aquifer observation well. The pumping test was conducted at an average pumping rate of 536.5 m^3/day and the results were analyzed using various methods. Whitaker (1982a,b, p. 21-22) quotes the results of this test but provides slightly different values for the transmissivity. Beckie Hydrogeologists Ltd. (1979) calculated a value of the storage coefficient of 5.16 x 10^{-4}. Whitaker (1982a,b) reported the results of a recovery test conducted on the Page Rapdan source well 06-09-04-20-W3. Several single well pumping tests were conducted on the two Judith River aquifer wells used by the village of Frontier (well #6 and #7) for its water supply.

Whitaker (1982) suggests that the maximum hydraulic conductivity of a Judith River aquifer sand bed could be 15 m/day (≈ 1.7 x 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 (≈ 5.8 x 10^{-5} m/s). The data in Table 9 indicate that a hydraulic conductivity in the 0.1 to 5 m/day (≈ 1.2 x 10^{-6} to 5.8 x 10^{-5}) range can be taken as a general characteristic for the Judith River aquifer sands.

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 10.

Table 10 Groundwater withdrawals from the Judith River aquifer for enhanced oil recovery

Land Location LSD-Sec-Tp-Rg-M	Period of withdrawals	Total volume withdrawn m^3	Highest annual withdrawal m^3	Highest annual withdrawal rate m^3/day	Highest annual withdrawal rate L/s
Judith River – Active wells					
03-05-12-17-W3	1966-2002	1,601,813	146,954	402.6	4.66
11-24-09-18-W3	1985-2005	595,528	49,853	136.6	1.58
01-26-09-18-W3	1963-1978	1,994,673	228,758	626.7	7.25
09-05-10-18-W3	1963-2004	3,710,855	203,703	558.1	6.46
06-08-11-18-W3	1995-2005	365,312	168,770	462.4	5.35
12-06-05-19-W3	1968-1998	265,279	50,965	139.6	1.62
13-17-07-19-W3	1970-2005	462,897	72,601	198.9	2.30
01-23-08-19-W3	1988-2005	102,287	9,881	27.1	0.31
13-32-08-19-W3	1971-1985	107,821	10,478	28.7	0.33
14-01-09-19-W3	1968-2005	690,013	57,346	157.1	1.82
10-27-10-19-W3	1960-2005	1,291,478	77,805	213.2	2.47
05-34-11-19-W3	1970-1998	1,069,309	96,148	263.4	3.05
06-12-12-19-W3	1997-2005	243,755	50,372	138.0	1.60
06-09-04-20-W3	1974-2005	216,056	13,118	35.9	0.42
05-11-04-20-W3	1962-2003	3,668,034	214,112	586.6	6.79
13-12-04-20-W3	1963-2005	2,054,989	167,911	460.0	5.32
05-11-07-20-W3	1963-1983	1,752,704	210,358	576.3	6.67
13-11-07-20-W3	1970-2005	3,648,725	168,368	461.3	5.34
13-14-07-20-W3	1962-1992	2,553,284	199,048	545.3	6.31
13-23-07-20-W3	1963-1984	2,741,287	185,644	508.6	5.89
14-24-04-20-W3	1964-1969	502,222	124,486	341.1	3.95
	Total	**29,638,321**			
Judith River – Non-active wells					
02-27-10-19-W3	1960-1969	473,112	116,003	317.8	3.68
06-29-05-20-W3	1965-1967	42,236	20,587	56.4	0.65
08-07-10-18-W3	1960-1966	214,212	66,558	182.4	2.11
10-27-10-19-W3	1960-1991	179,877	46,680	127.9	1.48
12-27-10-19-W3	1960-1966	32,258	25,266	69.2	0.80
13-11-07-20-W3	1960-1962	328,254	145,511	398.7	4.61
13-01-07-200W3	1963-1979	846,913	69,108	189.3	2.19
	Total	**2,116,860**			
Judith River – Abandoned wells					
08-07-10-18-W3	1960-1968	214,212	66,558	182.4	2.11
14-01-09-19-W3	1964-1967	58,558	22,675	62.1	0.72
02-27-10-19-W3	1960-1973	473,112	116,003	317.8	3.68
10-27-10-19-W3	1960-1991	179,877	46,680	127.9	1.48
12-27-10-19-W3	1960-1966	32,258	25,266	69.2	0.80
06-29-05-20-W3	1965-1967	42,236	20,587	56.4	0.65
13-01-07-20-W3	1963-1979	846,913	101,349	277.7	3.21
13-11-07-20-W3	1960-1962	328,254	145,511	398.7	4.61
	Total	**2,175,418**			
Total withdrawals	**1959-2005**	**33,930,599**			

Since 1959 a reported total volume of nearly 34,000 dam^3 was withdrawn by the oil industry. In 2005, a total volume of 378,439 m^3 was withdrawn from 10 wells (Table 11). The locations of these wells are shown in Figure 12.

Table 11 Reported withdrawals by the oil industry from the Judith River aquifer in 2005

Land Location LSD-Sec-Tp-Rg-M	Reported withdrawals in 2005 m^3
11-24-09-18-W3	49,853
06-08-11-18-W3	32,742
13-17-07-19-W3	693
01-23-08-19-W3	200
10-27-10-19-W3	54,208
06-09-04-20-W3	7,871
14-01-09-19W3	37,593
06-12-12-19-W3	29,478
13-12-04-20-W3	46,221
13-11-07-20-W3	119,580
TOTAL	**378,439**

The Village of Frontier is the only municipal entity in the Cypress Hills area that uses water from the aquifer for its water supply. Data provided by the Village show that since 1995 the volume produced from the Judith River aquifer increased from about 90 to 140 m^3/day.

Withdrawals from domestic/farm wells can be considered minor.

5.4.4 Groundwater Levels and Groundwater Regime

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. Throughout the Cypress Lake area the water table is higher than the water level in the Judith River aquifer and therefore, there is downward flow into the aquifer throughout the entire area.

Based on the large scale topographical setting, the general flow direction in the aquifer in the Cypress Lake area will be from Little Rocky Mountain area in Montana to the north. The Judith River aquifer in southern western Saskatchewan discharges into the South Saskatchewan River.

Whitaker (1982a) argues that isostatic rebounds following deglaciations induced fractures and therefore, the Bearpaw Formation would exhibit fracture permeability. Whitaker (1982a, Figure 4.2) shows that beneath the Cypress Hills upland a strong vertical downward gradient of 0.49 exists. Based on the strong gradient and the assumption of fracture permeability, Whitaker (1982a) considers the Cypress Hills upland as a secondary recharge area. There would be lateral flow away from the upland, both to the north and to the south.

The available point-groundwater elevation level data for the Judith River aquifer are shown in Figure 26. The water levels shown are based mainly on depth to waters reported on SWA E-logs. The water level elevation data can not be contoured because of the distribution of the data and the water level elevation values. There are no water level data available for the central portion of the Cypress Lake area as a shallower aquifer unit (Eastend - Cypress Hills aquifer) is present this area. Where water level elevation data are available elevations may vary over short distance (*e.g.* Tp 10, Rg 27). The variability is due in part to the fact that a depth to water measurement was taken after the construction of a well and ages of the wells spans decades. Also, the depth of water reported may not have been the "true" static water level at the time of measurement.

In a very general sense Figure 26 shows a flow direction from the south to the north. The low water level elevations in the northwestern part of the Cypress Lake area likely reflects the impact of pumping by the oil industry. Low water elevations also occur in (Tp 2, Rg 19 and 20). The distribution of the available water level data does not allow for contouring of the water level elevations.

The total thickness of the Bearpaw Formation beneath the Cypress Hills upland is about 360 m; 320 m of Bearpaw silts and clays and 40 m of sands. The Judith River aquifer beneath the uplands is about 150 m. Assuming that 50% of the thickness is sand with hydraulic conductivity in the 0.1 – 5 m/day (1.2 x 10^{-6} to 5.8 x 10^{-5} m/s) range, the transmissivity is in the m^2/day range. Based on a vertical hydraulic conductivity in the 8.64 x 10^{-6} (facture permeability) to 8.64 x 10^{-8} m/day (matrix permeability) (1 x 10^{-10} – 1 x10^{-12} m/s) range for the Bearpaw silts and clays, the vertical resistance (see equation [2]) would be between 100,000 and 10,000,000 years. These assumptions yield L values (see equation [1]) in the 17 to 1,200 km range. Considering the large L values it is highly unlikely that the recharge beneath the Cypress Hills uplands would result in a measurable recharge mound within the Judith River aquifer beneath it. Furthermore, for a gradient of 0.49 to exist, the water levels in the Judith aquifer will have to be low. Considering that the discharge is 100 – 125 km north of the uplands, a "low' water level in the Judith aquifer implies that the aquitard would have to have a low vertical hydraulic conductivity. Furthermore, a vertical downward gradient of 0.49 and a hydraulic conductivity in the 8.64 x 10^{-6} to 8.64 x 10^{-8} (1 x 10^{-10} – 1 x10^{-12} m/s) range imply a recharge rate between 0.015 to 1.5 mm/year. Based on the depth to the top of the aquifer, the thickness of the Bearpaw Formation and/or the drift this range of recharge is realistic for recharge to the aquifer in the entire Cypress Lake area. Therefore, considering the reasoning above, it is highly unlikely that the Cypress Hills uplands are a significant area of recharge to the Judith River aquifer.

Very little information is available on the actual impact of withdrawals on the water level(s) in the aquifer. Since 1980 the water level in the Judith River aquifer has been recorded at the site of the provincial groundwater level observation well SWA Instow (NW-01-26-09-18-W3). Prior to 1980 this well was a water source well for enhanced oil recovery. Well details have been provided by Maathuis *et al.* (2001). The location of the Instow observation well and nearby water source wells is shown in Figure 27. In the vicinity of the observation well there are ten water source wells completed in the Judith River aquifer withdrawals from which could affect the water level in the observation well. Withdrawals from four (4) of these wells are relevant as pumping from the other wells ceased by 1970. These four wells are located at: 11-24-09-18-W3, at 10-27-10-19-W3 (two wells) and 13-32-08-19-W3. Figure 28 shows the hydrograph for the observation well as well as the withdrawal data from the Instow well and the four water source wells identified. Since recording started in 1980, the water level increased till 1986 in response to ceasing on pumping from the well but then dropped significantly till 1989. The decrease in water level appears to be related to the start of pumping from the well at 11-24-09-18-W3. Since 1989 the water continued to drop but at a slower rate. Considering the closeness to the Instow observation well it is not surprising that the water level fluctuations in the well appear to reflect the pumping from 11-24-09-18-W3. However, some interference from the well located at 10-27-10-19-W3 and wells farther away are likely.

5.4.5 Groundwater Quality in the Judith River Aquifer

The available water quality data for the Judith River aquifer are listed in Table 12. The listing includes data for source wells for secondary oil recovery. These wells are often completed across both the Outlook member of the Bearpaw Formation and the main body of the Judith River. The locations of wells for which there are water quality data are shown in Figure 29. Based on the most recent water quality data,

Figure 30 shows a Piper-plot of the water quality data for the Judith River aquifer. Both Table 12 and Figure 30 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. The TDS (sum ions) ranges from 1,315 to 5,740 mg/L but typically is in the 1,500 to 3,000 mg/l range (Figure 29). In many areas the sodium and chloride or sulfate concentrations exceed the Saskatchewan drinking water quality objectives.

5.4.6 Theoretical Yield of Wells Completed in the Judith River Aquifer

Based on the reported highest annual volumes pumped, the pumping rate from source wells used by the oil industry may range form 27 to 726 m^3/day (≈ 0.3 – 7.3 L/s). Higher shorter term rates (*i.e.* monthly rates) up to 780 m^3/day (9 L/s) have been reported in Tp 7, Rg 20.

The Judith River aquifer is a semi-confined aquifer and equation [1] can be used to estimate the theoretical yield from individual wells completed in the aquifer and the extent of the drawdown.

Well yields were estimated using the following aquifer/aquitard characteristics: vertical hydraulic conductivity of the aquifer K_v = 8.64 x 10^{-6} - 8.64 x 10^{-8} m/day (1 x 10^{-10} – 1 x10^{-12} m/s), thickness of aquitard 150 – 300 m, thickness of Judith River aquifer (50% of the total thickness); 100 – 150 m, hydraulic conductivity of aquifer sands: K = 0.1 – 5 m/day (1.2 x 10^{-6} to 5.8 x 10^{-5} m/s). It was further assumed that the well had a radius of 0.075 m. Based on the few available data, the available drawdown of 100 m can be considered as a reasonable estimate for the Cypress Lake area. The theoretical yields are summarized in Table 13.

Table 13 Theoretical yields for wells completed in the Judith River aquifer and leakage length for various aquifer and aquitard thicknesses and hydraulic properties, and available drawdown of 100 m

Vertical conductivity of aquitard (m/day)	Effective thickness aquitard (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}	150	50	5 - 250	265 – 11,300	9 - 66
8.64 x 10^{-6}	150	75	7.5 - 375	390 – 16,800	11 - 80
8.64 x 10^{-6}	300	50	5 - 250	260 – 11,200	13 – 93
8.64 x 10^{-6}	300	75	7.5 - 375	380 – 16,500	16 - 114
8.64 x 10^{-8}	150	50	5 - 250	222 – 9,800	93 - 660
8.64 x 10^{-8}	150	75	7.5 - 375	330 – 14,500	114 - 805
8.64 x 10^{-8}	300	50	5 - 250	217 – 9,600	132 - 930
8.64 x 10^{-8}	300	75	7.5 - 375	320 – 14,250	160 – 1,140

The values in Table 13 show that the theoretical yield 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. For an average hydraulic conductivity of 1 m/day for the aquifer sands, the yield would be in the 2,400 to 3,000 m^3/day range and L values would be between 30 to 510 km.

Table 13 illustrates a very important characteristic of the impact of major withdrawals from the Judith River aquifer in the Cypress Lake area, namely; the very large values for the leakage length L. The L values may range from tens 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.

Based on the values for the thickness of the aquitard and its vertical hydraulic conductivity c values are in the range of 47,000 to 9.5 million years. This implies that developing of steady sate conditions will take years as is the recovery after ceasing of pumping. In fact, these high c values raise the question if the current groundwater flow system within the Judith River aquifer is in equilibrium with the present climatic conditions.

It is not possible to determine the safe yield of the Judith aquifer in the Cypress Lake area as the aquifer extends well beyond the borders of the Cypress Lake 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 modelled 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 31. 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 Cypress Lake 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. Although the silts and clays between the sand members have been named (Figure 14), they have not been separated on the cross sections. The extent of the Bearpaw Formation and its sand members is shown in Figure 32. The Bearpaw Formation is present throughout the Cypress Lake area except in the utmost northwestern part of the area where it is removed by erosion (Figure 32: see also cross sections H-H’ and I– I’). The absence of the Bearpaw Formation in Tp 2, Rg 30 is speculative and is based on the topographical setting and interpreted thickness of the drift.

The sand members of the Bearpaw Formation form aquifers whereas the silt and clay units are aquitards. Whitaker (1982a) included the Outlook and Matador sand members in the same hydrostratigraphical unit as the Judith River aquifer as these members are hydraulically connected to the Judith River aquifer. The Demaine member and Bearpaw sand members above it are completely separated from the Judith River aquifer and therefore, must be considered as separate aquifers. The sand members are typically 5 to 20 m thick and are mostly composed of fine to medium-grained sands.

Figure 32 shows the extent of the Outlook – Metador, Demaine – Ardkenneth and Cruikshank – Oxarat sand members. The stratigraphic position of the members is also shown in the cross sections. Sands member of the Bearpaw Formation are present throughout the Cypress Lake area except in the utmost northwest, southwest and southeast. The importance of the Bearpaw sand members as a water supply source is limited to the areas north and south of the extent of the Eastend to Cypress Hills aquifer.

5.5.2 Hydraulic Properties

Information on the hydraulic parameters of the Bearpaw sand members is limited. The PFRA (1984) conducted a pumping test on the Village of Piapot Well #2 and reported a transmissivity of about 1 m/day (1.2×10^{-5} m^2/s) for a 2 m thick Bearpaw sand (Demaine sand member). Based on the lithological description of the sediments 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. The Village of Piapot has two wells completed a Bearpaw sand directly underlying till (PFRA, 1984). The combined average daily withdrawal from these wells for the period 1984 – 2004 was 27 m^3.

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 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 33. In Figure 34, the groundwater quality data are presented in the form of a Piper-plot.

The TDS (sum of ions) ranges from 270 to 10,000 mg/L but typically is in the 500 to 2,500 mg/L range. As is evident from Figure 34, 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 35. 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 - Cypress Hills Aquifer

5.6.1 Definition and Extent of Eastend - 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. Christiansen (1983) indicates that the bottom portion of the unit consists of blanket sands and that the discontinuous sands in the upper portion likely represent sands deposited in alluvial channels. The sands in both the lower and upper portion typically are fine to medium-grained.

The extent and depth to the Eastend – Cypress Hills aquifer is shown in Figure 36. Over large portions of its extent the aquifer is exposed at the ground surface or is covered by a thin layer of drift. Locally the aquifer is covered by a thick layer of drift, up to 80 m. The thickness of the aquifer (Figure 37) varies from zero (0) meters at its erosional edges to 290 beneath the Cypress Hills in Tp 8, Rg 27.

Because of its complex lithology the Eastend – Cypress Hills aquifer is an anisotropic aquifer. Over much of its extent the water level is below the top of the aquifer and therefore, the aquifer is unconfined. Locally, however, the aquifer is semi-confined.

Meneley (1983) studied the Eastend – Cypress Hills aquifer east of Range 22. The Eastend – Cypress Hills aquifer in this area was referred to as the Shaunavon aquifer (Meneley, 1983).

5.6.2 Hydraulic Properties of Eastend - Cypress Hills Aquifer System

A short-duration, single well pumping test conducted on SWA observation well Garden Head yielded a transmissivity of 8.1 m^2/day (9.3 x 10^{-5} m^2/s), corresponding to a hydraulic conductivity of about 6 m/day (6.9 x 10^{-5} m/s). A similar test conducted on SRC Shaunavon yielded a transmissivity of 15 m^2/day (1.7 x 10^{-4} m^2/s), and a hydraulic conductivity of 1.1 m/day (1.3 x 10^{-5} m/s).

The municipal water supply for the Town of Shaunavon is obtained from 8 wells, ranging in depth from 34 to 71 m and all completed in the Eastend - Cypress Hills aquifer. Pumping test results conducted in 1961 on two test wells yielded a reported transmissivity in the 76 - 86 m^2/day (8.8 x 10^{-4} – 1.0 x 10^{-3} m^2/s) range (Big Indian Drilling Ltd., 1961). The corresponding hydraulic conductivity is in the 17 – 19 m/day (1.9 x 10^{-4} – 2.2 x 10^{-4} m/s) range. Beckie Hydrogeologists Ltd. (1986) a summary of pumping test results conducted on the various Shaunavon wells (Table 15). Based on reported screen lengths, Table 15 also provides the corresponding hydraulic conductivities.

Table 15 Reported transmissivities and calculated hydraulic conductivities for pumping test conducted on the Town of Shaunavon wells

Well # - year installed	Reported transmissivity (m^2/day)	Screen Length (m)	Hydraulic conductivity (m/day)
PW1-61	127	5.2	24
PW6-78	90	13.1	6.9
PW7-81	45	8.2	5.5
TW1-85	93	14.7	6.3

Source: Beckie Hydrogeologists Ltd., 1986
PW = production well TW = test well

Based on specific capacities, Meneley (1983) suggested that the hydraulic conductivity of the aquifer in the Shaunavon area would be in the order of 1 to 5 m/day (1.1 x 10^{-5} to 5.8 x 10^{-5} m/s).

Based on reported values the hydraulic conductivities the hydraulic conductivity of the Eastend – Ravenscrag sands likely are in the 1 – 10 m/day (1.1 x 10^{-5} – 1.1 x 10^{-4} m/s), 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

The Town of Shaunavon is the largest user of water from the Eastend – Cypress Hills aquifer. During the period 1977 – 2004 it withdrew an average annual volume 377,620 m3 for its municipal water supply, corresponding to 1,034 m^3/day. In the period 1958 – 1986, the oil industry withdrew a total volume of about 5.5 x 106 m^3 from 5 wells completed in the aquifer just north of Shaunavon (see Figure 12). The reported withdrawals are listed in Table 16.

Table 16 Reported withdrawals by the oil industry from the Eastend - Cypress Hills aquifer

Ravenscrag (Active)	Period of withdrawals	Range of annual withdrawals m^3	Total volume withdrawn m^3	Highest annual withdrawal rate m^3/day
01-27-09-18-W3	1958-1986	562 - 110,489	1,863,650	303
09-05-10-18-W3	1962-1986	23,703 - 211,299	1,969,528	579
11-14-08-19-W3	1964-1976	9,266 - 58,180	462,695	159
15-33-09-18-W3	1958-1986	925 - 84,274	1,134,800	231
Ravenscrag - Non-active				
08-07-10-18-W3	1960-1965	10,096 - 57,619	121,622	158

The Cypress Hill Provincial Park obtains its water supply from the aquifer and over the period 1985 – 2004 withdrew an average annual volume of 62,170 m^3, or 170 m^3/day.

5.6.4 Groundwater Levels and Groundwater Regime

Available point water level data for the Eastend – Cypress Hills aquifer are shown in Figure 38. Over much of its extent, the water level in the Eastend – Cypress Hills aquifer is below the top of the aquifer and therefore, the aquifer is unconfined.

The distribution of the point-water level data and the complexity of the topographical setting does not allow contouring the data but the groundwater flow regime can only be described in a general sense. As is evident from the cross sections, the Eastend – Cypress Hills aquifer can be considered as a tabular mass overlying the Bearpaw formation which presumably as a low vertical hydraulic conductivity. The water level in the aquifer will be a subdued replica of the topography. Recharge to the aquifer takes places over virtually the entire extent of the aquifer. Discharge is limited to the creeks occupying the numerous valleys that dissect the area and to the erosional edges of the aquifer. Where the erosional edge outcrops at the ground surface springs can be expected.

Long-term water level records are available for two shallow wells completed in the Eastend- Cypress Hills aquifer: SWA Garden Head (22.6 m deep) and SWA Shaunavon (15.7 m deep). Construction details for these wells have been provided by Maathuis *et al.* (2001). The locations of the wells are shown in Figure 12. SWA Shaunavon was constructed to observe the possible impact of the groundwater withdrawals by the Town of Shaunavon and from a source well (11-14-08-19-W3) whereas SWA Garden Head was considered to be located far enough away to be beyond the drawdown cone induced by the withdrawals by Shaunavon and by the source well. The hydrographs for SWA Garden Head and Shaunavon are shown in Figure 39. Since recording started in 1966 the overall trend in the water level in both these wells has been upward. The water level in SWA Shaunavon, to an unknown extent, may be influenced by the pumping from the Shaunavon wells. The observed water level fluctuations in this well are not unusual for water level changes in shallow semi-confined aquifers in Saskatchewan. However, the significant increase in the water level of 2 m observed in SWA Garden Head since 1966 is unusually large. It can not be explained as being due to a climate effect.

5.6.5 Groundwater Quality in the Eastend to Cypress Hills Aquifer System

A listing of available water quality data for the Eastend – Ravenscrag aquifer is provided in Table 17. The locations of the sample points are shown in Figure 40. As the Geological Survey of Canada Open File report (Dyck, 1980) included data on the Cypress Hills aquifer, Table 18 provides a listing of available water quality data for this aquifer. In Tables 17 and 18 concentrations exceeding the Saskatchewan drinking water quality standards and objectives (Saskatchewan Environment, 2006) are highlighted. The water quality data for the Eastend – Ravenscrag and Cypress Hills aquifers are shown graphically in the form of a Piper-plot in Figures 41 and 42, respectively.

The TDS of waters from the Eastend – Ravenscrag aquifer ranges from 225 to 4,350 mg/L but typically is in the 500 to 1,500 mg/L range. As is evident from Figure 41, either sulfate or bicarbonate is the dominant anion. As the cation concentrations are highly variable, various water types can be found in the Eastend – Ravenscrag aquifer.

The TDS of waters from the Cypress Hills aquifer ranges from 250 to 4,500 mg/L but typically is less than 1,000 mg/L. The water commonly is either of the $Ca/Mg\text{-}SO_4$ or $Ca/Mg\text{-}HCO_3$ type.

5.6.6 Yield of Wells Completed in Eastend to Cypress Hills Aquifer

Considering the complexity of the aquifer it is not possible to determine theoretical sustainable well yields based on a semi-confined or unconfined analytical model. The 1,034 m^3/day withdrawn on average by the Town of Shaunavon doesn't appear to have had a significant impact on the water levels in the aquifer. Source wells have been pumped at a daily rate up to 580 m^3/day. Meneley (1983) suggested that individual wells in the Shaunavon aquifer could yield between 15 and 330 m^3/day.

5.6.7 Susceptibility of the Eastend - Cypress Hills Aquifer to Contamination

Point aquifer vulnerability index values for the Eastend – Cypress Lake aquifer are shown in Figure 43. Considering that over most of its extent the aquifer either outcrops at the ground surface or is confined by a thin layer of drift it is not surprising that over large areas the aquifer is very susceptible (AVI < 2) to contamination from the ground surface.

6.0 HYDROGEOLOGY OF QUATERNARY AQUIFERS

6.1 Definition of Extent of Quaternary Aquifers

Quaternary aquifers in the Cypress Lake area are formed by sands and gravels of the Empress and Saskatoon groups and the surficial stratified deposits. No aquifers within the Sutherland Group have been identified. None of the Quaternary aquifers have been named.

The extent, depth to and thickness of the aquifers formed by sands of the Empress Group are shown in Figure 44. The extent is inferred. Empress Group aquifers occur at depths ranging from 30 to 60 m and are up to 10 m thick.

The extent, depth to and thickness of Saskatoon Group aquifers are shown in Figure 45. The extent is inferred. The aquifers occur at depth ranging from 10 to 75 m and are of variable thickness.

The surficial aquifers are composed of alluvial, eolian, and fluvial materials deposited during and after the recession of the Wisconsinan glacier from the area. The extent of these aquifers is shown in Figure 46. Surficial sands range in thickness from zero (0) to 80 m. The greatest thickness is found in the alluvial fill of the Frenchman river. The thicknesses indicated in Figure 46 represent the total thickness of the surficial deposits and not the aquifer thickness as the thickness of the unsaturated zone is unknown. Small, not mappable, occurrences of surficial sands may locally form an important water supply source. For example, it is known that the Village of Frontier obtains a significant portion of its water supply from a surficial aquifer.

6.2 Hydraulic properties of Quaternary Aquifers

Mollard & Associated Ltd. (1968) documents the results of a pumping test done on a 15 m deep well completed in an intertill gravel. The transmissivity of the 4.3 m thick aquifer was reported to be 835 m^2/day (9.7 x 10^{-3}). The associated hydraulic conductivity is 195 m/day (2.3 x 10^{-3}). Whitaker (1981) conducted a pumping test on a well completed in a sand and gravel at the bottom of the alluvial fill of the Frenchman river. The transmissivity of the zone was determined to be 57 m^3/day (6.6 x 10^{-4} m^2/s): the corresponding hydraulic conductivity is 8.2 m/day (9.4 x 10^{-5} m/s). Pumping tests conducted on two wells completed at different depth in intertill aquifers near the Town of Maple Creek yielded transmissivities ranging from 26 to 142 m^2/day (3.4 x 10^{-4} to 1.6 x 10^{-3} m^2/s) (Beckie Hydrogeologists Ltd, 1985). Based on reported screen lengths, the transmissivities translate to hydraulic conductivities in the 4.3 to 30 m/day (4.9 x 10^{-5} to 3.5 x 10^{-4}). Beckie Hydrogeologist (1990) Ltd. (1999) documented a pumping test on another well near the Town of Maple Creek. The well was completed in an intertill aquifer and the transmissivity was found to be 0.66 m^2/day (7.6 x 10^{-6} m/s) and the hydraulic conductivity 0.22 m/day (2.5 x 10^{-6} m/s).

Even though the available information on the hydraulic properties is limited, the reported ranges are not unrealistic for the large variability in the lithology of intertill aquifers.

6.3 Groundwater Withdrawals from Quaternary aquifers

There are a number of towns/villages that obtain, in part or entirely, its water supply from Quaternary aquifers. These towns/villages include Climax and Maple Creek.

The Town of Maple Creek gets its water supply from wells completed in various intertill aquifers. The average annual withdrawal from these wells for the period 1991 – 2004 was 430,680 m^3, equivalent to an average of 1,180 m^3 per day. The Village of Climax obtains its water from a shallow Quaternary aquifer. The average annual volume withdrawn over the period 1985 – 2004 was 51,400 m^3 (average of 143 m^3/day).

Many domestic/farm wells in the areas north and south of the extent of the Eastend – Cypress Hills aquifer will be shallow large bored diameter wells, completed either in fractured till or in a sand seam of limited extent. The yield of these wells is generally low.

6.4 Groundwater Regimes and Groundwater Level

There are insufficient water level data to assess the groundwater regimes in the Quaternary and surficial aquifers. The Empress and Saskatoon group aquifer are recharged by vertical downward flow from the water table. The amount of recharge will be small because of the low vertical hydraulic conductivity of tills. Surficial aquifers are recharged by precipitation that infiltrates to the water table.

6.5 Groundwater Quality in Quaternary aquifers

A listing of available water quality data for the Quaternary aquifer is provided in Table 19. Concentrations exceeding the Saskatchewan drinking water quality standards and objectives (Saskatchewan Environment, 2006) are highlighted in Table 19. The locations of the sample points are shown in Figure 47. In Figure 48, the groundwater quality data are presented in the form of a Piper-plot.
The TDS of waters from the Cypress Hills aquifer ranges from 100 to 29,000 mg/L but typically is less than 2,000 mg/L. The water commonly is either of the $Ca/Mg\text{-}SO_4$ or $Ca/Mg\text{-}HCO_3$ type.

6.6 Yields of Quaternary Aquifers

The sustainable yield of wells completed in Empress and Saskatoon Group aquifers will be variable depending on the extent, thickness of the overlying aquitard, thickness and hydraulic conductivity of the sands. Considering the extent and settings of these aquifers their sustainable yield will be low.

6.7 Susceptibility of Quaternary Aquifers to Contamination

Point aquifer vulnerability index values for the Empress Group, Saskatoon Group and surficial aquifers are shown in Figures 49, 50 and 51, respectively.

Point AVI values for the Empress Group aquifers range from low to extremely low (Figure 48). Considering the depths at which the Empress Group aquifers occur, the aquifers over their entire extent are well protected against contamination from the ground surface.

