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Compilation of Alberta Groundwater Information from Existing Maps and Data Sources

Energy Resources Conservation Board

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Alberta Geological Survey

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Abstract

Alberta Geological Survey (AGS) has been involved in mapping the province's geological framework for almost 90 years. Much of this map information can be used to help develop a broad understanding of Alberta's groundwater resources. In addition, other organizations and agencies have also compiled information on groundwater in Alberta, most notably the Prairie Farm Rehabilitation Administration through its county-scale hydrogeological mapping program. Some of the products from these additional mapping initiatives contain digital data that can also be used in the compilation of groundwater resource information.

During 2007, AGS and Alberta Environment staff gathered the available digital datasets, PDF files and hard-copy maps from the internal and external sources listed above to create an initial view of the extent and nature of groundwater resources in Alberta. This report provides details on the data used, the limitations of the data and any assumptions made during the creation of the products.

1 Introduction

Water use and sustainability are increasingly of concern in Alberta. Alberta Geological Survey (AGS) and Alberta Environment (AENV) have recently begun a groundwater inventory that includes mapping, modelling and management initiatives to better understand groundwater quantity, quality and sustainability in the province. Alberta Geological Survey has been charged with creating the groundwater maps and models and, in conjunction with AENV, developing groundwater-management tools. This activity will occur in stages, the first stage being the mining of existing information on the geology and hydrogeology of Alberta.

Since its inception, AGS has focused on mapping many aspects of the geology of Alberta. One of the types of maps that AGS created during the 1970s and 1980s was a series of hydrogeological maps based on the concept of a 20-year safe yield for a well. These maps were intended to provide general details on the groundwater conditions in an area but no specifics that could be used for planning purposes. Through a recent digitization and data-processing project, AGS now has versions of these maps in a digital format, and they are managed by a geodatabase. In addition, AGS is currently mapping the geology of the bedrock, the near surface and the drift. This type of information can be used to infer the hydrogeology of an area based on the material properties of the mapped rocks and sediments.

Other organizations have also mapped groundwater resources and generated hydrogeological maps. For example, the Prairie Farm Rehabilitation Administration (PFRA) created a number of hydrogeological maps at the county scale in Alberta. Some of these maps have also been distributed in a digital form.

This report describes the compilation of existing and newly created digital information and its applicability to mapping groundwater resources, as well as the processes adopted by AGS to build a preliminary picture of the groundwater resources of Alberta. The first section discusses the work done by AGS to recreate the paper hydrogeological maps in digital form. The second section discusses the use of existing digital data to create maps of potential near-surface, confined-drift and confined-bedrock aquifers. The third section examines the geographic distribution of water use in Alberta, based on estimates of use from Government of Alberta documents.

2 Digitization of Archive Provincial Hydrogeological Maps

2.1 Data Sources

Between 1968 and 1983, the Alberta Research Council (ARC) completed the hydrogeological mapping of most of Alberta (Tokarsky, 1968, 1972, 1974, 1977a, b; LeBreton, 1971; Borneuf, 1972, 1973, 1976, 1979a, b, 1981; Ozoray, 1972, 1974, 1980a, b, 1982; Bibby, 1974; Ozoray and Lytviak, 1974; Hackbarth, 1975, 1977; Currie and Zacharko, 1976; Stein, 1976, 1982; Barnes, 1977, 1978; Stevenson and Borneuf, 1977; Ozoray and Barnes, 1978; Vogwill, 1978, 1983; Ceroici, 1979a, b; Borneuf and Pretula, 1980; Ozoray et al., 1980a, b).

The areas of the province that have been mapped are shown in Figure 1, and a mosaic of the maps themselves is shown in Figure 2. The maps were designed to provide general information on the average expected yield of groundwater from a well and were based on either the geology or properties of the rocks and sediments, or on available pump or aquifer-test information. The maps were not intended to be used for groundwater inventory work, nor for groundwater management. However, the information presented in the maps can be used as a starting point in creating a groundwater inventory.

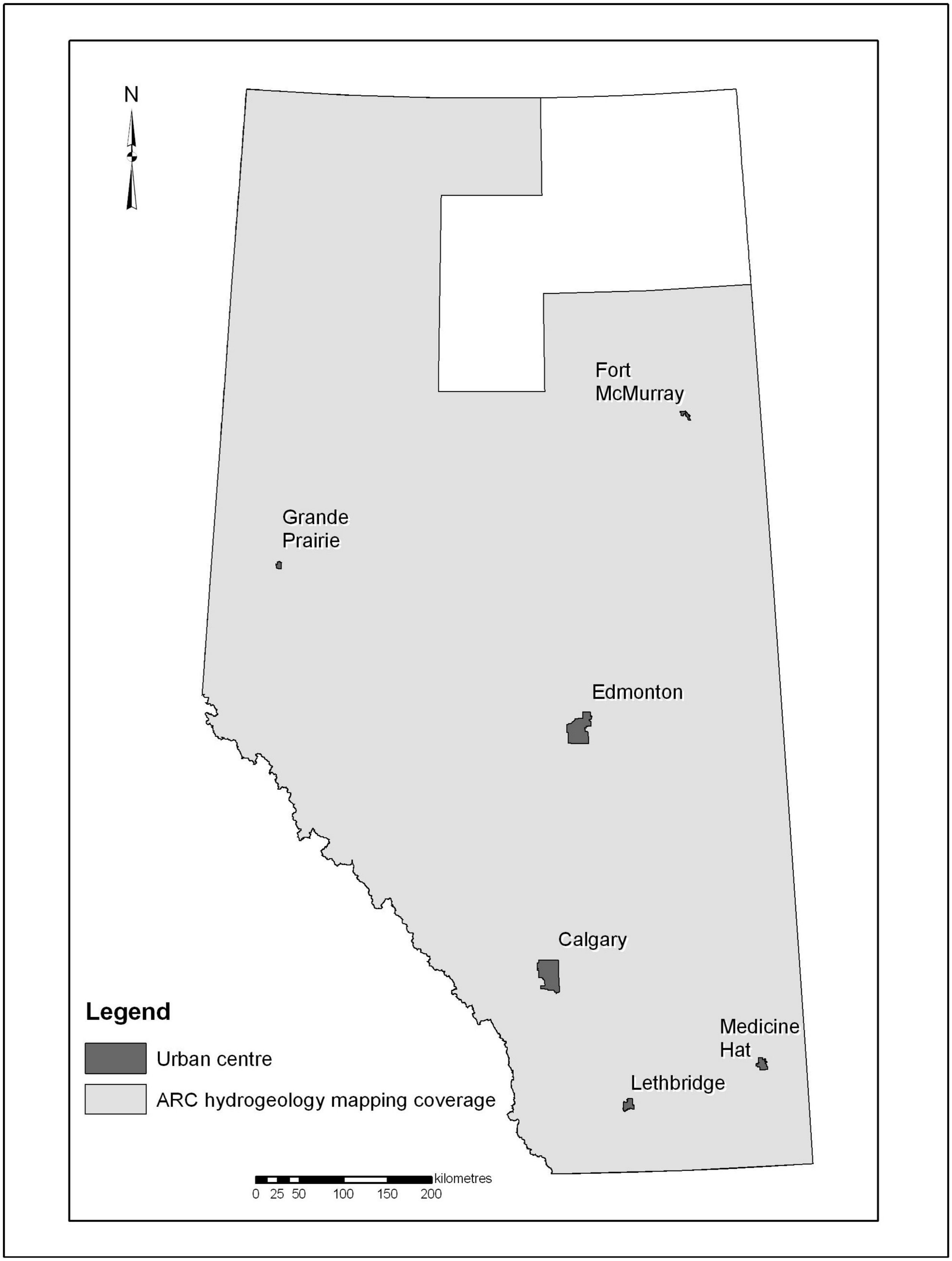


Figure 1. Area covered by the Alberta Research Council (ARC) hydrogeological mapping program, 1968–1983.

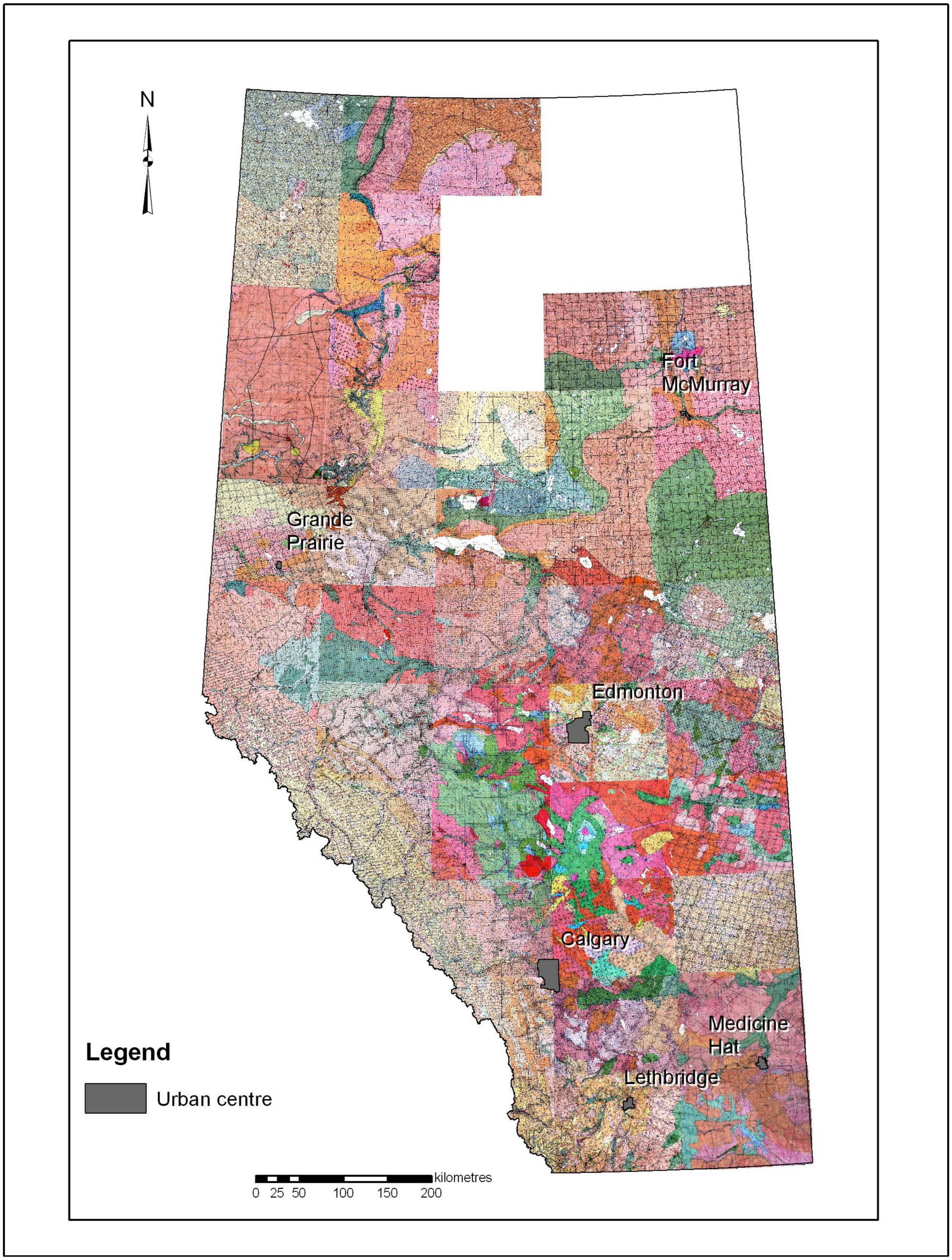


Figure 2. Mosaic of compiled scanned images of the Alberta Research Council hydrogeology maps.

Since their release, AGS has created scanned images of those paper maps that have been assigned geospatial attributes, which permit them to be managed in a geographic information system (GIS). The mosaic of these scanned maps provides a general synthesis of the hydrogeology of the province (Figure 2). Prairie Farm Rehabilitation Administration has also used these original maps to create GIS files of provincial hydrogeological elements (Figure 3). These two data sources form the basis for the construction of a digital provincial hydrogeology map managed within a GIS.

2.2 Compilation of Existing Digital Information

The digital AGS hydrogeology maps are raster images with associated geographic information, such as lake, river and town names, rather than vector products. They provide a background on which to plot other features, such as water wells or surficial geology, but cannot be used to query data and answer such questions as "How many wells are within a given area?" The PFRA's GIS information, on the other hand, is captured in attributed vector format but is incomplete and contains digitization errors.

By combining both sources of information, AGS was able to compile the ARC hydrogeology maps into a new AGS map. The scanned images were used as a basis for the digitization of groundwater-yield polygons where PFRA did not digitize the original ARC hydrogeology maps. The scanned images were also used to check the PFRA digitized linework. Where digitization errors were encountered, AGS either corrected or redigitized the PFRA linework. Digitization errors were defined as differences of 100 m or more between the position of the PFRA linework elements and the georeferenced hydrogeology map image. The 100 m value was chosen because we felt that an error of less than this magnitude would not significantly reduce the usefulness of the digital version of the regional map. Information on the georeferencing and digitization processes is provided in Appendix 1.

The groundwater-yield polygons represent a range of estimates of the average yield that a well located within the polygon could expect to produce at over time. The maps also contain information on the geology and therefore the age of the sediments within the extent of the polygons. All of this information was captured so that hydrogeology maps similar to those of the original ARC series could be created and it would be possible to create additional maps based on the aquifer age and geology.

After attributes were assigned to the vector polygons, they were edited to ensure that neighbouring polygons properly shared common edges.

2.2.1 Creation of Derivative Maps

Three maps were generated in ArcMap® from the compilation of the original ARC hydrogeology maps. The first is a yield map (Figure 4) showing polygons that are colour-coded based on yield values assigned by ARC hydrogeologists. The shapefile used to create Figure 4, containing the polygons and the yield-value attributes, is available in DIG 2009-0003 that accompanies this report.

The second is a map of aquifer type (Figure 5), based on the type of geological sediment identified as being representative of the aquifer present within the polygon. Geological sediments were classified into one of four types: surface, drift, bedrock and multiple. Where the material appears to be related to surficial deposits (defined as surficial in the original ARC maps), the polygon is classified as a surface aquifer. Where the material appears to be related to glacial drift (defined as Quaternary) below the surface, the polygon is classified as a drift aquifer. Where the material appears to be related to bedrock sediments below the surface, the polygon is classified as a bedrock aquifer. Where the types of materials appear to represent a combination of surface/drift/bedrock types, the polygon is classified as a multiple aquifer type.

