HCL
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Upper Athabasca Region Groundwater Supply and Allocation Assessment

West–Central Alberta
Upper Athabasca Region

Prepared for
Alberta Environment and Parks

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Groundwater and Surface Water Solutions for a Changing Environment

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The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

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Executive Summary

The present report has been prepared on behalf of Alberta Environment and Parks (AEP) to provide a broad overview of the state of the groundwater resource in the Upper Athabasca Region (UAR). The UAR Administrative Boundary encompasses most of the western half of the Athabasca River Basin, terminating in the west at the border between Alberta and British Columbia; the UAR encompasses eight Counties and Municipal Districts.

The report will delineate the geologic units (geounits) within the UAR and determine the general hydrogeological characteristics of each geounit. The number of groundwater authorizations and the number of water wells that are diverting groundwater from each geounit will also be determined.

The report will quantify the amount of groundwater recharge within each water management unit (WMU) and the UAR as a whole, and will compare the calculated recharge with the amount of groundwater that is allocated to both authorized users and protected domestic and domestic & stock users. The actual volume of groundwater diverted in 2017 within the UAR as a whole and within each WMU will also be estimated, and the actual diversion will be compared to the amount of groundwater recharge taking place.

Several trends in groundwater use, groundwater authorizations, and groundwater records have been identified. The drilling of new water wells, including industrial, domestic, and domestic & stock water wells, within the UAR has been declining since 2000. The total volume of authorized groundwater diversions has plateaued since approximately 2014; a decline may be masked because of a large number of licences that do not expire, which contributes to the authorized total but may not have been used in decades. Reported groundwater usage peaked in 2007 and has slowly declined for the last several years, levelling off at approximately 4,000,000 cubic metres of groundwater diversion per year. The majority of the groundwater authorizations within the UAR are for industrial purposes (approximately 50% of the total authorized volume); the remaining authorized volumes are evenly split between agricultural purposes (approximately 25%) and municipal purposes (approximately 25%). Based on the trend of new water wells being drilled, additional licences being issued, and the overall trend of water use being reported, it appears that groundwater demand within the UAR is flat or in decline.

There are four main bedrock geounits that constitute aquifers within the UAR; the surficial deposits are a high-yielding and highly utilized aquifer in much of the UAR. The table below is a summary of the geounits in the UAR and how they relate to the groundwater resource.

Formation or Interval	Number of Records	Average Q_{20} (m^3/day)	Total Authorized Diversion (m^3/year)	Total Protected Diversion (m^3/year)
Surficial	12,541	196	7,757,234	16,791,460
Paskapoo	12,214	209	6,745,360	8,478,658
Scollard	745	79	253,544	1,050,142
Wapiti	15,700	91	6,636,125	24,879,240
Lea Park	1,738	99	19,050	2,452,946

Q_{20} – long-term yield
m^3/day – cubic metres per day
m^3/year – cubic metres per year

The surficial deposits, the Paskapoo Formation, and the Wapiti Interval are the most important aquifers within the UAR. Water wells that are completed in the Paskapoo Formation and the surficial deposits tend to have higher yields than the other aquifer systems.

The amount of groundwater recharge was estimated for each WMU and compared to the allocated volume (protected and authorized), estimated domestic use, and diversion data reported to the Water Use Reporting System.

Region Designation	WMU Designation	Groundwater Recharge (Million m³/year)	Total Allocated (Million m³/year)	Percent Currently Allocated	2017 Diversion (Million m³)	Percentage of Recharge Used in 2017
Mountains	07AA	-	-	-	-	-
	07AB	-	-	-	-	-
	07AC	320	0.2	0.1%	0.07	0.0%
Paskapoo and Scollard	07AD	204	3.8	1.9%	0.30	0.1%
	07AE	329	1.3	0.4%	0.06	0.0%
	07AF	229	5.2	2.3%	0.67	0.3%
	07AG	446	10.6	2.4%	2.19	0.5%
	07BA	382	2.9	0.8%	0.92	0.2%
Paskapoo and Wapiti	07AH	458	2.6	0.6%	0.61	0.1%
	07BB	670	20.0	3.0%	7.62	1.1%
Wapiti and Lea Park – Thick Surficial Deposits	07BC	342	11.9	3.5%	3.32	1.0%
	07BD	264	1.6	0.6%	0.49	0.2%
	07BE	209	7.6	3.6%	2.22	1.1%
Wapiti and Lea Park – Thin Surficial Deposits	07BF	702	1.7	0.2%	0.55	0.1%
	07BG	213	0.2	0.1%	0.01	0.0%
	07BH	151	0.2	0.1%	0.04	0.0%
	07BJ	238	0.5	0.2%	0.12	0.1%
	07BK	636	1.3	0.2%	0.33	0.1%
	07CA	740	7.8	1.1%	3.03	0.4%

The table above shows that the WMUs within the UAR that have the most allocations and diversions as a percentage of recharge are 07BB, 07BC, and 07BE; these WMUs represent the Wapiti Interval and the surficial deposit aquifers.

It is unlikely that the current allocations on a regional scale would represent a negative impact on these aquifer systems or the ecosystem in the UAR; on a local scale, large groundwater diversions could represent a higher percentage of groundwater recharge and could have an impact on these aquifers or the ecosystems in the UAR. However, further study is needed to determine what percentage of groundwater recharge should be allowed for future groundwater diversions.

1. Introduction

1.1. Project Description

The Upper Athabasca Region (UAR) Administrative Boundary encompasses eight Counties and Municipal Districts in the western half of the Athabasca River Basin, terminating in the west at the border between Alberta and British Columbia. Map 1 on the following page shows the UAR Administrative Boundary, the Upper Athabasca River Basin, and the Counties and Municipal Districts within the UAR.

1.2. Purpose

Hydrogeological Consultants Ltd. (HCL) was retained by Alberta Environment and Parks (AEP) to prepare a report that will provide a broad overview of the state of the groundwater resources in the UAR. The present report will delineate the geologic units (geounits) within the UAR and determine the general hydrogeological characteristics of each geounit. The number of groundwater authorizations and the number of water wells that are diverting groundwater from each geounit will also be determined.