Point AVI values for Saskatoon Group aquifers ranges from extremely high to extremely low (Figure 49). In general, the aquifers are very well protected against contamination from the ground surface. The AVI values of some small occurrences of Saskatoon Group aquifers ranges from moderate to extremely high as the aquifer is near the ground surface at these locations.

Surficial aquifers by definition are highly susceptible to contamination from the ground surface.

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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."

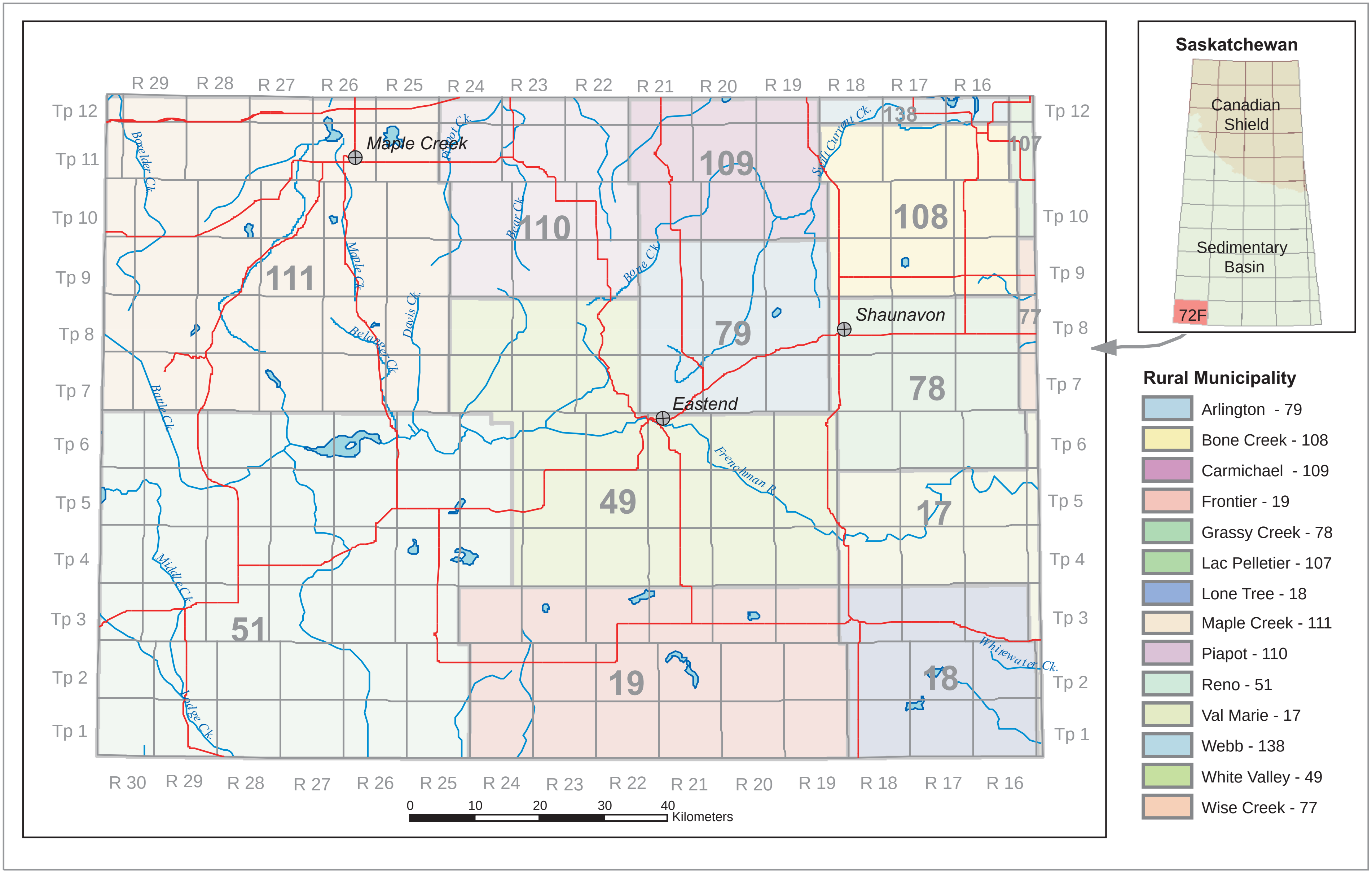
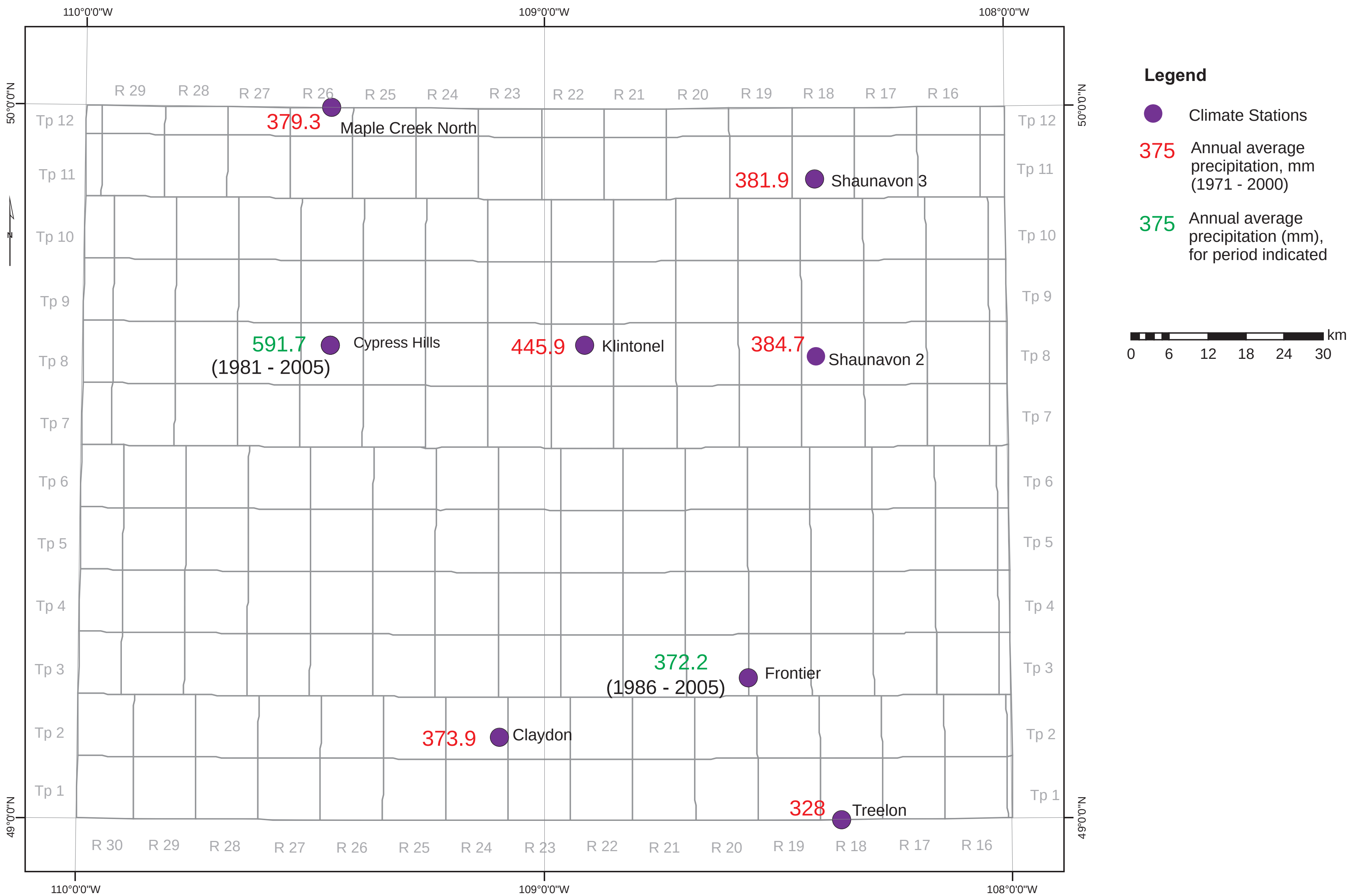


Figure 1 Location of study area



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

Figure 2 Locations of climate stations and average annual precipitation

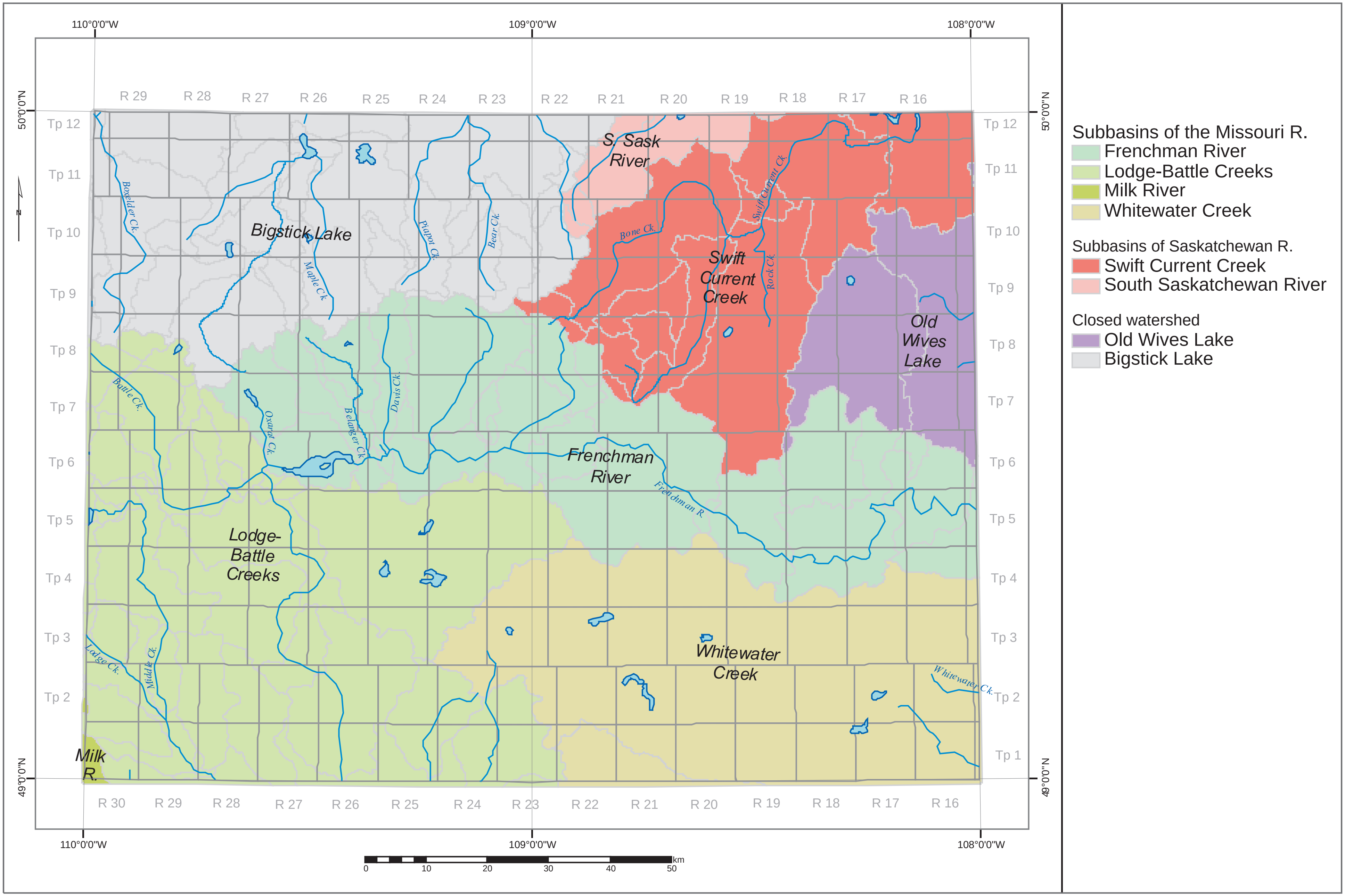


Figure 3 Drainage basins in the Cypress Lake area

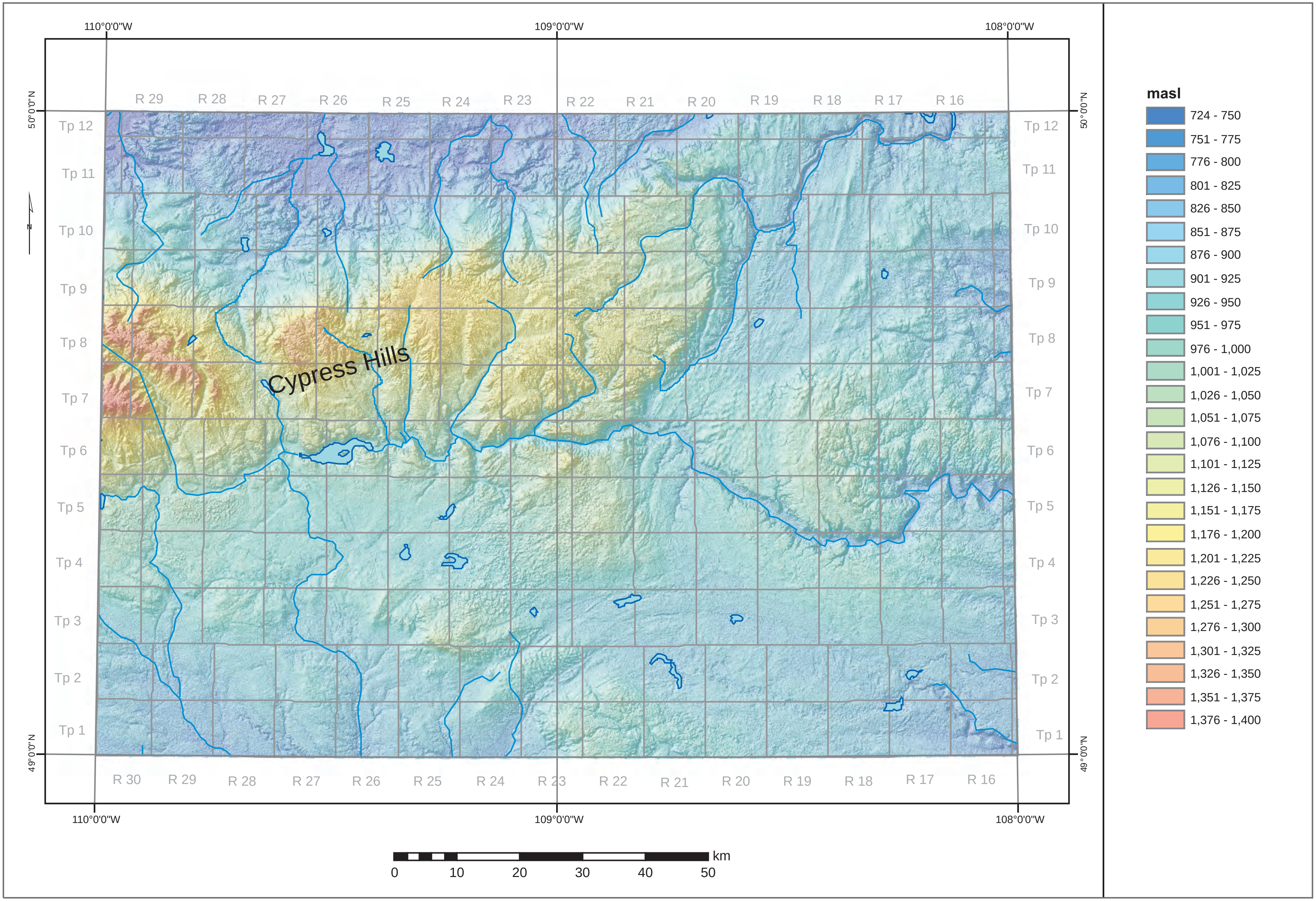


Figure 4 Topography of the Cypress Lake area

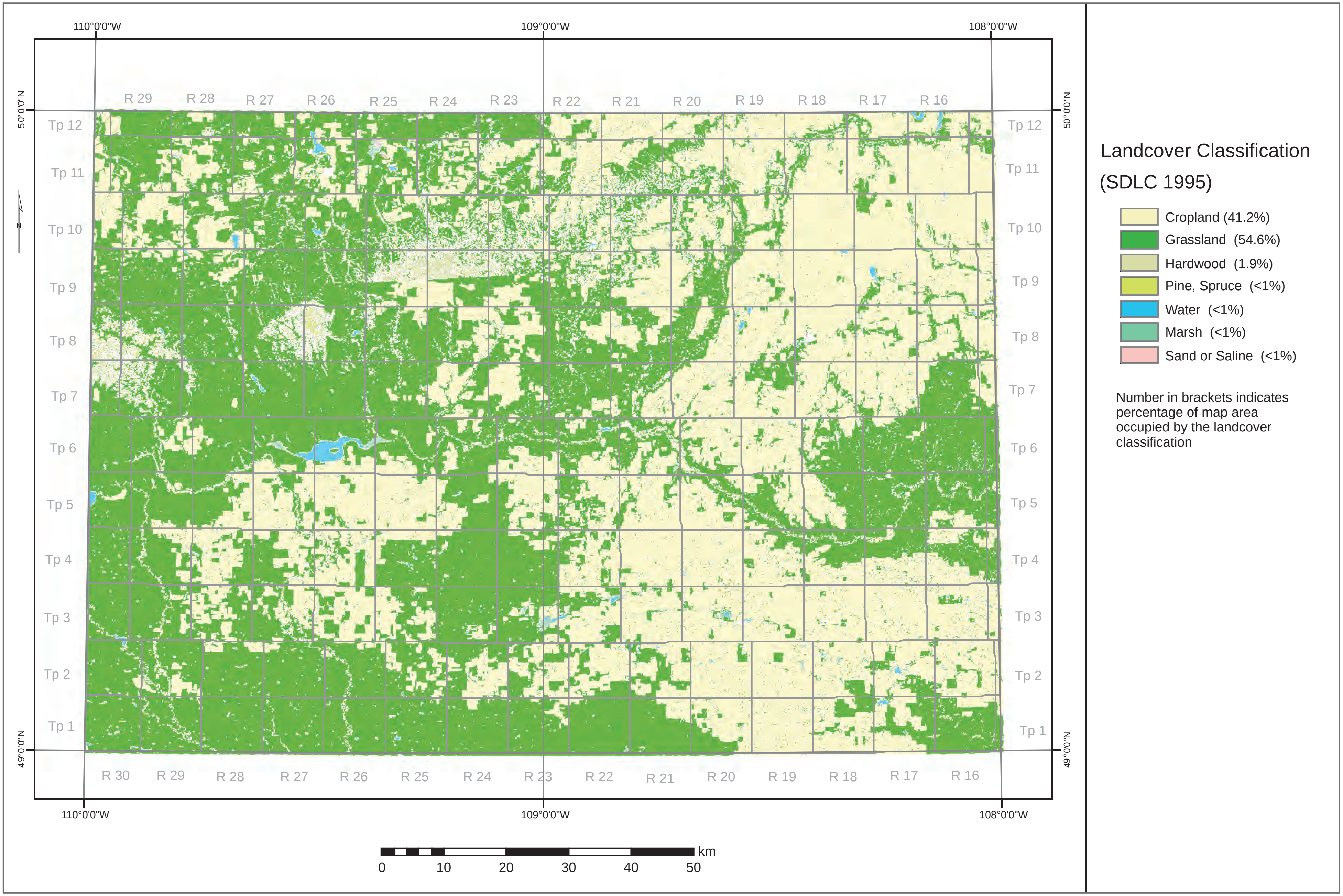


Figure 5 Land use in the Cypress Lake (72F) area

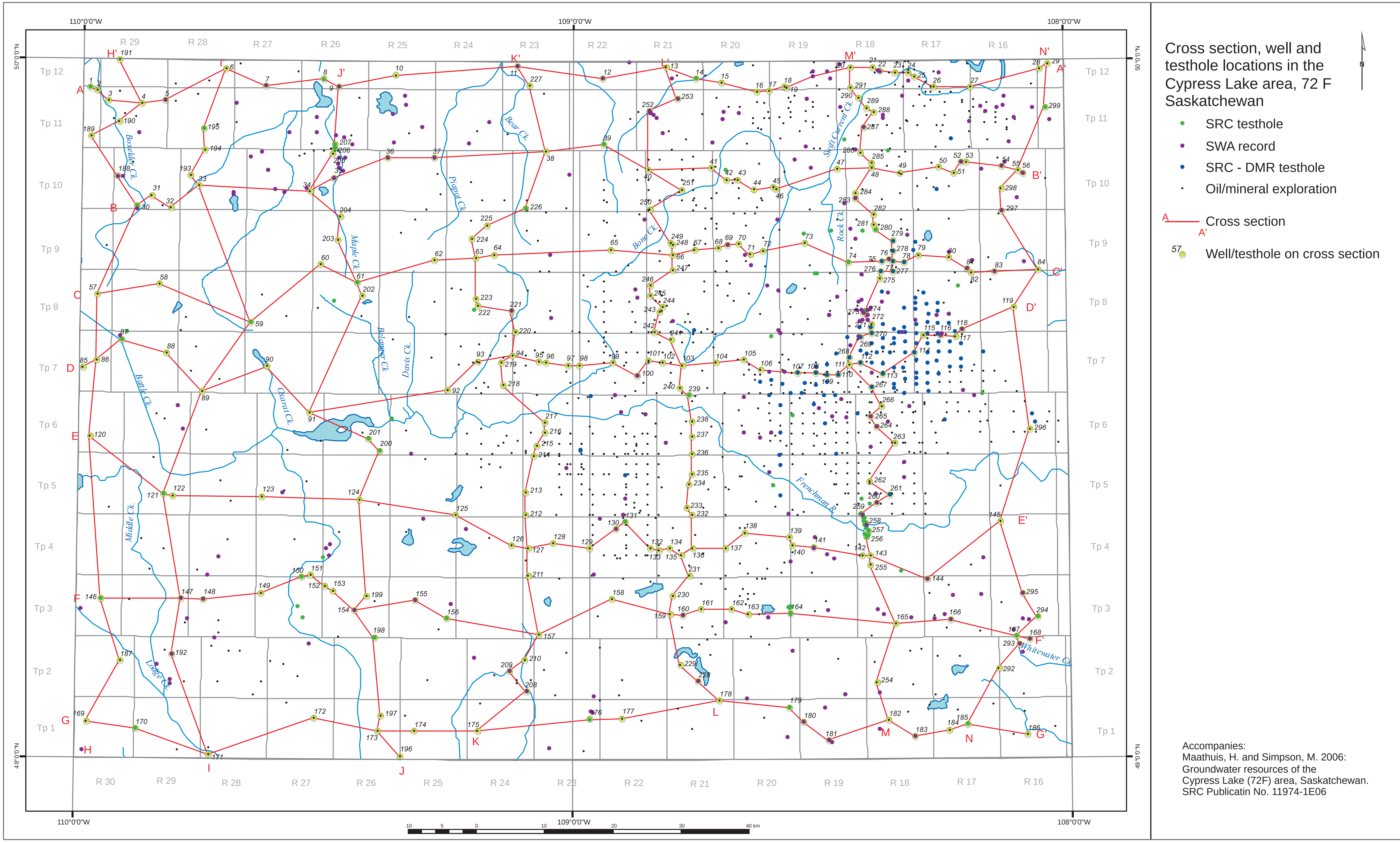


Figure 6 Locations of testholes and cross sections lines in the Cypress Lake map sheet area

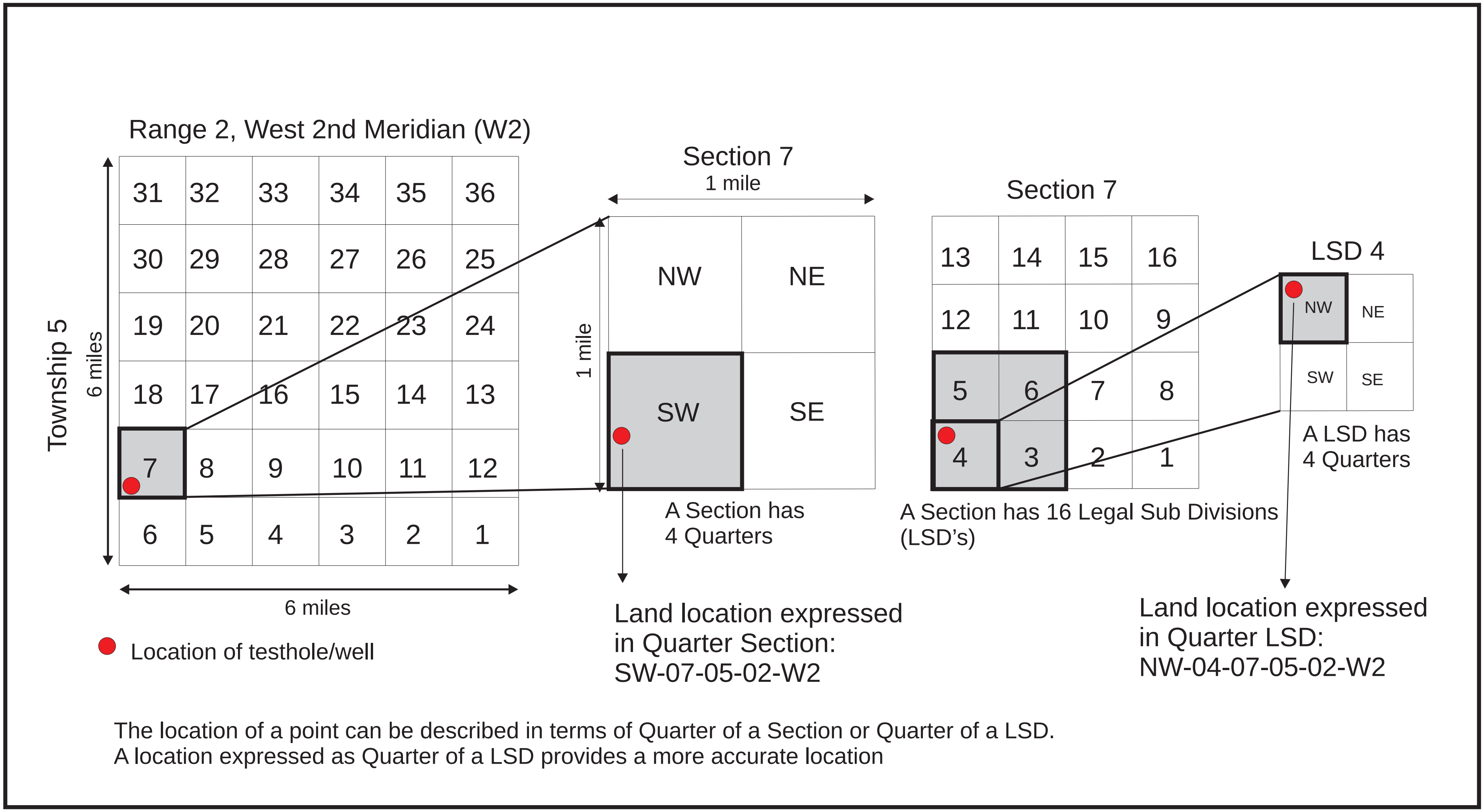


Figure 7 Schematic illustration of the Canada Dominion Land Survey System

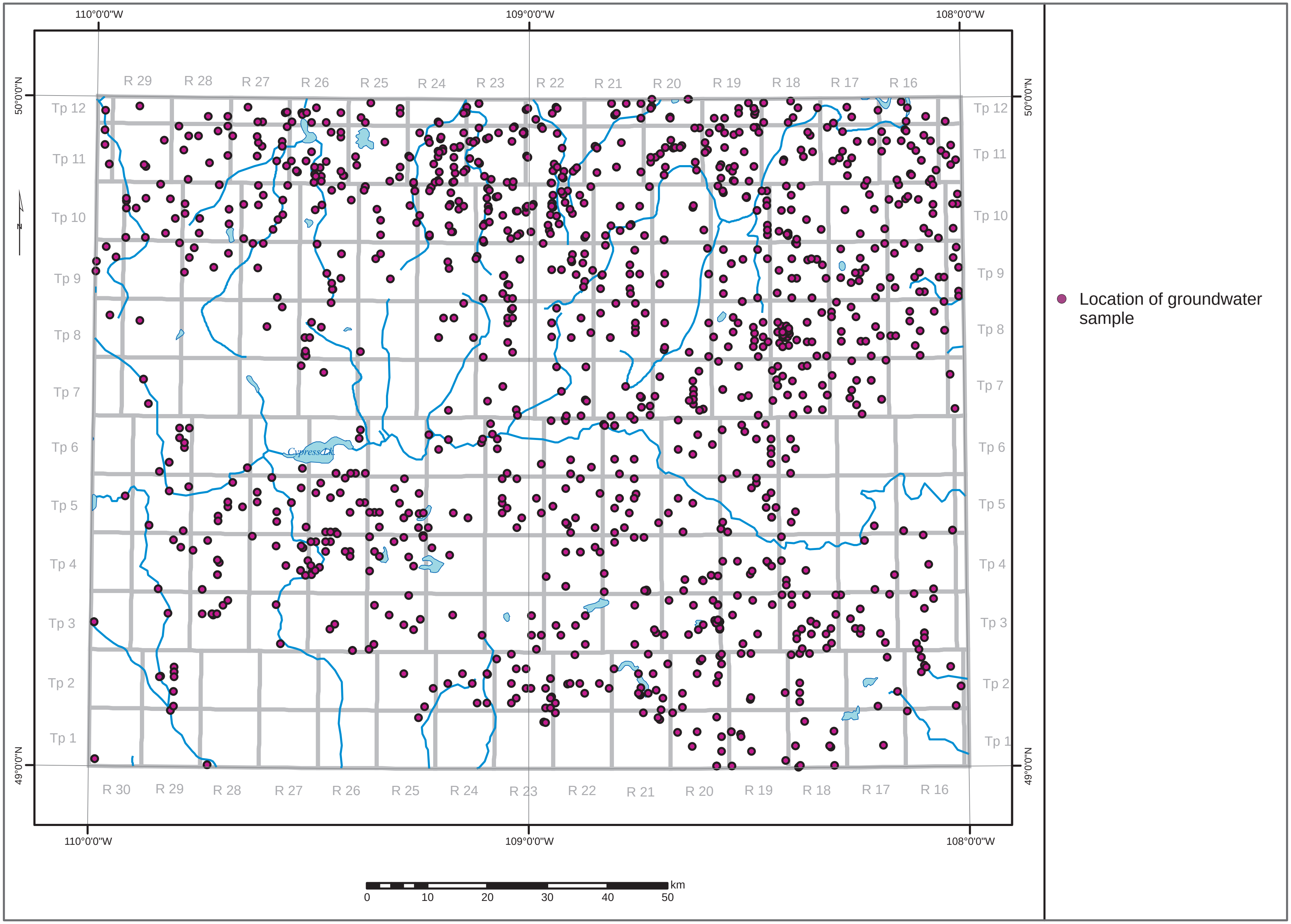


Figure 8 Locations of groundwater quality sample points in the Cypress Lake area

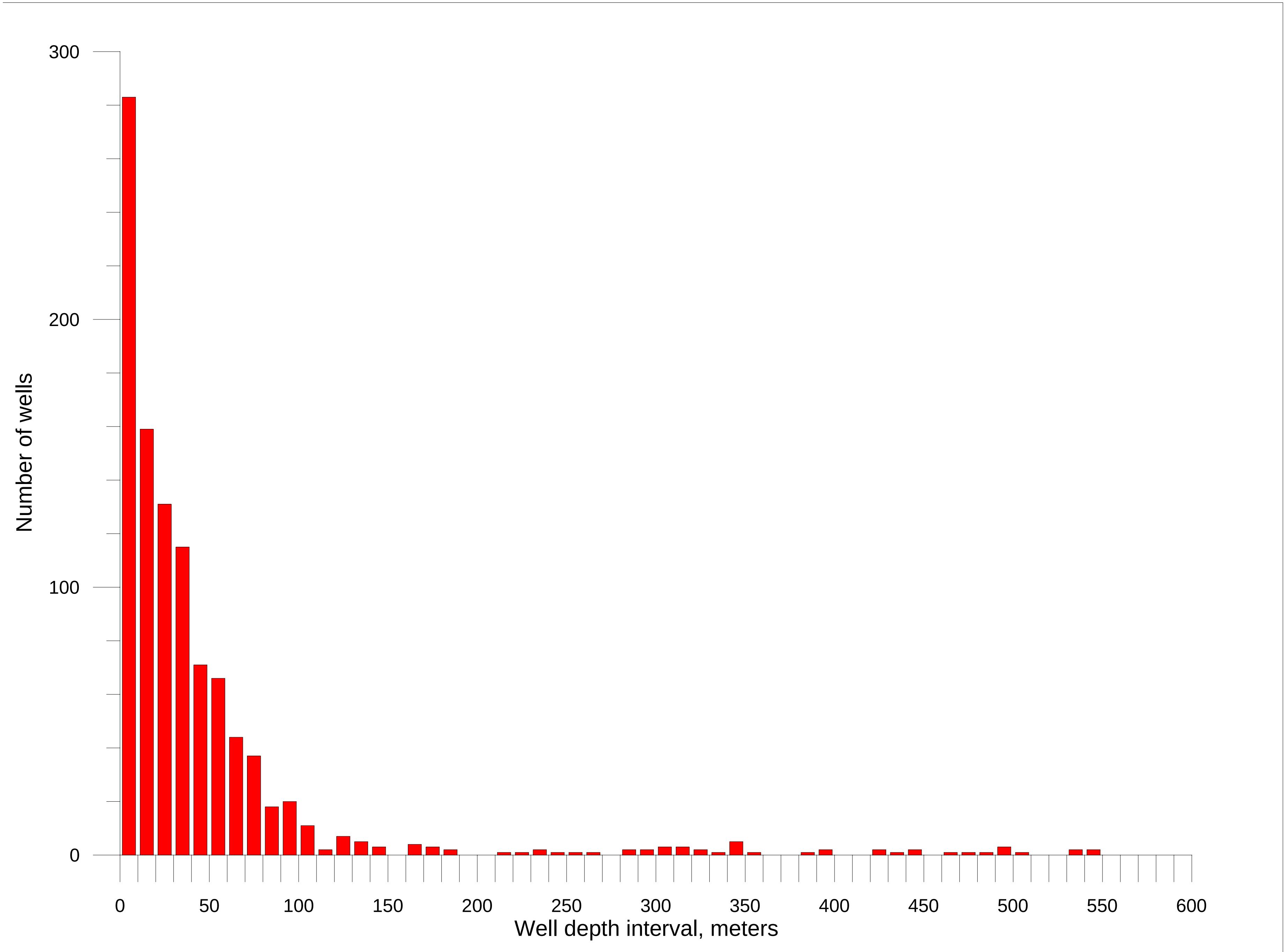


Figure 9 Depth distribution of groundwater quality samples in the Cypress Lake area