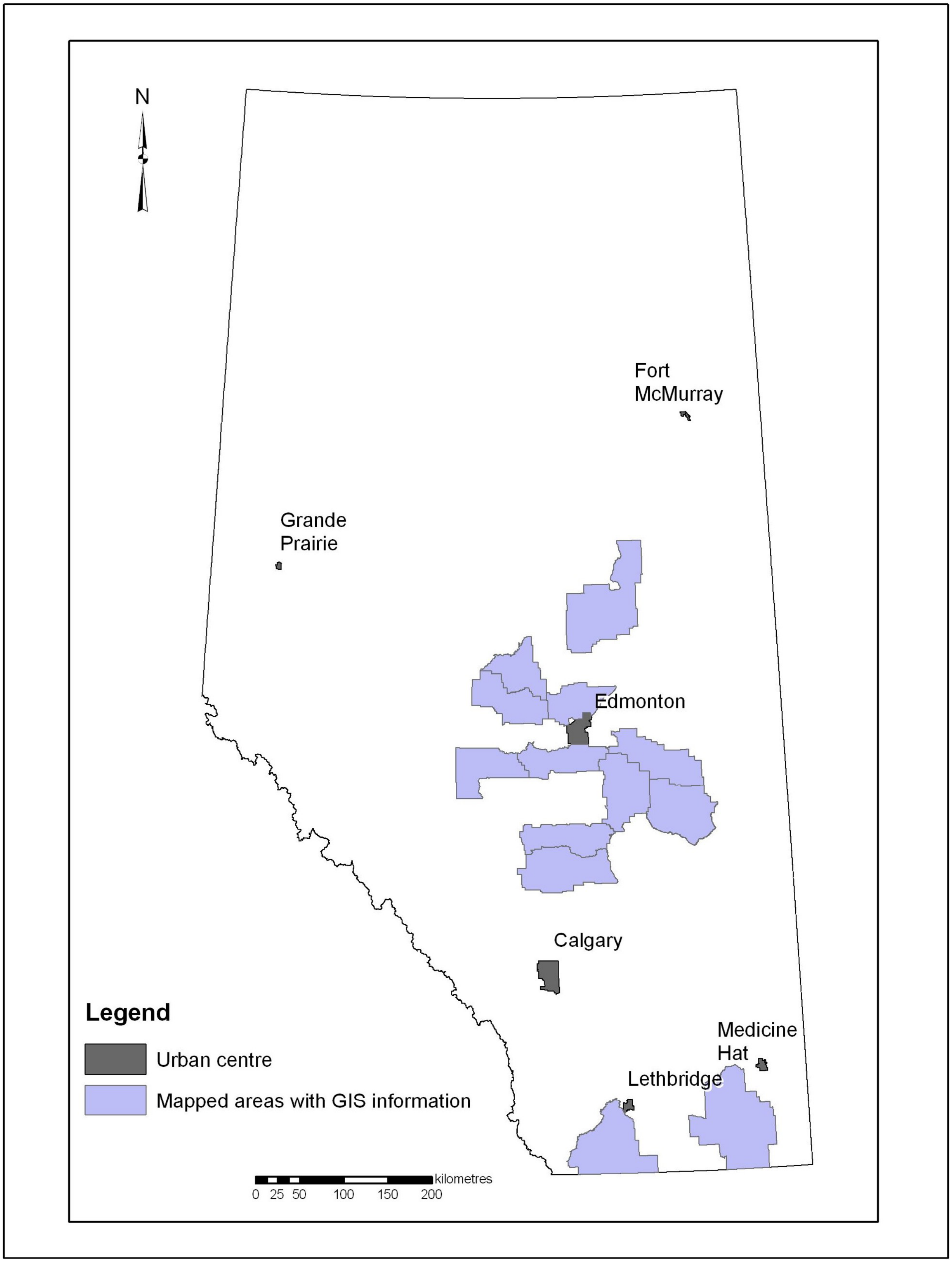


Figure 3. Prairie Farm Rehabilitation Administration hydrogeology map GIS material.

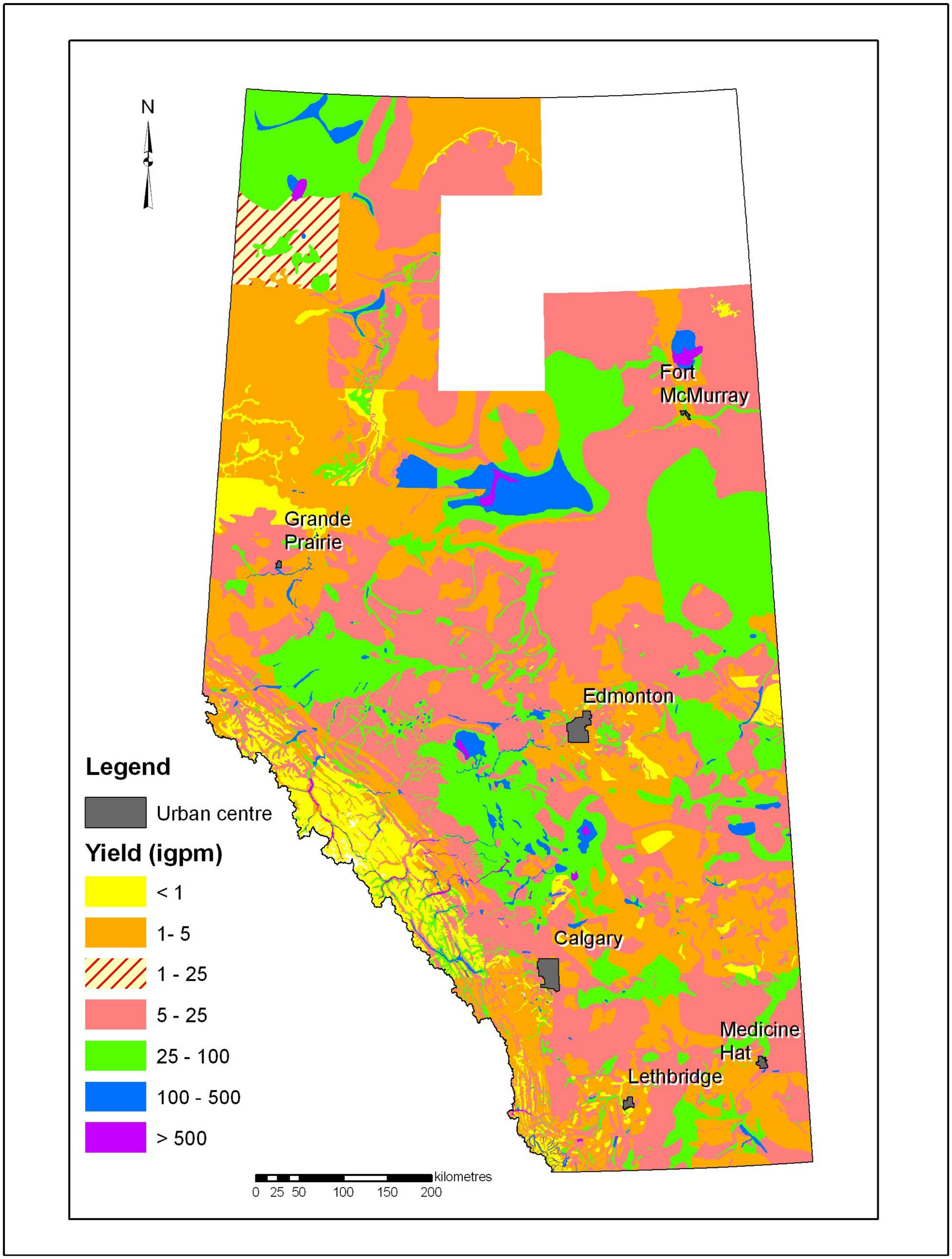


Figure 4. Compilation of water-well yields. Abbreviation: igpm, imperial gallons per minute.

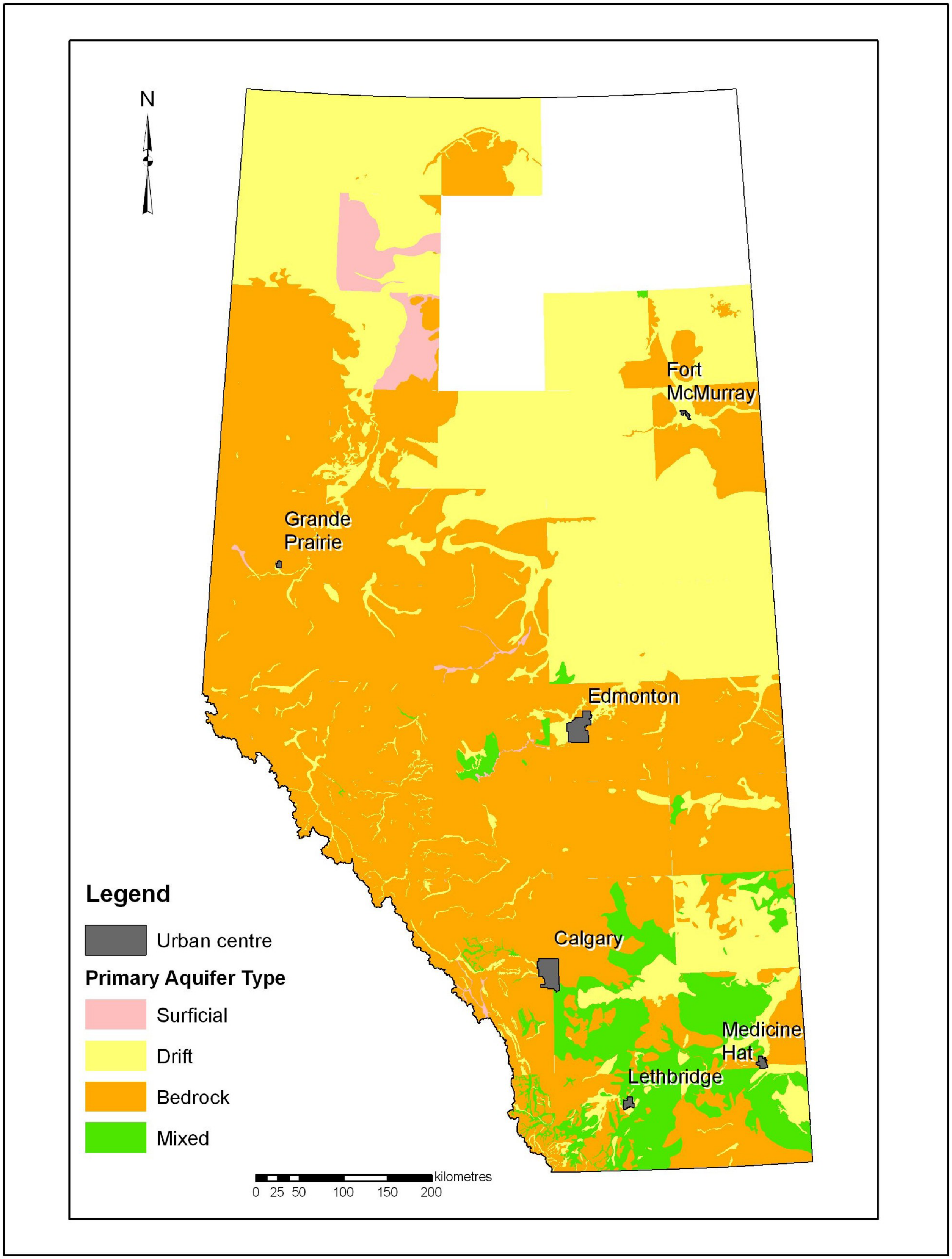


Figure 5. Compilation of aquifer types.

The third map shows yield polygons classified according to geological age of the formation with which the individual polygons appear to be associated (Figure 6).

3 Compilation of Geological Information for Hydrogeological Use

In addition to mapping groundwater, AGS and others have been, and currently are, mapping geology in the province. In particular, PFRA has generated maps of the extent of certain geological features that are significant to groundwater mapping. Geological information can add to our knowledge of the hydrogeology of Alberta by showing the areal and vertical extent of bodies that might be aquifers or have an influence on the way groundwater moves through the Earth. This section describes the processes that were used to compile information on, and map the extent of, potentially significant hydrogeological materials at the surface, in the drift and within bedrock.

3.1 Mapping Hydrogeologically Significant Materials at or near the Land Surface

The first materials that were examined were those present at or very near the land surface. Alberta Geological Survey has mapped these materials since 1968 and continues to map them through two types of mapping initiatives.

The first type of initiative is surficial mapping work (Westgate, 1968; Roed, 1970; Bayrock, 1971, 1972a–d Berg and McPherson, 1972; Bayrock and Reimchen, 1974, 1980; Boydell et al., 1974; Andriashek and Fenton, 1979; Fenton and Andriashek, 1983; Moran, 1986a–d; Fox et al., 1987; Shetsen, 1981, 1987, 1990; Andriashek, 2001a; Campbell et al., 2002a–e; Paulen et al., 2003, 2004a, b, 2005a, b, 2006a–c, 2007; Fenton et al., 2003a–c; Paulen, 2004a–d; Kowalchuk et al., 2006; Plouffe et al., 2006, 2007; Trommelen et al., 2006; Paulen and Plouffe, 2007a, b; Plouffe and Paulen, 2007).

The second type involves the assessment of aggregate resources (Edwards et al., 2003a–g, 2004a–s, 2007a–c; Budney et al., 2004a–d; Edwards and Budney, 2004a–e, 2007a–d). The GIS files for these various maps were queried to select the coarse-grained materials (if saturated, these might constitute unconfined surface aquifers) and display them as zones of hydrogeological interest. The compilation map in Figure 7 shows the distribution of these materials.

3.1.1 Limitations on the Use of the Map

Some constraints on the use of this map are that

- it should not be used to infer information regarding thickness of coarse-grained materials;
- the source maps used in its compilation were at different scales, resulting in varying levels of detail regarding coarse-grained sediment accumulations; and
- the map does not depict any information regarding groundwater associated with these sediments.