The report will quantify the amount of groundwater recharge within each water management unit (WMU) and the UAR as a whole, and will compare the calculated recharge with the amount of groundwater that is allocated to both authorized users and protected domestic users. The actual volume of groundwater diverted in 2017 within the UAR as a whole and within each WMU will also be estimated, and the actual diversion will be compared to the amount of groundwater recharge taking place.

1.3. Scope

HCL has processed the data available from the following sources:

- Water well records within the UAR, including lithological details, construction details, aquifer test data, and water-level data
- *Water Resources Act* and *Water Act* authorizations within the UAR provided by AEP
- Water Use Reporting System (WURS) data provided by AEP
- Stratigraphic information available from the Alberta Geological Survey (AGS) and published reports
- Grid files available from the AGS, including stratigraphic, bedrock, and topographic surfaces
- Runoff data from the federal government
- Evapotranspiration data from the provincial government
- Stream-flow data, including baseflow data from rivers and streams in the UAR
- Topographic data for the UAR
- Existing data for sand and gravel deposits, including buried bedrock valleys

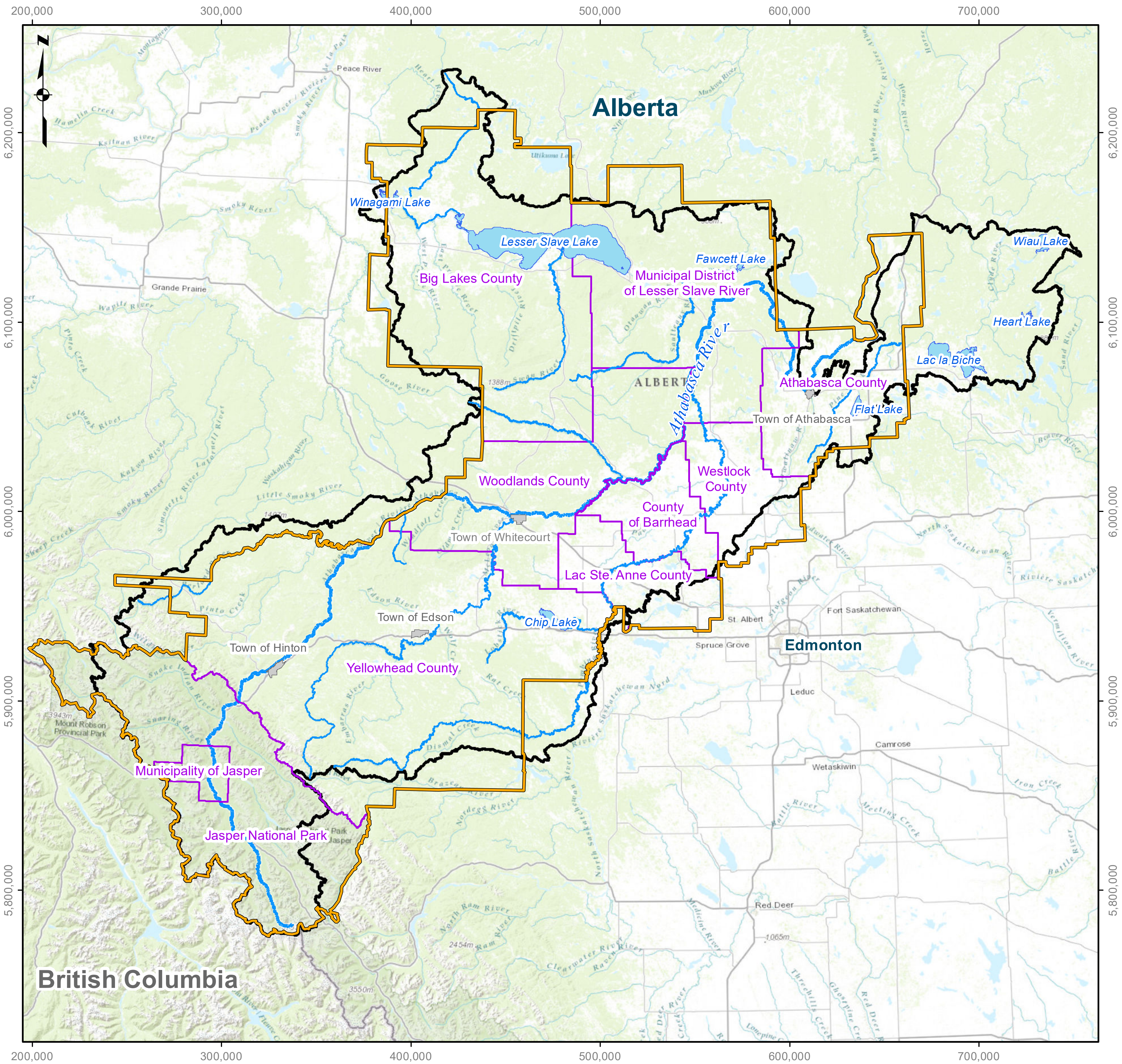
All data used in the present report are current up to July 19, 2018.

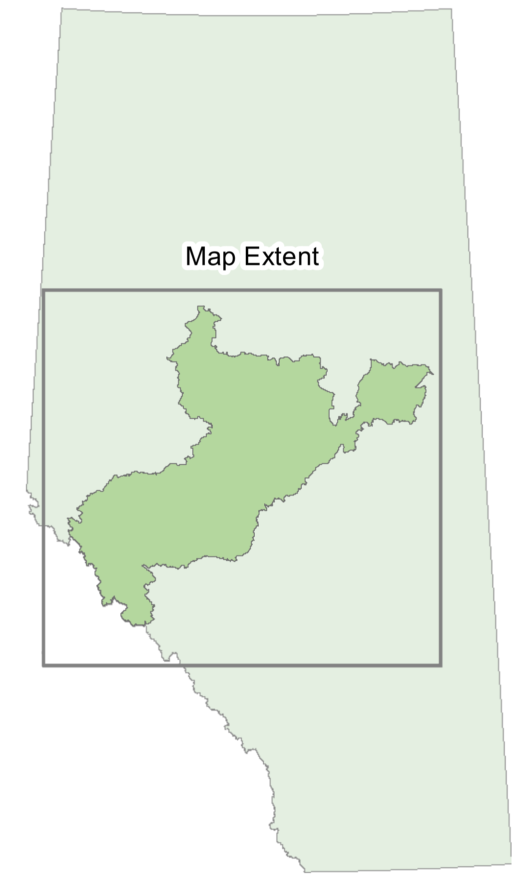
The data were used to prepare detailed maps of the surficial deposits and bedrock geounits present in the UAR. Groundwater authorizations and water wells in the UAR were assigned to the surficial deposits or a specific bedrock geounit. Geounits that are deeper than 150 metres below ground level (BGL) were not considered.