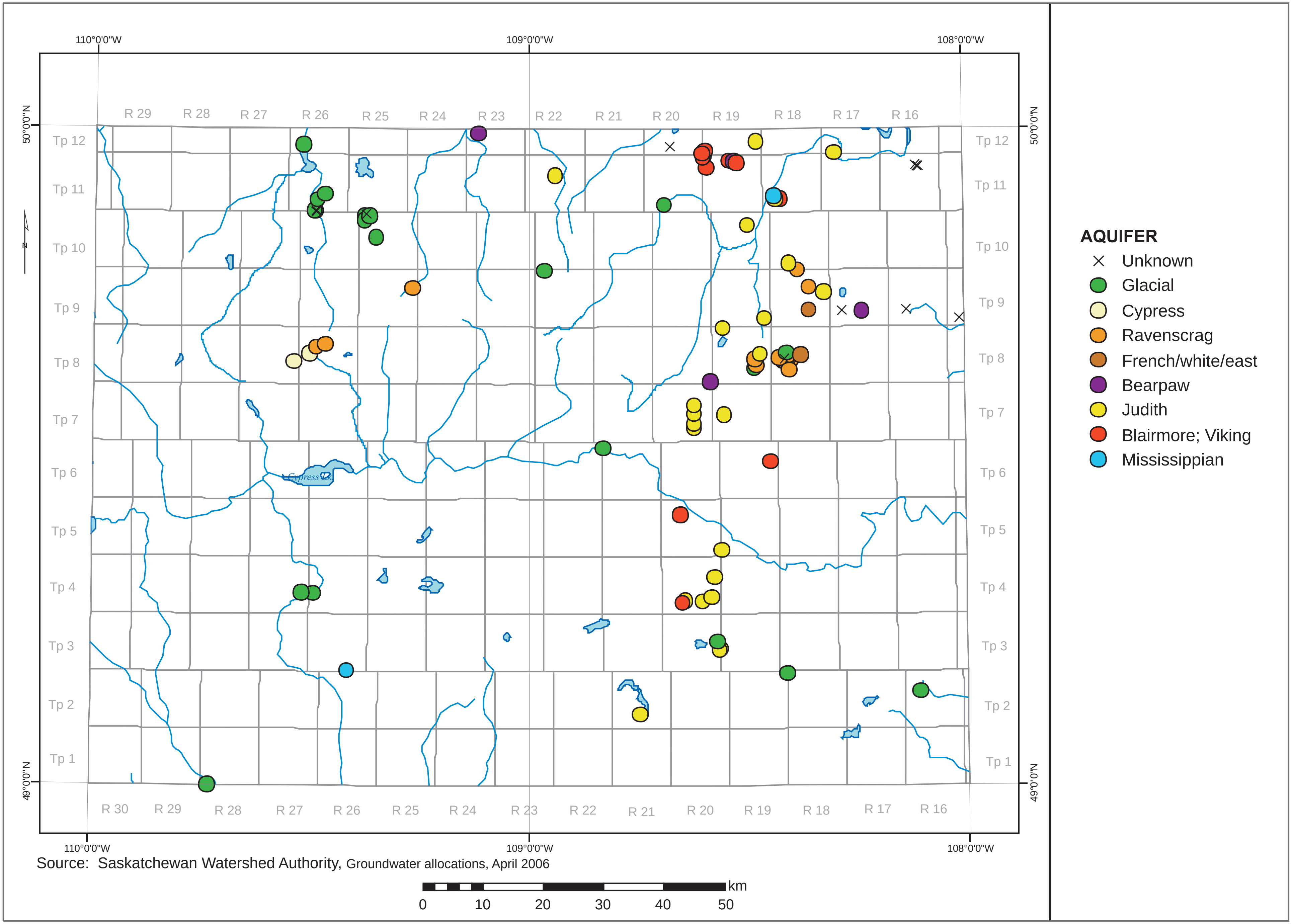


Figure 10 Locations of groundwater allocations in the Cypress Lake area, by aquifer

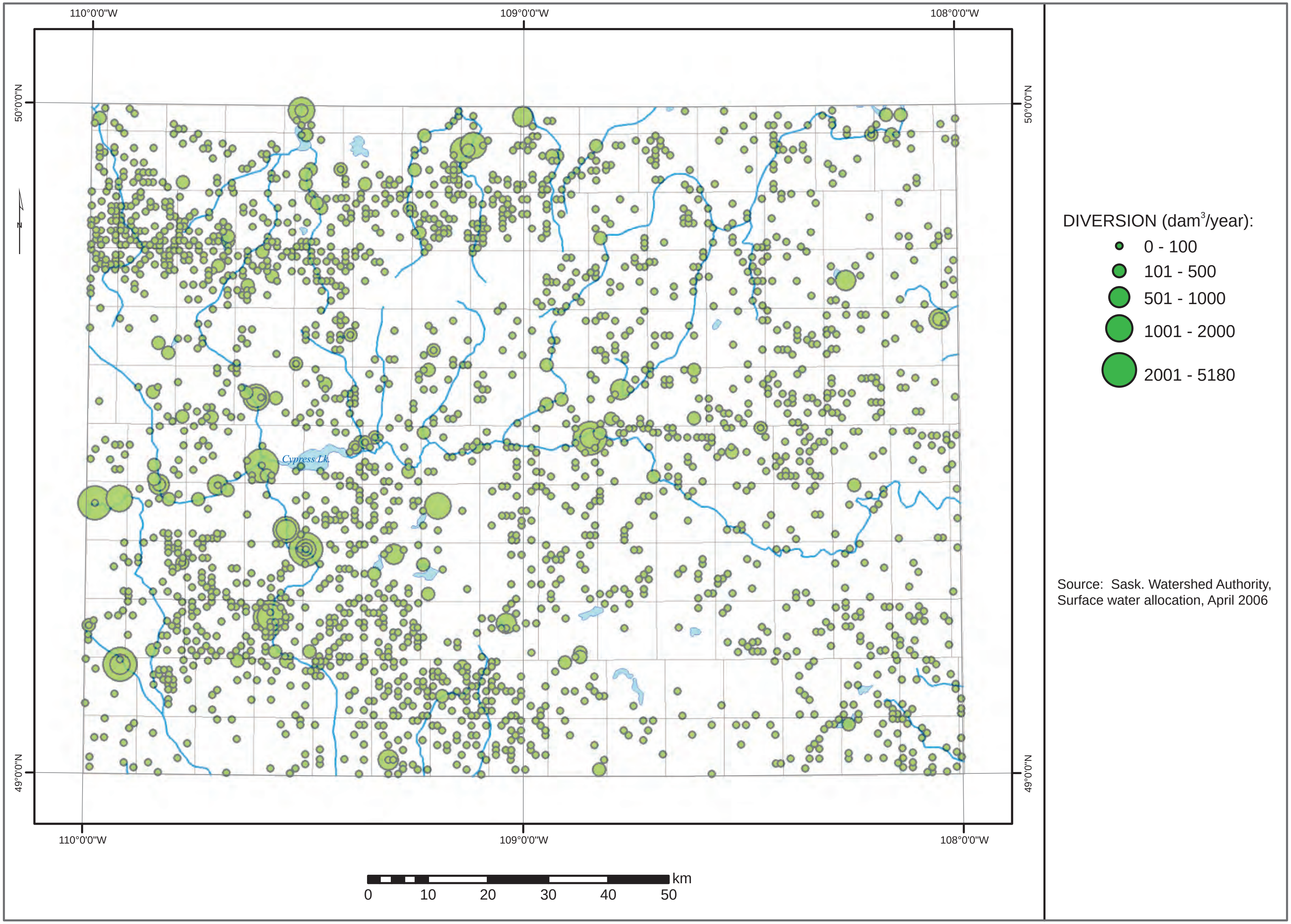


Figure 11 Locations of surface water diversions in the Cypress Lake area

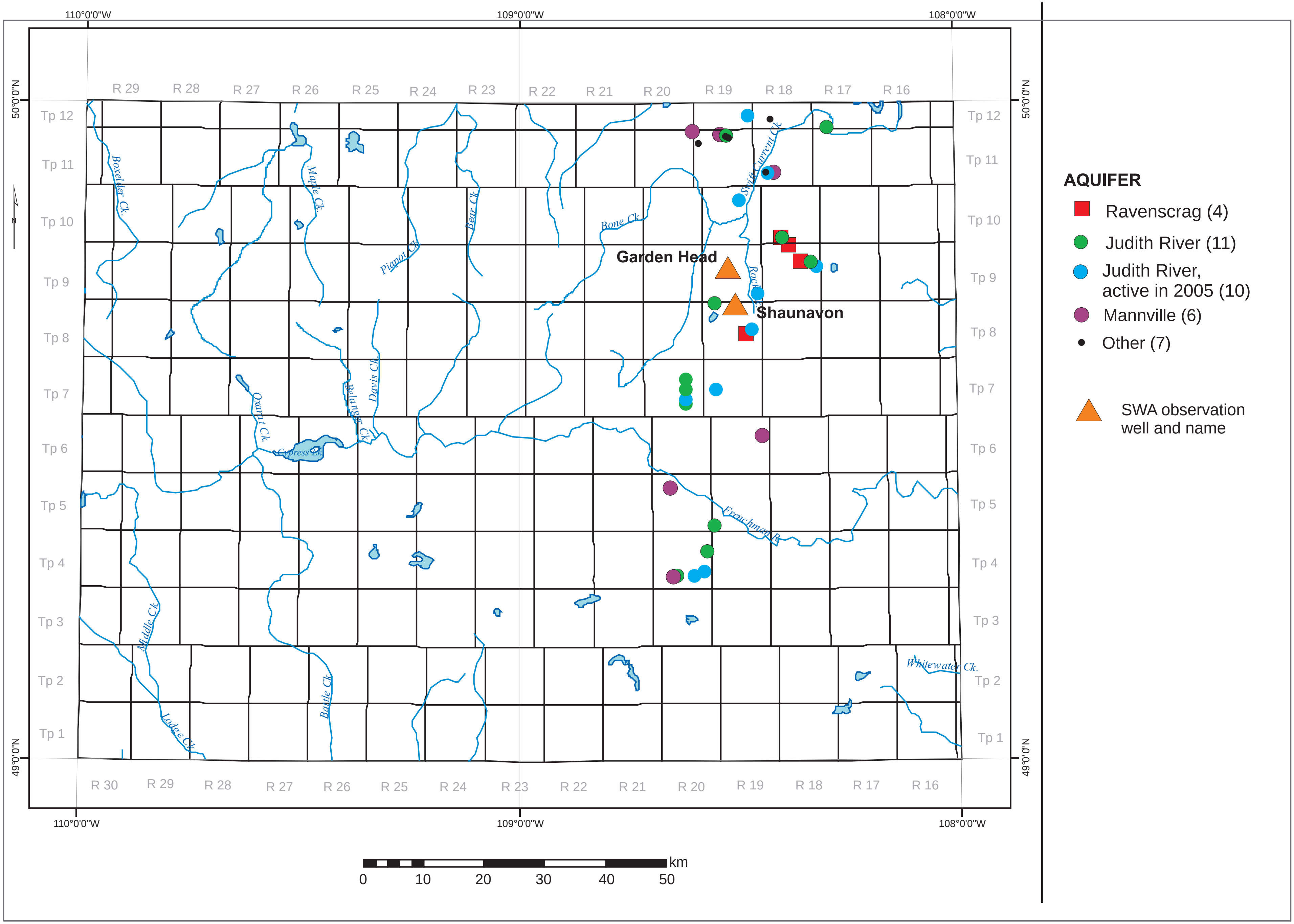


Figure 12 Locations of active source wells for enhanced oil recovery

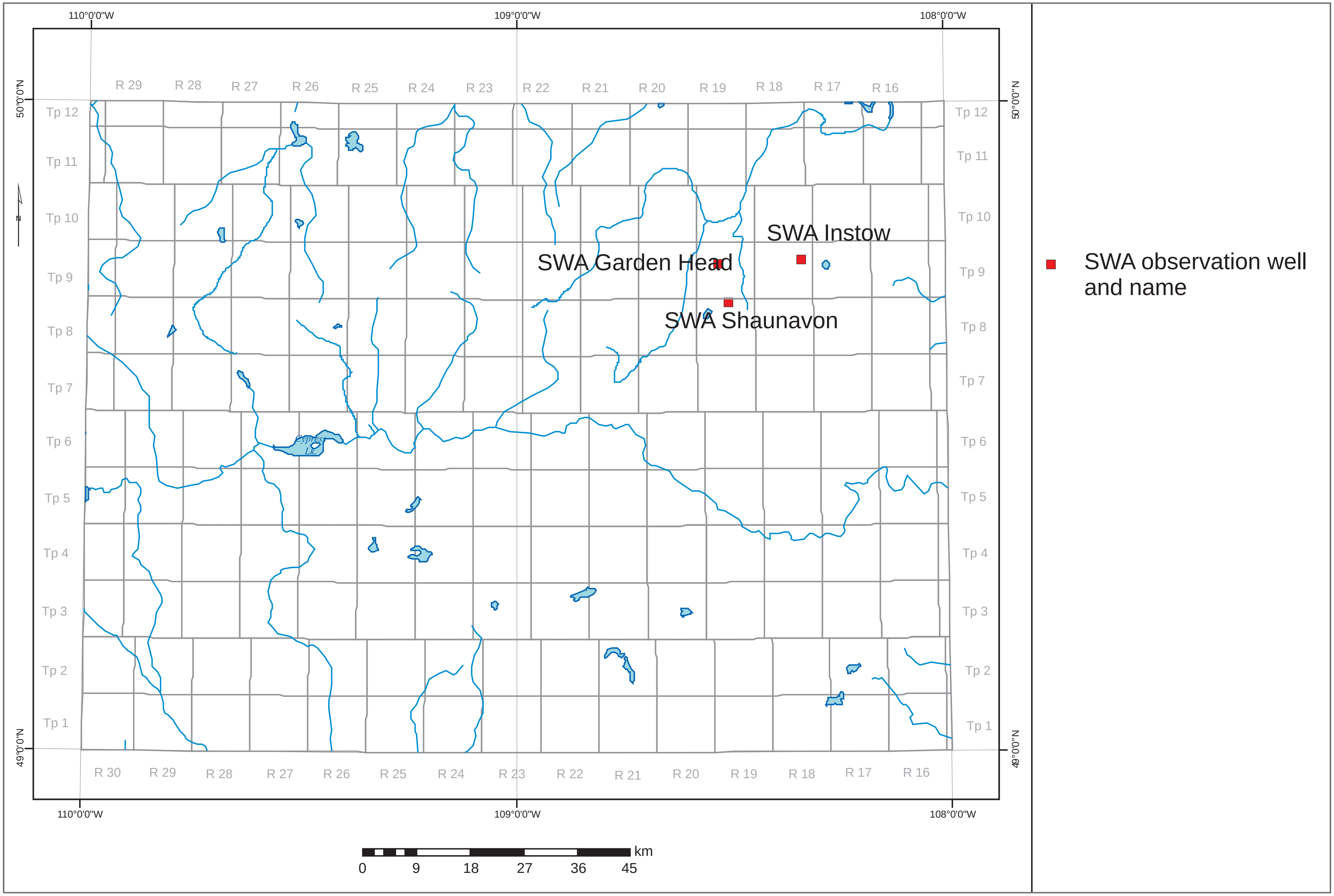


Figure 13 Locations of provincial groundwater level observation wells

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)

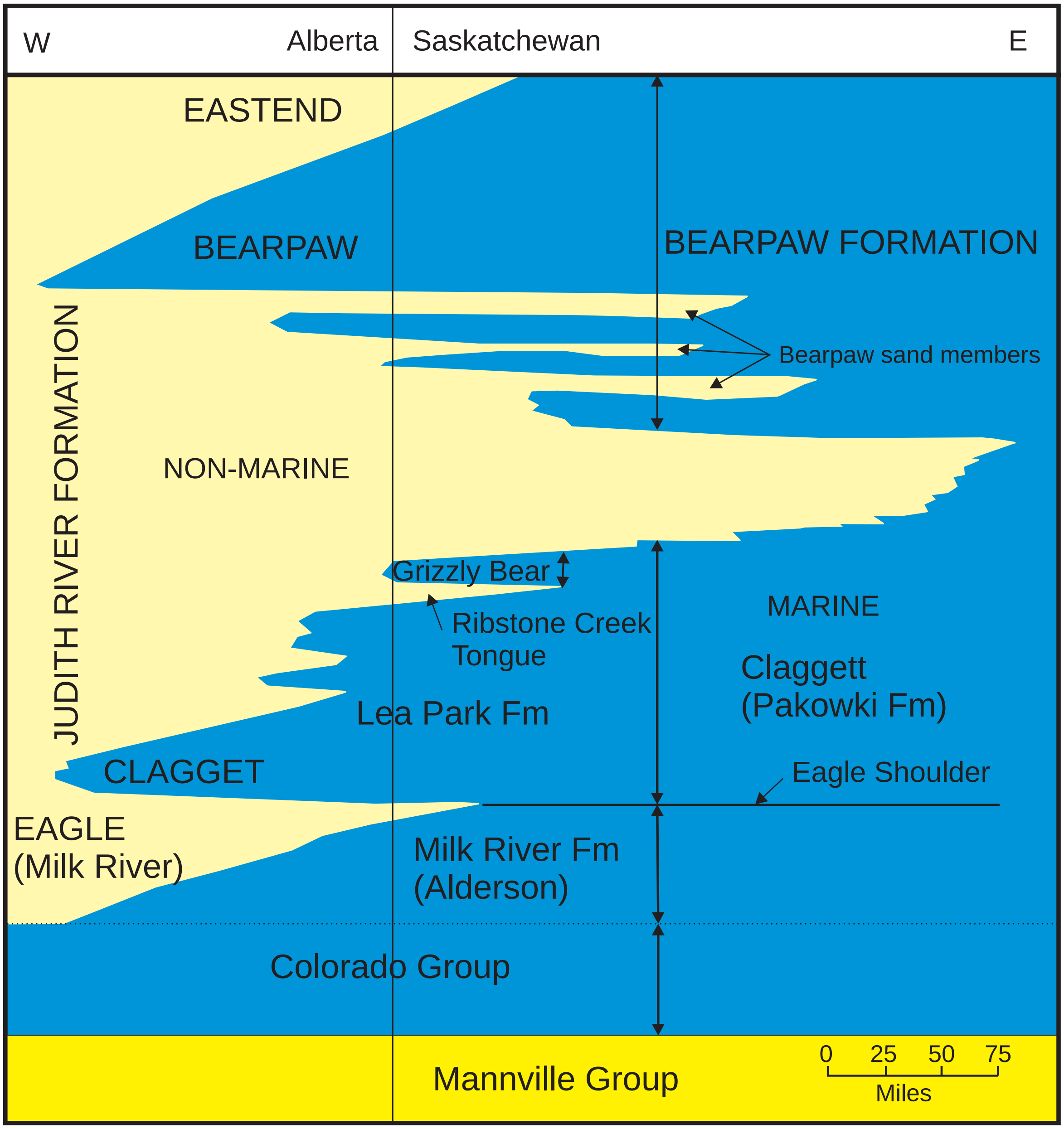


Figure 15 Schematic cross section through Late Cretaceous sediments in eastern Alberta and western Saskatchewan (after McLean, 1971)

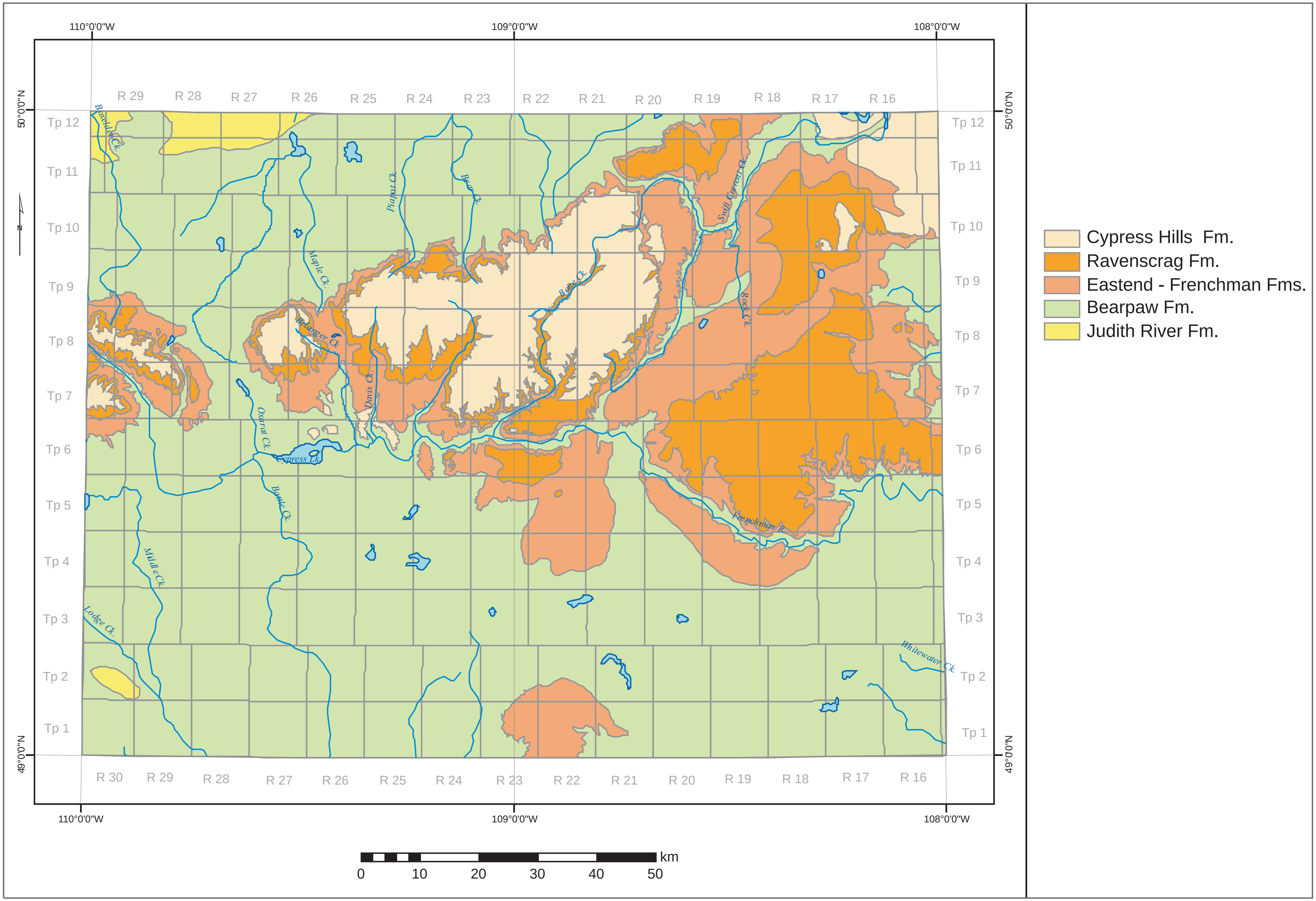


Figure 16 Bedrock geology of the Cypress Lake area

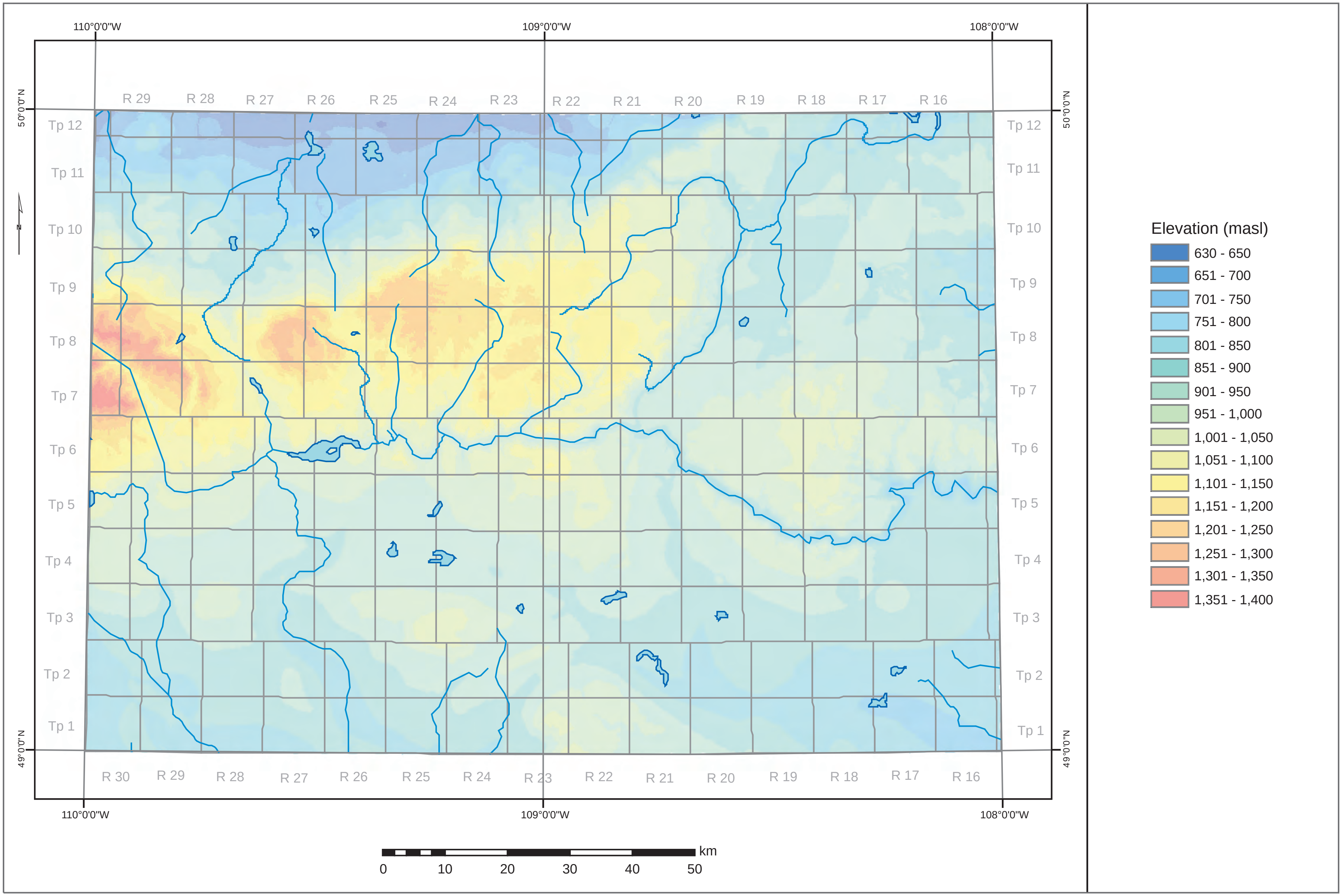


Figure 17 Bedrock surface topography in the Cypress Lake area

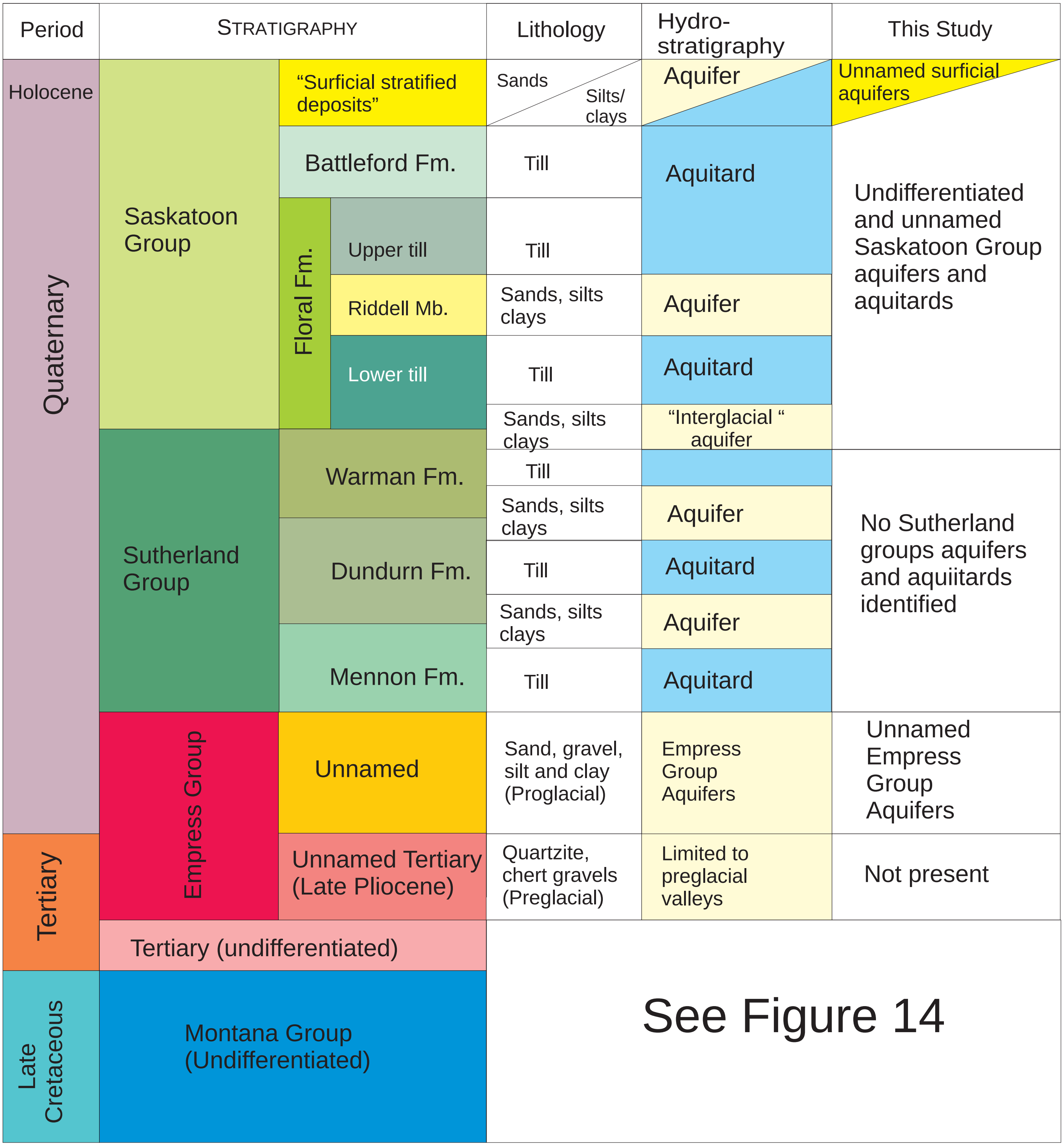


Figure 18 Schematic stratigraphic, lithologic, and hydrogeologic settings of the Quaternary deposits. (Stratigraphy after Christiansen, 1992)