3.2 Mapping Hydrogeologically Significant Elements within the Drift

Hydrogeologically significant drift elements refer to those coarse-grained geological materials present below the ground surface but above the bedrock surface. Detailed mapping of these sediments has been completed only in a limited area by AGS (Andriashek, 2003; Parks et al., 2005; Parks, 2006; Andriashek and Atkinson, 2007). Where detailed assessments of drift sediments have not been done, other sources of information can be used to highlight areas where coarse-grained materials may be present. Inferences can be made, based on bedrock topography, of where coarse-grained sediments are likely to occur, since sand and gravel are commonly present on the floors of buried paleo–river valleys. Alberta Geological Survey has completed extensive mapping of bedrock topography and the channels that appear to cut into the

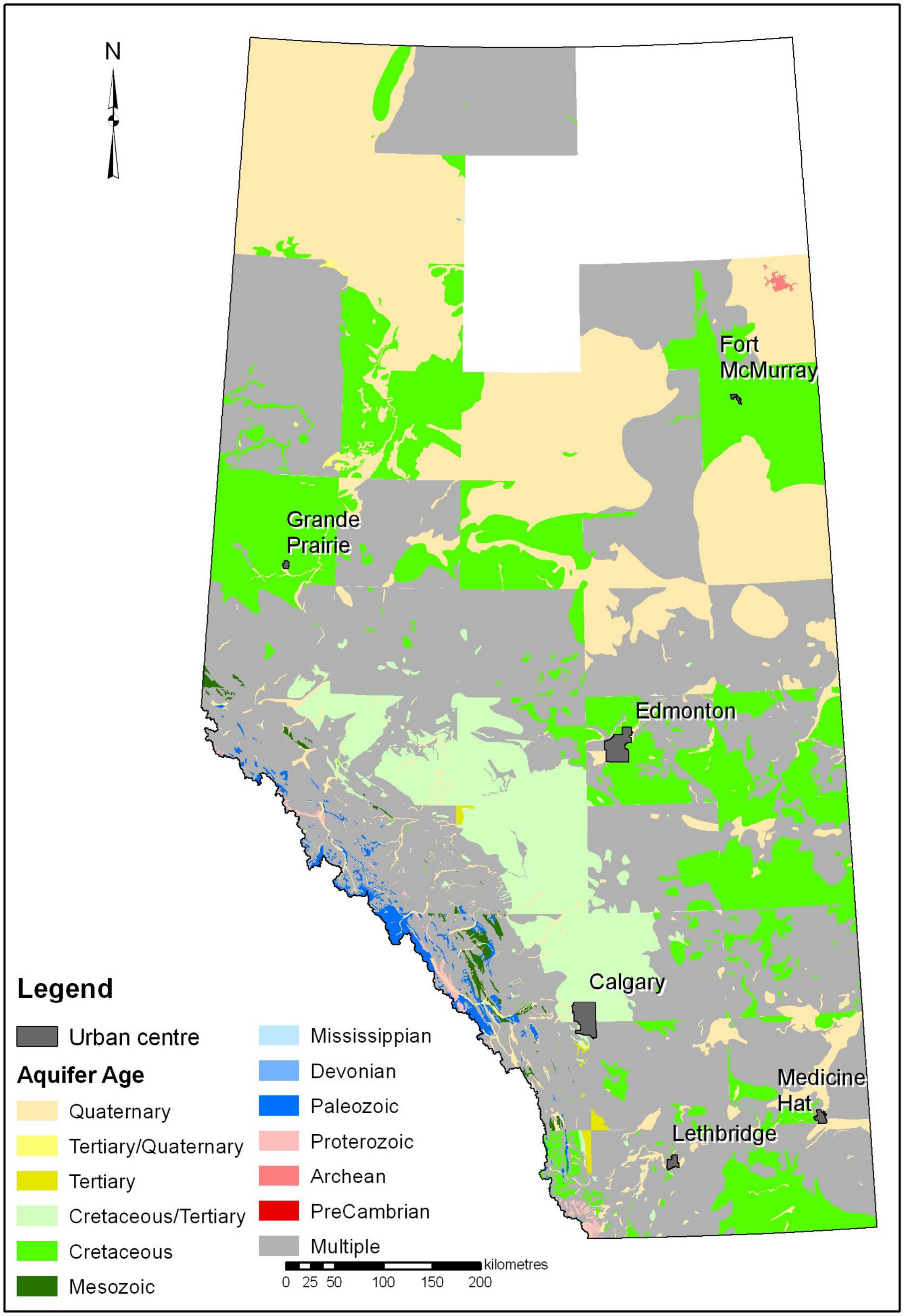


Figure 6. Compilation of aquifer ages.

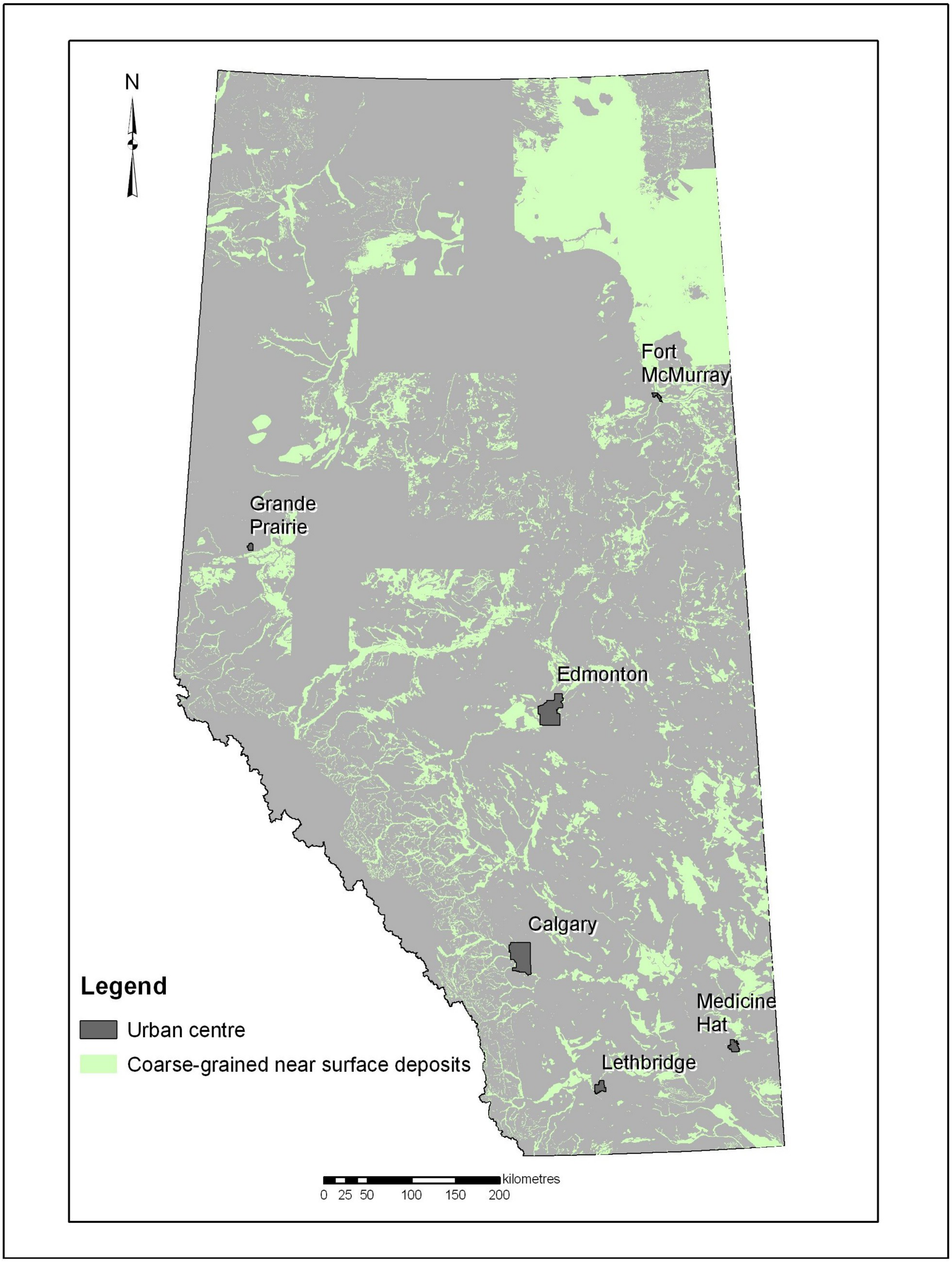


Figure 7. Compilation of coarse-grained materials close to or at the land surface.

bedrock surface (Pawlowicz and Fenton, 1995, 2004, 2005; Andriashek, 2001b; Parks et al., 2005; Pawlowicz et al., 2005; Andriashek and Atkinson, 2007; Pawlowicz et al., 2007). Prairie Farm Rehabilitation Administration has also completed mapping of channel incisions into the bedrock (Prairie Farm Rehabilitation Administration, 2001a–d, 2003, 2004, 2005a, b). The compilation map developed from these sources is presented in Figure 8.

3.2.1 Limitations on the Use of the Map

Mapped accumulations of coarse-grained sediments are commonly based on minimal lithological information supplemented with downhole geophysical-log information. The nature of the geological materials will therefore not always be known, aside from gross characteristics. Inferences about water content should not be made on sediment characteristics alone.

Sediments within buried valleys are not always coarse grained, as fine-grained clay and till can also be found. This can lead to an overestimate of the extent of possible drift aquifers based on the extent and geometry of buried valleys. Conversely, coarse-grained deposits are also found in terraces associated with buried valleys and, except where specifically mapped, information on the extent of other terrace aquifers may be underestimated based on the extent of buried valleys. Therefore, inferences about water content should not be made based solely on the extent of buried valleys.

3.3 Mapping Hydrogeologically Significant Elements in the Bedrock

Although maps of coarse-grained bedrock sediments have been created, few of them currently exist in digital form. Alberta Geological Survey has created digital versions of maps that show the thickness of sand within the Scollard and Paskapoo formations. Geophysical logs were examined to determine the thickness of coarse-grained sediments within the two formations. The nature of the sediments was determined for successive 50 m slices from the base of the Scollard Formation to 700 m above the base of the Scollard Formation. Areas with 30 m or more of cumulative coarse-grained sediments within the individual 50 m slices were identified and compiled into the map shown in Figure 9. This figure shows the distribution of the stacked accumulations of coarse sediments.

3.3.1 Limitations on the Use of the Map

Interpretation of the thickness of coarse-grained material was based solely on geophysical-log interpretation. Log signatures indicate coarse-grained material, but aquifer potential of the sediment packages is difficult to confirm. The presence of 30 m or more of coarse-grained sediments within a 50 m slice does not necessarily imply that there is a 30 m thick, continuous, coarse-grained sediment package within the 50 m slice, but more likely multiple, discrete and thinner units. The polygons on the map represent the combined extent of all of the various mapped slices. Overlaps in the extent of thicker coarse-grained sediments between slices should not be taken to mean that coarser grained sediments are in direct connection with one another across slices.

Since the Paskapoo and Scollard formations are not common targets for oil and gas exploration, geophysical logging of these two formations is not common, but oil and gas exploration boreholes do penetrate these formations to target deeper reservoirs of oil and/or gas. Because the Paskapoo Formation and, to a lesser extent, the Scollard Formation are common targets for water-well installations, regulations exist to protect these formations from the potential impacts of drilling of oil and/or gas wells. The measures taken to protect these formations typically include the installation of casing and the use of cement. Geophysical logging of these formations through the casing is less reliable. Some logging is done prior to casing installation, but the limited number of geophysical logs collected in this manner means that the number of candidate wells for determining the extent of coarser grained sediments within Paskapoo

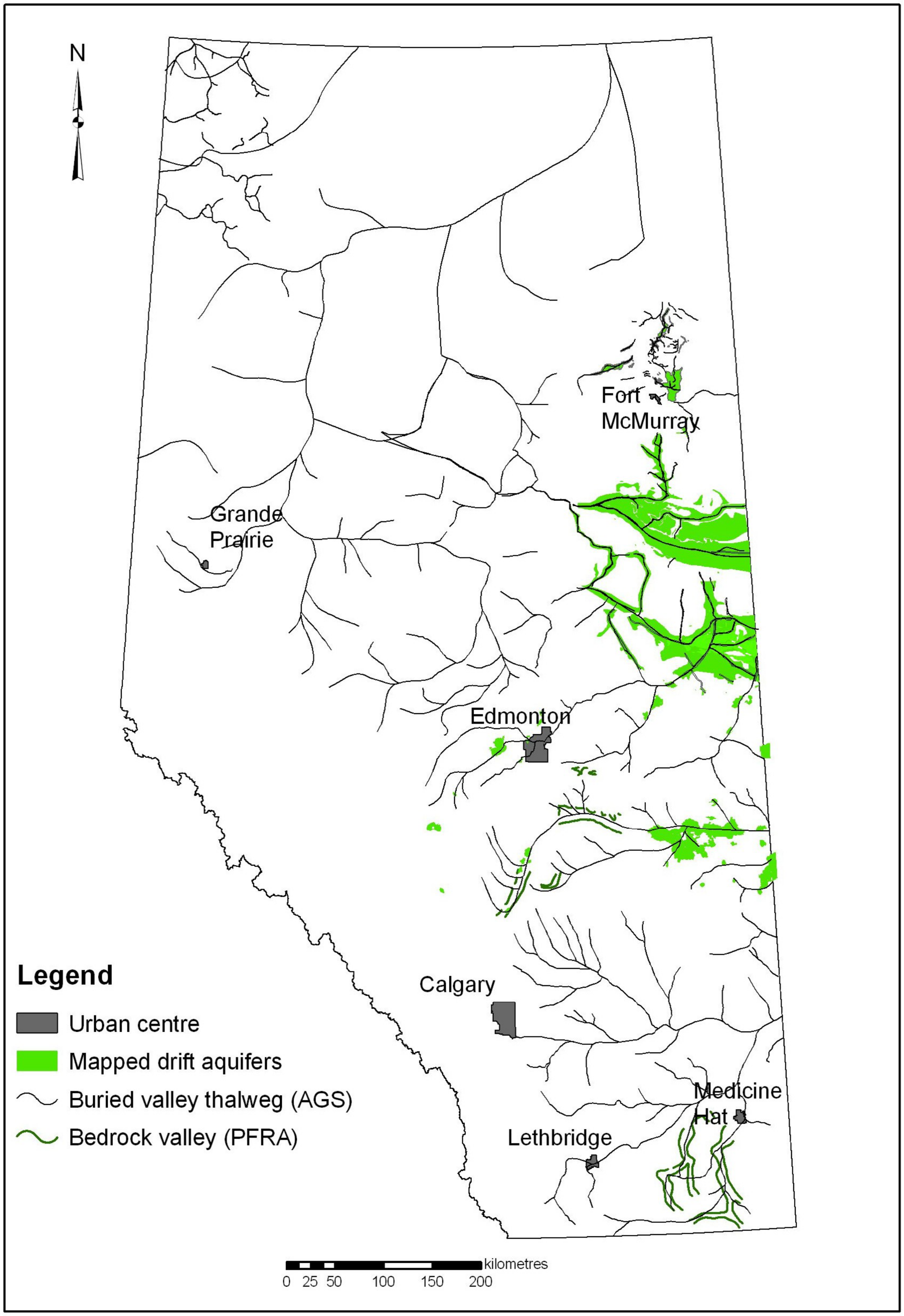


Figure 8. Compilation hydrogeologically significant drift elements.