Groundwater allocations within the UAR were reviewed, categorized, and interpreted; trends in groundwater allocation over time were identified.

Determinations of baseflow, evapotranspiration, and groundwater recharge were made for each WMU, in addition to comparisons of groundwater recharge and allocated groundwater authorizations.

The present report is limited in scope to only groundwater allocations, groundwater availability, and general hydrochemistry, and will not touch on surface water allocations or availability.





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- County/Municipal District
- Athabasca River
- River
- Lake

0 60 120 180

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 1. Index Map

2. Methodology

2.1. Existing Data Sources

Data are collected and compiled from a variety of existing hydrogeological and administrative sources. These sources include the following:

- AEP
- Esri[1]
- Alberta Water Well Information Database[2]
- Water (Ministerial) Regulation
- AEP Authorization Viewer[3]
- AGS[4]
- Municipal Government
- Federal Government
- The Groundwater Centre (TGWC) Database[5]

2.1.1. Data from AEP

Details related to the project include *Water Resources Act* and *Water Act* authorizations and WURS groundwater monitoring data within the UAR.

2.1.2. Maps and Aerial Imagery

The map references used are the 1:250,000 National Topographic Series map sheets, with local detail available from the 1:50,000 map sheet. Digital ortho-imagery is obtained from the Esri program ArcGIS.

2.1.3. Data from Government Sources

2.1.3.1. Alberta Government

2.1.3.1.1. Alberta Water Well Information Database

The Alberta Water Well Information Database includes water well records prepared by water well drillers, water wells identified during various field programs with little or no information, and boreholes with varying amounts of information. The database also includes groundwater-quality information from before 1988 for groundwaters from some water wells. Data collected since 2006 as part of the Baseline Water Well Testing Program are in the Alberta Water Well Information Database.

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[1] https://esri.ca/en

[2] http://aep.alberta.ca/water/reports-data/alberta-water-well-information-database/default.aspx

[3] http://aep.alberta.ca/land/land-industrial/programs-and-services/authorization-viewer.aspx

[4] http://ags.aer.ca

[5] http://www.tgwc.com

Many of the records in the Alberta Water Well Information Database have horizontal spatial control based on a land location rather than a point location, and there is very little quality control related to the verification of the land location. Historically, the most commonly used designation is a quarter section, with an area of 640,000 square metres, and the horizontal coordinates given for the water well are the centre of the quarter section. More recently, horizontal coordinates are determined by the water well driller using a consumer-grade handheld GPS (global positioning system receiver).

2.1.3.1.2. Alberta Environment and Parks Authorization Viewer

The *Water Act* regulates the diversion of water from groundwater and surface water sources by a variety of methods, including statutory rights for household purposes, registrations for traditional agriculture uses, and licences. A list of authorized groundwater users in the UAR is provided by AEP through its Authorization Viewer database.

2.1.3.1.3. Alberta Geological Survey

AGS regional groundwater reports are referenced and various AGS shapefiles are used as required to determine the stratigraphic surfaces, bedrock surface, and topographic surface.

2.1.3.1.4. Other Reports

Evapotranspiration data are obtained from the Government of Alberta.

2.1.3.2. Municipal Governments

Regional groundwater assessments, prepared on behalf of the Prairie Farm Rehabilitation Administration (PFRA), a branch of Agriculture and Agri-Food Canada (AAFC), are accessed where available.

2.1.3.3. Federal Government

Climate data are obtained from the Environment Canada website. Stream-flow data collected at various gauge stations within the UAR are used as required. Runoff data are obtained from the Government of Canada.

2.1.4. Data from Non-Government Sources

2.1.4.1. The Groundwater Centre Database

TGWC database includes records for features that directly and indirectly relate to non-saline and saline groundwater.

The data in TGWC database that are related to non-saline groundwater are enhanced versions of the data in the Alberta Water Well Information Database. TGWC database for the UAR also houses hydrogeological data collected during the present program.

Unless more detailed information is available, the horizontal coordinates assigned to groundwater records are the centres of their reported legal locations.

Information in TGWC database has been used in the preparation of thematic maps and to determine regional aquifer parameters.

2.1.5. Published and Unpublished Reports

The Bibliography in Section 8 of this report includes documents that relate to hydrogeology in the general area of the UAR.

2.2. Data Processing

2.2.1. Transmissivity

Transmissivity values for a confined aquifer are calculated from aquifer test data from pumped water well(s) using the Cooper-Jacob approximation of the Theis non-equilibrium equation. Transmissivity values from observation water well data are determined using type-curve matching to solve the Theis non-equilibrium equation.

2.2.2. Storativity

The storage coefficient for a confined aquifer represents water derived relative to the following: (1) the expansion of water as the aquifer is depressurized; and (2) compression of the aquifer. Storativity is calculated from the analysis of drawdown measured in a suitable observation water well using the Cooper-Jacob approximation of the Theis non-equilibrium equation. In the absence of observation water well data, the storativity is estimated based on the lithology of the aquifer.

2.2.3. Long-Term Yield

The long-term yield is calculated using the Modified Moell method (Government of Alberta, 2011) and is based on the water level in the pumped water well being lowered by 70% of the available drawdown after 20 years of groundwater diversion.

When the aquifer is fully confined, the available drawdown is the linear distance from the non-pumping water level to the top of the aquifer. When the aquifer is not fully confined, the available drawdown is two thirds of the linear distance from the non-pumping water level to the bottom of the aquifer.

2.3. Spatial Coordinates

Horizontal coordinates are based on a 10-degree Transverse Mercator projection, with the central meridian of 115 degrees west longitude, using NAD83 (North American Datum of 1983). Horizontal coordinates are determined for features identified in the field using a consumer-grade handheld GPS. Vertical coordinates are from the digital elevation model (DEM) provided by AltaLIS Ltd., the agent for Alberta Data Partnerships Ltd.