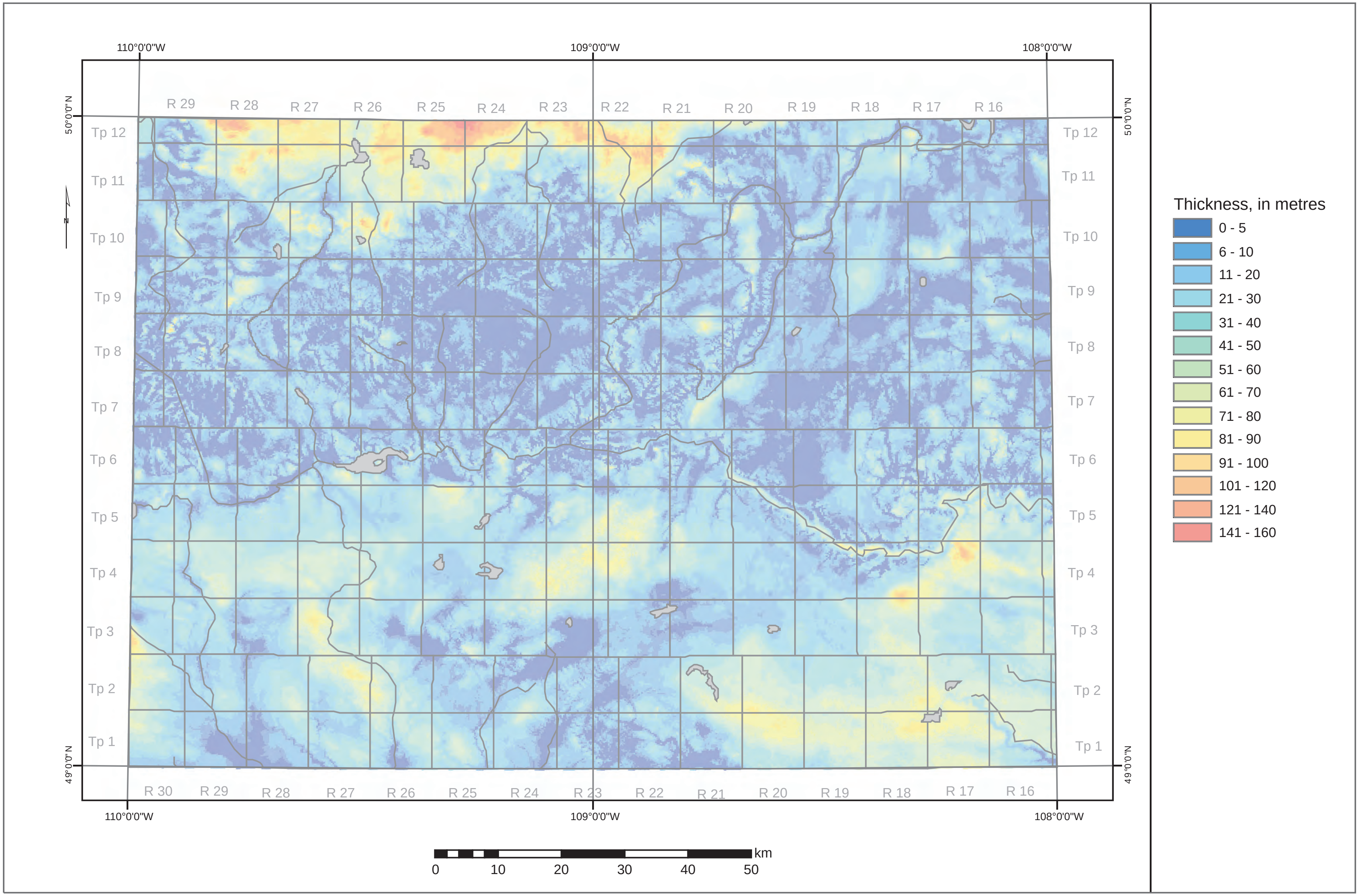


Figure 19 Thickness of the drift in the Cypress Lake area

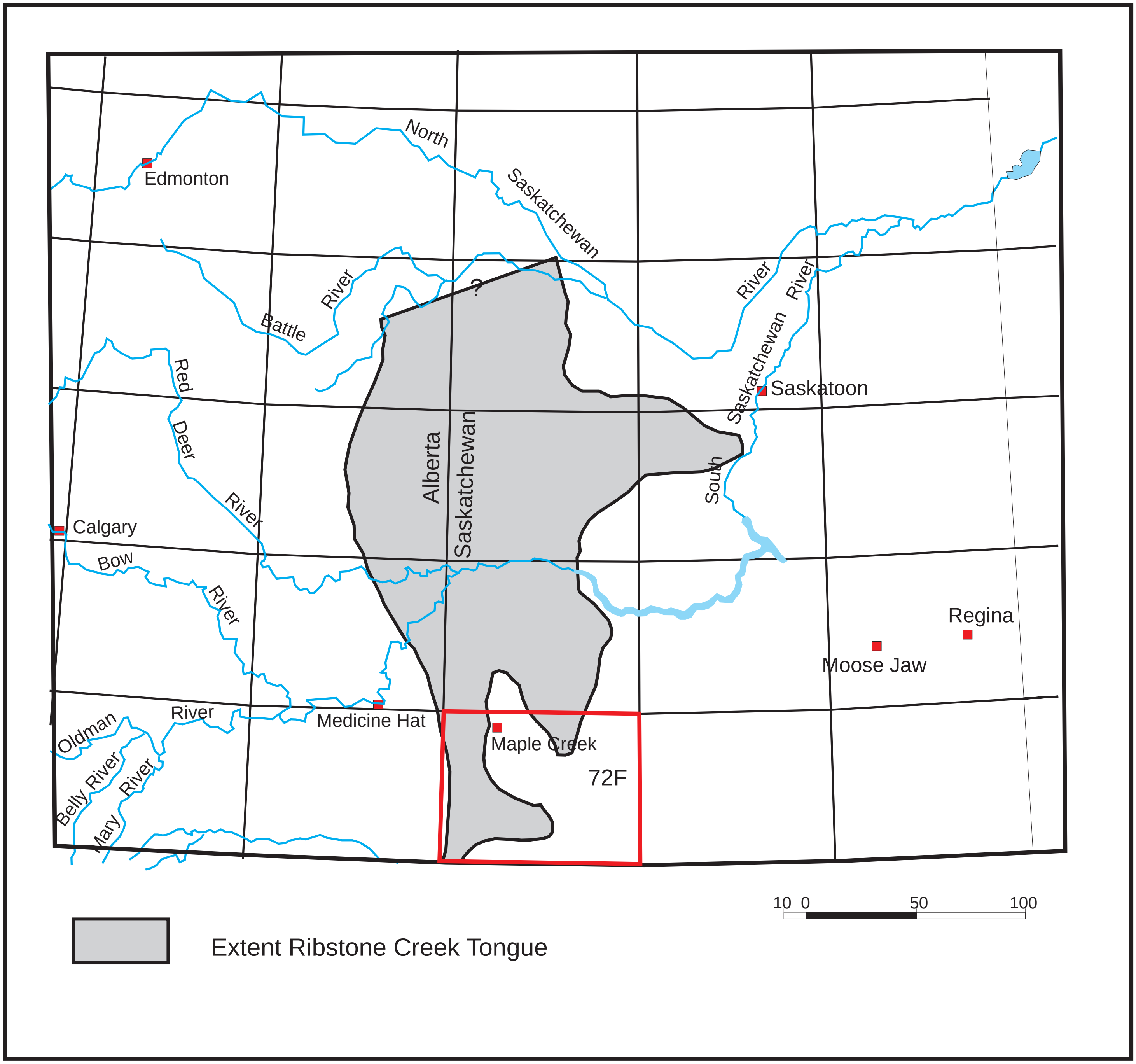


Figure 20 Extent of the Ribstone Creek aquifer in Saskatchewan and Alberta (after Mclean, 1972)

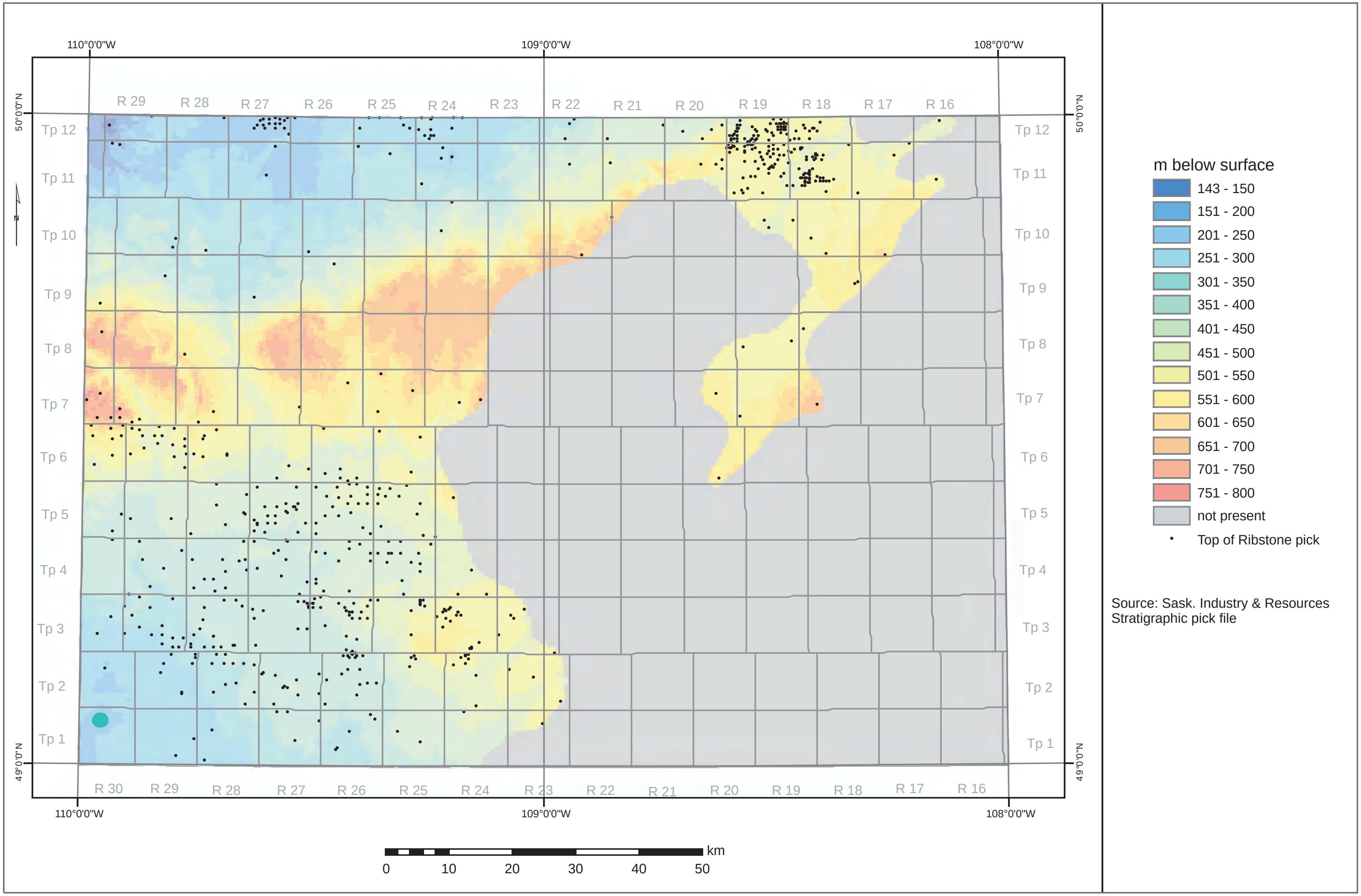


Figure 21 Depth to the top of the Ribstone Creek aquifer in the Cypress Lake area

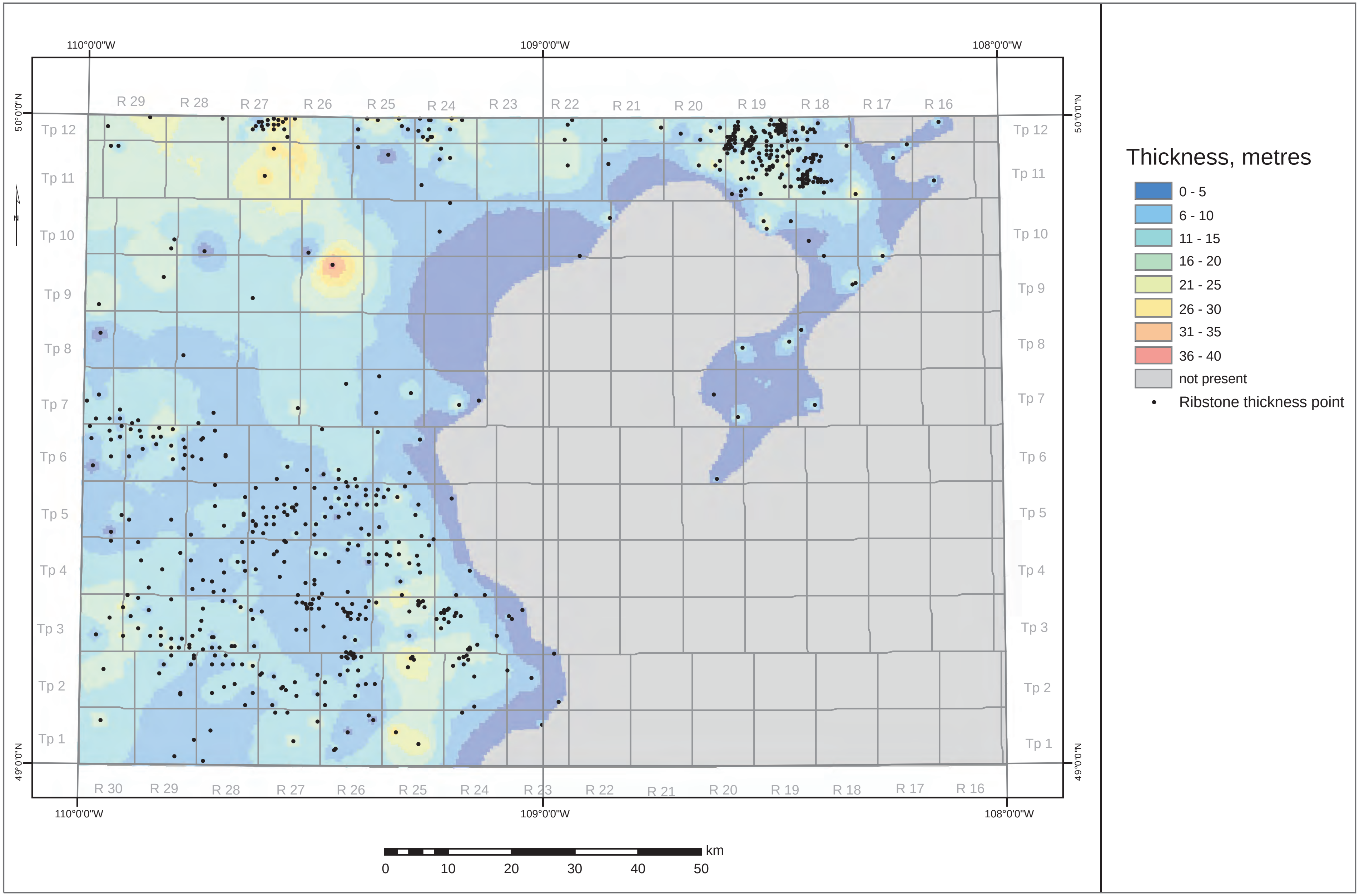


Figure 22 Thickness of the Ribstone Creek Tongue in the Cypress Lake area

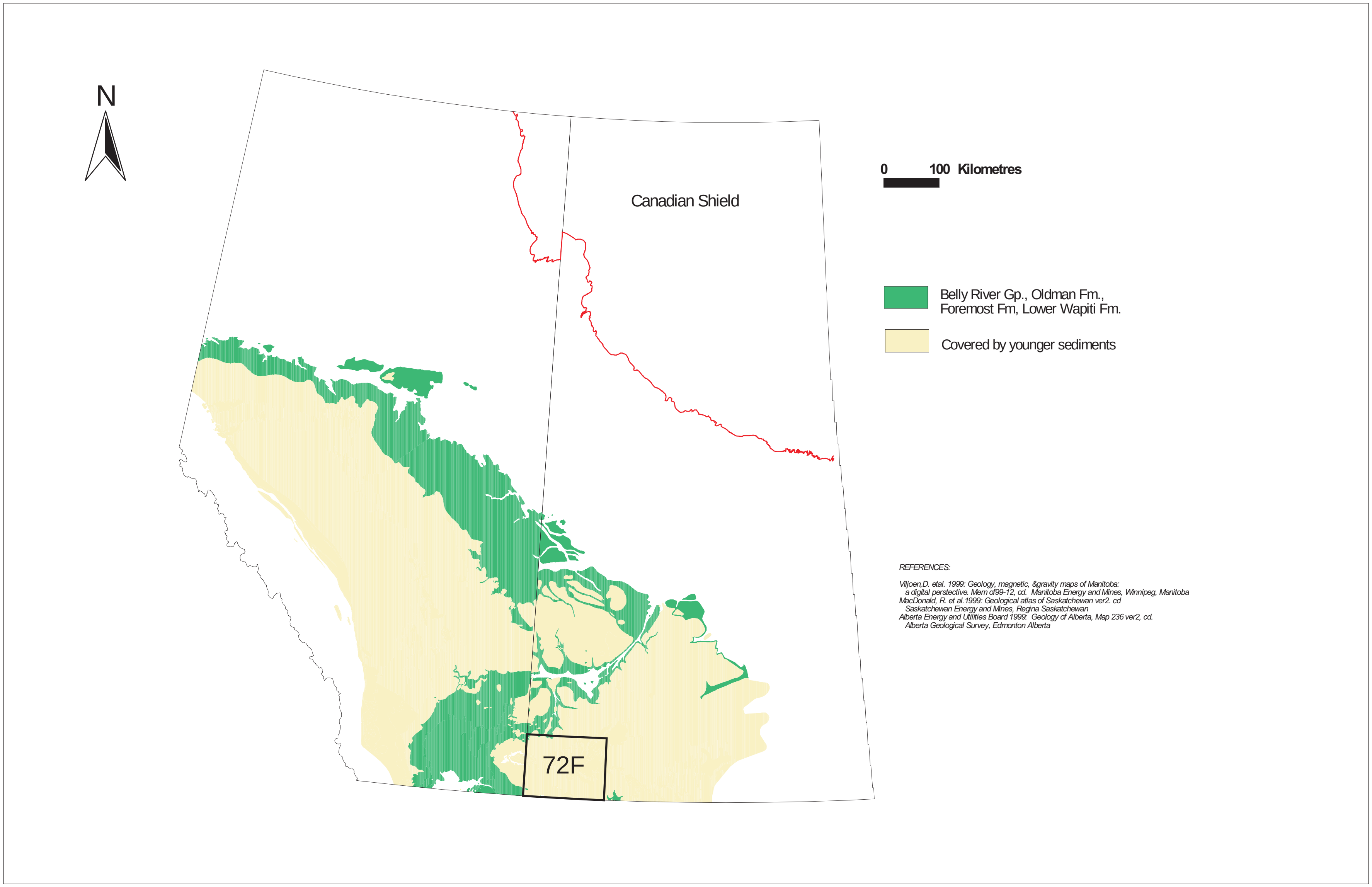


Figure 23 Extent of the Judith River Formation in Alberta and Saskatchewan

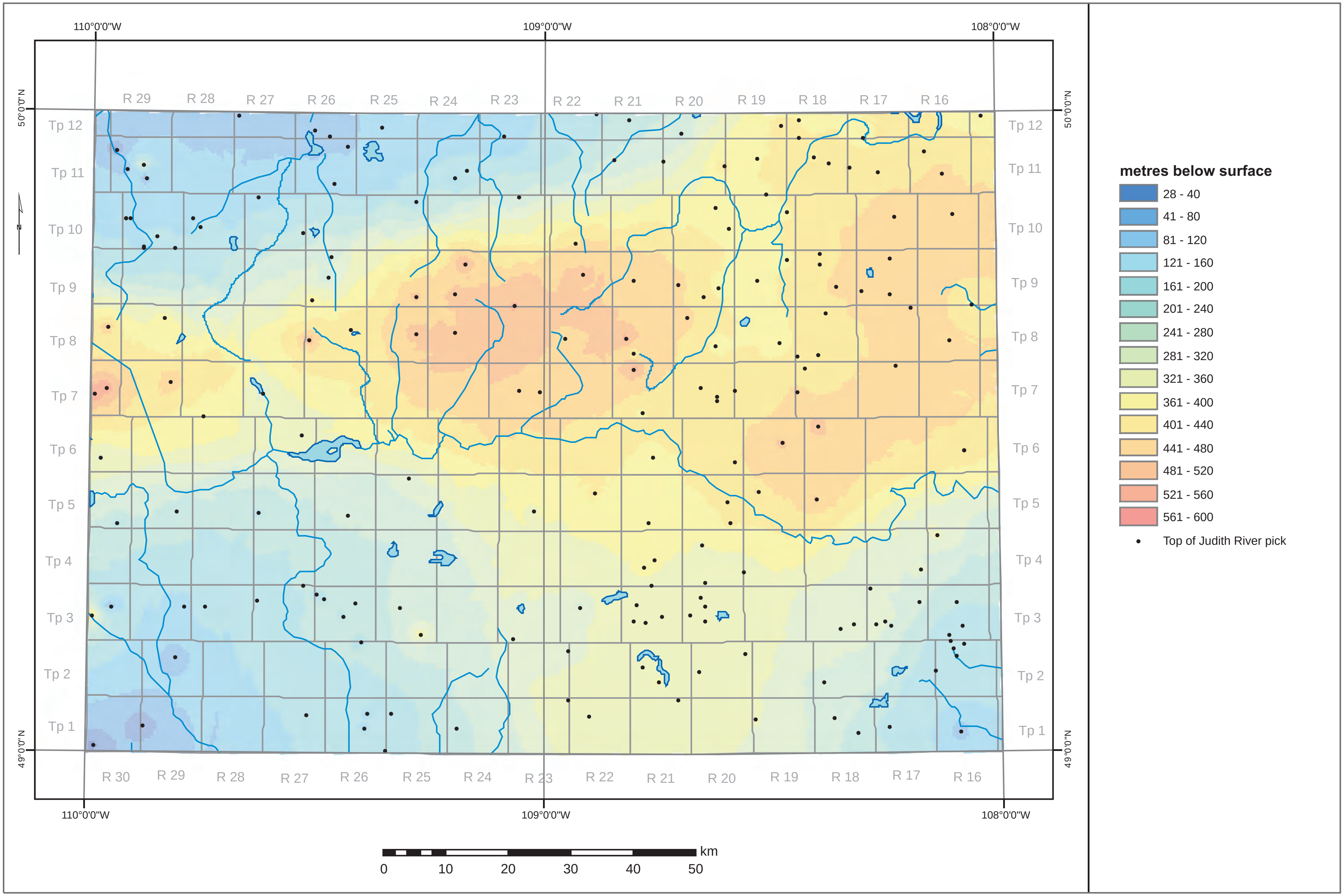


Figure 24 Depth to the top of the Judith River Formation in the Cypress Lake area