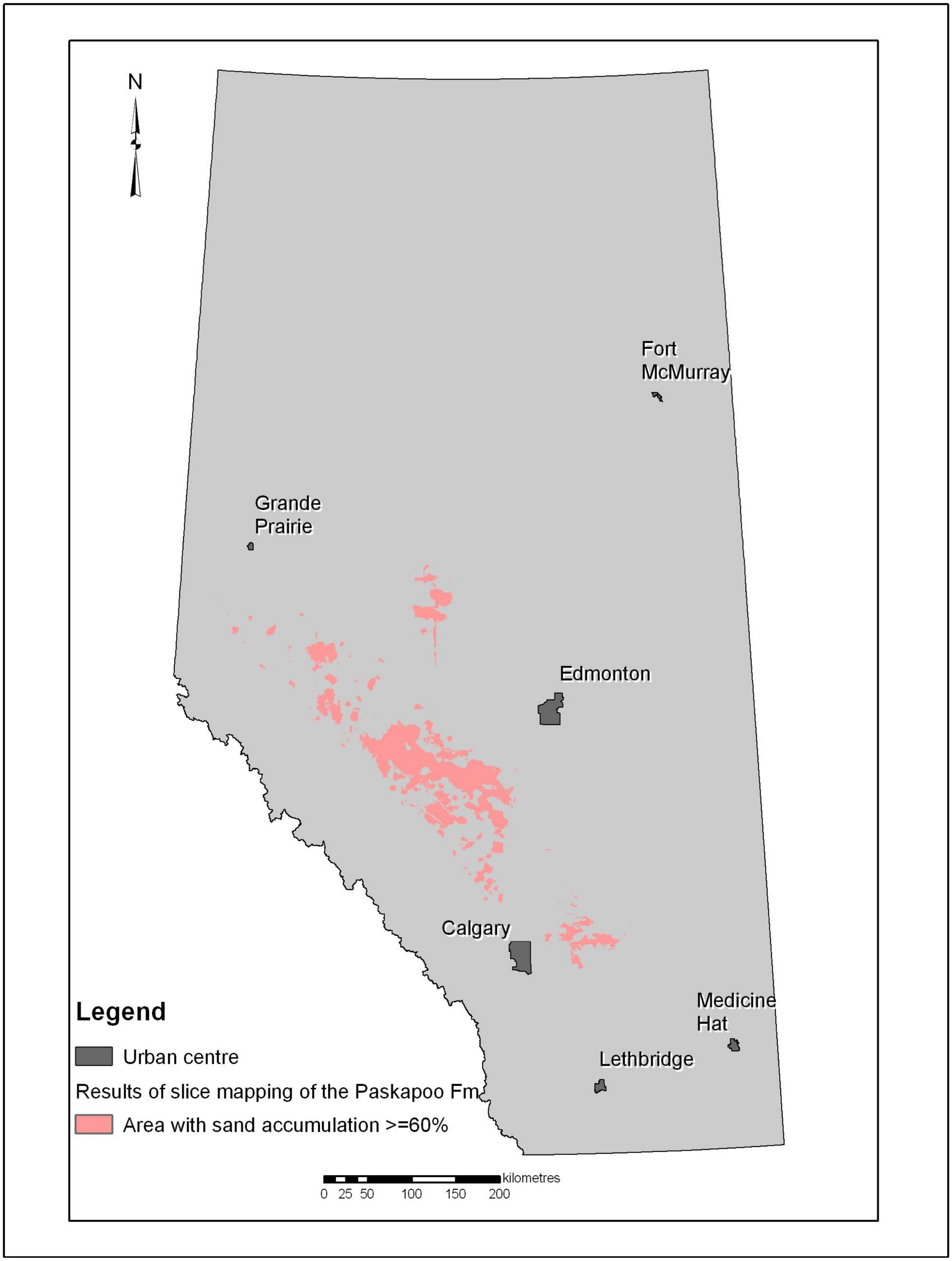


Figure 9. Compilation of hydrogeologically significant bedrock sediments.

and Scollard formations is small. As such, the mapped areas from Figure 9 likely underestimate the extent of aquifers within the Paskapoo and Scollard formations.

4 Preliminary Interpretations of Provincial Groundwater Use

Groundwater use in Alberta has been estimated under a number of scenarios (AMEC, 2007), and summarized for municipal, agricultural, petroleum, commercial, industrial and other uses for each of the thirteen major river basins in the province (Figure 10). The AMEC (2007) estimates of groundwater use by category differ from major basin to major basin, since groundwater use will vary geographically. For instance, certain areas of the province will need more groundwater for agricultural purposes, whereas other areas will have a greater need for municipal use.

With the creation of the maps discussed above comes the opportunity to examine groundwater use at a variety of scales. Specifically, a preliminary assessment of groundwater use can be undertaken with respect to the groundwater-yield polygons and to townships.

4.1 Estimate of Groundwater Use by Yield Polygon

The estimate of groundwater use by yield polygon is a multistep process involving a number of assumptions and generalizations. Any conclusions based on these estimates should therefore be tempered by this knowledge. The steps carried out to determine groundwater use by yield polygon included

1) assigning water wells to major river basins;
2) calculating or estimating water use for each well;
3) assigning water wells to the appropriate yield polygons; and
4) calculating the total number of water wells and groundwater use for each yield polygon.

4.1.1 Assignment of Water Wells to Major River Basins

Alberta Geological Survey's data holdings include GIS files of the major river basins and water-well locations for the province. To exclude water wells that might be abandoned, only wells that are 20 years old or less were selected. Water-well locations were based on the legal land locations of the wells in the AENV water-well database. The location was then used to assign each well to a major river basin polygon. Each major river basin has at least one well located within it. Table 1 shows the distribution of water wells by major river basin. Accuracy of the geographic locations used to assign wells to major river basins depends on the precision of the legal land location. Errors associated with the location of the water wells could mean that certain wells were assigned to the wrong major basin, potentially skewing the results of the calculations described below and summarized in Tables 1 and 2.

4.1.2 Calculation of Groundwater Use by Well

Water wells can have a variety of proposed uses. This information is captured in the database of submissions of water-well data to AENV. Water wells that are 20 years of age or younger fall into the categories shown in Table 2.

The AMEC (2007) report forecasted groundwater use by type of use and major river basin for low, medium and high water-use scenarios in cubic decametres (dam^3). Estimates were provided for the years 2005, 2010, 2020 and 2025. This type of information, combined with the number of water wells, can be used to estimate groundwater use that is site specific or regional in scale. The medium water-use scenario was chosen because it represented a reasonable starting point for examining water-use data. The year 2010 values were chosen because 2010 is closest to the present. An example of the information provided in the AMEC (2007) report is provided in Table 3.

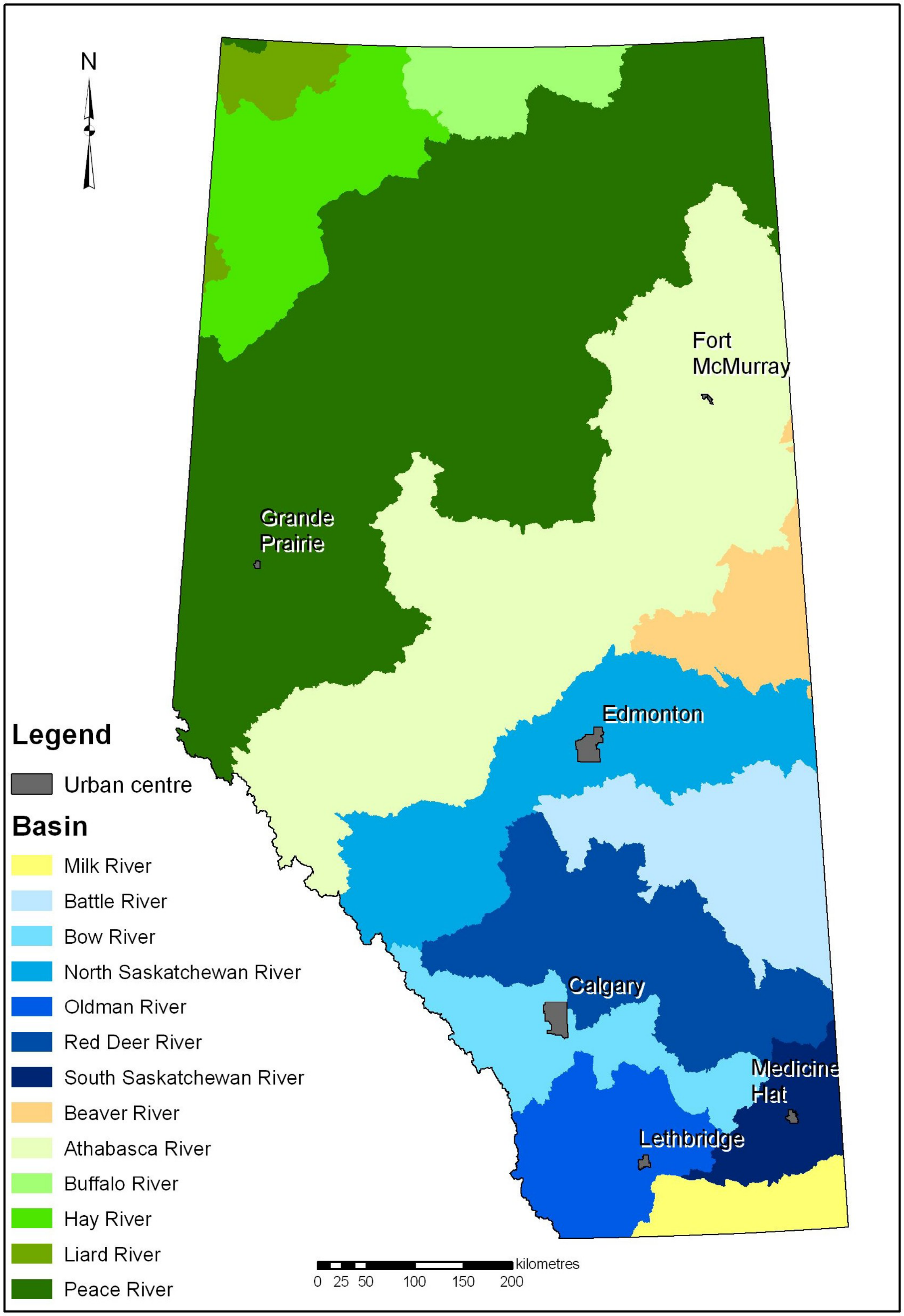


Figure 10. Major river basins of Alberta.

Table 1. Summary of water-well information by major river basin.

Basin ID	Major River Basin	Number of Water Wells (estimated)
1	Athabasca River	11,123
2	Battle River	9,170
3	Beaver River	2,596
4	Bow River	10,906
5	Buffalo River	1
6	Hay River	197
7	Liard River	25
8	Milk River	400
9	North Saskatchewan River	20,011
10	Oldman River	3,650
11	Peace River	4,996
12	Red Deer River	16,531
13	South Saskatchewan River	1,228

A comparison of Tables 2 and 3 shows differences in descriptions of proposed use. To reconcile the two tables, AGS chose to first simplify proposed uses in the AENV database (Table 4).

The Commercial, Petroleum, Industrial and Other types of use in Table 3 do not have an equivalent category in Table 4. In order to standardize these values, these four types of use were assigned to the Industrial category. The use values were then summed to provide a single value of industrial use.

The Agricultural use category in Table 3 is not separated into irrigation and stock water use. However, an estimate of this breakdown was provided in the AMEC (2007) report for each major basin and is summarized for the Athabasca River basin in Table 5.

An estimate of groundwater use for the different agricultural sectors was made using these numbers and the following calculations:

> Stock watering use percentage = (8055 / (8055 + 2094)) × 100% = 79.4%
> Irrigation use percentage = 100% – stock water use percentage = 20.6%
> Estimate of groundwater use for stock watering purposes = 4834 dam^3 × 0.794 = 3838 dam^3
> Estimate of groundwater use for irrigation = 4834 – 3838 = 996 dam^3

The estimated-use value in Table 5 represents combined surface-water and groundwater use. The distinction between stock-watering use and irrigation use for groundwater may therefore not be the same as for the total water use. Alberta Geological Survey recognizes that the use of groundwater for irrigation could be overestimated, causing an underestimate of use for stock watering, or vice versa. In the absence of other information, the ratio was used as shown above.

Table 2. Summary of the number of water wells (20 years old or younger) by proposed use and major river basin.

Proposed Use Category	Number of Wells by Major Basin ID													Total Number of Wells
	1	2	3	4	5	6	7	8	9	10	11	12	13	
Domestic	4,726	5,456	1,453	8,903		25	4	179	12,170	2,310	2,470	9,805	714	48,217
Domestic and Industrial	30	4	2	10		2			34	2	13	23	1	121
Domestic and Irrigation	12	16	21	1					28	3	2	12		95
Domestic and Stock	1,572	1,658	515	749				76	2,792	470	609	2,353	190	10,984
Industrial	3,477	354	107	275	1	166	21	11	1,989	113	1,745	1,823	31	10,113
Industrial and Stock	1	2							1	5	1	4		14
Irrigation	14	37	22	23					38	12	7	15	9	177
Municipal	110	108	31	109		4		10	142	52	73	130	49	818
Municipal and Industrial		1								6				7
Municipal and Observation				3					1	1		5		10
Stock	1,181	1,534	445	833				124	2,816	2,470	165	2,361	234	10,369

Table 3. Forecast of groundwater use in cubic decametres (dam^3) by type of use for the Athabasca River basin under a medium water-use scenario (*from* AMEC, 2007, Table 11-37, p. 478).

Type of Use	2005	2010	2015	2020	2025
Municipal	1,605	1,731	1,860	1,985	2,099
Agricultural	4,554	4,834	5,131	5,446	5,781
Commercial	1,014	1,066	1,125	1,189	1,260
Petroleum	16,933	45,709	54,020	50,169	49,843
Industrial	1,729	1,729	1,729	1,729	1,729
Other	169	169	169	169	169
Total	**26,004**	**55,238**	**64,034**	**60,687**	**60,881**

Table 4. Simplified Alberta Environment (AENV) proposed use categories.

AENV Proposed Use Category	Simplified Proposed Use Category
Domestic	Domestic
Domestic and Industrial	Industrial
Domestic and Irrigation	Irrigation
Domestic and Stock	Stock
Industrial	Industrial
Industrial and Stock	Stock
Irrigation	Irrigation
Municipal	Municipal
Municipal and Industrial	Municipal
Municipal and Observation	Municipal
Stock	Stock

Table 5. Estimated breakdown of water use by agricultural sectors for the Athabasca River Basin (*from* AMEC, 2007, Table 11-35, p. 476).