2.4. Measurements

Vertical measurements associated with the present report may have been recorded to two or more decimal places. However, most vertical measurements are provided in the report to one decimal place and may therefore not agree with the number of decimals presented in the appendices and in tables. The reference point for water-level measurements is the top of casing, and all water-level measurements are reported as metres below top of casing (BTOC) unless otherwise noted; most other vertical measurements are reported as metres BGL.

2.5. Other

All gridding uses the Kriging method with a linear variogram model as provided in Surfer, a Golden Software program. Cross-sections are created using AutoCAD and, for illustrative purposes, are enhanced using CorelDRAW. Maps are created and analyzed in ArcGIS.

3. Existing Data

3.1. Background Hydrogeology

The hydrogeological maps for the area prepared under various AGS reports (Barnes, 1977; Barnes, 1978; Bibby, 1974; Borneuf, 1973; Borneuf, 1980, Borneuf, 1981; Ceroici, 1979; Ozoray, 1972; Ozoray, 1974; Ozoray and Lytviak, 1980; Ozoray, et al., 1980; Tokarsky, 1971; Tokarsky, 1977a; Tokarsky, 1977b; Vogwill, 1978; Vogwill, 1983) have been combined to create Map 2 on the following page, which shows the long-term yields within the UAR. The map shows that throughout most of the UAR, water well yields are expected to be 30 to 160 cubic metres per day (m^3/day).

3.2. Groundwater Records

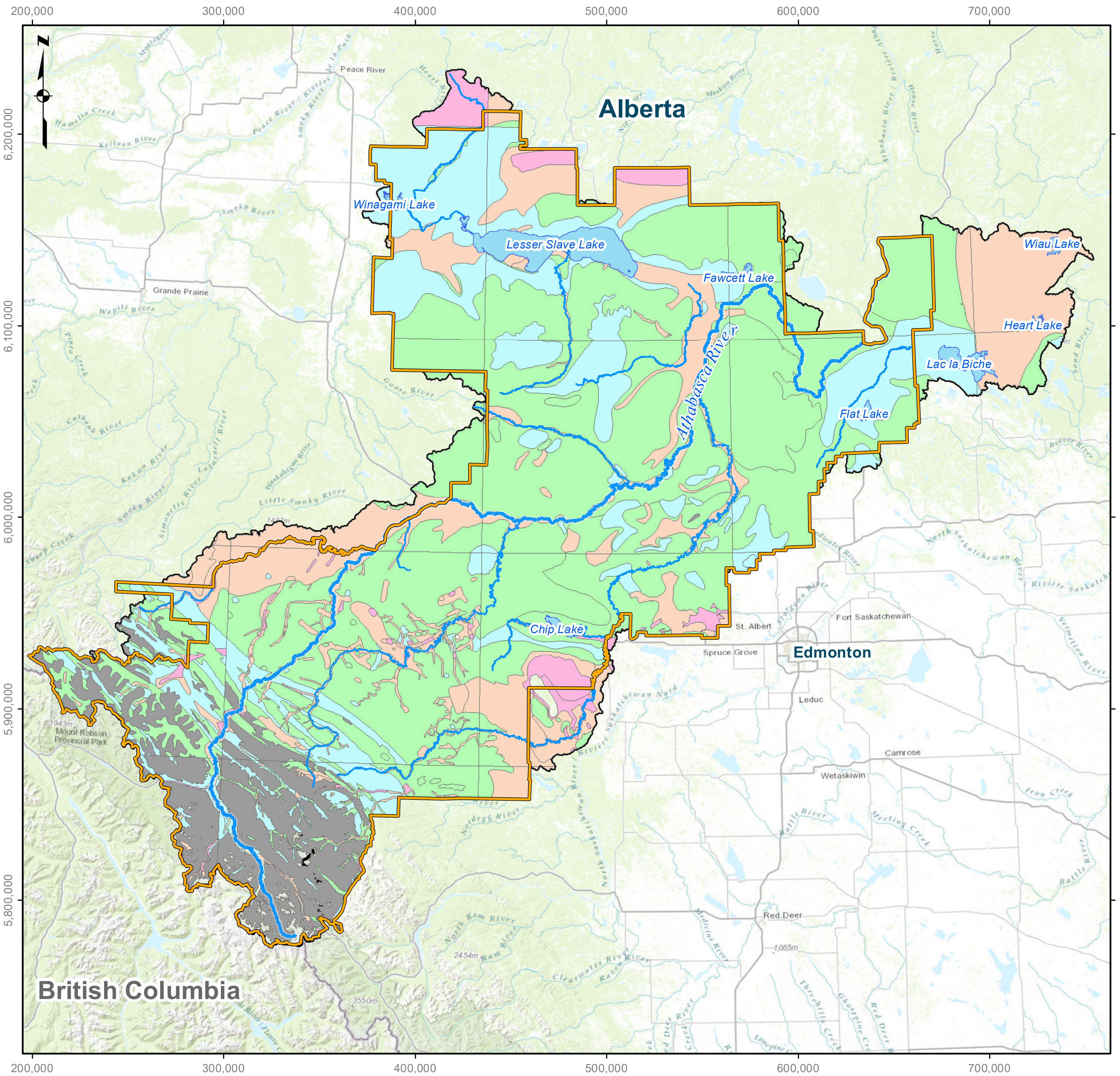
3.2.1. Overview of Records Related to Groundwater

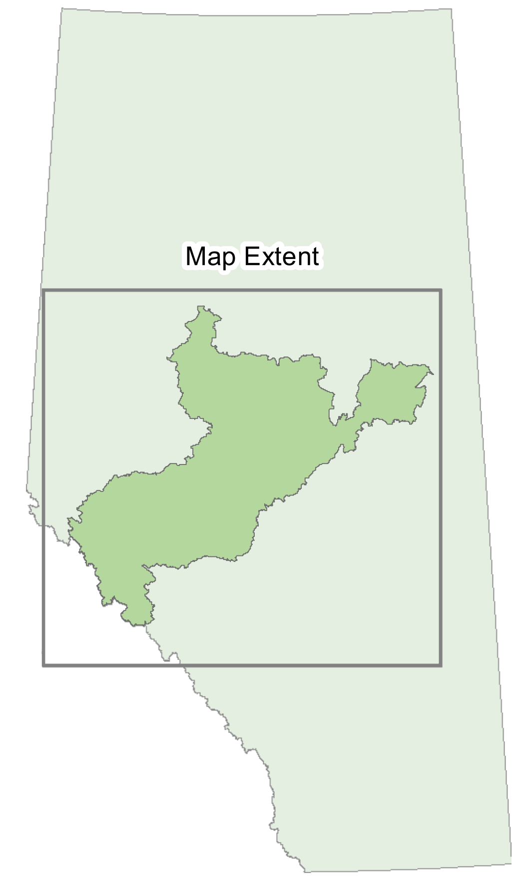
TGWC database includes 62,021 records for the UAR that are directly or indirectly related to non-saline groundwater. The number of records for each groundwater-related feature is given in Table 1. The water wells were drilled by 458 different water well drilling contractors.