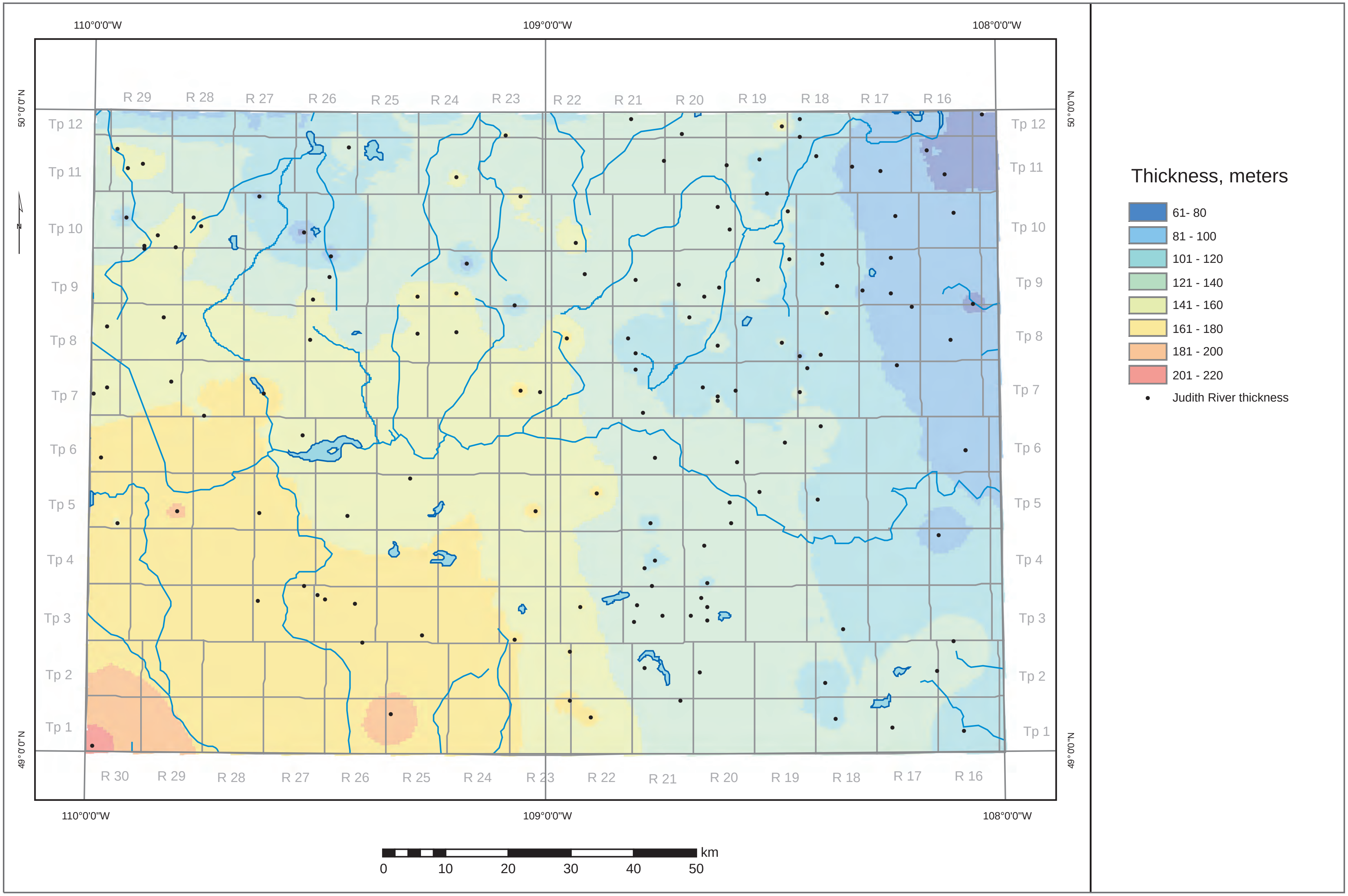


Figure 25 Thickness of the Judith River Formation in the Cypress Lake area

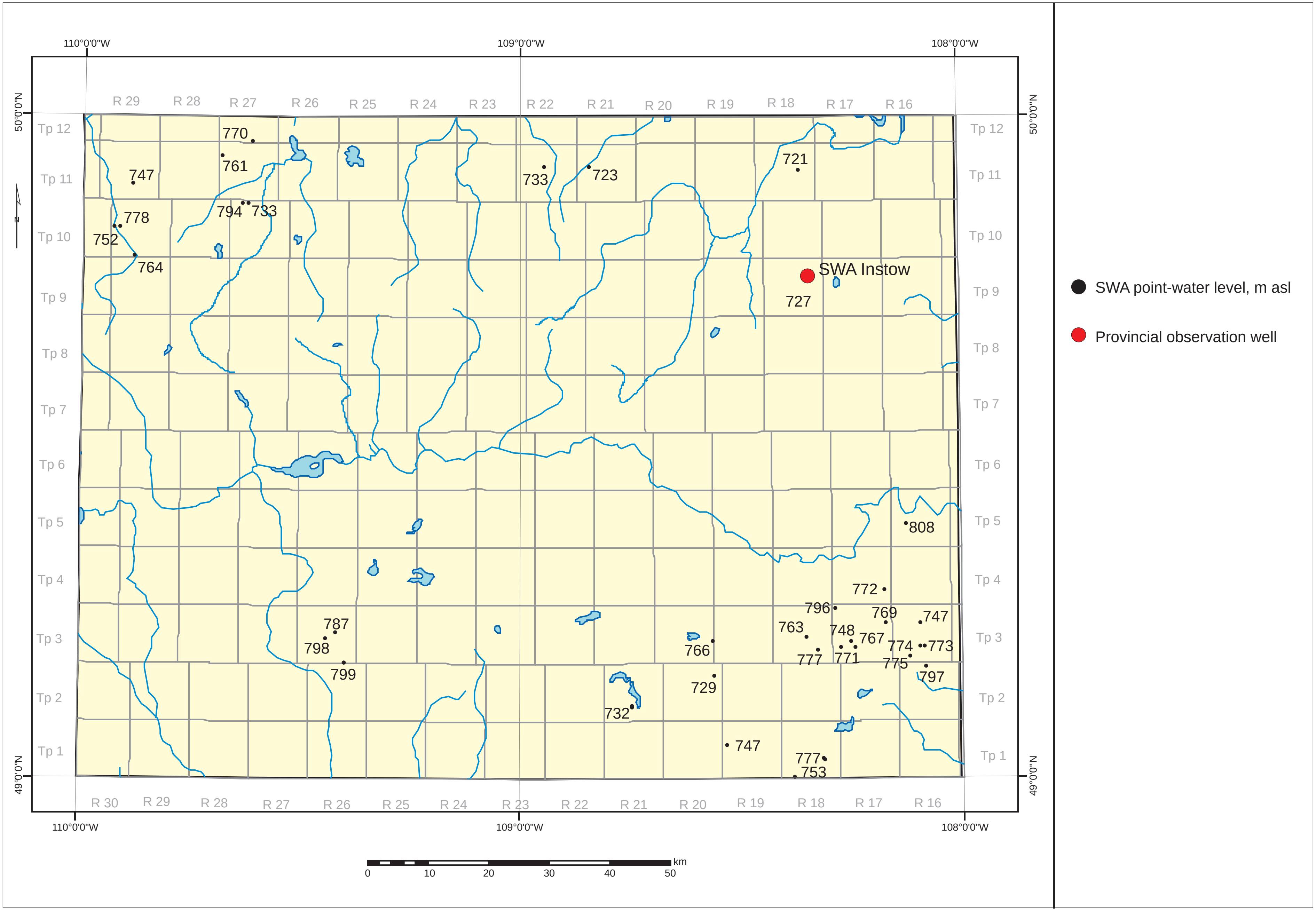


Figure 26 Point-water level elevations in the Judith River aquifer in the Cypress Lake area

ID#	Company	Well Name	Land Location
1	Universal Exploration	Instow Unit	11-24-09-18-W3
2*	Marathon Petroleum	Instow Unit	01-26-09-18-W3
3	Encore Energy Corp	Instow Unit	08-07-10-18-W3
4	ICG Resources LTD	Leon LK	13-32-08-19-W3
5	Suncor Energy INC	Shaunavon	14-01-09-19-W3
6	Suncor Energy INC	Leitchville B	14-01-09-19-W3
7	Wascana Energy INC	Bone Creek Unit A	02-27-10-19-W3
8	Wascana Energy INC	Bone Creek Unit A	10-27-10-19-W3
9	Wascana Energy INC	Bone Creek Unit	10-27-10-19-W3
10	Wascana Energy INC	Bone Creek Unit A	12-27-10-19-W3
*	Sask. Watershed Authority	SWA Instow	01-26-09-18-W3

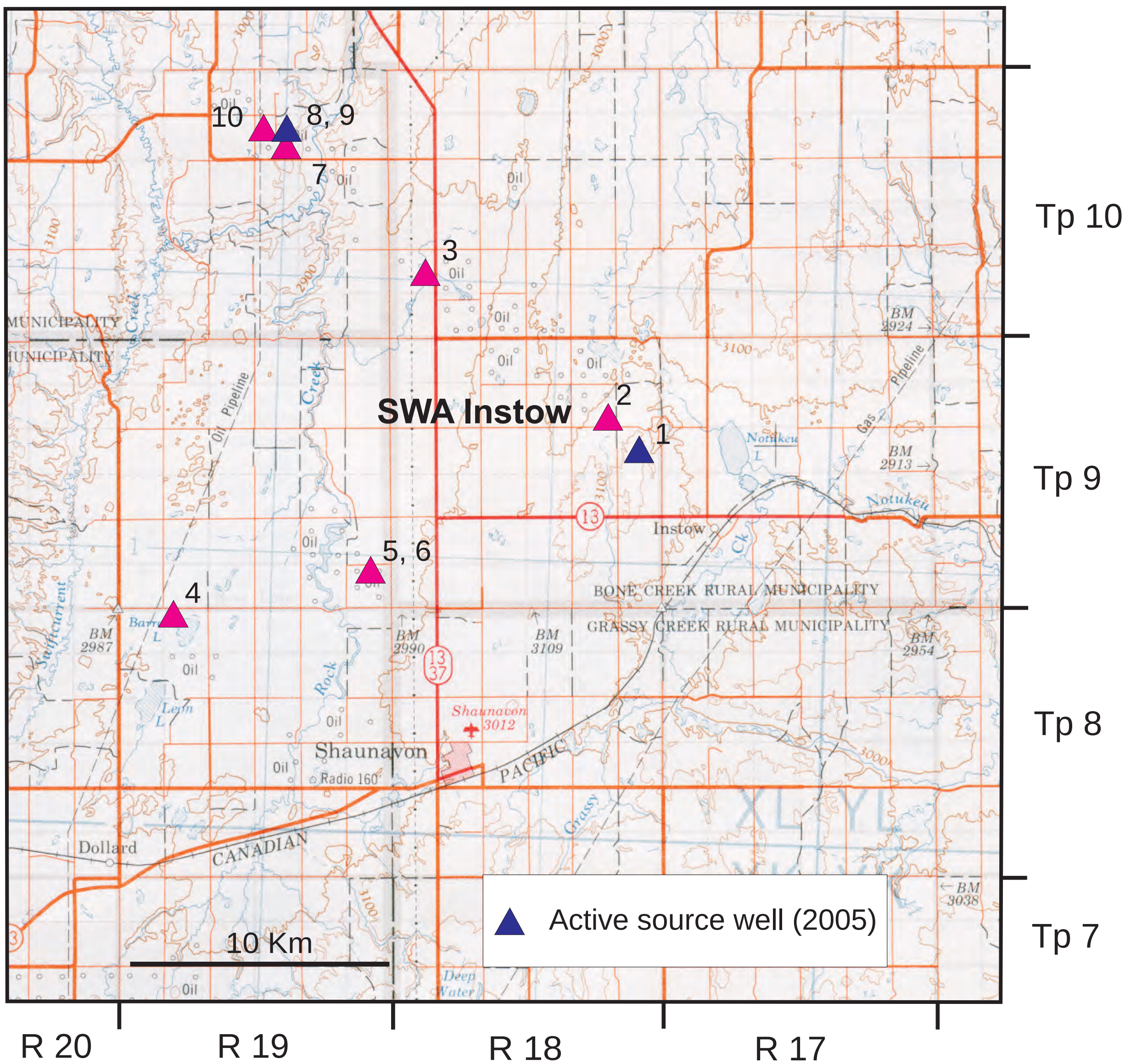


Figure 27 Locations of water source wells completed in the Judith River aquifer in the vicinity of SWA Instow

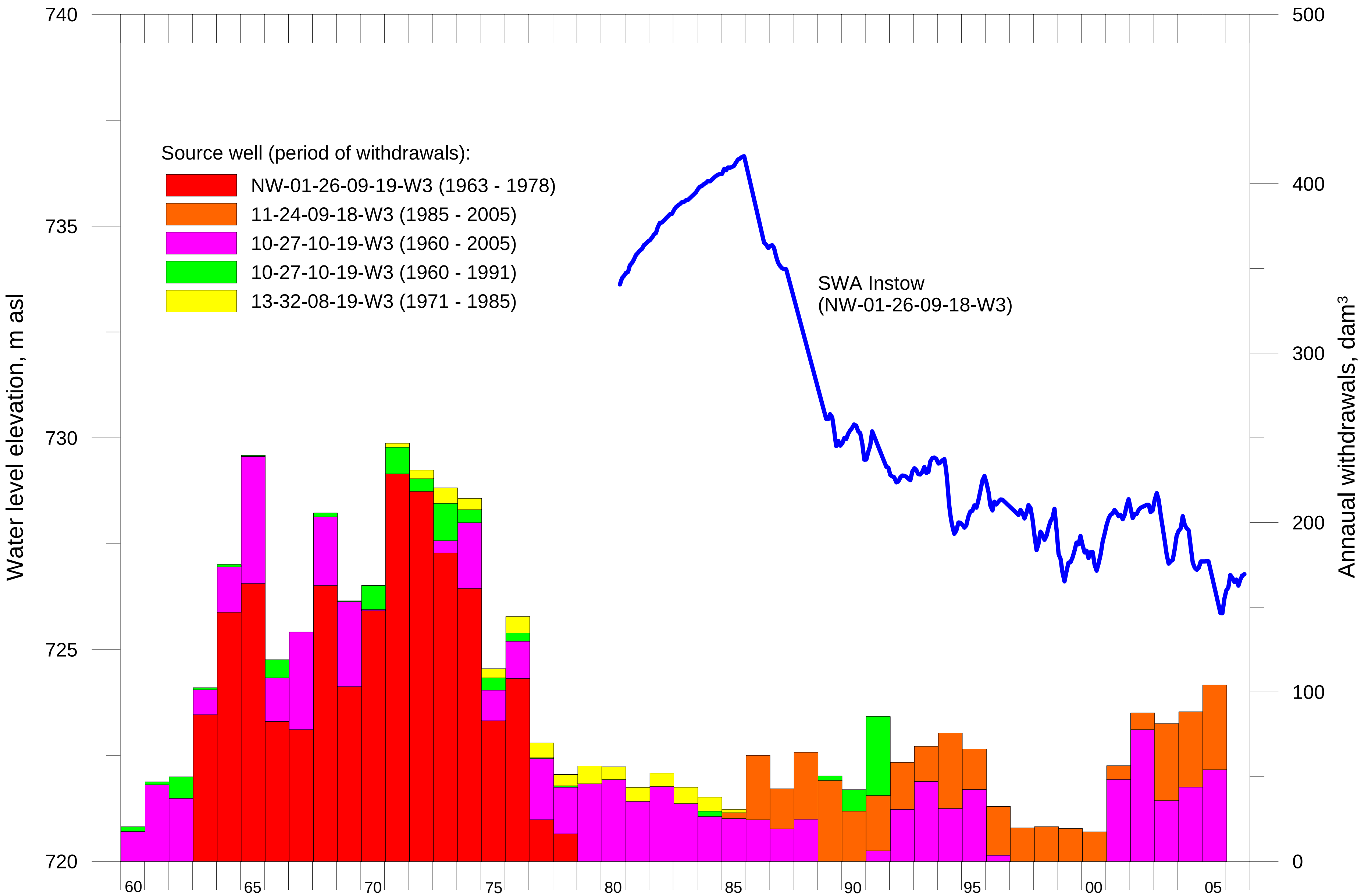


Figure 28 Hydrograph for SWA groundwater level observation well Instow and withdrawals from SWA Instow and nearby source wells

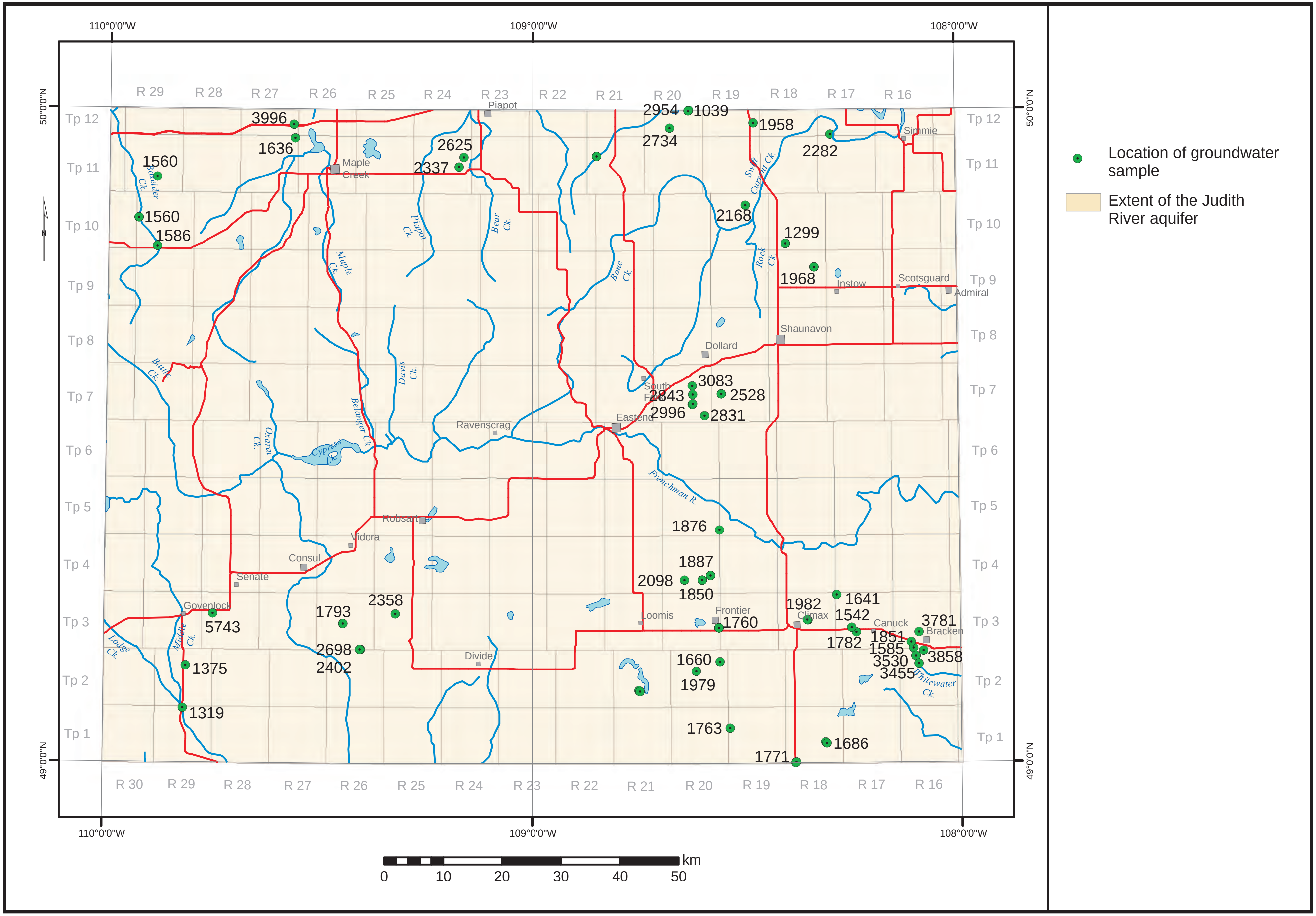


Figure 29 Locations of groundwater samples from the Judith River aquifer

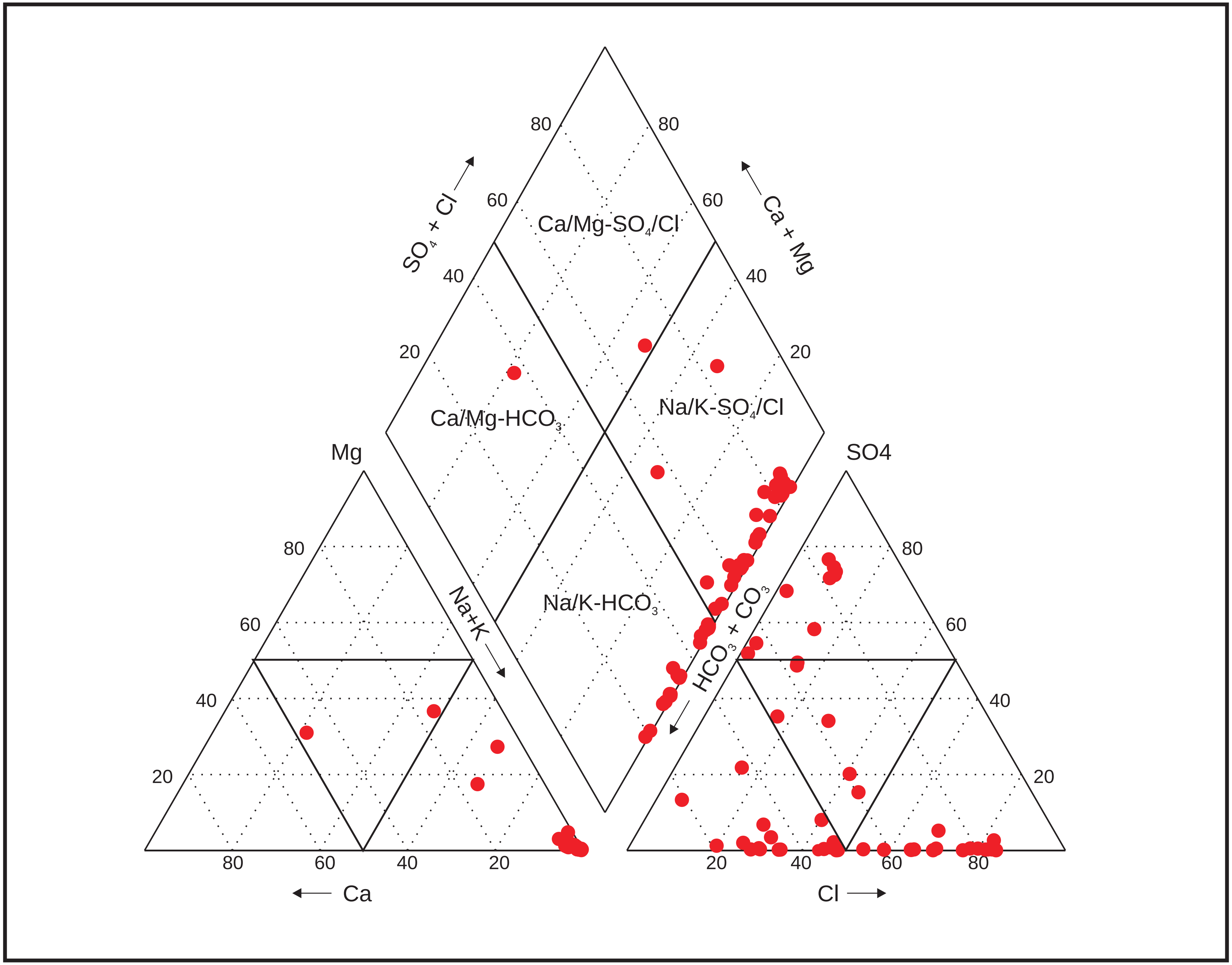


Figure 30 Piper-plot of groundwater quality data for the Judith River aquifer in the Cypress Lake area

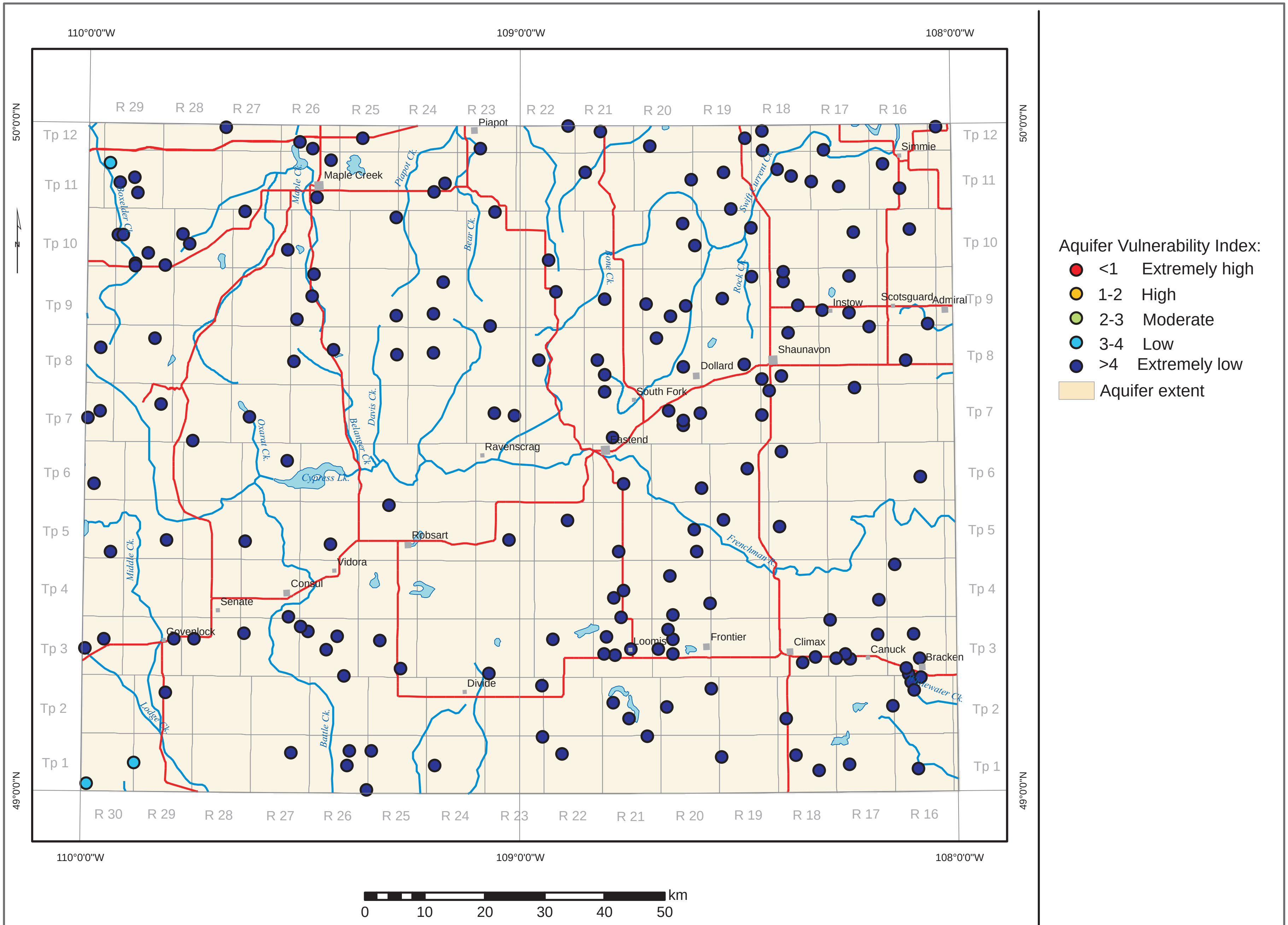


Figure 31 Aquifer vulnerability index for the Judith River aquifer in the Cypress Lake area

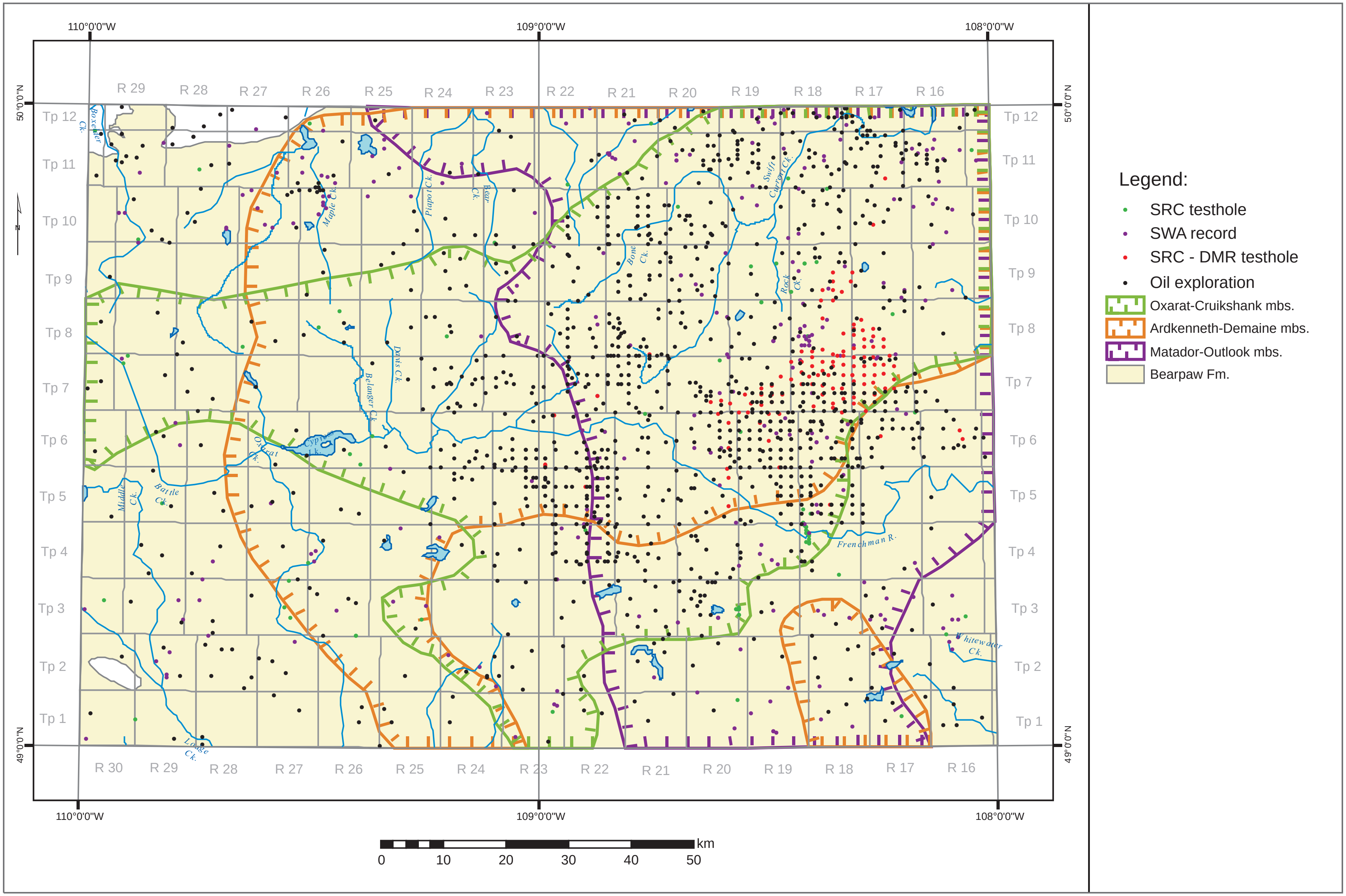


Figure 32 Extent of the Bearpaw Formation and sand members within the Bearpaw Formation in the Cypress Lake area