Sector	Estimated Use (dam^3)	Estimated Percentage of Licensed Use	Estimated Percentage of Total Use
Stock watering	8,055	88	3
Irrigation	2,094	100	1

As shown in Table 3, the AMEC (2007) report did not provide estimates of domestic use. However, estimates of use can be obtained from other sources of information. Environment Canada (2004) indicated that, on average, each Canadian uses 335 L/d. According to Statistics Canada (2006), the average family size for Alberta is three people. This would indicate that each family uses approximately 1000 L/d. If the assumption is made that each domestic well serves one family, then the use of each domestic well can be estimated to be 1000 L/d. Since the estimated domestic-use value was not presented in the AMEC (2007) report, one must be calculated. Multiplying the number of domestic wells present within the basin by the use value can provide this. For the Athabasca River basin, the domestic use of groundwater can be determined using the following calculation:

$$\text{Domestic groundwater use} = 1000 \text{ L/d/domestic well} \times 4726 \text{ domestic wells} = 4\,726\,000 \text{ L/d}$$

The final step in the process was to standardize the units of measure for groundwater use. The yield units for the original ARC hydrogeology maps are imperial gallons per minute (igpm). The use units from the AMEC (2007) report are dam^3 per year (dam^3/a). The domestic water-use values from Environment Canada (2005) are L/d. Alberta Geological Survey chose to standardize the units to those used in the original ARC maps, but converted them to imperial gallons per year (igpa). The following conversion factors were used to standardize units:

1 igpm = 525,600 igpa
1 L/d = 80.3 igpa
1 dam^3/a = 219,969 igpa

Using the total number of water wells, the simplifications in the proposed use categories, the conversion factors and the calculated domestic groundwater use, Table 3 has been modified as an example of the sorts of values calculated for groundwater use within a major river basin (Table 6).

Table 6. Modified forecast of groundwater use in dam³ and igpa by type of use for the Athabasca River basin under a medium water-use scenario for 2010.

Water Source	Type of Use	Original 2010 Estimate (dam³)	Converted 2010 Estimate (igpa)	Number of Wells	Use per Water Well (igpa)
Groundwater	Domestic	1,734	381,340,940	4,726	80,690
	Stock	3,838	844,241,022	2,754	306,551
	Irrigation	996	219,089,124	26	8,426,505
	Municipal	1,731	380,766,339	110	3,461,512
	Industrial	48,673	10,706,551,140	3,507	3,052,909
	Total	56,972	12,532,073,870	11,123	1,126,681

4.1.3 Assignment of Water Wells to Yield Polygons

Using a process similar to that described in Section 4.1.1, the water wells were assigned to the appropriate yield polygons, along with the estimates of water use per well. Depending on the accuracy of the water-well location provided in the AENV database, the locations will be more or less accurately located within a given yield polygon. Therefore, water wells could be assigned improperly to yield polygons, potentially skewing estimates of groundwater use for that polygon.

4.1.4 Calculation of Groundwater Use by Yield Polygons

After each well was assigned to a yield polygon, the number of wells and the amount of groundwater use were summed for each of the yield polygons. Individual maps were created for the different proposed use categories. Because of the number of assumptions used in calculating the groundwater-use values, we felt that the numbers could be misleading if presented quantitatively. As such, maps of groundwater use are defined qualitatively using categories of least to most use. As a very general estimate, each classification of groundwater use would be ten times greater than the previous classification. These maps are presented in Figures 11–16.

4.2 Estimate of Groundwater Use by Township

The process for determining estimates of groundwater use and the number of wells per township is more straightforward than the one described in Section 4.1. Each well will have an associated description of its legal land location. Once the groundwater-use value has been determined for a well (as described in Sections 4.1.2 and 4.1.4), the groundwater use and number of wells can be calculated by township. Similarly, the number of wells in each proposed use category and the groundwater use for each category can be summarized for each township. As with the estimate of groundwater use by yield polygon, groundwater use is defined qualitatively using categories from least to most use, rather than being defined numerically. The results are presented in Figures 17–22.

4.2.1 Observations and Discussion

Groundwater use by township shows some distinct patterns, geographically as well as by use type. Estimates of groundwater use by township can help guide decision-making on groundwater. This smaller

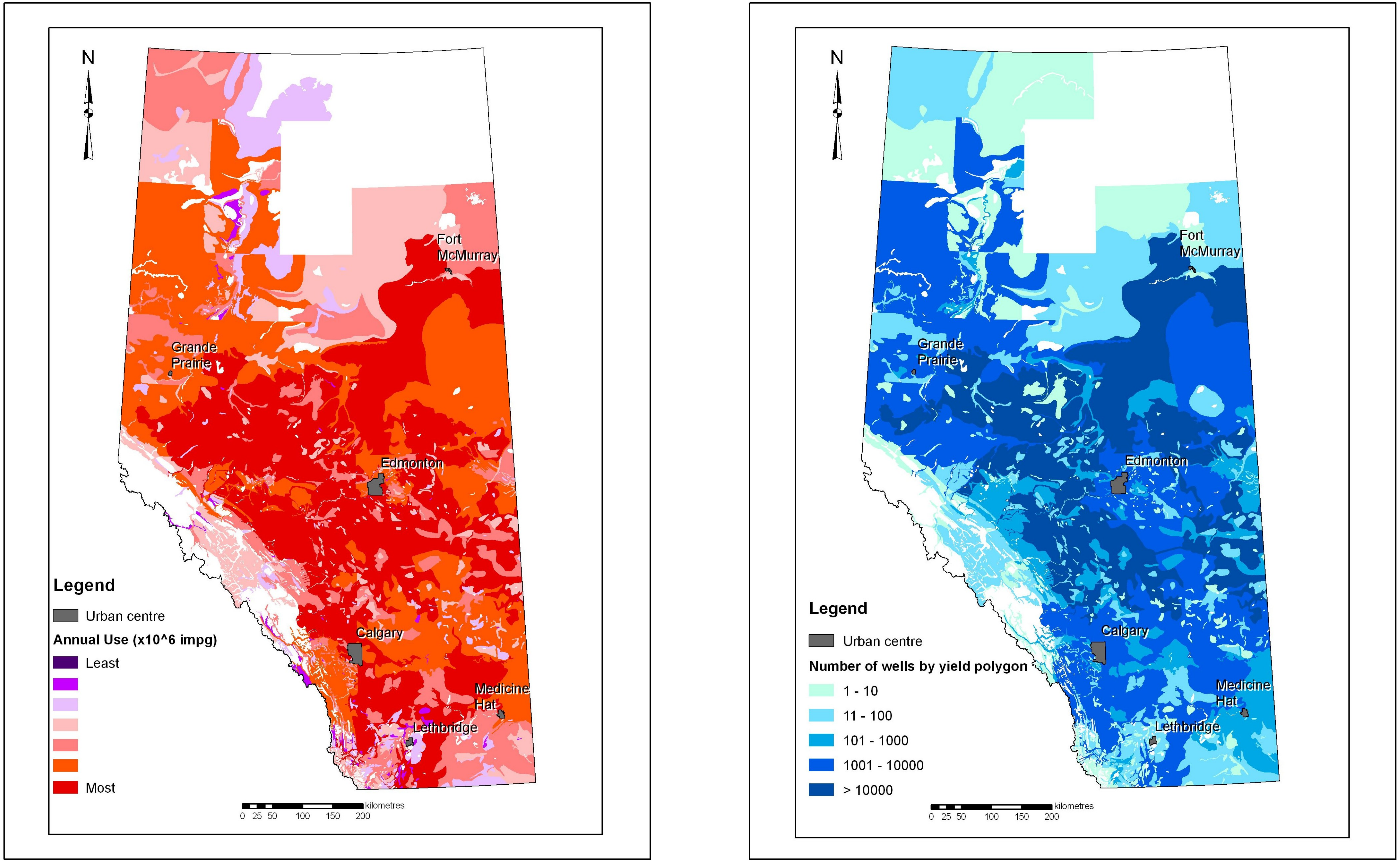
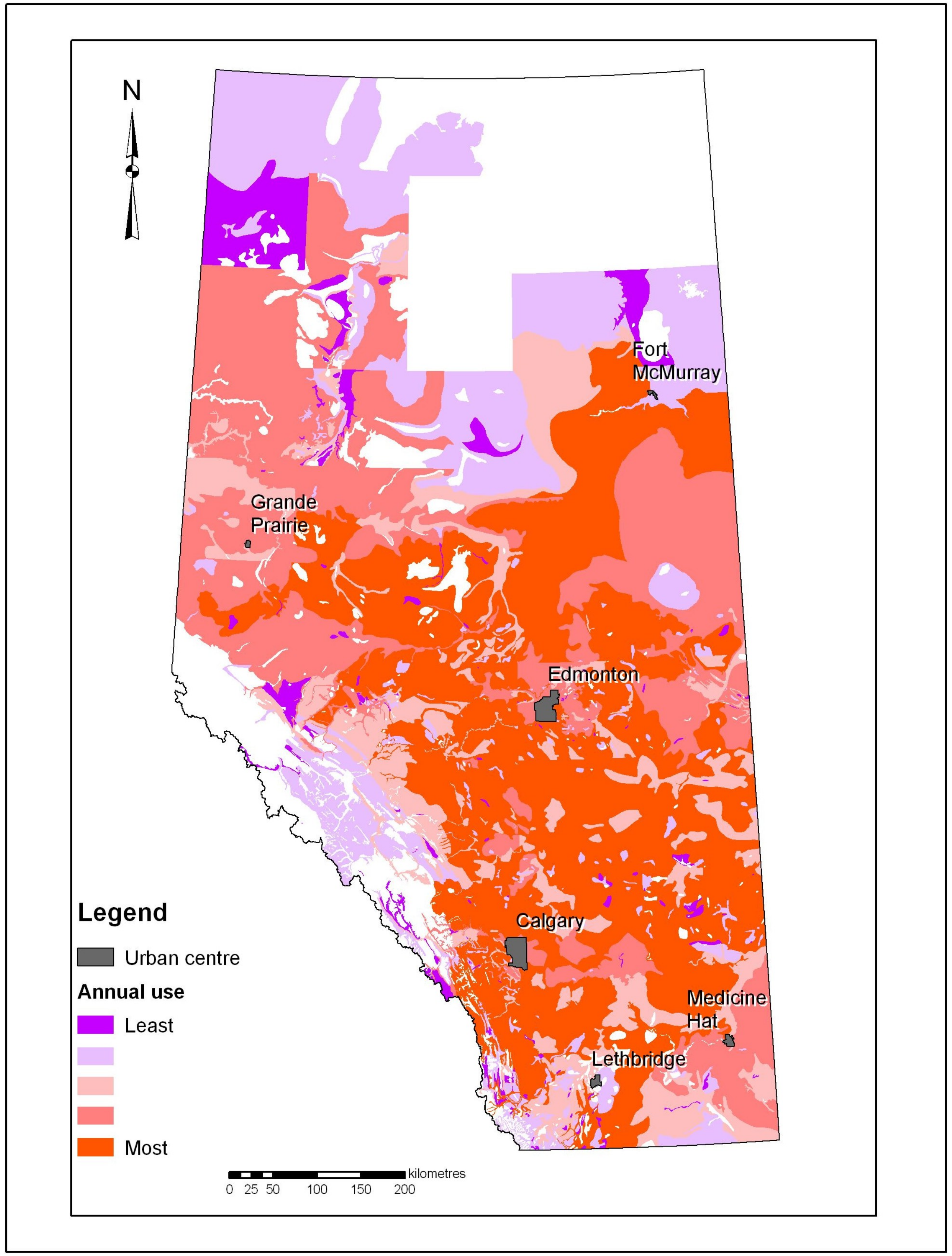


Figure 11. Total groundwater use and number of water wells, by yield polygon.



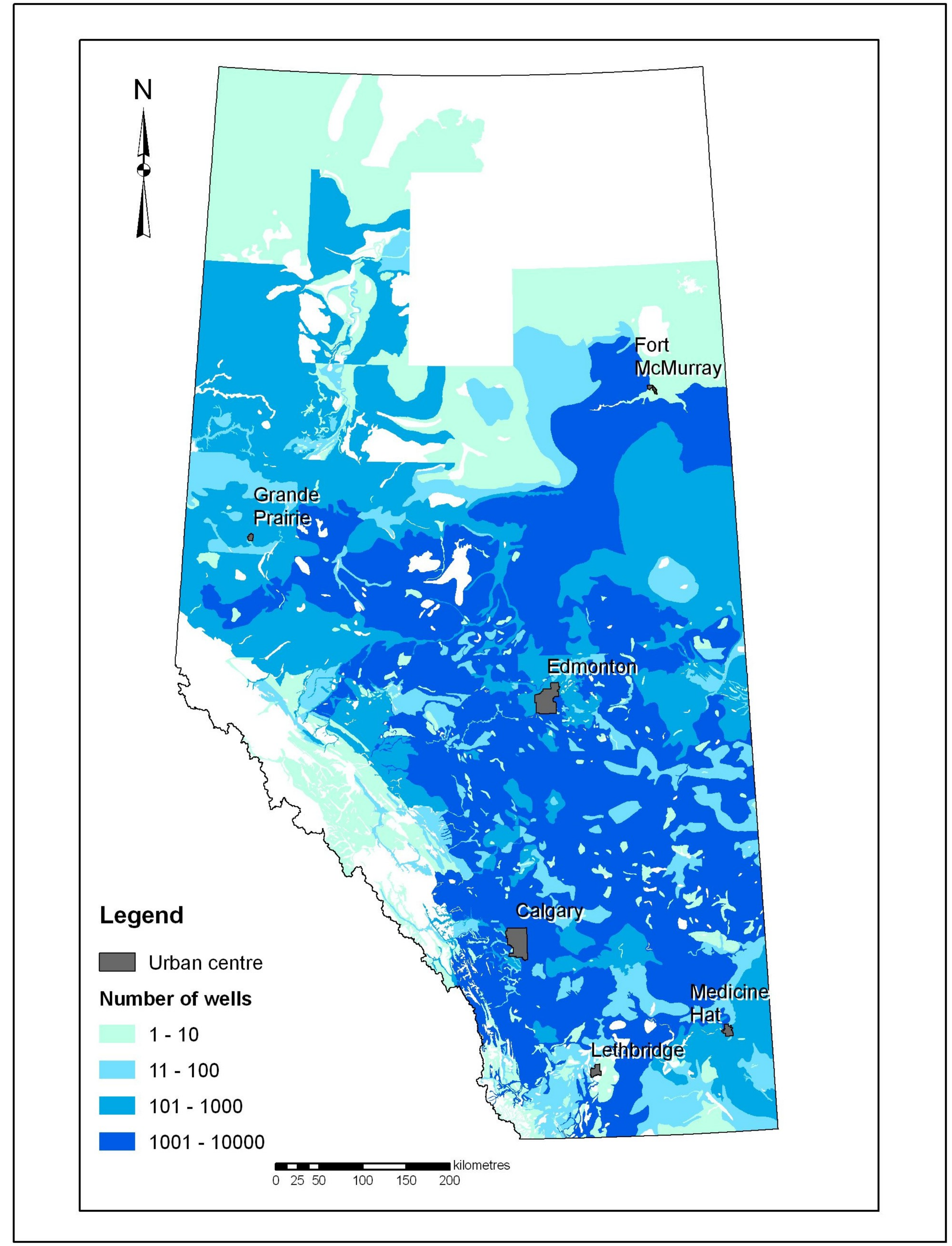


Figure 12. Groundwater use for domestic purposes and number of domestic wells, by yield polygon.