These data were collected from the Alberta Water Well Information Database. It is likely that the details for a number of existing groundwater-related features within the UAR have not been submitted for inclusion in the Alberta Water Well Information database; however, it is not possible to estimate the number of groundwater-related features that are not stored in the database.

Feature Type	Number
Water Well	42,867
Reclaimed Water Well	7,663
Flowing Shot Hole	9,460
Structure Test Hole	1,262
Spring	477
Piezometer	69
Undetermined	223
Total	62,021

Table 1. Summary of Groundwater Records for the UAR





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake

AGS Determined Long-Term Yield (m³/day)

- 1- 5
- 30 - 160
- 160 - 650
- 650 - 3,300
- Unknown

0 60 120 180

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

(Barnes, 1977; Barnes, 1978; Bibby, 1974; Borneuf, 1973; Borneuf, 1980, Borneuf, 1981; Ceroici, 1979; Ozoray, 1972; Ozoray, 1974; Ozoray and Lytviak, 1980; Ozoray, et al., 1980; Tokarsky, 1971; Tokarsky, 1977a; Tokarsky, 1977b; Vogwill, 1978; Vogwill, 1983)

Map 2. Long-Term Water Well Yields Within the UAR

3.2.2. Water Well Completion Details

There are 50,530 records for water wells and reclaimed water wells within the UAR. Of these, there are 48,769 records with a value for depth drilled. Table 2 and Figure 1 show the number of records for water wells and reclaimed water wells within the UAR by depth drilled.

Depth Drilled (m)	Number of Water Well Records	Percentage
0 – 25	12,835	26.3%
25 – 50	17,149	35.2%
50 – 75	10,955	22.5%
75 – 100	5,040	10.3%
100 –125	1,805	3.7%
125 – 150	477	1.0%
150+	508	1.0%
Total	48,769	100.0%

Table 2. Summary of Water Well Records Within the UAR by Depth Drilled

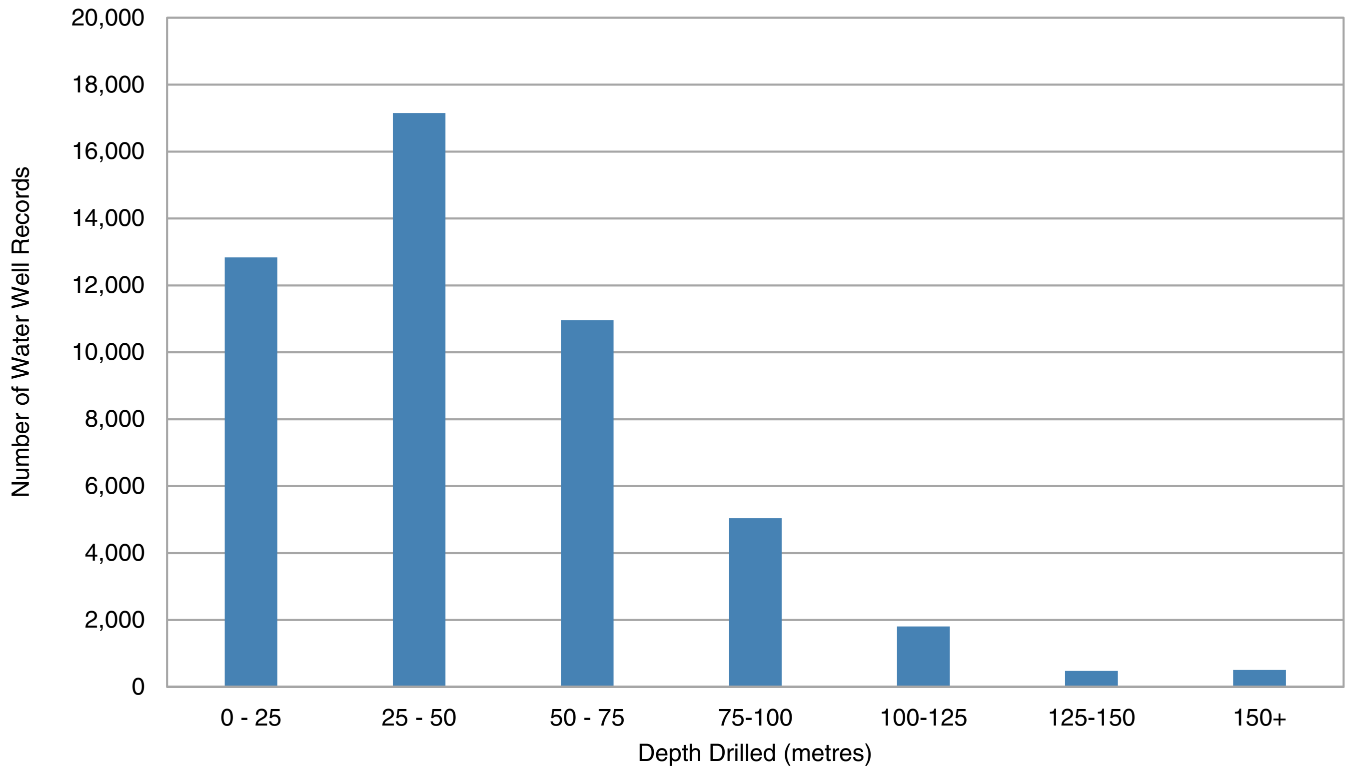


Figure 1. Summary of Water Well Records Within the UAR by Depth Drilled

Water wells that are deeper than 150 metres BGL require approval from the Government of Alberta. The vast majority of the water wells that are completed in the UAR are less than 150 metres deep; water wells that are deeper than 150 metres BGL are mainly owned by upstream oil and gas companies intending to produce saline or non-desirable groundwater.