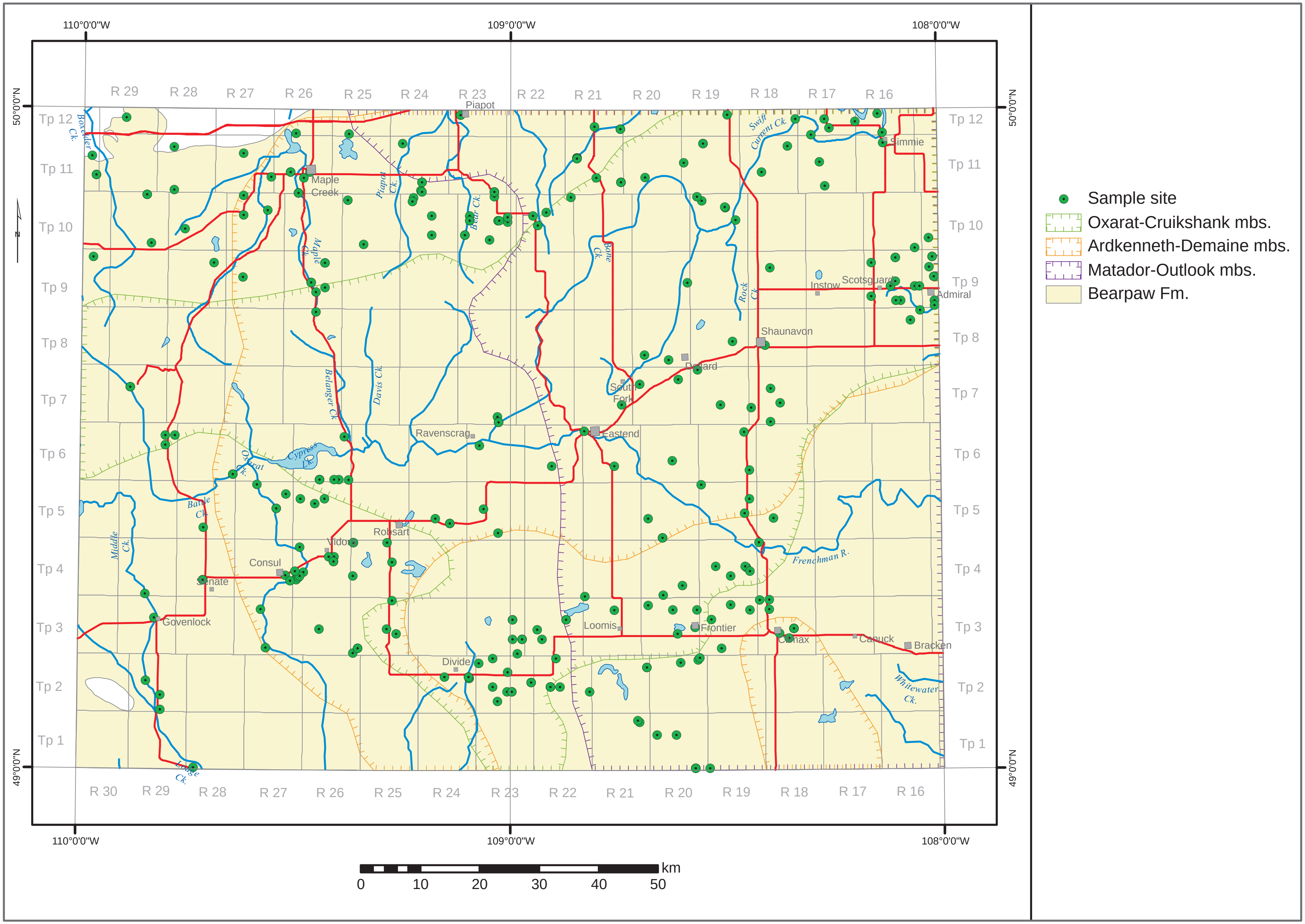


Figure 33 Locations of groundwater samples from Bearpaw Formation sands

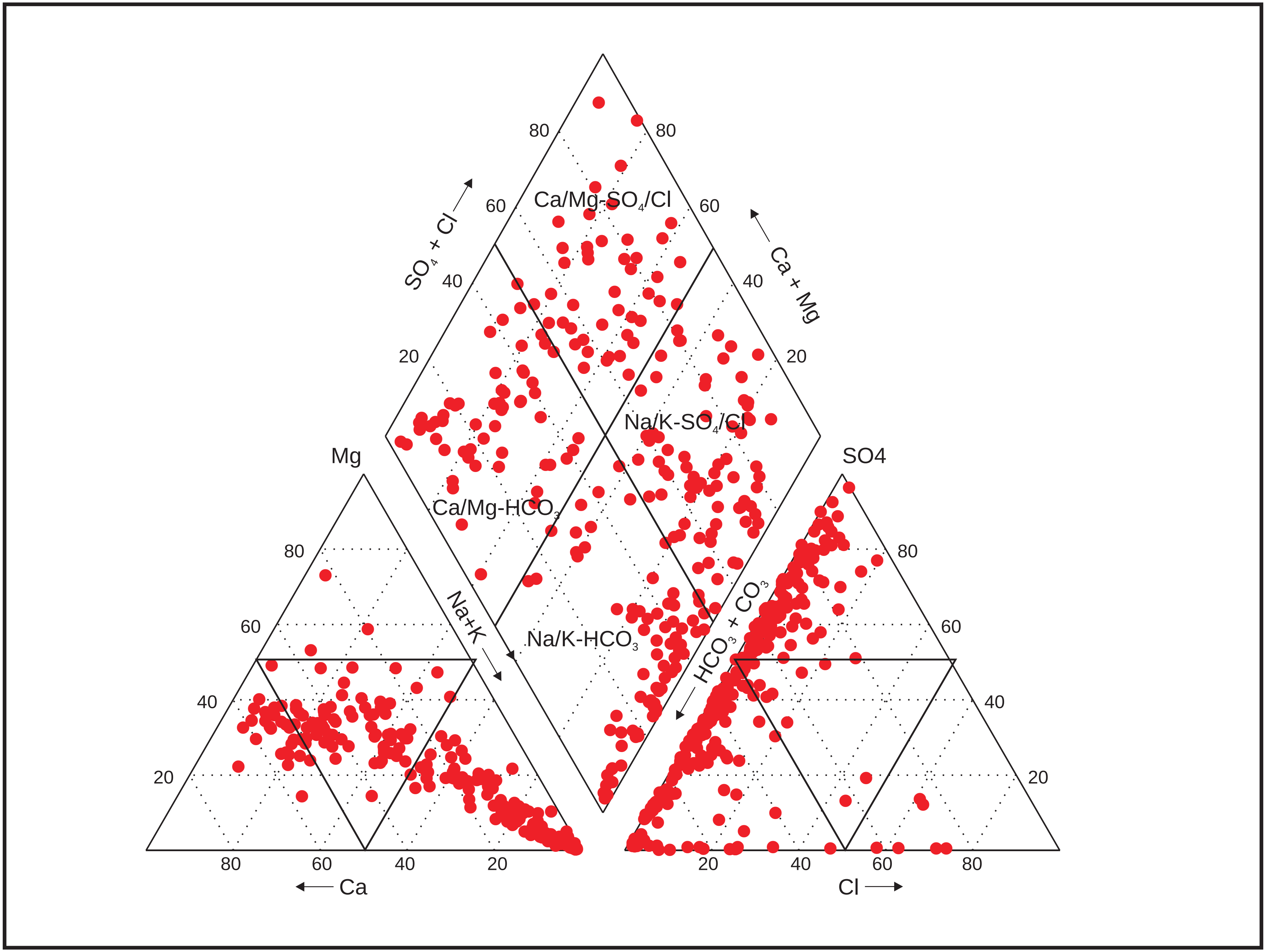


Figure 34 Piper-plot of groundwater quality data for Bearpaw sands in the Cypress Lake area

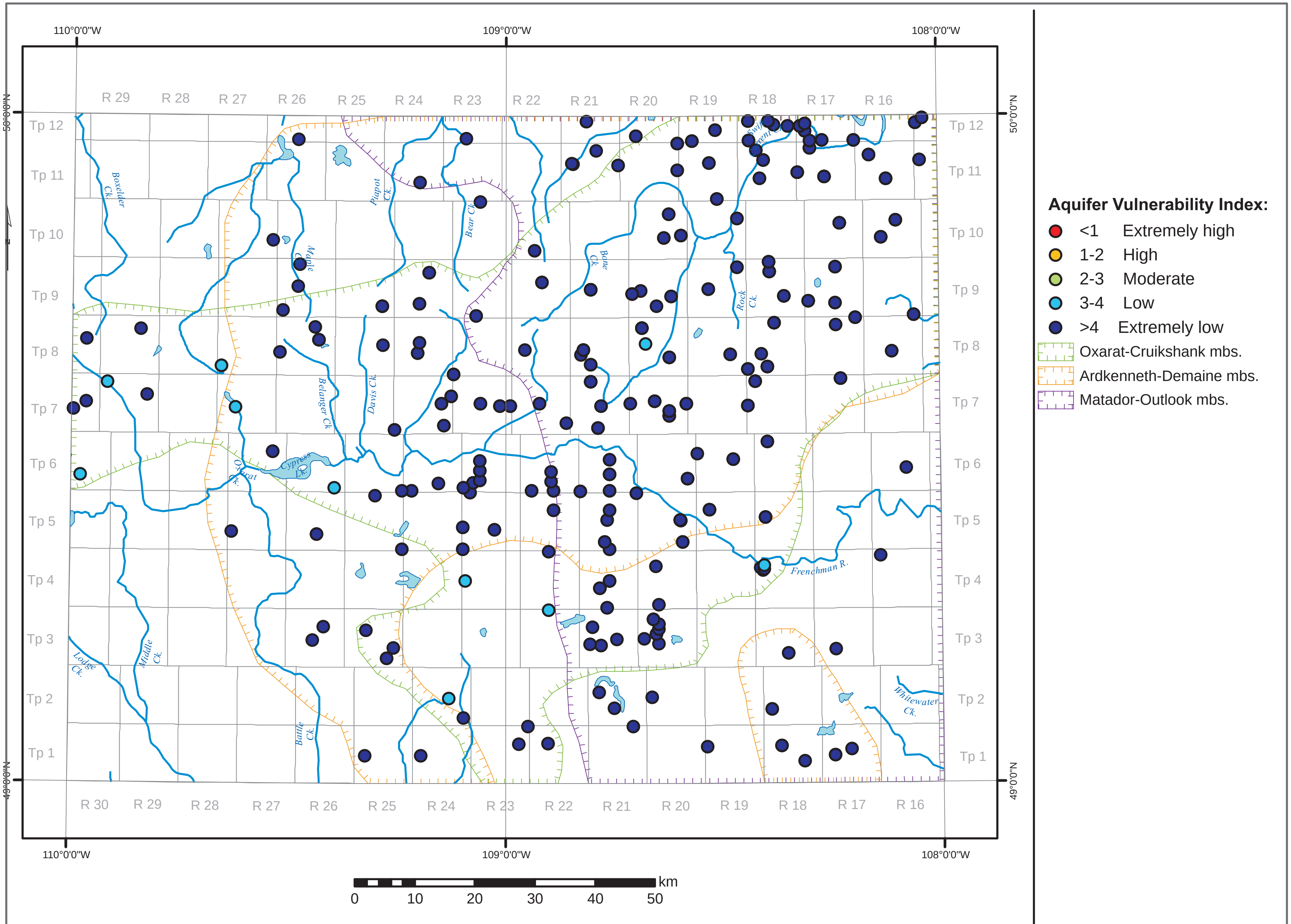


Figure 35 Aquifer vulnerability index for the Bearpaw sand members aquifer in the Cypress Lake area

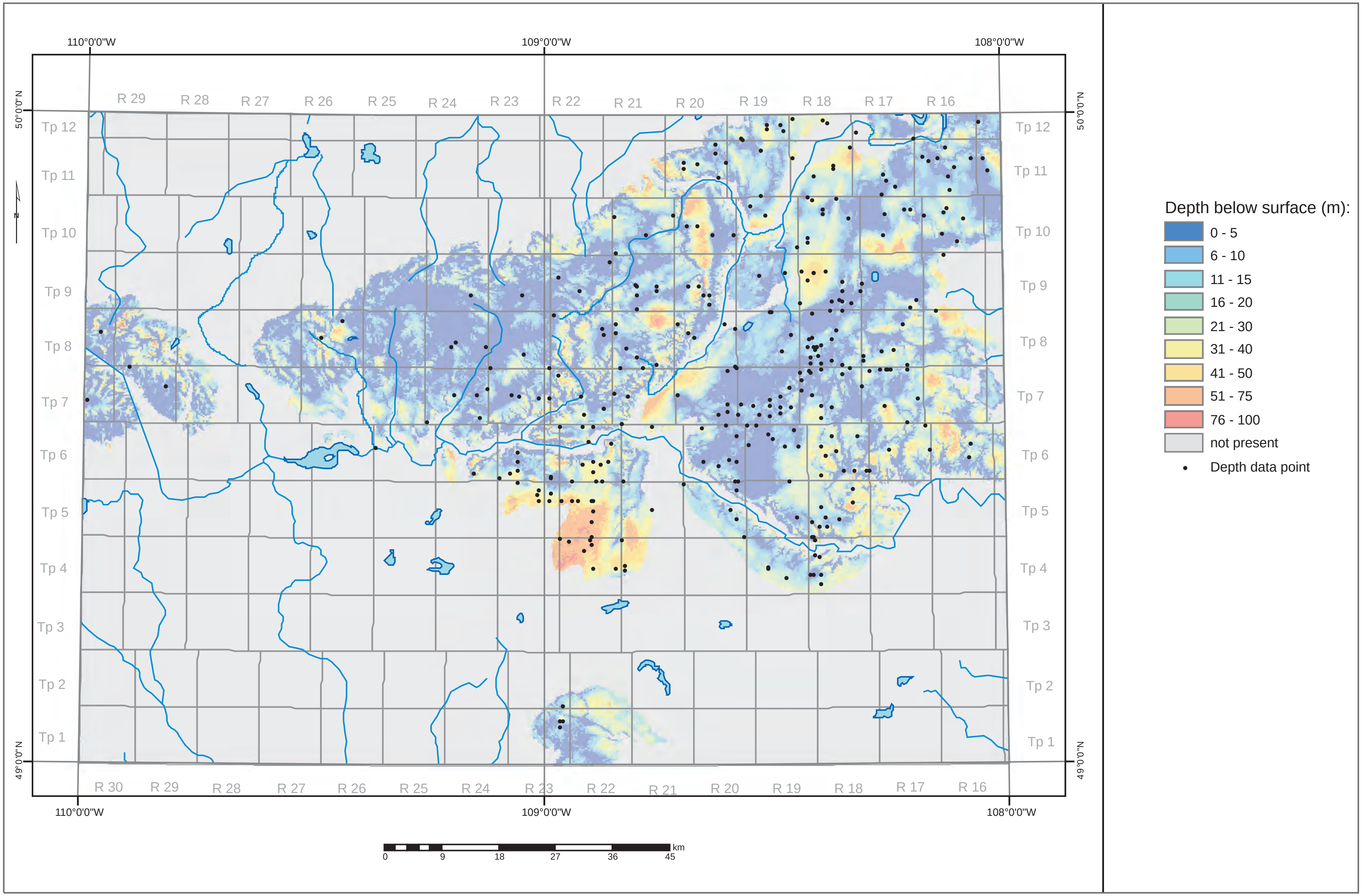


Figure 36 Extent and depth to the Eastend - Cypress Hills aquifer in the Cypress Lake area

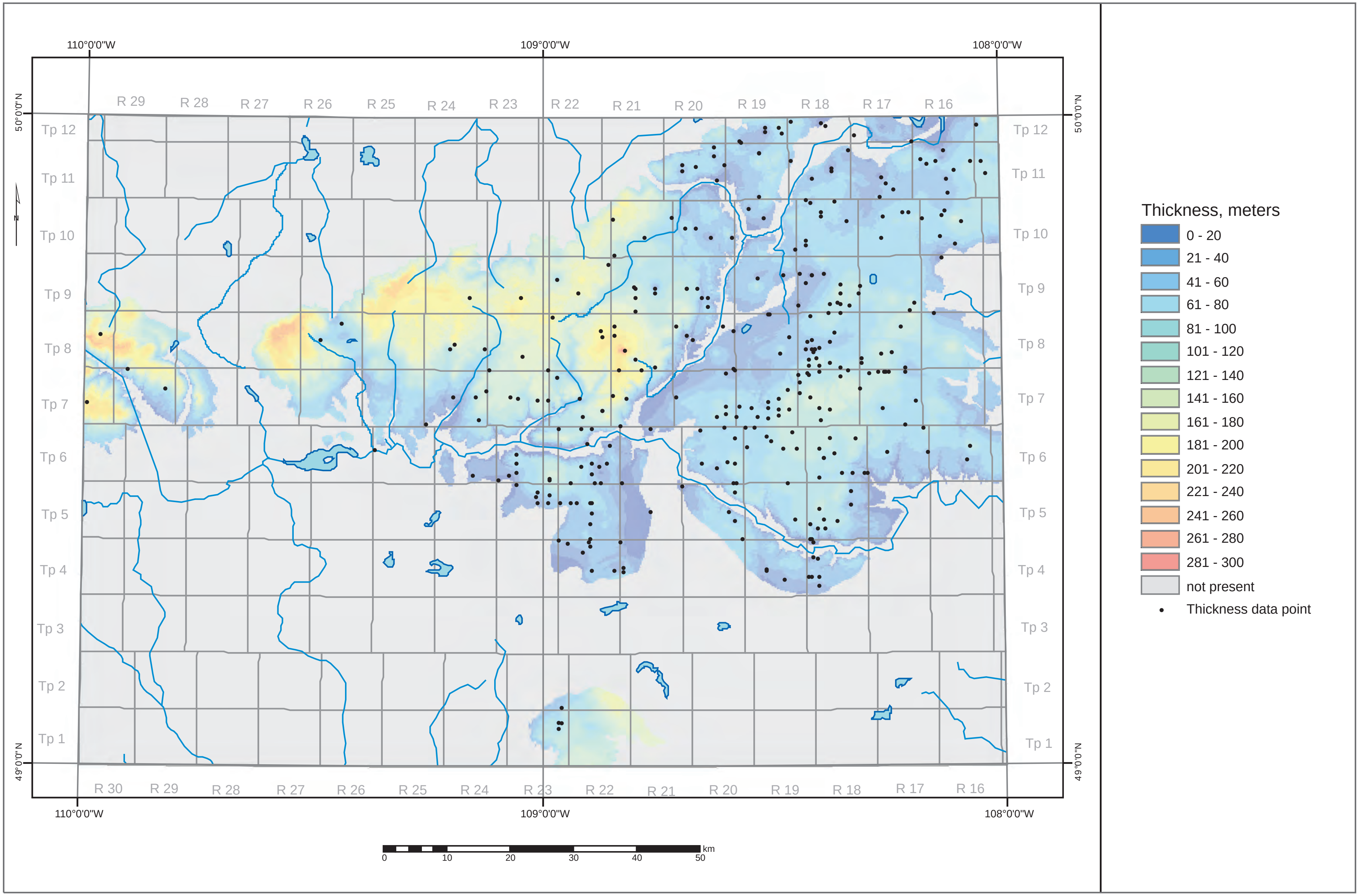


Figure 37 Thickness of the Eastend - Cypress Hills aquifer in the Cypress Lake area

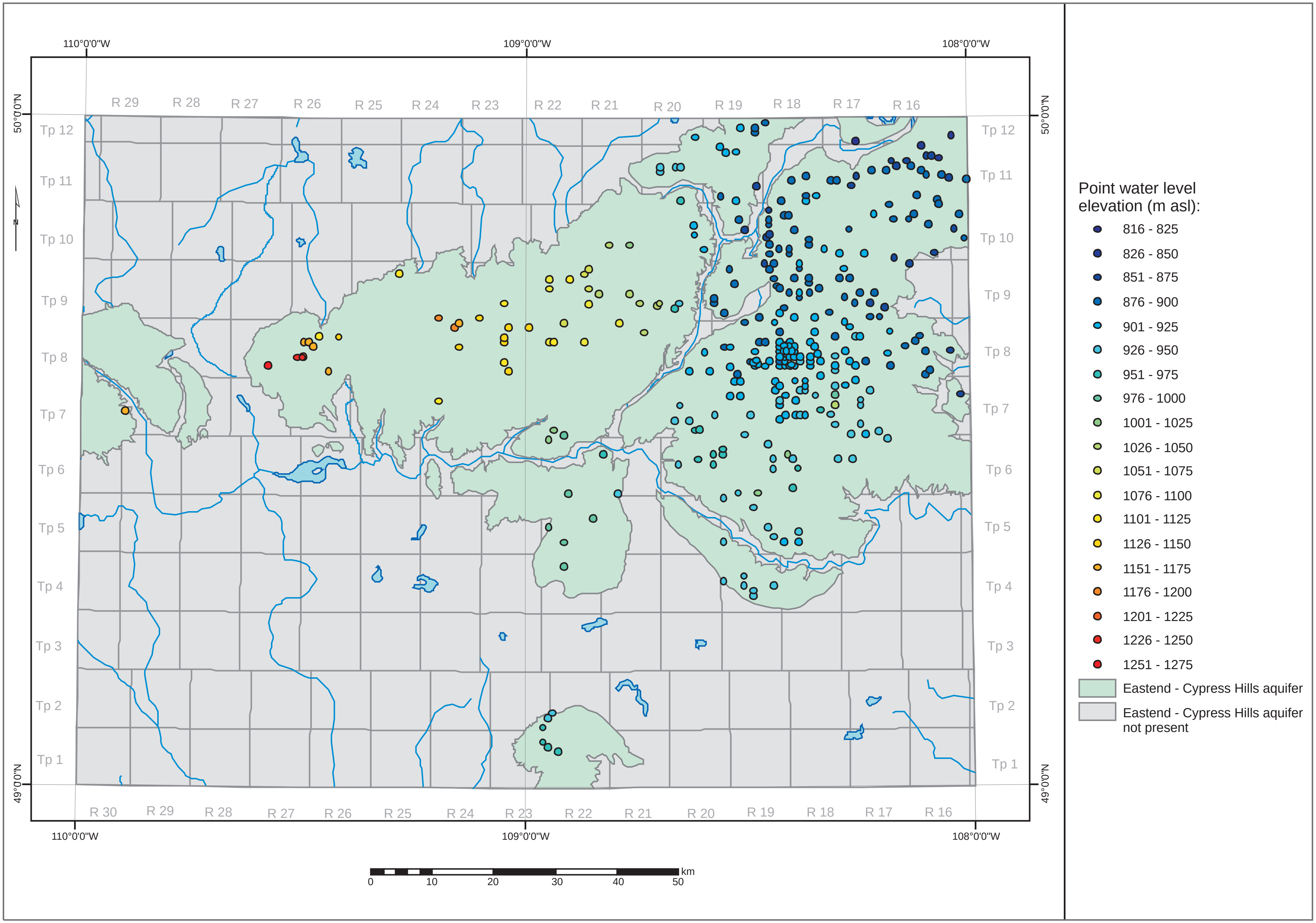


Figure 38 Point-water levels in the Eastend - Cypress Hills aquifer

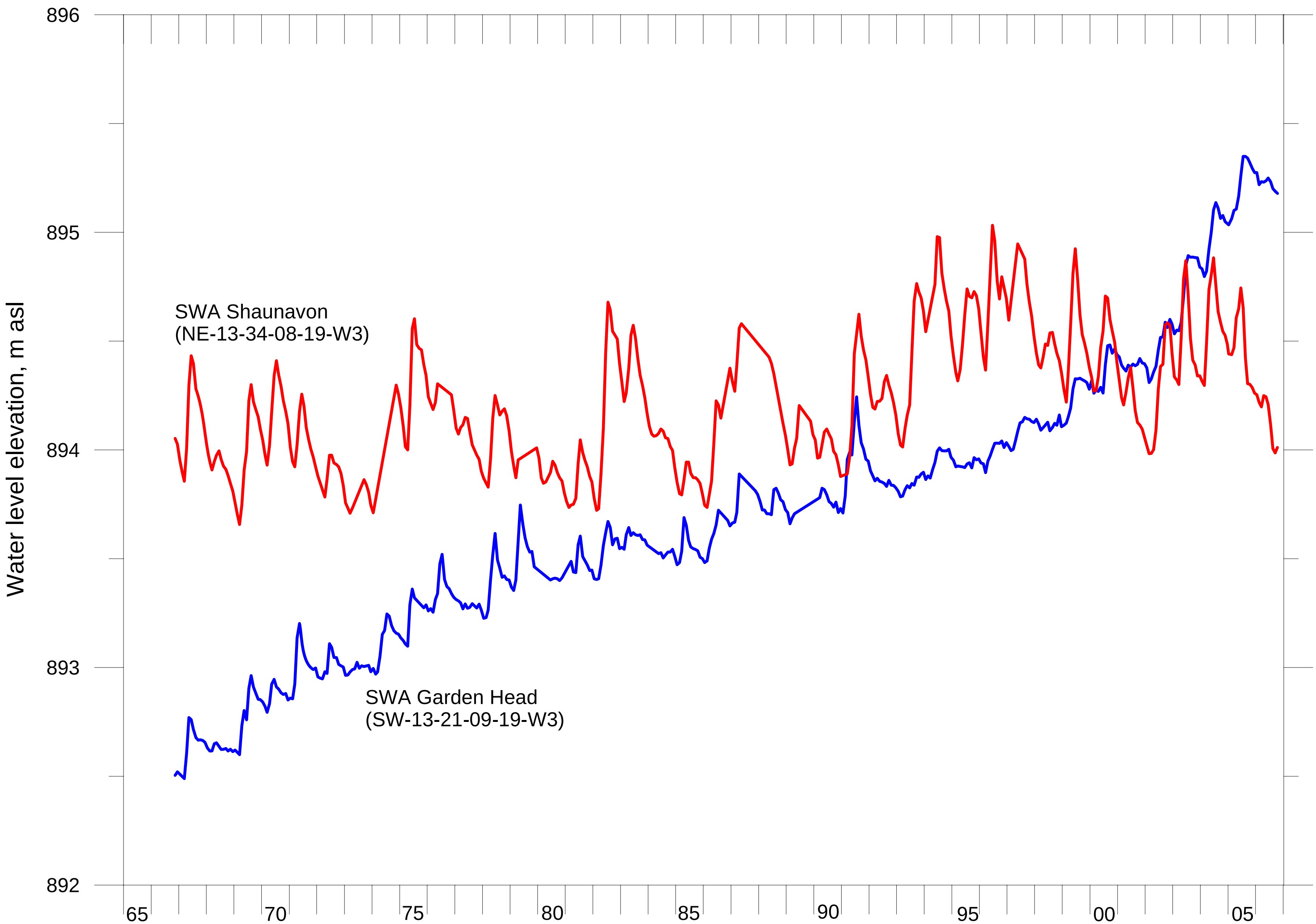


Figure 39 Hydrographs for groundwater level observation wells SWA Garden Head and Shaunavon

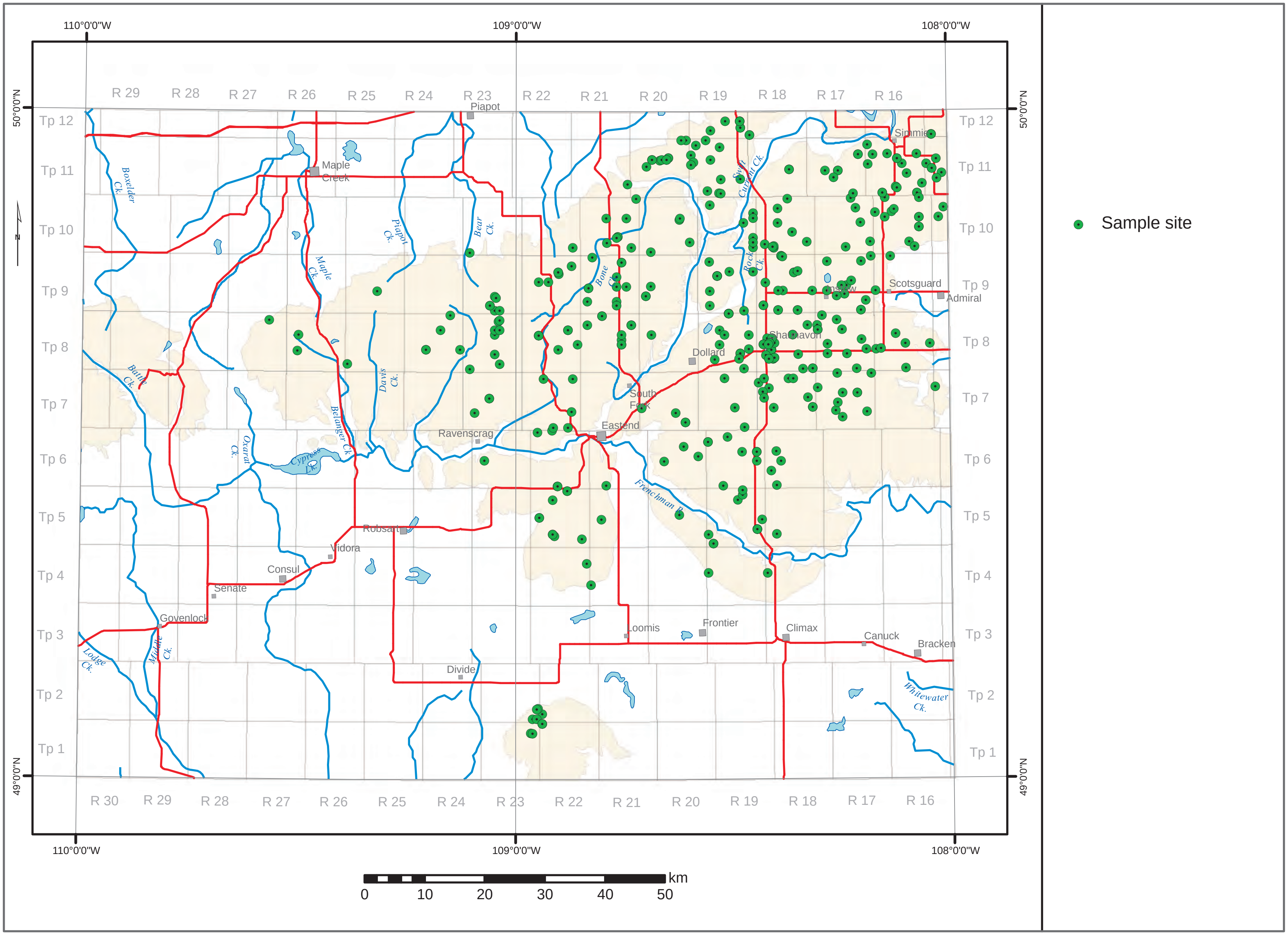


Figure 40 Locations of groundwater samples from the Eastend – Cypress Hills aquifer

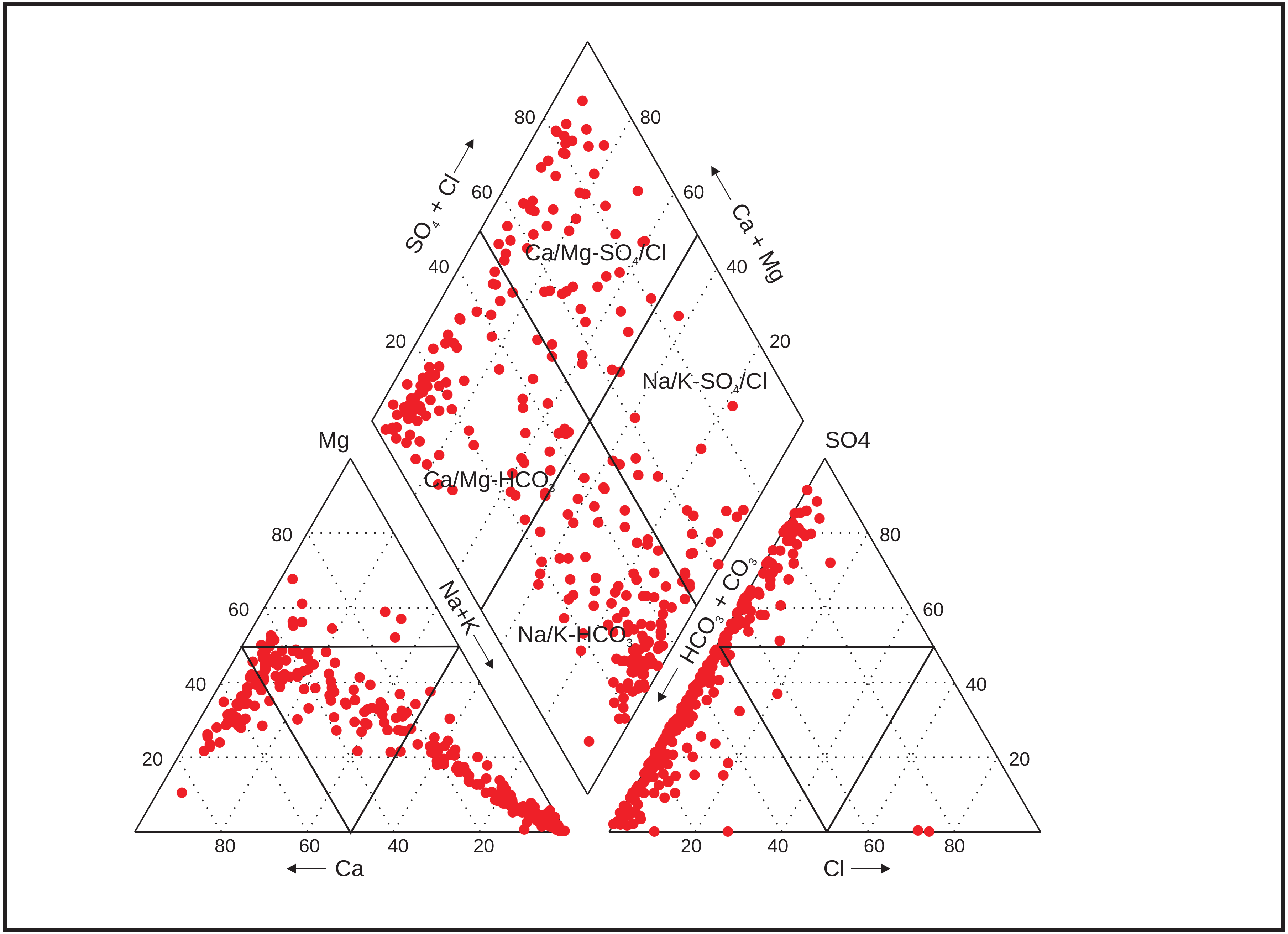


Figure 41 Piper-plot of groundwater quality data from the Eastend – Ravenscrag aquifer