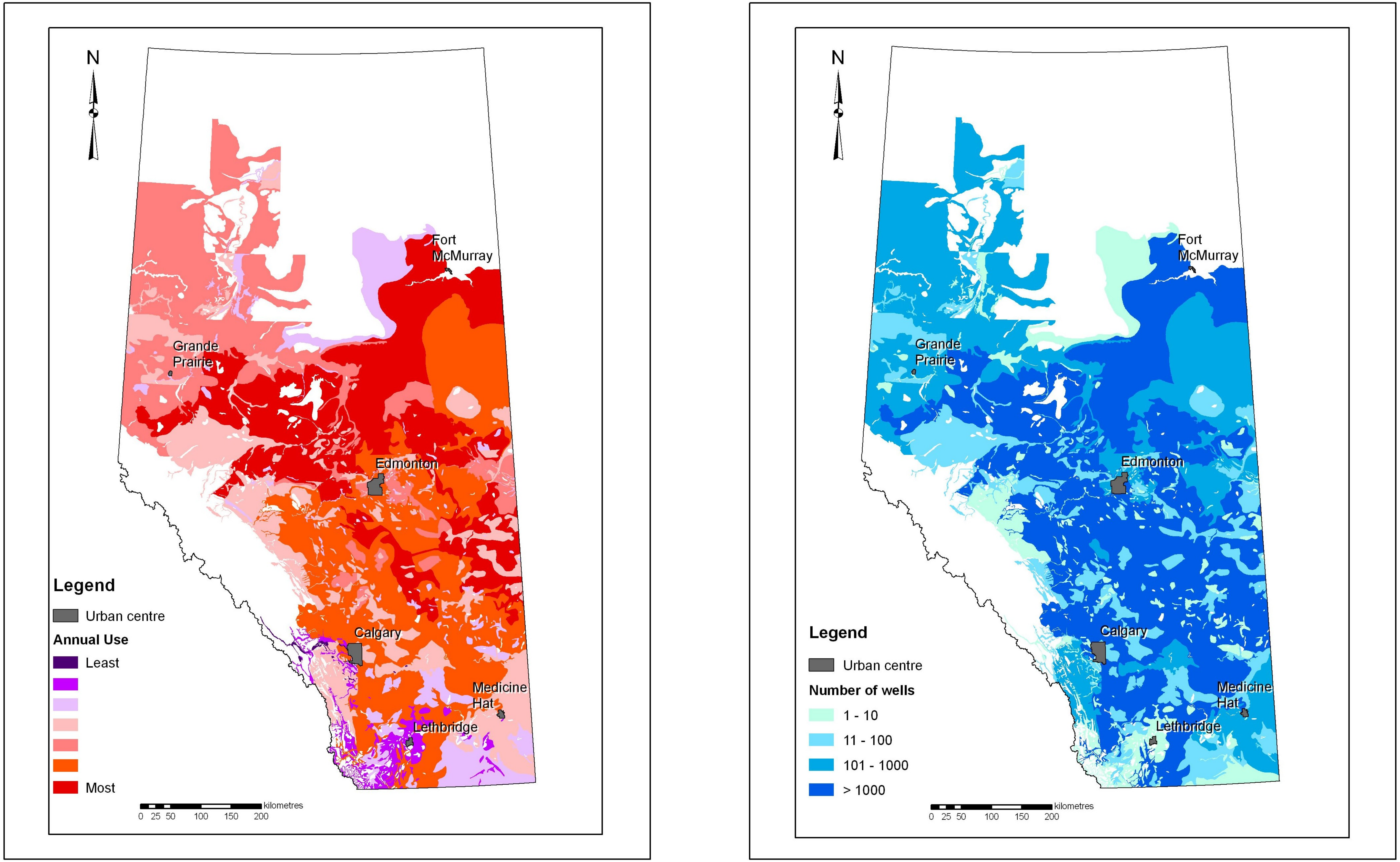


Figure 13. Groundwater use for livestock and number of livestock wells, by yield polygon.

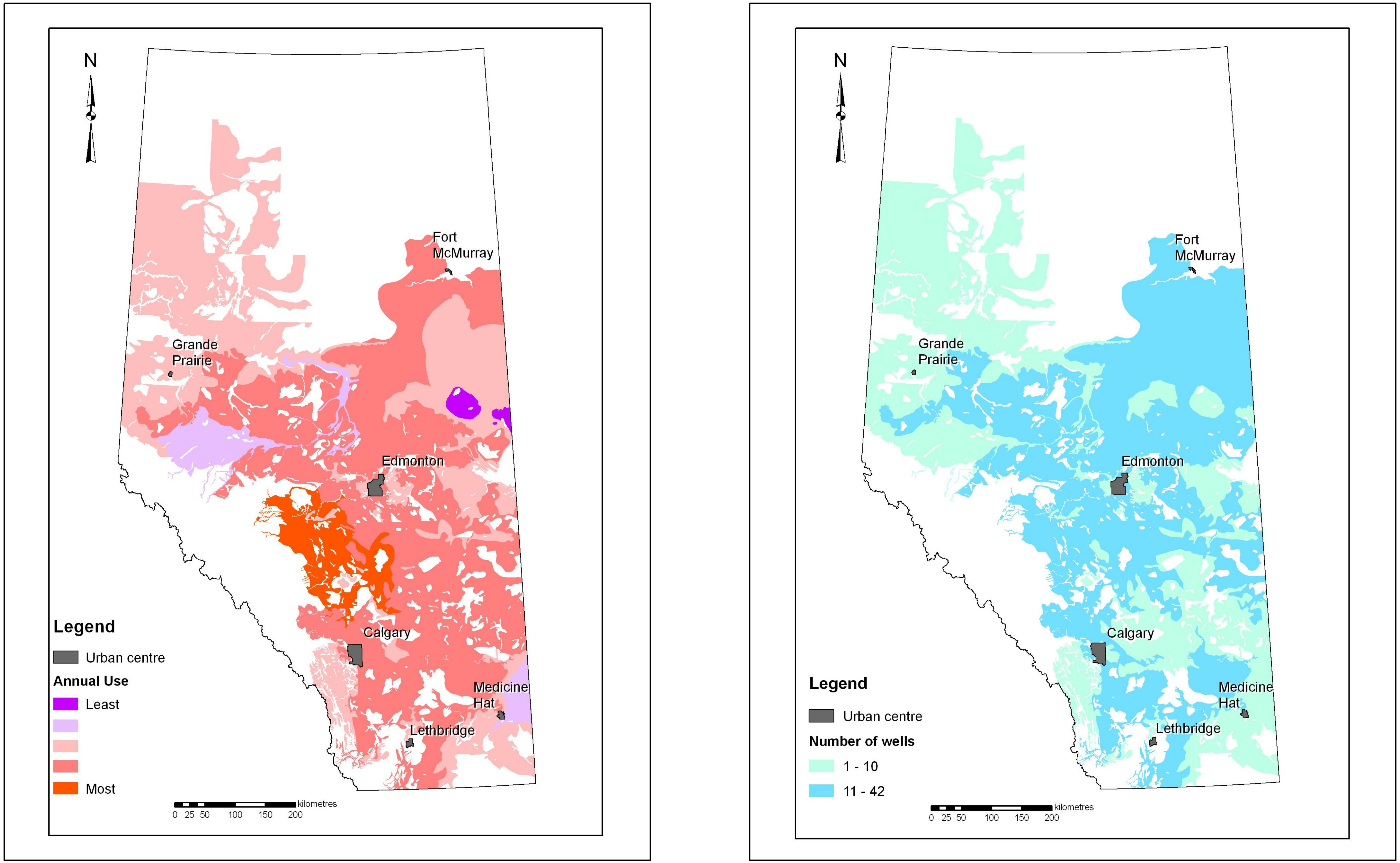


Figure 14. Groundwater use for irrigation and number of irrigation wells, by yield polygon.

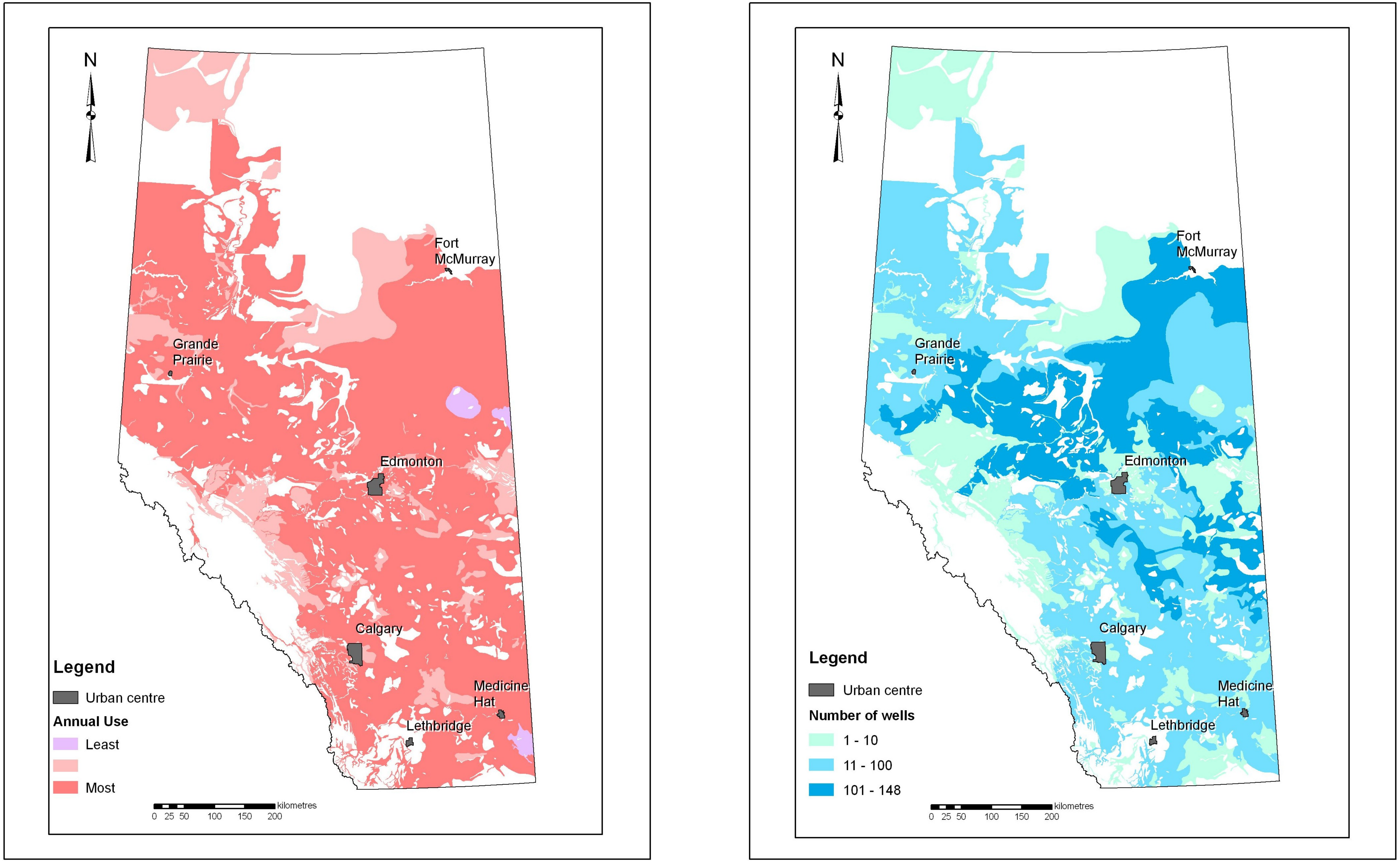


Figure 15. Groundwater use for municipal purposes and number of municipal wells, by yield polygon.

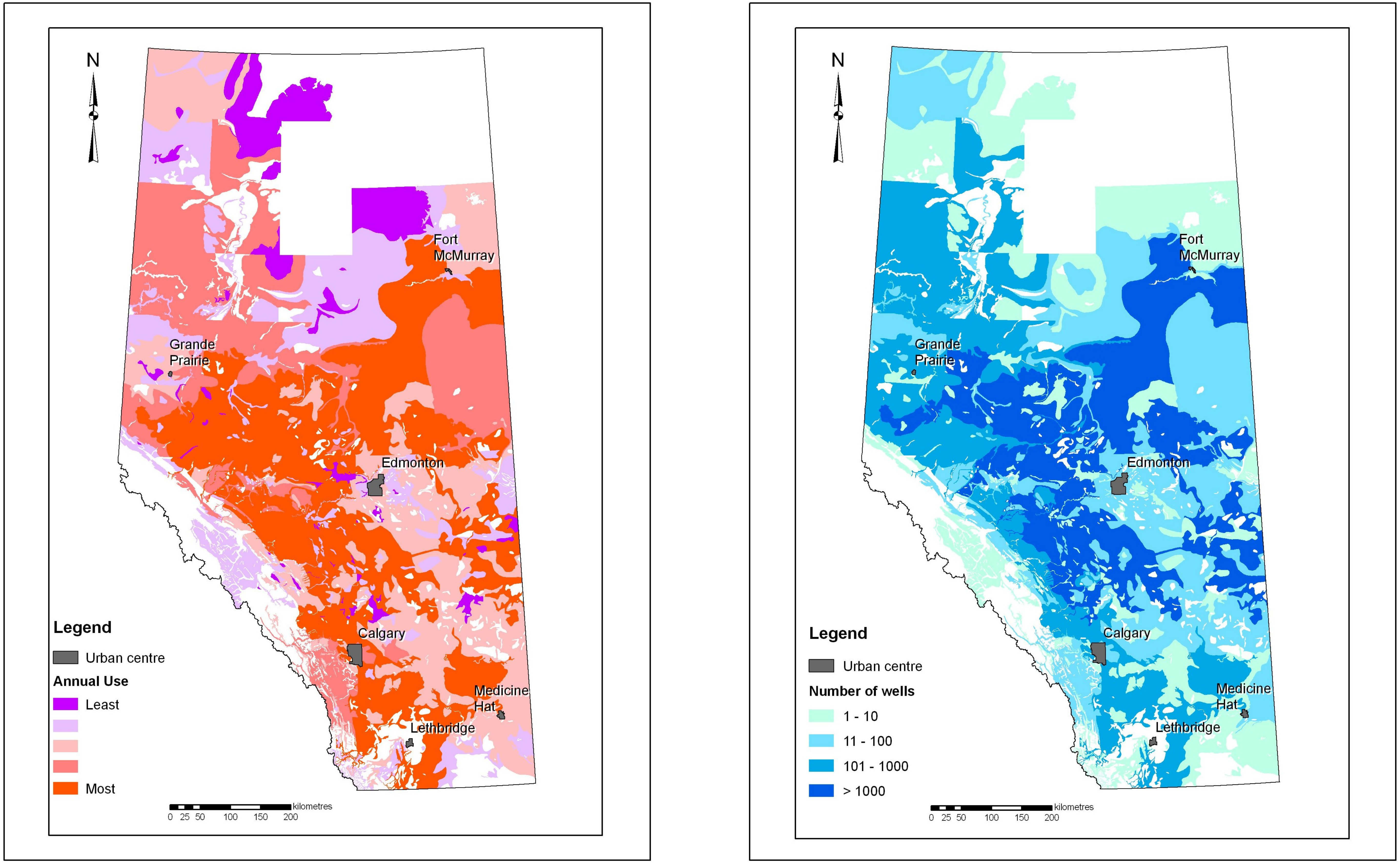


Figure 16. Groundwater use for industrial purposes and number of industrial wells, by yield polygon.

scale assessment may be more applicable to more localized decision-making, and therefore might involve different levels of co-ordination and co-operation between parties. This method of examining groundwater use might also result in creative and innovative strategies to address and examine groundwater-use issues as the parties work through them.