Within the UAR, there 31,231 records for water wells and reclaimed water wells with completion interval details. Table 3 and Figure 2 show the number of records for water wells and reclaimed water wells within the UAR by completion interval length. Section 47(g) of the Water (Ministerial) Regulation states that the maximum completion interval length of a water well must not exceed 7.6 metres, unless the aquifer is clearly defined and is thicker than 7.6 metres (Province of Alberta, 1998).

Completion Interval Length (m)	Number of Water Well Records	Percentage
0 – 10	13,988	44.8%
10 – 20	9,139	29.3%
20 – 30	3,160	10.1%
30 – 40	2,122	6.8%
40 – 50	1,139	3.6%
50+	1,683	5.4%
Total	31,231	100.0%

Table 3. Summary of Water Well Records Within the UAR by Completion Interval Length

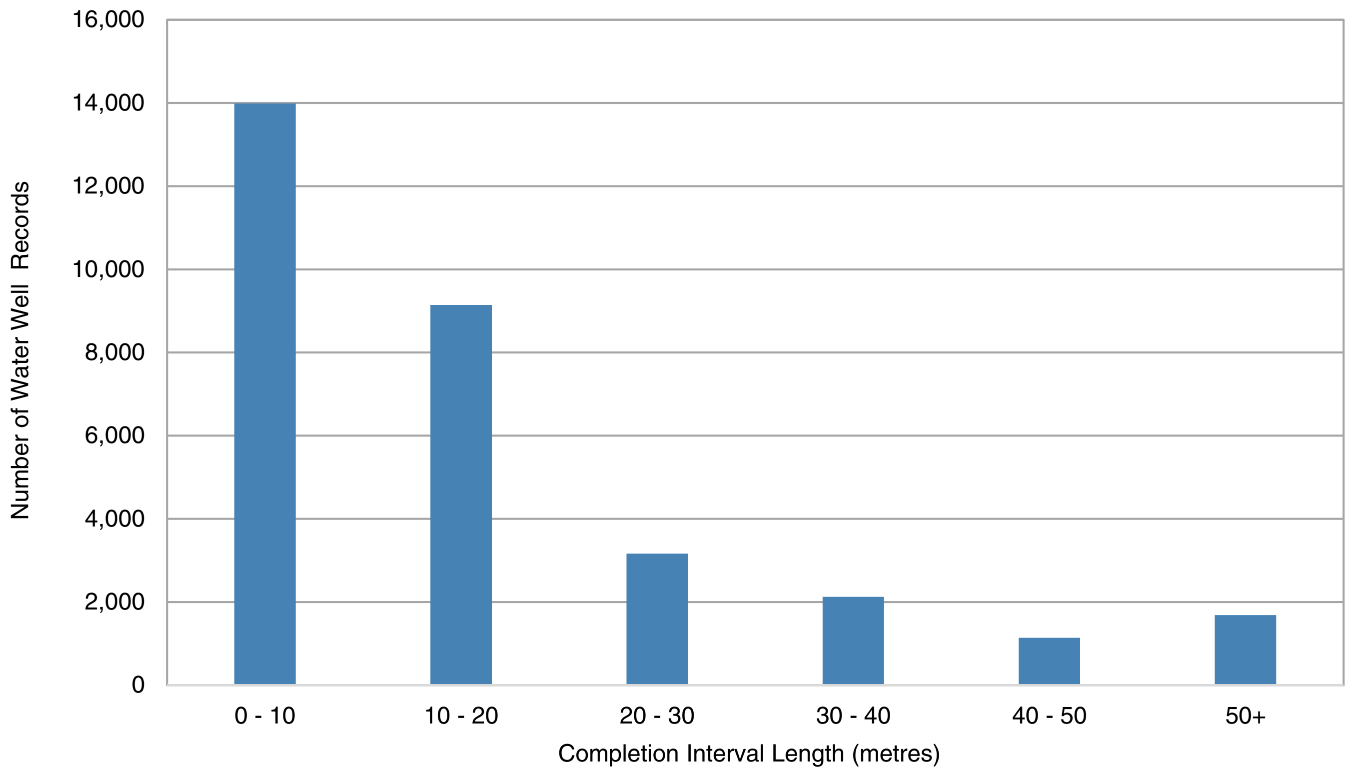


Figure 2. Summary of Water Well Records Within the UAR by Completion Interval Length

3.3. Water Well Purposes

When a water well drilling contractor submits a water well drilling report for inclusion in the Alberta Water Well Information Database, a proposed use is indicated on the report. Within the UAR, a total of 42,222 water well records were submitted with a proposed use shown on the report. As shown in Table 4 and Figure 3, the majority of the water wells within the UAR are used for domestic purposes.

Proposed Water Well Use	Number of Water Well Records	Percentage
Domestic	26,360	62.4%
Industrial	8,219	19.5%
Domestic & Stock	5,591	13.2%
Municipal	699	1.7%
Other	1,353	3.2%
Total	42,222	100.0%