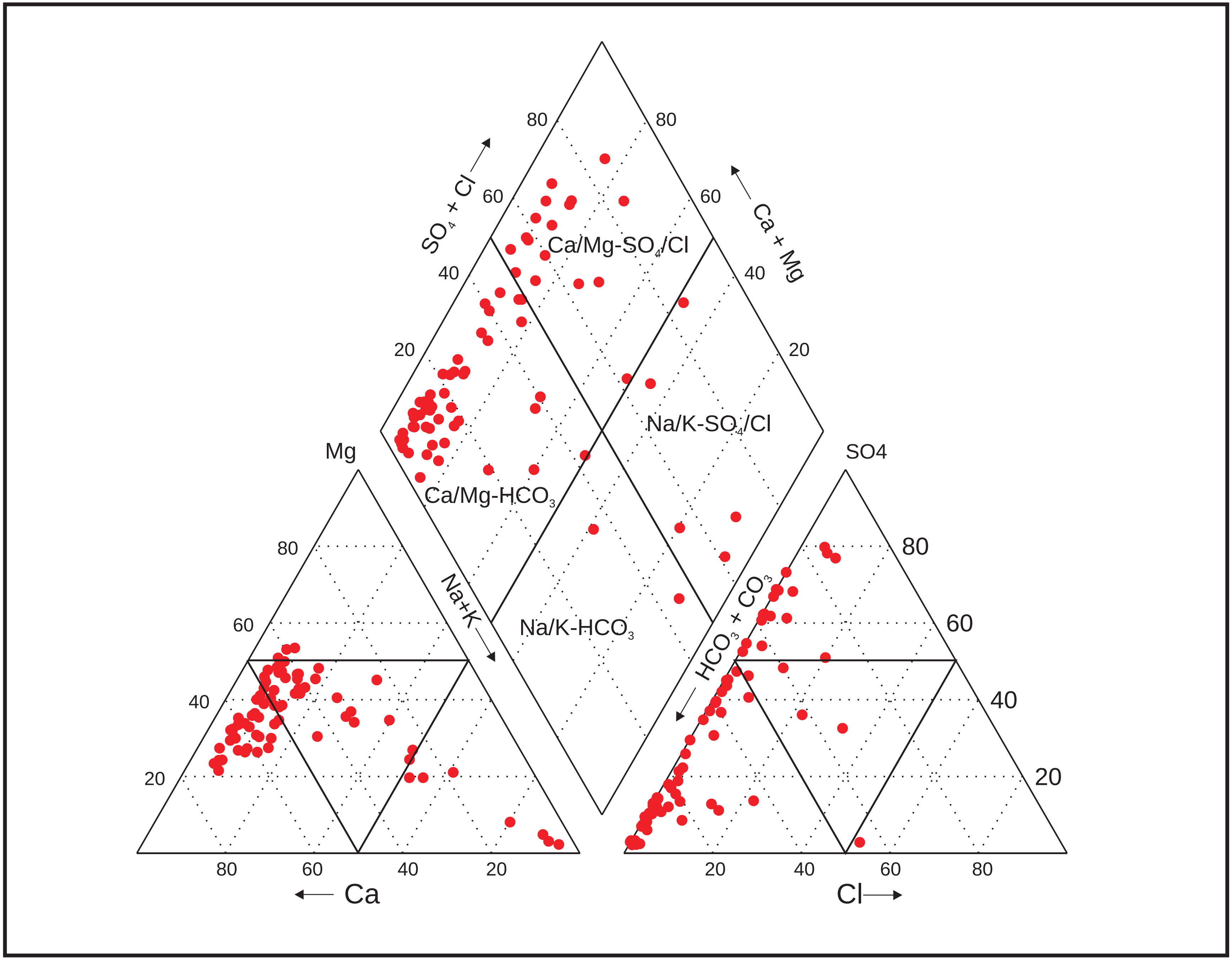


Figure 42 Piper-plot of groundwater quality data from the Cypress Hills aquifer

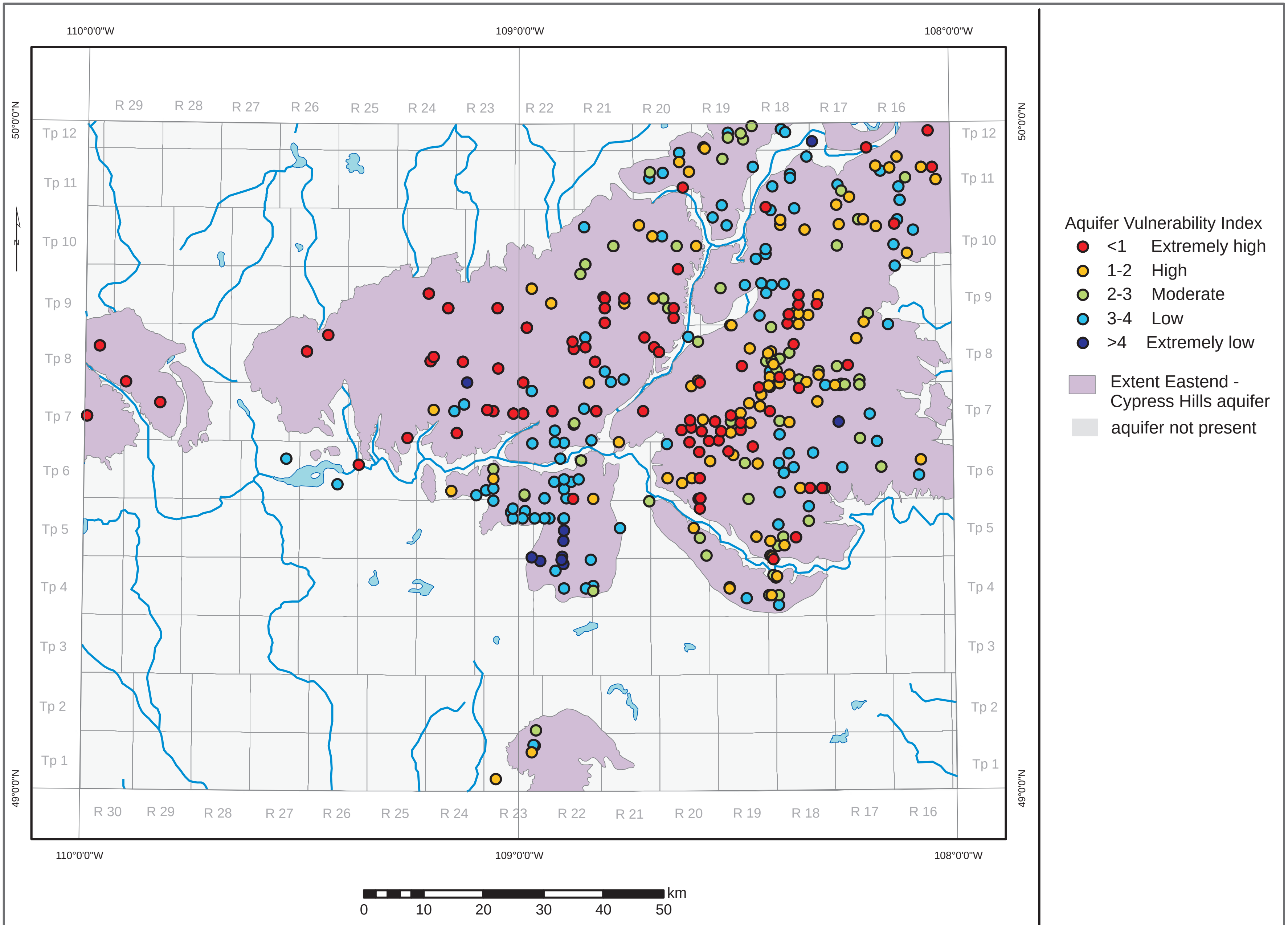


Figure 43 Aquifer vulnerability index for the Eastend to Cypress Hills aquifer in the Cypress Lake area

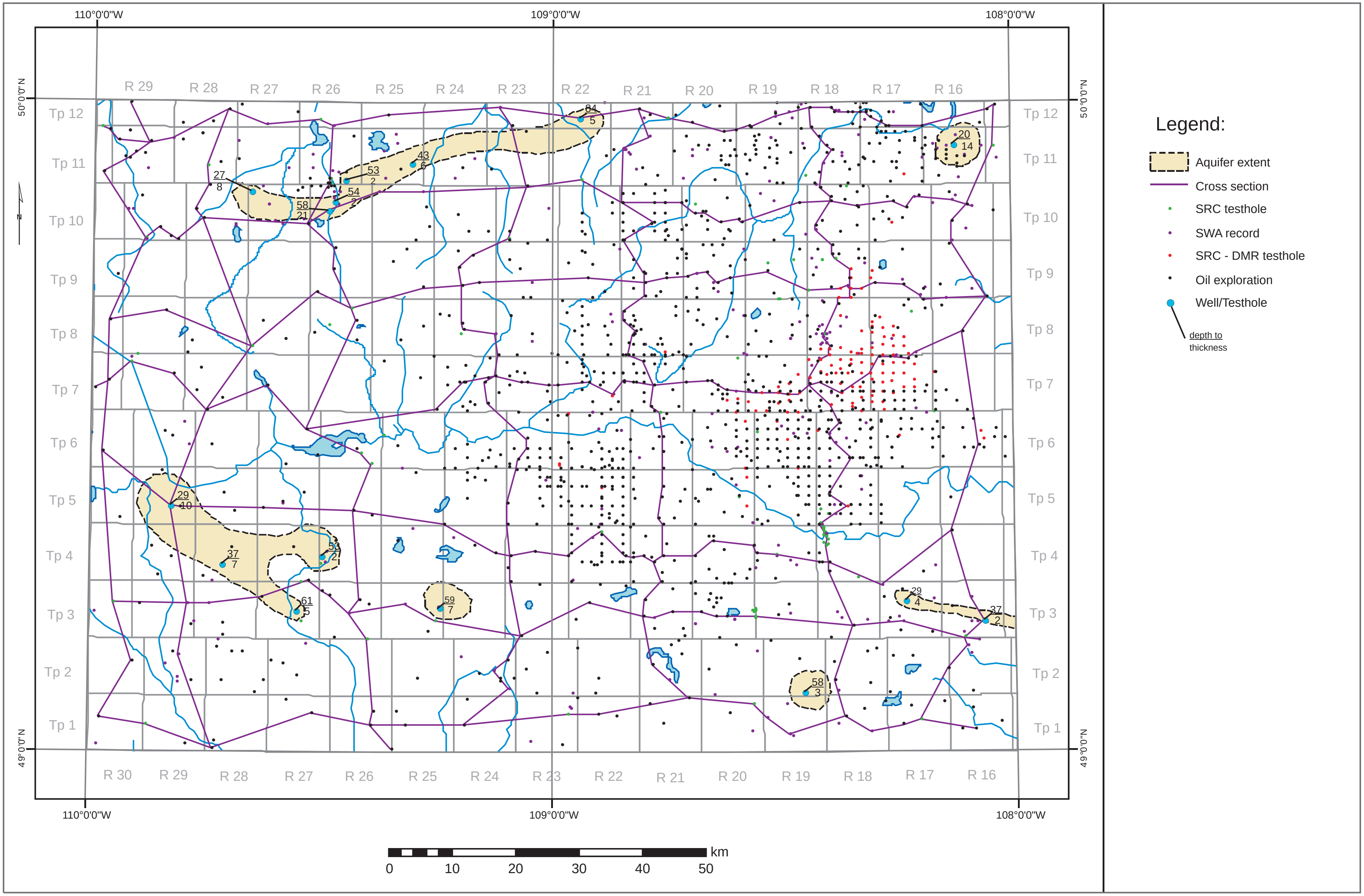


Figure 44 Extent, depth to and thickness of Empress Group aquifers in the Cypress Lake area

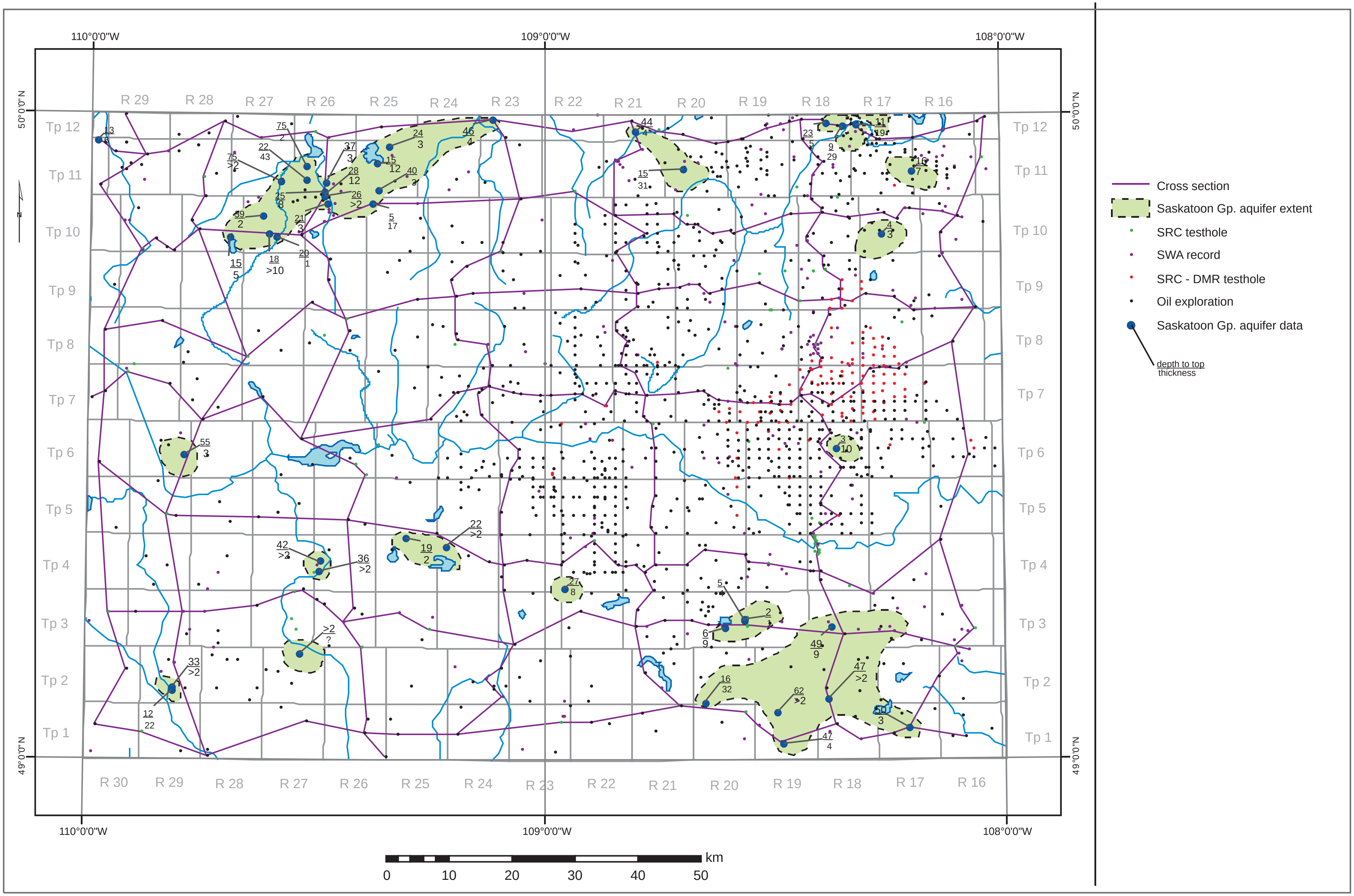


Figure 45 Extent, depth to and thickness of Saskatoon Group aquifers in the Cypress Lake area

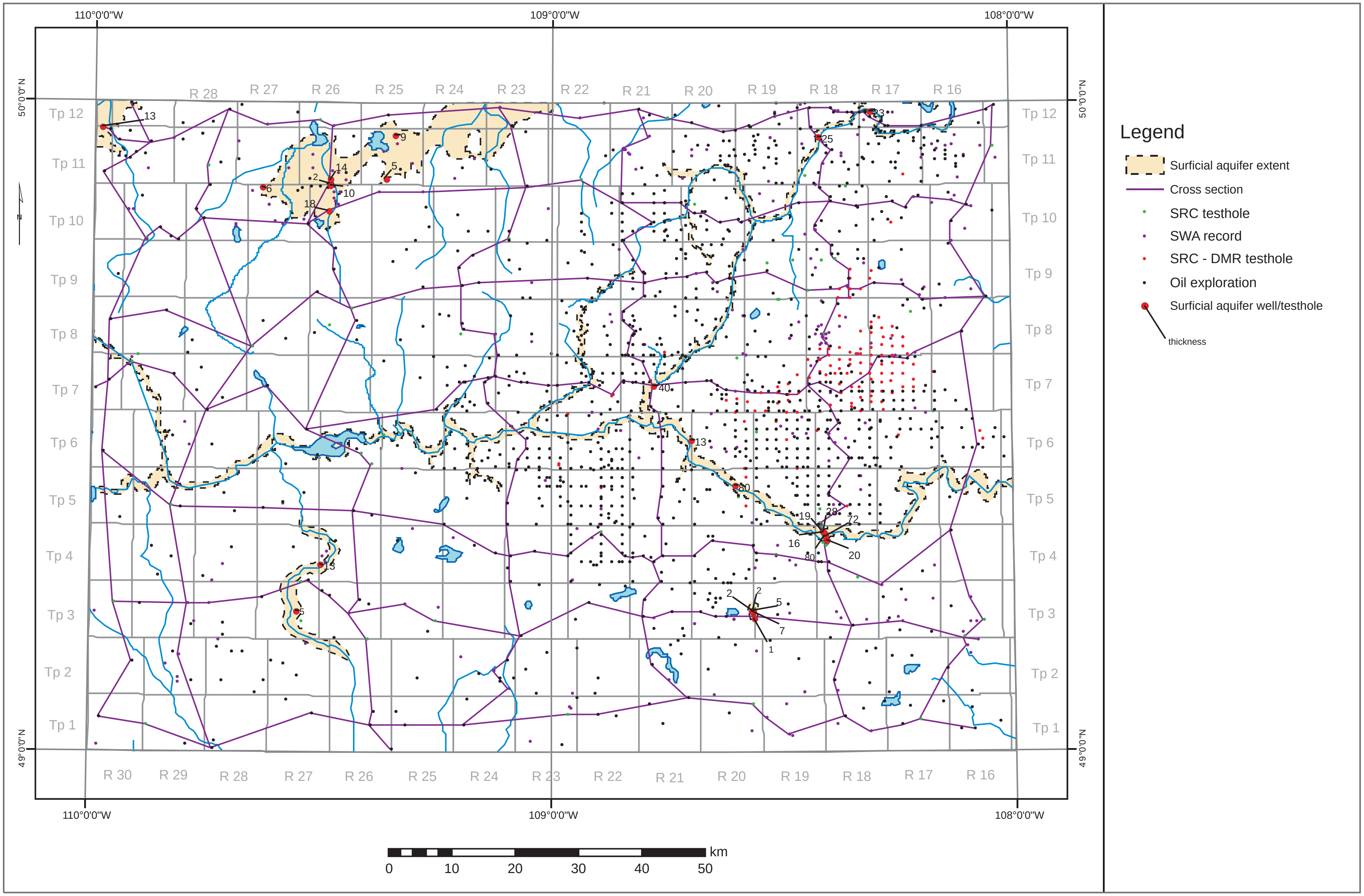


Figure 46 Extent and thickness of surficial aquifers in the Cypress Lake area

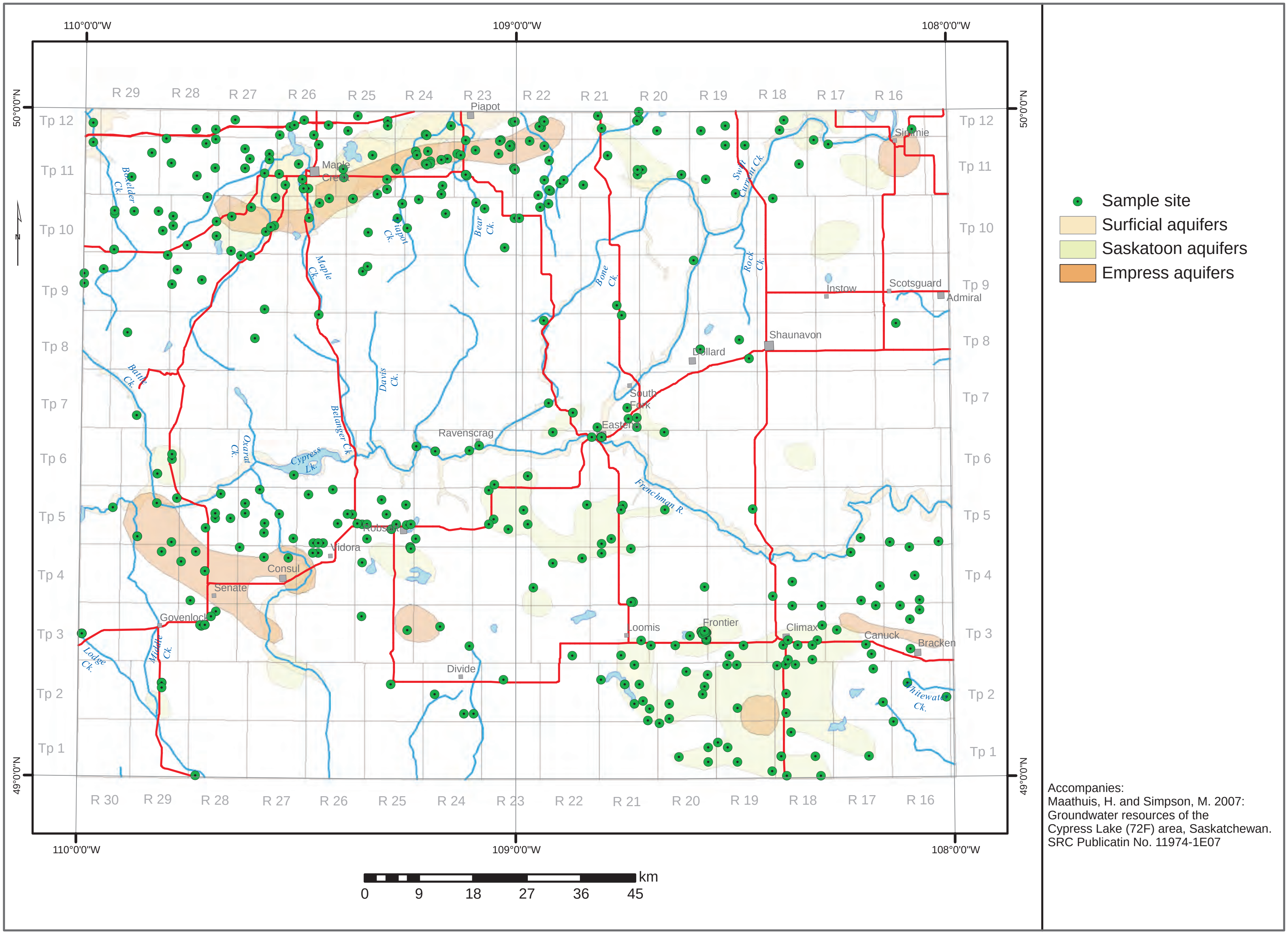


Figure 47 Locations of groundwater samples from Quaternary aquifers

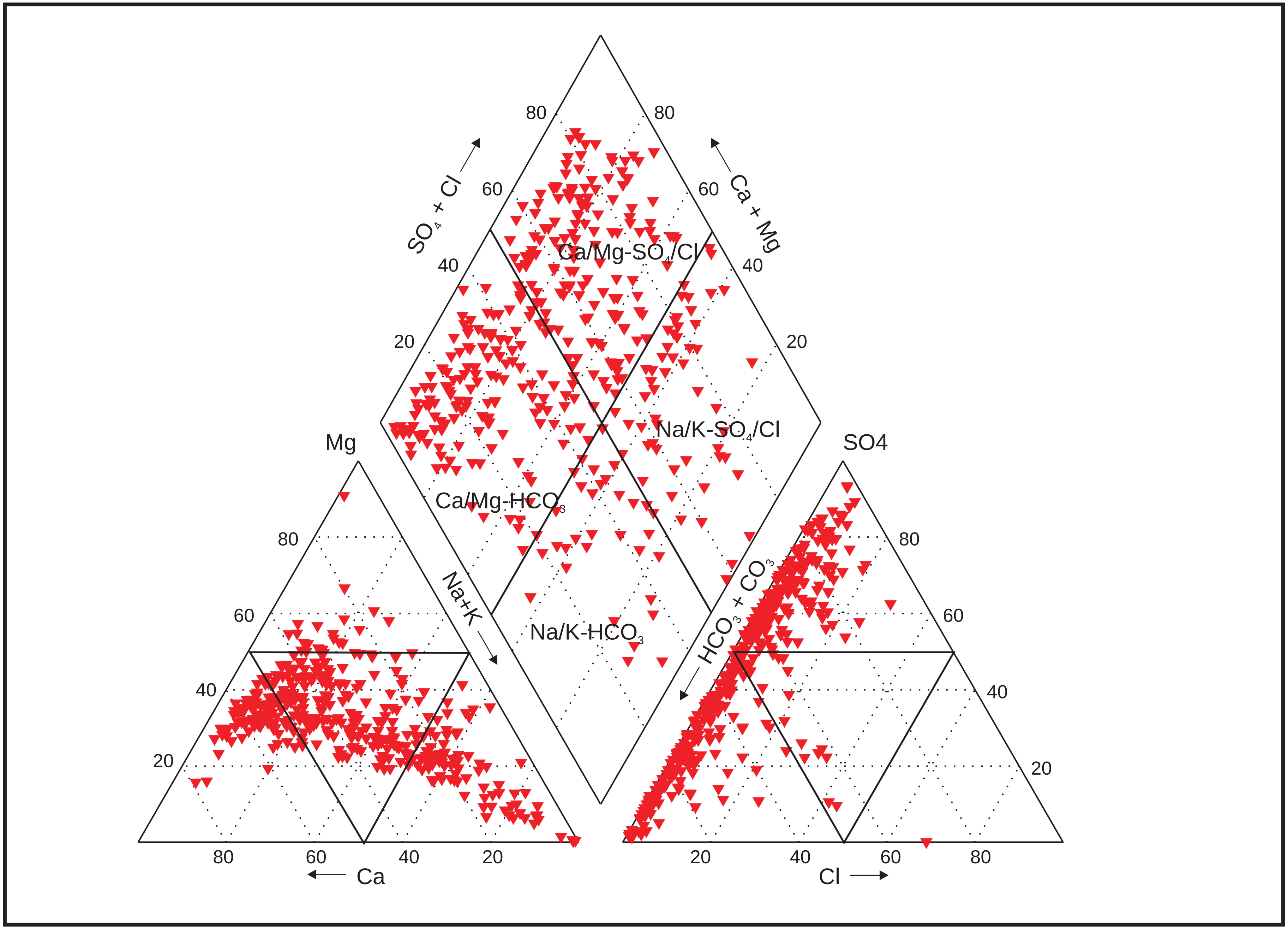


Figure 48 Piper-plot of groundwater quality data from the Quaternary aquifers

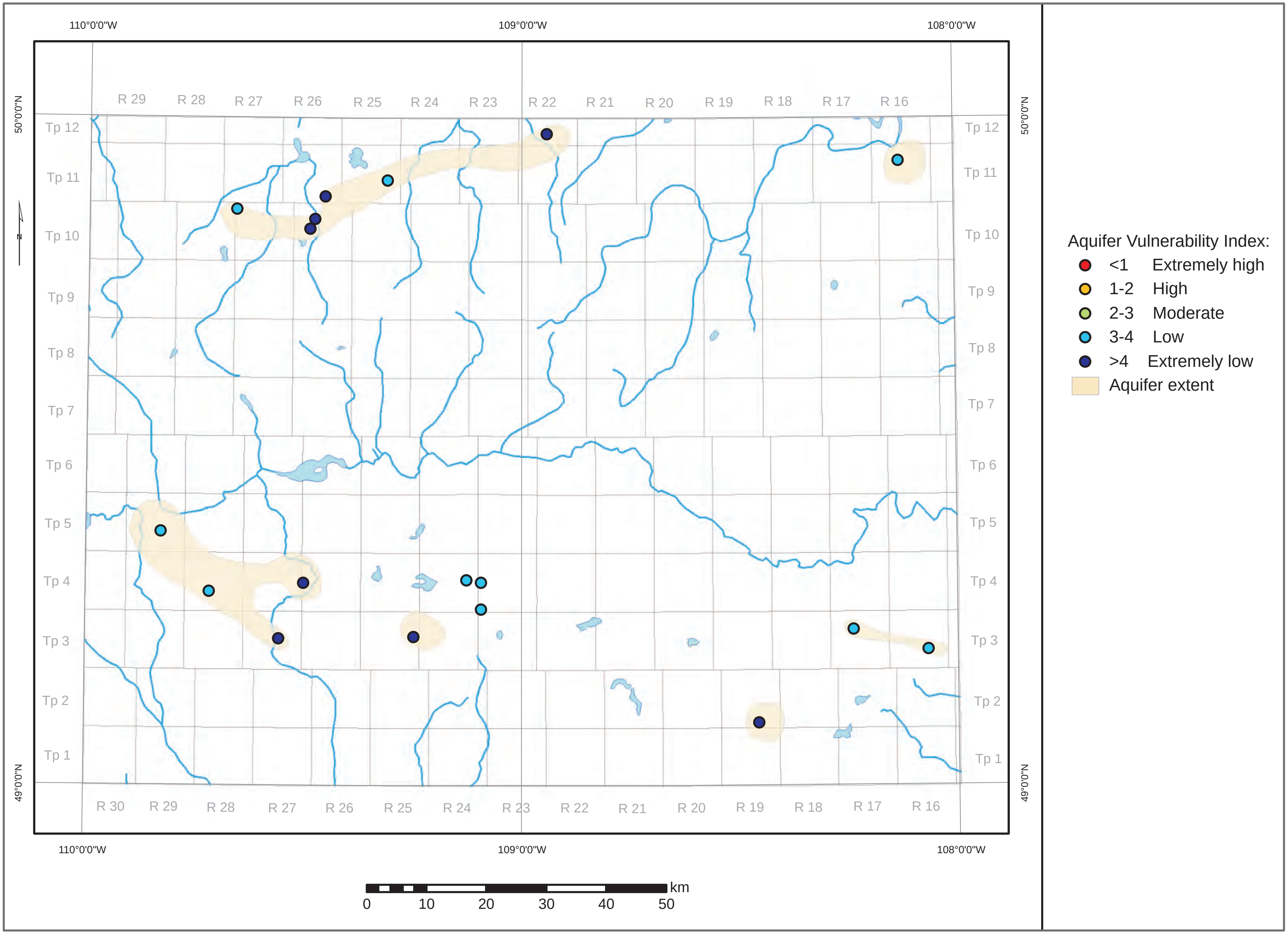


Figure 49 Aquifer vulnerability index for Empress Group aquifers in the Cypress Lake area