5 Conclusions

The compilation in digital form of previous hydrogeological maps, as well as the assembly of already-available digital geological datasets, provides an opportunity to assess a number of hydrogeologically significant features and characteristics of the province. The compiled hydrogeological maps are the first regional overview of the groundwater potential of Alberta. The compilation of geological materials of hydrogeological significance at the Earth's surface and in the subsurface generates a regional picture of geological units to be further evaluated in terms of groundwater flow supply and groundwater protection. The examination of estimates of groundwater use, compared to the expected yield of geological materials, shows that there could be areas where groundwater use exceeds the capacity of the units, which will have an impact on other elements of the hydrological cycle, such as lakes, rivers or wetlands. The examination of groundwater use in relation to geographic locations shows that its use for various activities is heavier in certain areas of the province than others. These areas of concentrated use can help establish priority areas for closer examination of issues related to specific types of uses.

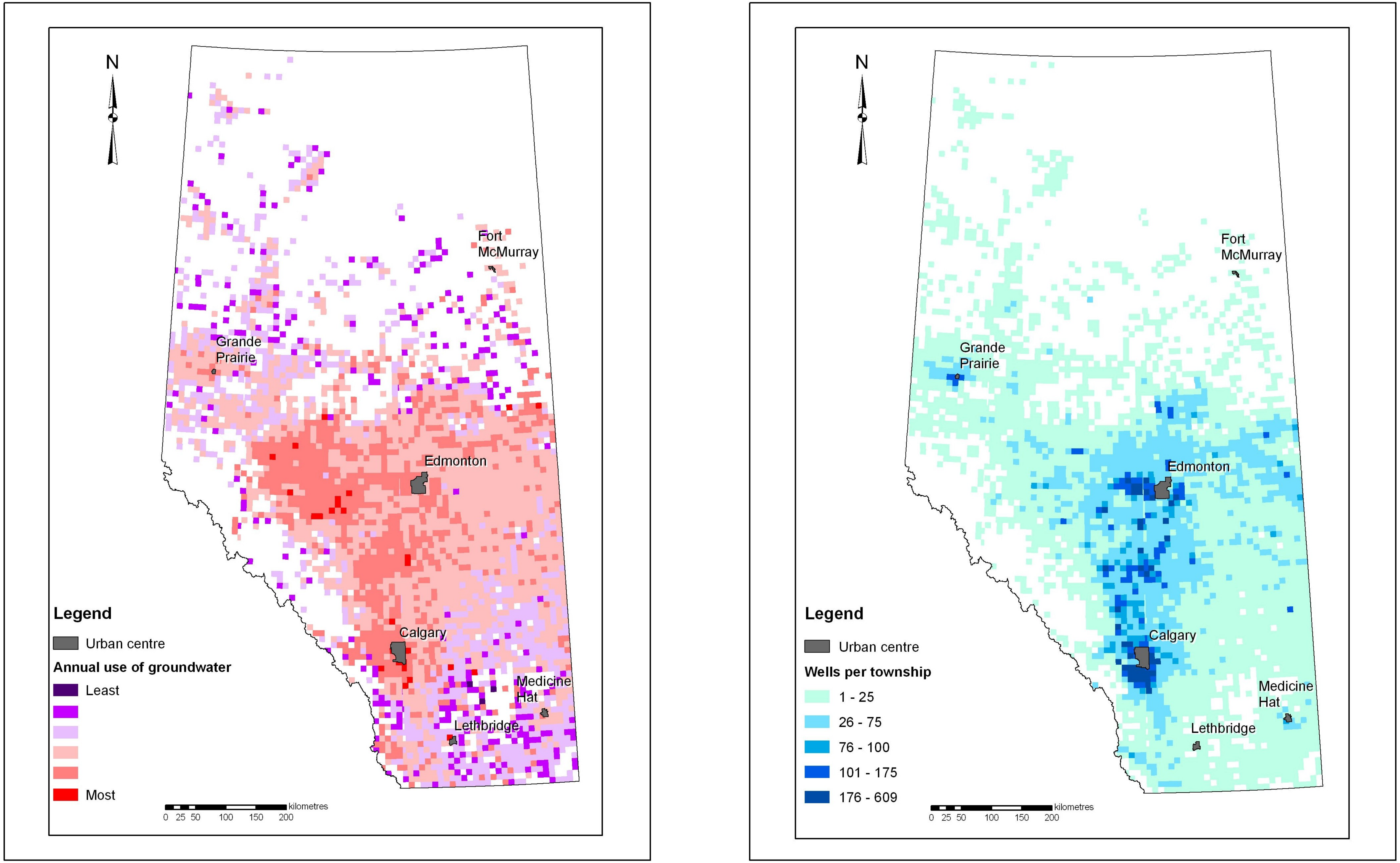


Figure 17. All groundwater use and number of water wells, by township.

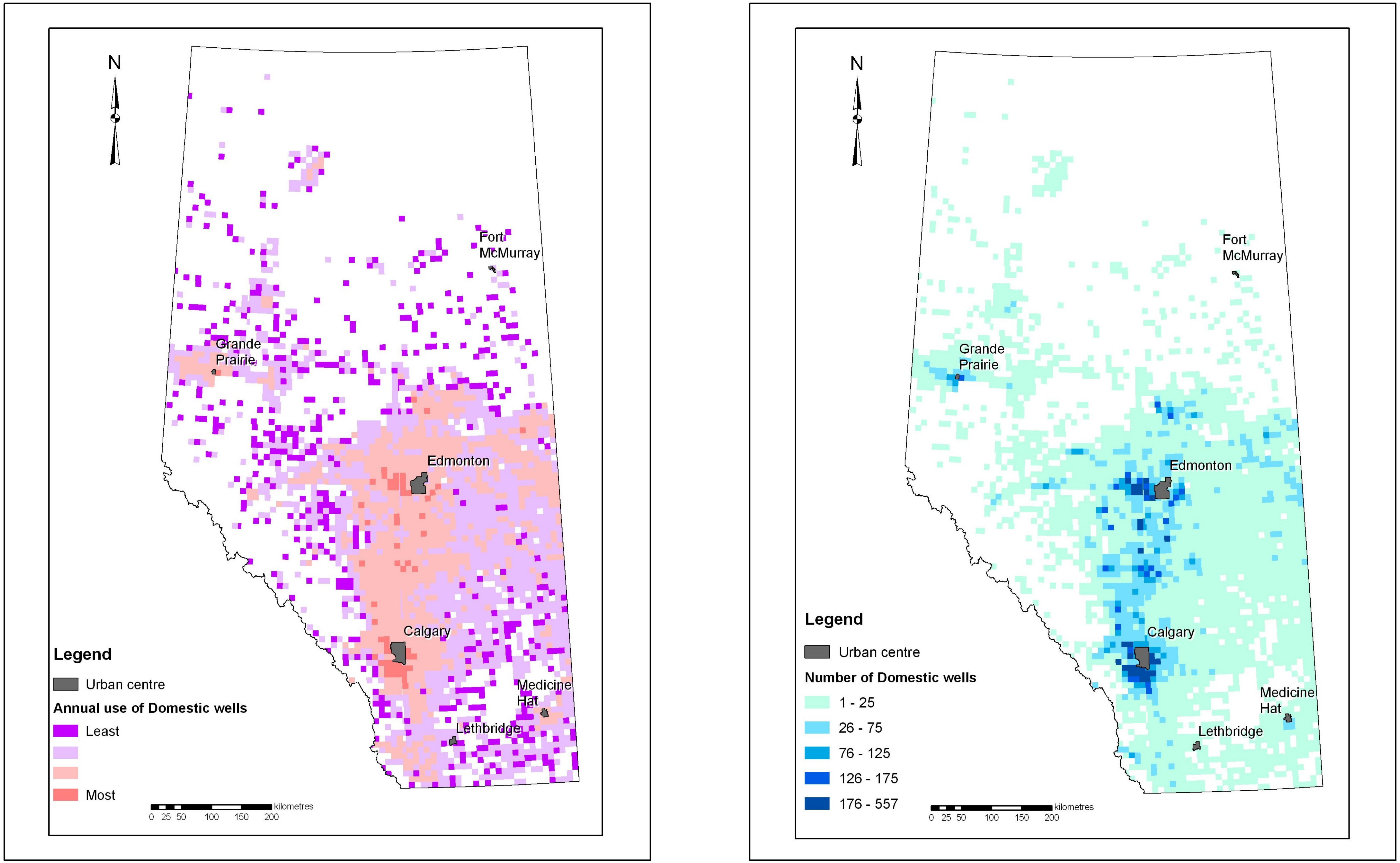


Figure 18. Groundwater use by domestic wells and number of domestic wells, by township.

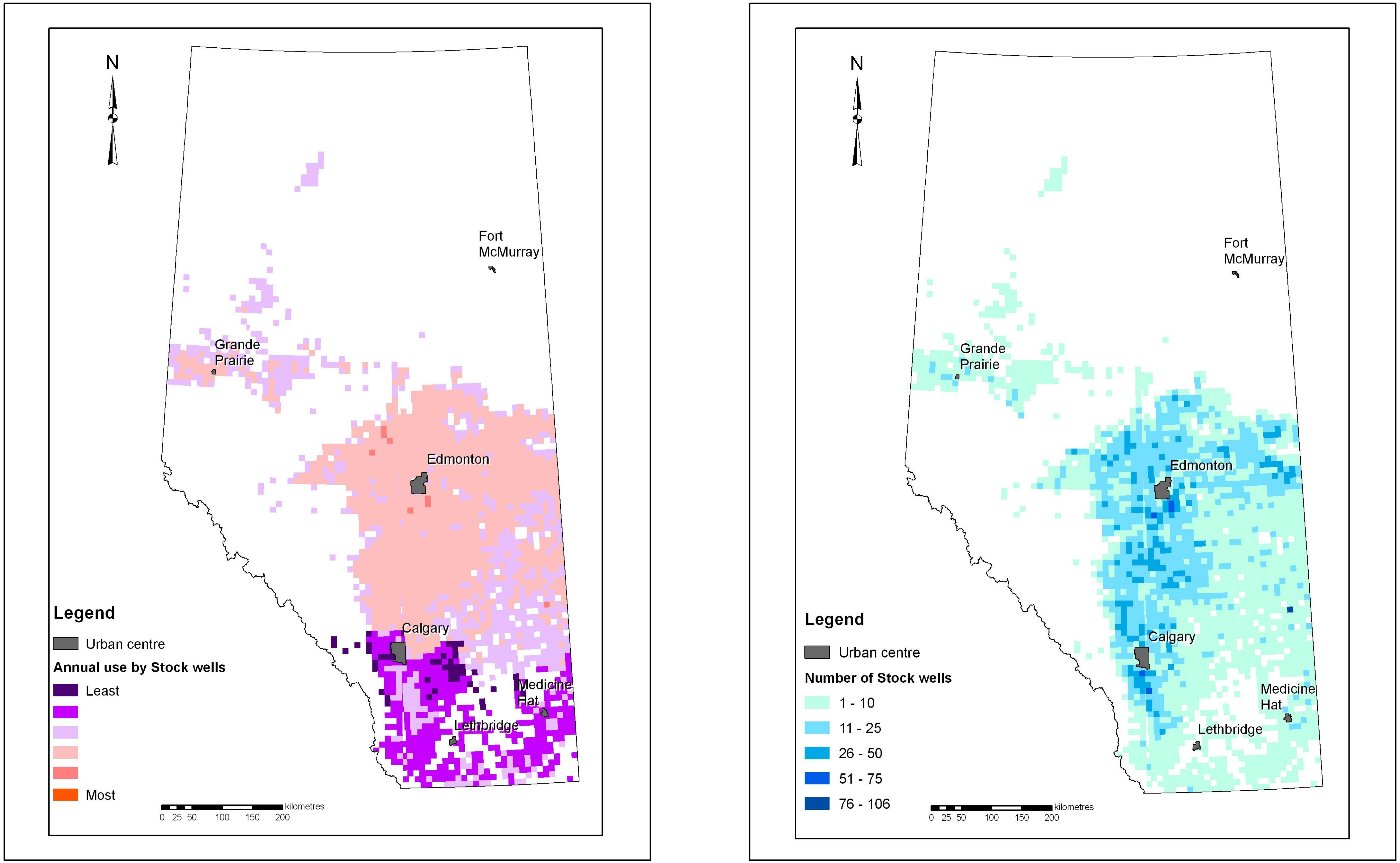


Figure 19. Groundwater use by stock wells and number of stock wells, by township.