Table 4. Summary of Water Well Records by Proposed Water Well Use

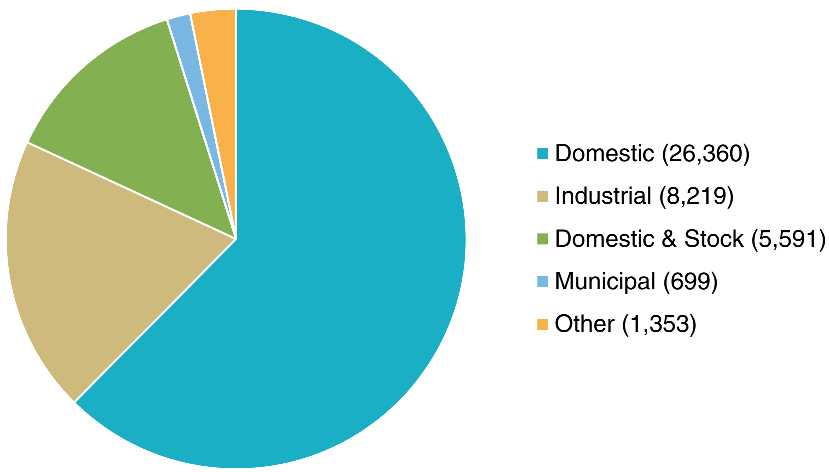
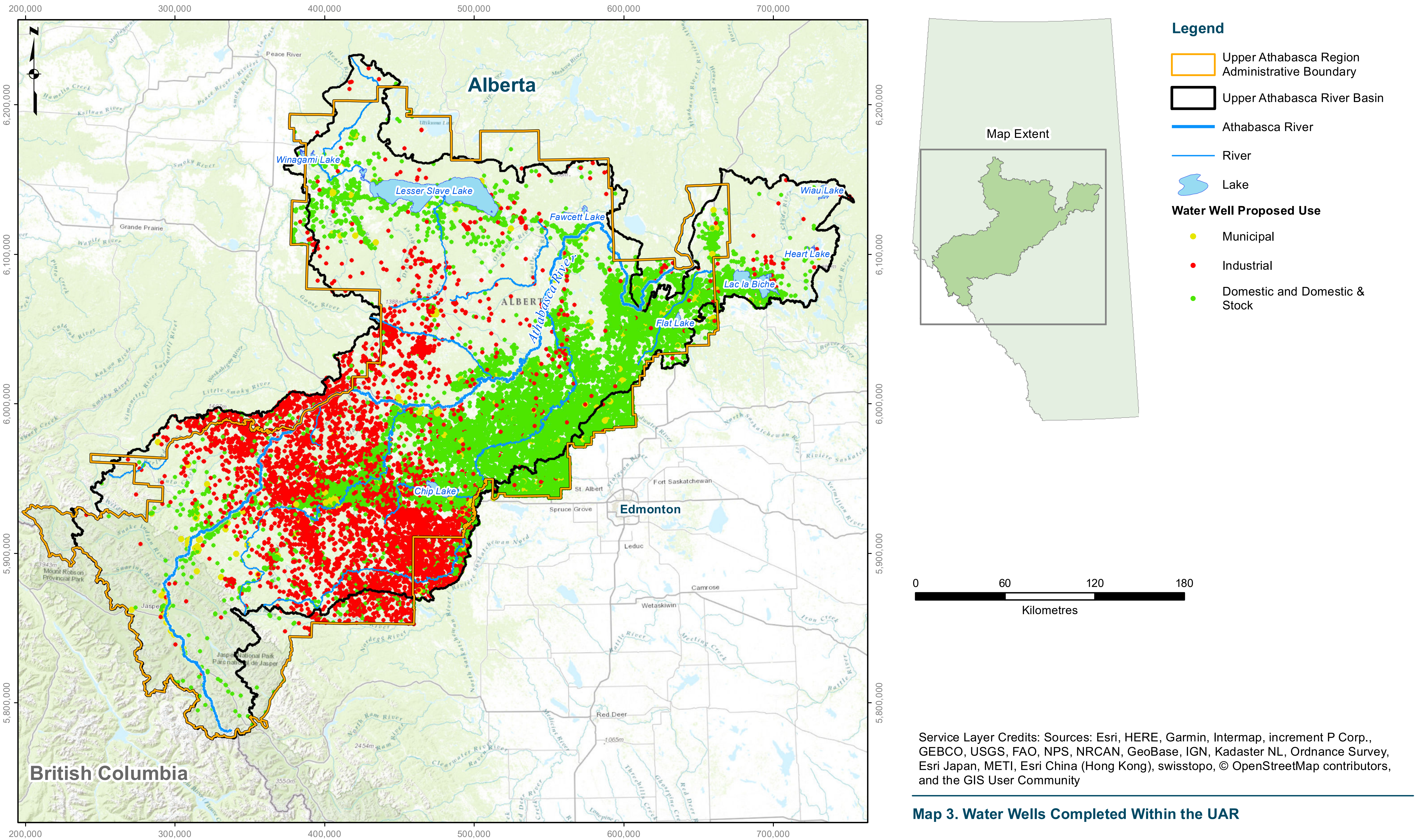


Figure 3. Proposed Uses of Water Wells in the UAR

Map 3 on the following page shows the locations of all water wells within the UAR. As shown on the map, domestic water wells are mainly in the southern portion of the eastern half of the UAR, and industrial water wells are mainly in the western portion of the UAR, where most oilfield development has occurred.



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 3. Water Wells Completed Within the UAR

3.3.1. Industrial Water Wells

Any water wells used for industrial purposes must be licensed under the *Water Act* (Province of Alberta, 2000). Within the UAR, there are 4,847 records for existing water wells that are used for industrial purposes and 3,372 records for reclaimed water wells that were used for industrial purposes. Figure 4 shows the years in which the existing industrial water wells were drilled. Figure 5 on the following page shows the years in which the reclaimed water wells used for industrial purposes were drilled.