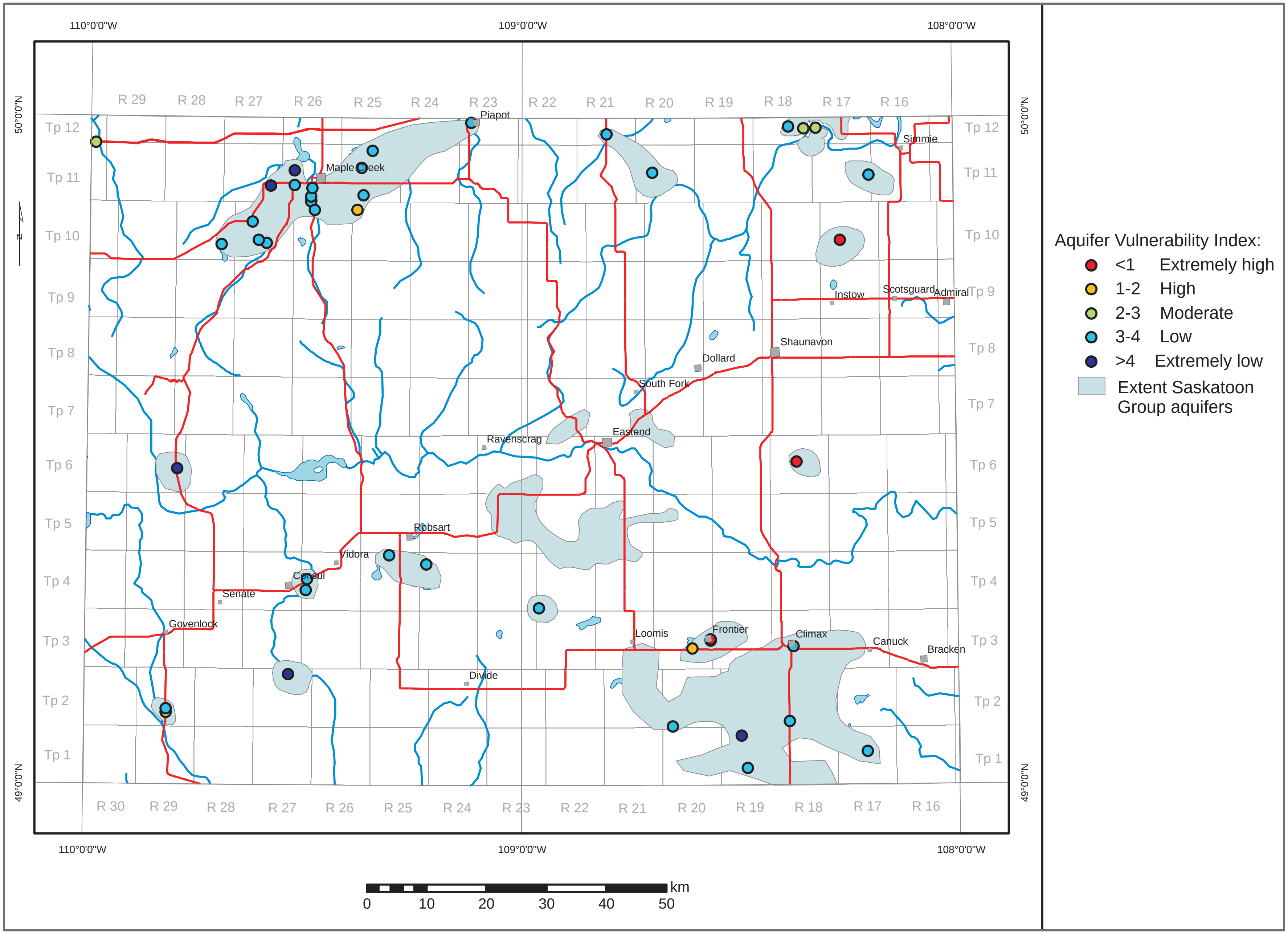


Figure 50 Aquifer vulnerability index for Saskatoon Group aquifers in the Cypress Lake area

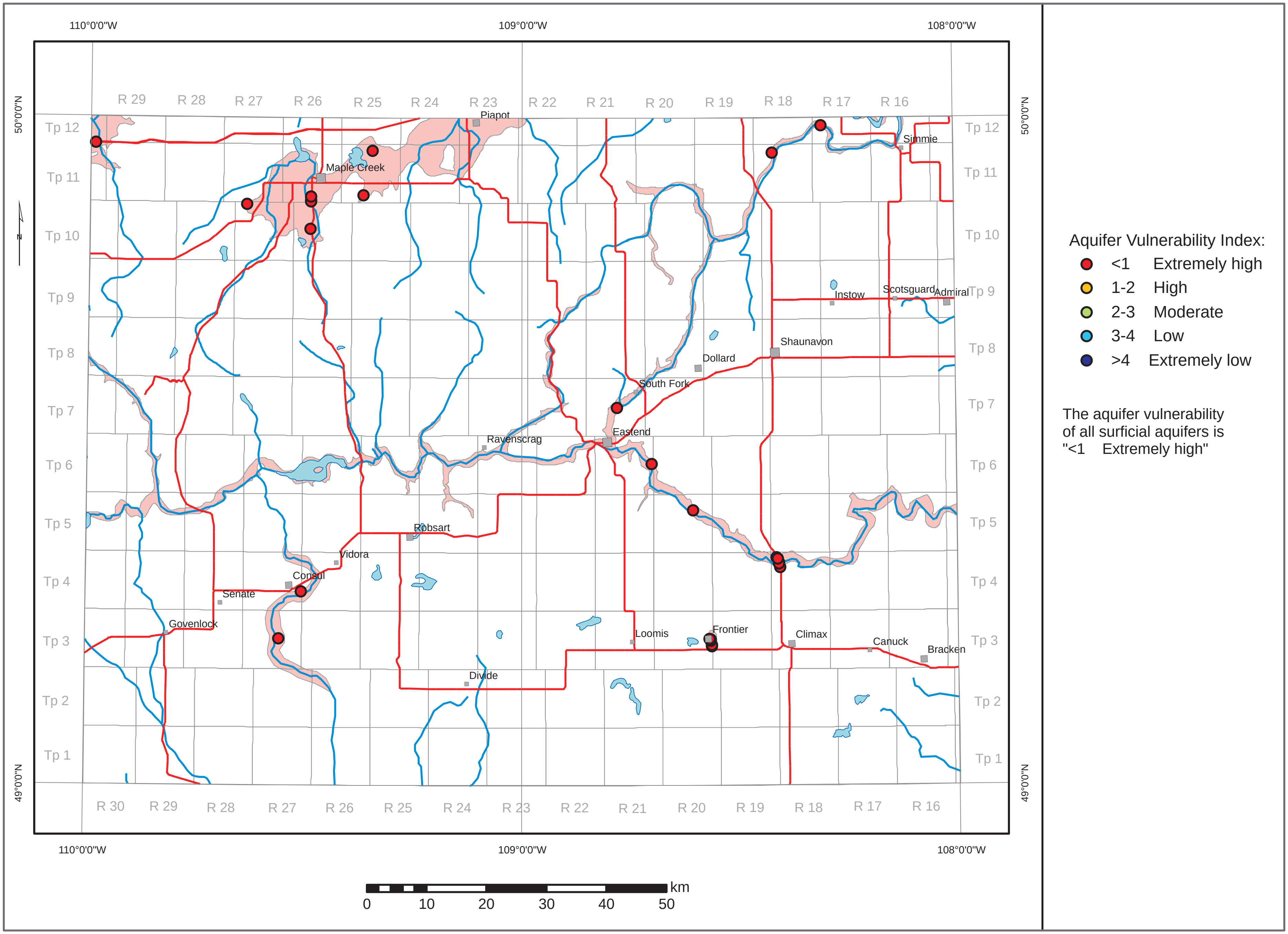


Figure 51 Aquifer vulnerability index for surficial aquifers in the Cypress Lake area

Appendix A:

Cross Section Log Index and Cross sections

Log Index #	Name	QtrLsd	Lsd	QtrSec	Sec	Twp	Rg	Mer
1	RCA WALSH	NE	16		35	11	30	3
2	CYPRESS NUCO CYPRESS		10		36	11	30	3
3	CAN SOUTHERN BOXELDER CREEK		10		30	11	29	3
4	CYPRESS NUCO CYPRESS		7		27	11	29	3
5	GOTTLIEB HEINE			NE	25	11	29	3
6	AMUREX SOUTHERN FERGUSON		13		12	12	28	3
7	BLUMHAGEN BERT			SE	4	12	27	3
8	MAPLE CREEK	NE	16		5	12	26	3
9	MUND WALTER			SW	3	12	26	3
10	BARHAR ZAMORA BA CARDELL		6		9	12	25	3
11	VILLAGE OF PIAPOT	SE	4		17	12	23	3
12	WRIGHT KENNETH M	SE	1		9	12	22	3
13	CAN DELHI TOMKINS 1		2		16	12	21	3
14	CARMICHAEL	SW	3		12	12	21	3
15	CAN DEVONIAN DAGNAIS		10		5	12	20	3
16	SMDC 91-29			NE	35	11	20	3
17	SOCONY GULL LAKE 125-70		16		36	11	20	3
18	SMDC 91-30		0	SW	5	12	19	3
19	WHITEHALL ILLERBRUN 67		3		5	12	19	3
20	SOCONY NORTH ILLERBRUN		4		17	12	18	3
21	WHITEHALL ILLERBRUN 63		4		15	12	18	3
22	KLINK MIKE	C	15		10	12	18	3
23	WHITEHALL ILLERBRUN 12		12		12	12	18	3
24	WHITEHALL ILLERBRUN 3A		11		7	12	17	3
25	WHITEHALL ILLERBRUN 7		1		7	12	17	3
26	MARATHON ILLERBRUN CR		2		4	12	17	3
27	SOCONY WESTERN NO 125-20		1		1	12	17	3
28	TW VESPER STH 367		13		7	12	15	3
29	TW PELLETIER CROWN		8		18	12	15	3
30	BOX ELDER	SW	5		4	10	29	3
31	CAN SOUTHERN CLEARSIGHT		6		10	10	29	3
32	AMUREX SOUTHERN SEPT		4		1	10	29	3
33	AMUREX ALBERCAN EMERENKO		7		17	10	28	3
34	AMUREX MCLEOD		15		12	10	27	3
35	HOBBS GRAHAM			SE	20	10	26	3
36	TOWN OF MAPLE CREEK	NW	2		31	10	25	3
37	BOWYER LLOYD	SE	8		35	10	25	3
38	SOCONY EDGELL		16		33	10	23	3
39	SKULL CREEK	SW	12		3	11	22	3
40	COLUMBIAN NORTH EXP 146 EASTEN		4		30	10	21	3
41	SMDC 91-16			SE	25	10	21	3
42	SMDC GARDEN HEAD 8	3	4		20	10	20	3
43	SMDC GARDEN HEAD 7	3	4		21	10	20	3
44	SMDC GARDEN HEAD 4	2	2		15	10	20	3
45	CAN DELHI HUSKY P R GARDEN HEA		6		13	10	20	3
46	SMDC GARDEN HEAD 1	2	2		13	10	20	3

47	CAN DELHI BONE CREEK		4		25	10	19	3
48	SMDC 91-42			SW	28	10	18	3
49	SMDC 91-45			NE	23	10	18	3
50	SMDC 91-52			SW	28	10	17	3
51	SOCONY INSTOW		10		22	10	17	3
52	BOLTON JOHN	NW	13		26	10	17	3
53	SMDC 91-54			NE	26	10	17	3
54	BOLTON ELDON	SE	8		29	10	16	3
55	MOBIL WOODLEY SOUTHERN SCOTSGU		14		22	10	16	3
56	LARSON LAWRENCE		9		22	10	16	3
57	CAN DELHI HUSKY PHILLIPS HARRI		10		23	8	30	3
58	PHILLIPS COULEEA		12		26	8	29	3
59	GAP	NE	14		6	8	27	3
60	SOCONY ARCTIC CYPRESS PARK 1		10		6	9	26	3
61	JACKPOT LAKE	NE	16		27	8	26	3
62	AMUREX TRANS EMPIRE CO-OP BENS		1		11	9	25	3
63	RICHFIELD JACK POT LAKE 2		7		9	9	24	3
64	SMDC 19-25			NW	11	9	24	3
65	SMDC 19-15			SE	16	9	22	3
66	SMDC 19-34			NW	9	9	21	3
67	SMDC 92-41			SW	14	9	21	3
68	CAN DELHI HUSKY PHIL RICH JONE		6		18	9	20	3
69	BENCH COLONY	NW	13		9	3	20	3
70	SMDC 92-26			NW	16	9	20	3
71	SMDC 92-25			NW	10	9	20	3
72	CAN DELHI HUSKY PHIL RICH SWIF		3		14	9	20	3
73	CAN DELHI SHAUNAVON 1		13		16	9	19	3
74	SHAUNAVON 82-5-101	NW	13		6	9	18	3
75	DMR-SRC-EMR Cypress No.62	SW	4		10	9	18	3
76	NEWMAN JEFF	NE	1		10	9	18	3
77	DMR-SRC-EMR Cypress No.53	SW	4		11	9	18	3
78	DMR-SRC-EMR Cypress No.64	NW	13		1	9	18	3
79	TW INSTOW CROWN		11		7	9	17	3
80	TW EAST INSTOW CROWN		5		10	9	17	3
81	SIMMONS ROY	SW	2		2	9	17	3
82	PAN AM A-1 SCOTSGUARD CROWN		13		36	8	17	3
83	SONSTEBY ROBERT	NE	13		32	8	16	3
84	IMPERIAL TW ADMIRAL 1		4		1	9	16	3
85	PANEX FOX CREEK		6		15	7	30	3
86	CAN DELHI FOX 1		2		23	7	30	3
87	EAGLE NO.95-FORT WALSH	NW	1		31	7	29	3
88	CAN DELHI HUSKY PHIL BATTLE CR		16		23	7	29	3
89	HUSKY PHILLIPS ADAMS CREEK 1		4		4	7	28	3
90	CAN DELHI HUSKY PHILLIPS GAP 1		9		17	7	27	3
91	BA OIL CO-OP CALVAN CYPRESS LA		2		26	6	27	3
92	SOCONY STH 75-90		5		6	7	24	3
93	SMDC 19-32A			SE	21	7	24	3
94	SOCONY STH 75-45		16		24	7	24	3

95	SMDC 92-28			SW	21	7	23	3
96	SOCONY STH 75-104		1		21	7	23	3
97	SOCONY STH 75-102		16		14	7	23	3
98	SOCONY STH 75-103		16		13	7	23	3
99	SOCONY STH 75-82		1		21	7	22	3
100	HUMPHREY TODD & KEN		13		12	7	22	3
101	SOCONY STH 75-116		5		19	7	21	3
102	SMDC EASTEND 1		3		20	7	21	3
103	SOCONY STH 75-111		13		15	7	21	3
104	SOCONY STH 75-108		4		19	7	20	3
105	TW DOLLARD CROWN		7		21	7	20	3
106	TW DOLLARD CROWN		5		14	7	20	3
107	DMR-SRC-EMR Cypress No.38	SE	3		17	7	19	3
108	DMR-SRC-EMR Cypress No.4 R	SW	4		15	7	19	3
109	DMR-SRC-EMR Cypress No.36	NW	13		11	7	19	3
110	DMR-SRC-EMR Cypress No.51	NW	13		12	7	19	3
111	TW EAST DOLLARD CROWN		13		18	7	18	3
112	DMR-SRC-EMR Cypress No.34	SW	4		20	7	18	3
113	DMR-SRC-EMR Cypress No.18R	NW	13		10	7	18	3
114	DMR-SRC-EMR Cypress No.17R	SE	1		25	7	18	3
115	SMDC 93- 8			NE	31	7	17	3
116	WRIGHT RON	C	14		33	7	17	3
117	SUPERTEST WESTBURNE CLIMAX		10		34	7	17	3
118	HUSS ED	SE	5		2	8	17	3
119	BASS MOC SCOTSGUARD		8		16	8	16	3
120	CAN DELHI CYPRESS HILLS 1		9		9	6	30	3
121	BATTLE CREEK	SW	2		15	5	29	3
122	TEXACO BATTLE CREEK		14		11	5	29	3
123	IMPERIAL SENATE		14		7	5	27	3
124	BA OIL CYPRESS LAKE		12		10	5	26	3
125	IMPERIAL ROBSART		1		1	5	25	3
126	SOCONY STH 75-143		1		23	4	24	3
127	SOCONY STH 75-96A		14		18	4	23	3
128	SOCONY STH 75-93B		7		21	4	23	3
129	SOCONY STH 75-87		16		13	4	23	3
130	BREEN JOHN	NE	12		28	4	22	3
131	CLAY CENTRE	NW	5		34	4	22	3
132	SOCONY STH 75-142		14		13	4	22	3
133	SOCONY STH 75-139		12		18	4	21	3
134	SOCONY WOODLEY SOUTHERN EASTBR		13		17	4	21	3
135	SOCONY STH 75-138		4		16	4	21	3
136	SOCONY STH 75-62		13		15	4	21	3
137	SOCONY STH 75-66		13		18	4	20	3
138	TW FRENCHMAN CROWN 1		8		29	4	20	3
139	TW RAPDAN CROWN		16		24	4	20	3
140	OLIPHANT TW RAPDAN CROWN		4		19	4	19	3
141	CLIMAX	NW	13		16	4	19	3
142	SMDC FRENCHMAN S. 4		3		18	4	18	3

143	SMDC FRENCHMAN S. 3		4		17	4	18	3
144	RAPLEY MAYNARD		13		31	3	17	3
145	BA OIL CLIMAX FOSS		8		31	4	16	3
146	RCA ALTAWAN	NW	12		23	3	30	3
147	TRUMPER PAT	SW	13		24	3	29	3
148	PIERCE ALAN	NE	12		20	3	28	3
149	TEXACO CONSUL		6		30	3	27	3
150	NOTUKEU	NW	13		35	3	27	3
151	CAN SOUTHERN CALVAN CONSUL		1		2	4	27	3
152	IMPERIAL BATTLE CREEK		4		31	3	26	3
153	CANSO BATTLE CREEK		9		30	3	26	3
154	REAMER GORDON	NE	16		16	3	26	3
155	LEWIS GLEN	NW	11		21	3	25	3
156	RANGEVIEW	NW	13		12	3	25	3
157	CAN SOUTHERN SHELL KATHERINE		6		5	3	23	3
158	CAN SHELL SOUTHERN CLAYDON		16		20	3	22	3
159	TW LOOMIS CROWN		5		17	3	21	3
160	MEYERS SCOTT	SW	6		16	3	21	3
161	TW LOOMIS CROWN		16		15	3	21	3
162	TW FAM CROWN 1		15		18	3	20	3
163	CAN INDUS FRONTIER 3		5		16	3	20	3
164	SRC FRONTIER 11 PIEZ.	NE	8		13	3	20	3
165	IMPERIAL TW CLIMAX 6		6		10	3	18	3
166	BENNETT DALE	NW	13		9	3	17	3
167	SE BRACKEN JR.4	SE	4		4	3	16	3
168	WILSON RON	NW	16		33	2	16	3
169	CAN EXP GOVENLOCK		10		20	1	30	3
170	WILLOW CREEK	NW	13		18	1	29	3
171	CAN SOUTHERN SHELL WOODPILE		7		6	1	28	3
172	FRONTIER 174-7		4		26	1	27	3
173	FRONTIER TH 174-3		16		15	1	26	3
174	FRONTIER TH 174-4		13		17	1	25	3
175	FRONTIER TH 174-6		16		18	1	24	3
176	STAYNOR HALL	SE	1		26	1	23	3
177	TW BOUNDARY CROWN		1		29	1	22	3
178	TW SOUTH CLAYDON CROWN		15		35	1	21	3
179	FRONTIER	NE	1		35	1	20	3
180	BARSNESS RUEBEN	NE	11		19	1	19	3
181	OLSZEWSKI BYRON PATRICK	NE	14		9	1	19	3
182	TW IMPERIAL CLIMAX 2		16		20	1	18	3
183	BROWN BARRY	SE	3		14	1	18	3
184	TW CLIMAX CROWN 4		14		17	1	17	3
185	TREELON	NW	5		22	1	17	3
186	TENNECO CALSTAN LONETREE B		6		16	1	16	3
187	CAN EXP GOVENLOCK		10		23	2	30	3
188	SPRING CREEK HUTTERITE COLONY			SW	19	10	29	3
189	ALBERCAN BOXELDER CREEK 1		4		12	11	30	3
190	CYPRESS NUCO CYPRESS		10		17	11	29	3

191	AMUREX CANSO CUMMINGS		10		17	12	29	3
192	TRUMPER DON	NW	6		27	2	29	3
193	AMUREX CANADA SOUTHERN MCCOY		8		19	10	28	3
194	ALBERCAN MCCOY CREEK 1		13		33	10	28	3
195	KINCORTH	NE	13		10	11	28	3
196	FRONTIER TH 174-5		8		1	1	26	3
197	FRONTIER TH 174-2		5		26	1	26	3
198	SE SUPREME JR.6	SW	2		2	3	26	3
199	ALBERCAN BATTLE CREEK		1		27	3	26	3
200	CYPRESS LAKE	NE	8		2	6	26	3
201	CYPRESS LAKE	SE	9		10	6	26	3
202	CAN DEV JACKPOT LAKE		11		23	8	26	3
203	ORBIT MAPLE CREEK 1		4		21	9	26	3
204	RICHFIELD JACKPOT LAKE 3		6		33	9	26	3
205	HIRATE MAPLE CREEK 14		10		32	10	26	3
206	MAPLE CREEK TW-7	SE	1		4	11	26	3
207	MAPLE CREEK TW-6	SE	9		4	11	26	3
208	RUSH DAVE	NW	11		1	2	24	3
209	DARLING HARVEY	SW	16		15	2	24	3
210	BOSSORT DIVIDE		13		24	2	24	3
211	SOCONY STH 75-95		3		6	4	23	3
212	SOCONY STH 75-44		4		6	5	23	3
213	SOCONY STH 75-43A		5		18	5	23	3
214	SOCONY STH 75-91		16		31	5	23	3
215	SOCONY STH 75-92		13		5	6	23	3
216	SOCONY STH 75-8		1		17	6	23	3
217	SOCONY STH 75-14		1		20	6	23	3
218	SOCONY STH 75-4		13		1	7	24	3
219	SOCONY STH 75-49		1		23	7	24	3
220	SOCONY STH 75-72		4		6	8	23	3
221	WEST BENCH HUTTERITE COLONY		7		13	8	24	3
222	SMDC 19-28			NE	16	8	24	3
223	RICHFIELD JACK POT LAKE		7		21	8	24	3
224	SMDC 19-26			SW	21	9	24	3
225	AMUREX TRANS EMPIRE CO-OP FORE		10		27	9	24	3
226	KEALEY SPRINGS	SW	5		5	10	23	3
227	ANGLO AM GRIDOIL CRANE LAKE		6		4	12	23	3
228	HAM WILLIAM RM OF FRONTEIR	SE	9		9	2	21	3
229	TW CLAYDON CROWN 1		5		20	2	21	3
230	TW LOOMIS CROWN		3		29	3	21	3
231	SOCONY STH 75-63		1		4	4	21	3
232	SOCONY STH 75-61		4		3	5	21	3
233	SOCONY WOODLEY SOUTH N EASTBRO		15		4	5	21	3
234	SOCONY STH 75-58		1		21	5	21	3
235	SOCONY STH 75-69		4		27	5	21	3
236	SOCONY STH 28		4		3	6	21	3
237	MCALESTER GOLDSTON MCBRIDE		13		10	6	21	3
238	SOCONY STH 75-27		5		22	6	21	3

239	EASTEND	NW	16		33	6	21	3
240	SOCONY WOODLEY SOUTHERN SOUTH		9		4	7	21	3
241	SOCONY WOODLEY SOUTHERN SOUTH		5		33	7	21	3
242	SMDC EASTEND 3	2	2		6	8	21	3
243	INTERCONTENTAL RES 29 EASTEND		4		17	8	21	3
244	CAN DELHI HUSKY P R PINE COULE		11		17	8	21	3
245	SMDC 92-34			NW	19	8	21	3
246	SMDC 92-17			NW	30	8	21	3
247	SMDC 92-39			SW	4	9	21	3
248	SMDC 19- 8			NW	16	9	21	3
249	CAN DELHI HUSKY P R STONE		13		16	9	21	3
250	SMDC 91-13			SW	6	10	21	3
251	COLUMBIAN NORTH EXP 65 EASTEN		4		15	10	21	3
252	TOMPKINS HUTTERITE COLONY	NW	13		20	11	21	3
253	MCALLISTER STERLING		2		34	11	21	3
254	TW CLIMAX 3		9		7	2	18	3
255	SMDC FRENCHMAN S. 5	4	4		8	4	18	3
256	FRENCHMAN R. NO.01	NW	16		19	4	18	3
257	EAGLE NO.100 CLIMAX	NE	8		30	4	18	3
258	EAGLE NO.105 CLIMAX	SE	7		31	4	18	3
259	FRENCHMAN R. NO.09	NW	3		6	5	18	3
260	QUENNELL RALPH	SW	2		8	5	18	3
261	DMR-SRC-EMR Cypress No. 8	SE	1		16	5	18	3
262	IMPERIAL TW CHAMBERY		5		20	5	18	3
263	SMDC WHITE CREEK 5	3	3		10	6	18	3
264	GUENTHER HOWARD	NW	9		17	6	18	3
265	RABAEY ROBERT	NW	14		20	6	18	3
266	SMDC 93- 3			NW	28	6	18	3
267	DMR-SRC-EMR Cypress No.55	NW	12		4	7	18	3
268	DMR-SRC-EMR Cypress No.67	SW	12		19	7	18	3
269	DMR-SRC-EMR Cypress No.1 R	SW	12		32	7	18	3
270	DMR-SRC-EMR Cypress No.42	NW	13		33	7	18	3
271	DMR-SRC-EMR Cypress No.52	SW	12		4	8	18	3
272	TW SHAUNAVON CROWN 1		13		4	8	18	3
273	MELLOR VERN	NE	14		8	8	18	3
274	TOWN OF SHAUNAVON TH 1			SE	17	8	18	3
275	ALTANA PLAZA SHAUN		8		33	8	18	3
276	DMR-SRC-EMR Cypress No.58	SE	1		4	9	18	3
277	DMR-SRC-EMR Cypress No.60	SW	4		2	9	18	3
278	DMR-SRC-EMR Cypress No. 2	SW	4		14	9	18	3
279	DMR-SRC-EMR Cypress No.56	SW	4		23	9	18	3
280	SHAUNAVON 82-2-104	NW	2		28	9	18	3
281	TW NORTH SHAUNAVON		11		28	9	18	3
282	TW INSTOW CROWN		11		33	9	18	3
283	MOREAU ALFRED	SE	1		7	10	18	3
284	SMDC 91-61			NE	7	10	18	3
285	SMDC 91-43			NW	28	10	18	3
286	SMDC 91-44			NW	32	10	18	3

287	VOLL BILL	SW	3		16	11	18	3
288	SMDC 91-41A			NW	22	11	18	3
289	MOBIL SOUTHERN ILLERBRUN		2		28	11	18	3
290	WHITEHALL ILLERBRUN 62		1		32	11	18	3
291	WHITEHALL ILLERBRUN		4		5	12	18	3
292	TW CANUCK CROWN 1		16		13	2	17	3
293	KALICIAK ANTON	NE	8		32	2	16	3
294	BRACKEN	NW	13		11	3	16	3
295	RUTTLE ARCHIE	SW	2		28	3	16	3
296	SOCONY BEAVER VALLEY		7		15	6	16	3
297	WEISETH DAVID	NE	16		32	9	16	3
298	SOCONY GULL LAKE 125-76		1		17	10	16	3
299	SIMMIE	SW	2		30	11	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.

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

0 2 4
kilometres

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SRC
smart science solutions

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

LIMITATIONS:
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smart science solutions

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

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0 2 4
kilometres

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

Cypress Lake Area
72F
CROSS SECTION
E-E'

Accompanies:
Maathuis, H. and Simpson. M., 2007
Groundwater Resources of the Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

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.

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

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0 2 4
kilometres

SRC smart science solutions

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

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0 2 4
kilometres

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

Cypress Lake Area
72F
CROSS SECTION
J-J'

Accompanies:
Maathuis, H. and Simpson. M., 2007
Groundwater Resources of the Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

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0 2 4
kilometres

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

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0 2 4
kilometres

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.

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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.

SRC
smart science solutions

Cypress Lake Area
72F
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 Cypress Lake Area (72F), Saskatchewan.
SRC Report No.11974-1E07.