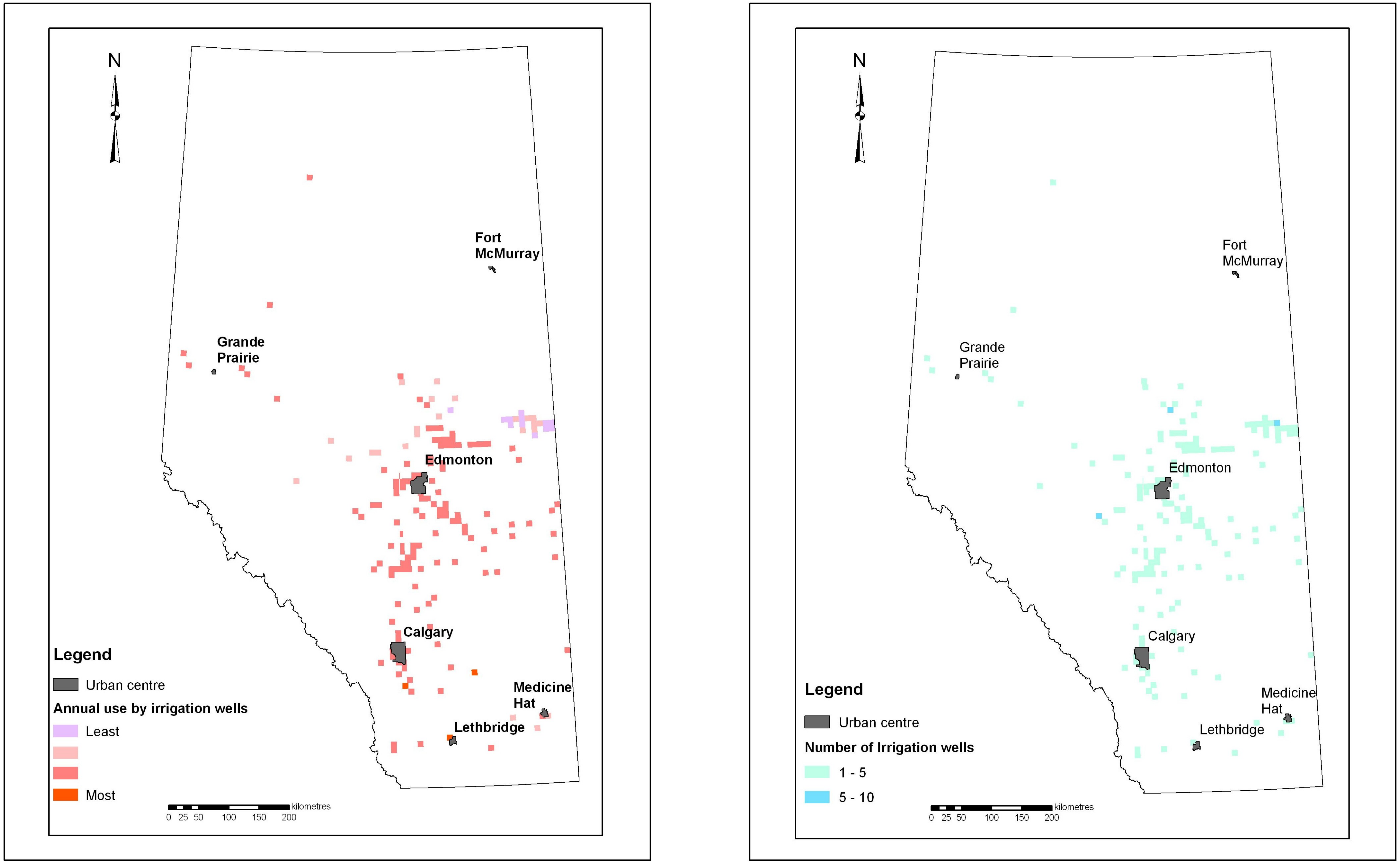


Figure 20. Groundwater use by irrigation wells and number of irrigation wells, by township.

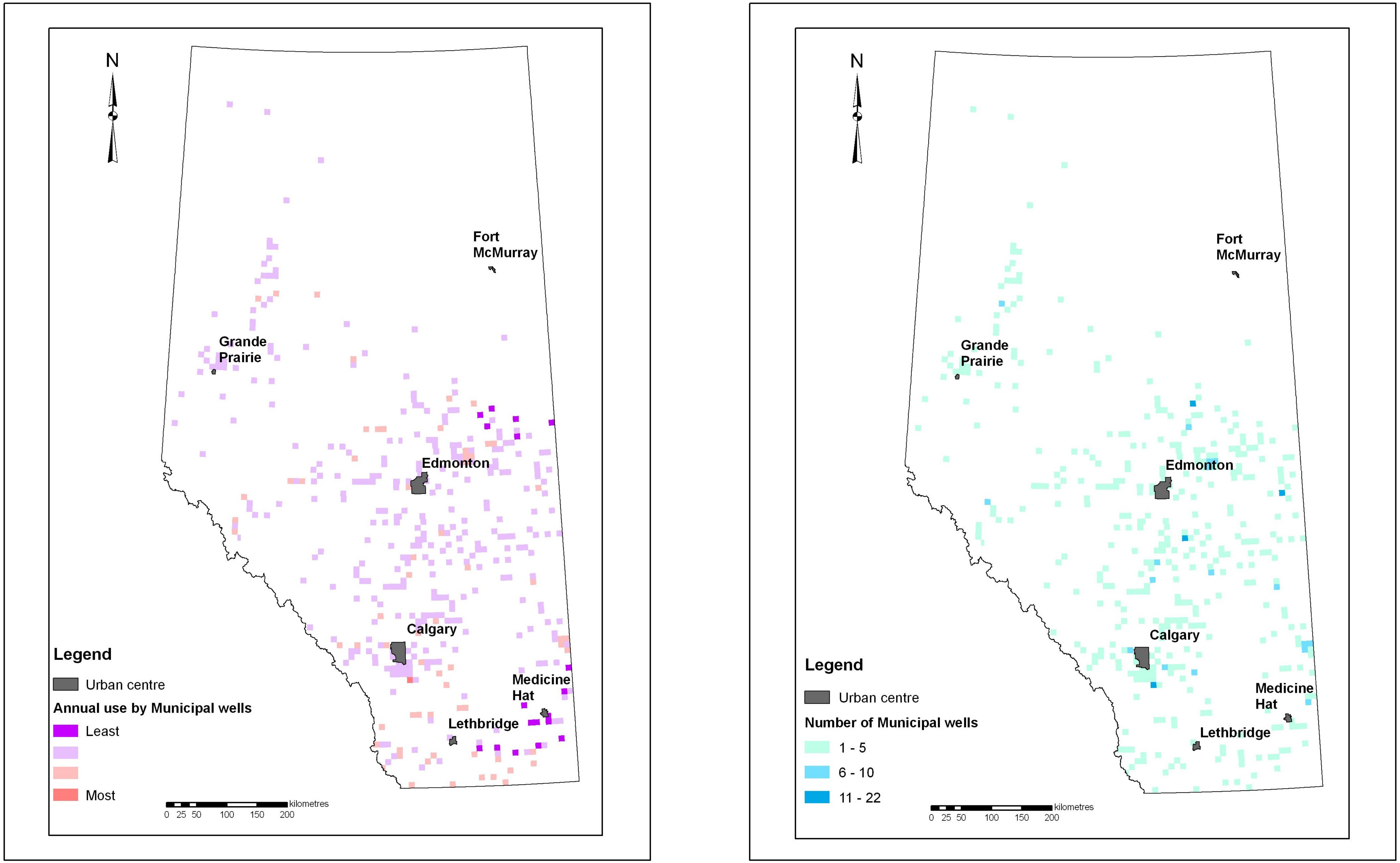


Figure 21. Groundwater use by municipal wells and number of municipal wells, by township.

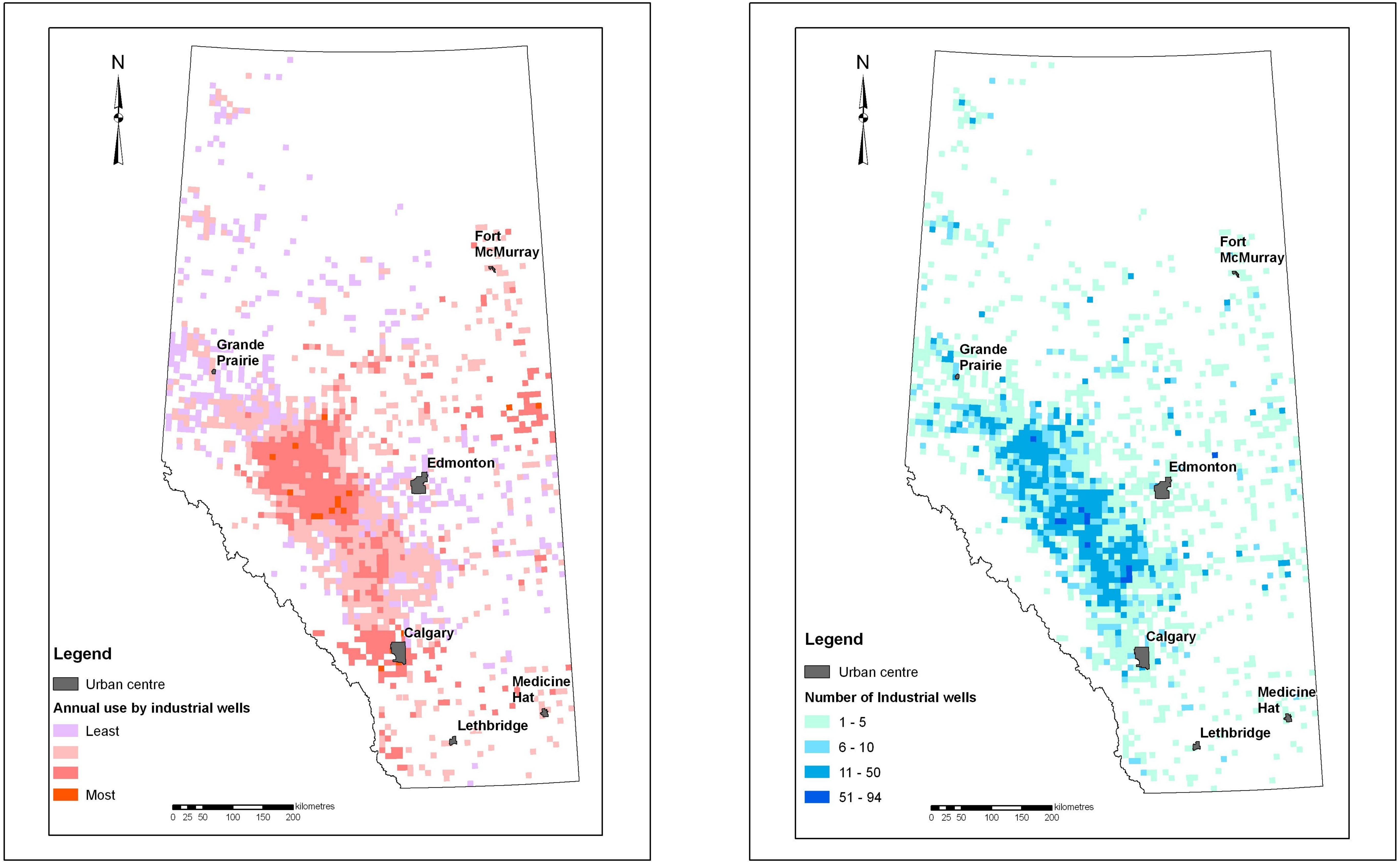


Figure 22. Groundwater use by industrial wells and number of industrial wells, by township.

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Appendix 1 – Georeferencing and Digitization Processes

Steps Involved in the Georeferencing Process

1) Alberta Geological Survey has scanned all of the hydrogeology map series maps as TIFF images. Locate the desired TIFF image in the information store.
2) Crop the image to the extents of the map and resave as a TIFF image.
3) In ArcMap®, load the shapefiles to be used for georeferencing purposes, such as NTS map-area boundary, rivers and lakes.
4) Using the Georeferencing Tool in ArcMap, use the Add Control Points tool to carefully match the feature from the scanned image to the shapefile features.
5) Rectify the map image, keeping the cell size and resample type default values.
6) Save the output image.

Steps Involved in Clipping a Multiband Image

1) Create a folder to store the rectified image during the clipping process.
2) Add three copies of the rectified image to the project.
3) Specify the properties of each image layer so that: for one, the only channel selected is Red; for the second, the only channel selected is Green; and, for the third, the only channel selected is Blue. Rename the layers so they will be distinct. Save each image to the folder created for the process.
4) Enable the ArcInfo® licence and ensure that the Spatial Analyst Extension is active.
5) Add the NTS map sheet for the area being worked on.
6) In ArcToolbox®, under the Spatial Analyst Tools, expand the Extraction tools and select 'Extract by Mask.'
7) Select the Red channel input image as the Input raster input, with the NTS map sheet as the Input mask, and save the output image to the same directory as the input image. Repeat these steps for the other bands.
8) From the Spatial Analyst toolbar, select 'Raster Calculator.' Enter the following command and evaluate it:

```
MAKESTACK imagename LIST [Band1] [Band 2] [Band 3]
Imagename = the output file name
Band 1 = red channel image name
Band 2 = green channel image name
Band 3 = blue channel image name
```

Steps Involved in Creating Polygons for the Hydrogeology Map Features

1) Load the georeferenced image for the area in question.
2) Add the NTS map sheet boundary for the same area.
3) Convert the NTS map area polygon into polylines using a tool such as XTools Pro, and specify the output file name.
4) Using the editor tool in ArcMap, begin drawing polylines with the sketch tool in the polyline file created above. Use care to join lines properly.

5) Once all of the lines have been digitized, go to ArcToolbox, expand the Data Management Tools item, select ‘Features’ and then ‘Feature to Polygon.’
6) Select the created polylines as the input feature. Specify an output polygon.
7) Set the cluster tolerance based on your assessment of how large the gaps are between the polyline start and end points. For instance, if the gaps are anticipated to be less than 50 m, then a cluster tolerance of 50 m should properly join the elements. Be aware that setting the cluster tolerance to a large value can result in modification of the final polygon shape.
8) Open ArcCatalog® and load the created shapefile into a personal geodatabase.
9) To eliminate errors, create topologies by right-clicking on the geodatabase item and choosing ‘New and Topology,’ entering a name and leaving the cluster tolerance field at the default value.
10) Select the feature that will be used in the topology determination.
11) Set the topology rules.
12) Validate the topology.
13) To fix any errors, load the constructed topology geodatabase into ArcMap.
14) Using the Editor, start editing the topology feature and then, using the Topology toolbar, choose the ‘Error Inspector’ function to bring up the errors.
15) The errors were corrected according to the ArcGIS® 9.2 Desktop Help section on correcting topology errors.
16) Save changes to the feature.