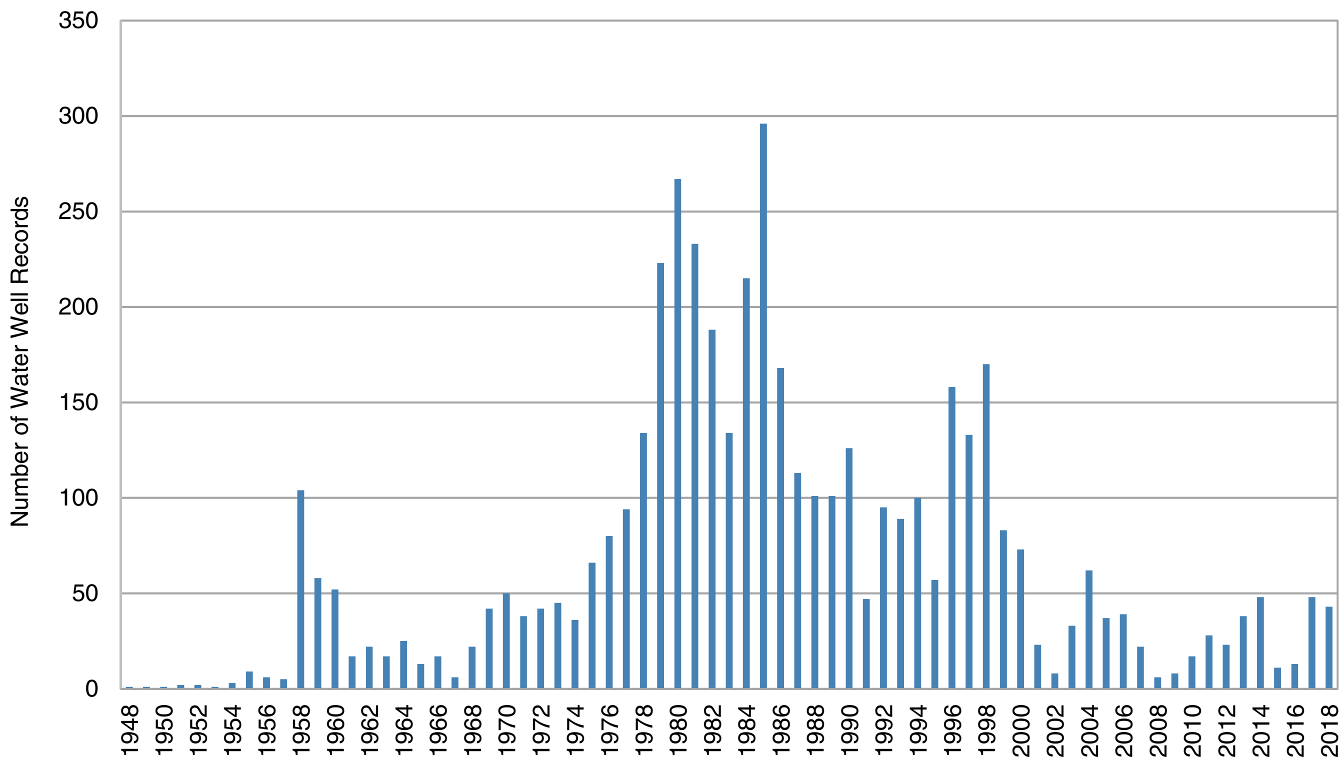


Figure 4. Drilling Dates for Existing Industrial Water Wells

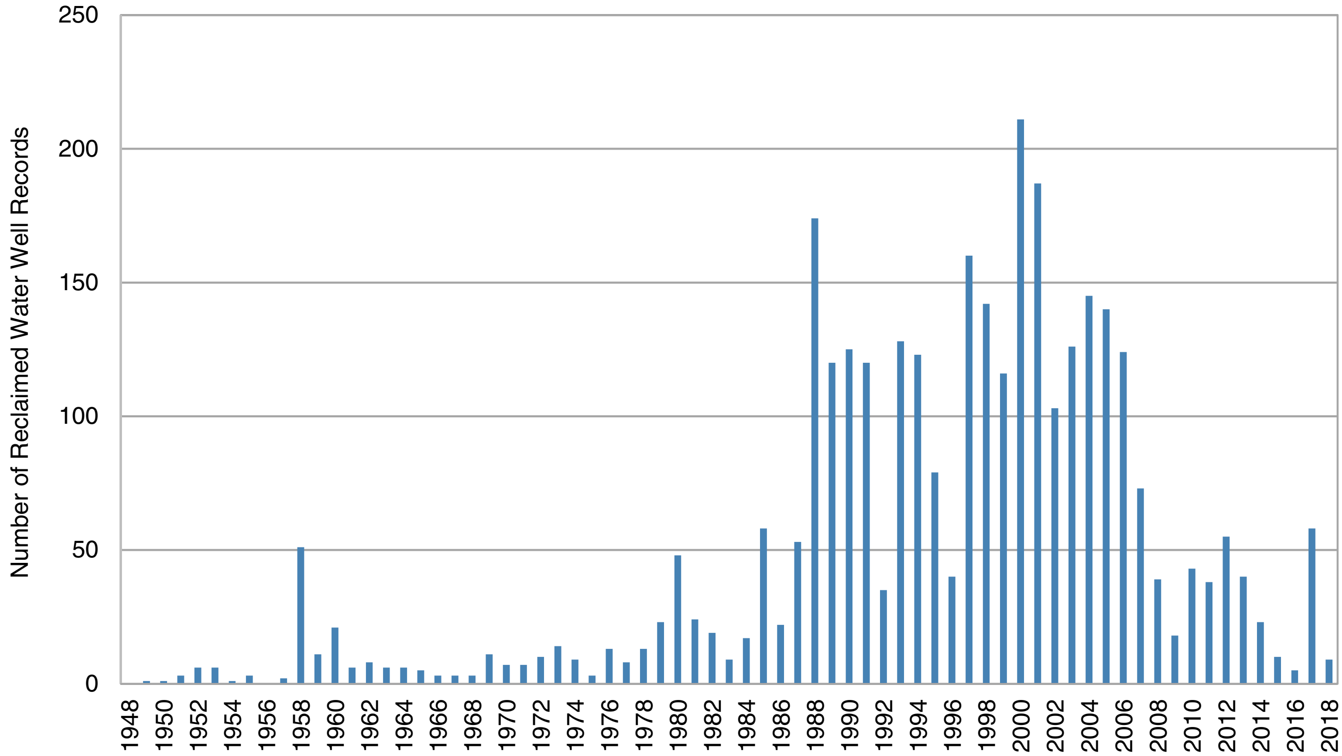


Figure 5. Drilling Dates for Reclaimed Industrial Water Wells

Figure 4 and Figure 5 show that the number of new industrial water wells being drilled within the UAR peaked in the 1980s and has seen a significant decline since the early 2000s. The decline in drilling activities for new industrial water wells suggests that there has been a decreased demand for groundwater for industrial purposes in the UAR.

3.3.2. Municipal Water Wells

There are a number of municipalities within the UAR that use groundwater to meet some or all of their water demands. These municipalities will be discussed further in Section 3.4 of the present report.

3.3.3. Domestic and Domestic & Stock Water Wells

Every domestic water well in Alberta is entitled to a protected groundwater volume of 1,250 cubic metres per year (m^3/year), while every domestic & stock water well is entitled to a protected groundwater volume of 6,250 m^3/year (Province of Alberta, 2000).

Within the UAR, there are 30,160 existing domestic and domestic & stock water wells, and 1,791 reclaimed domestic and domestic & stock water wells; of these, 23,704 water wells have a drilled date listed on the water well drilling report. Figure 6 on the following page shows the years in which these water wells were drilled, excluding the reclaimed water wells. Figure 7 on the following page shows the years in which the reclaimed water wells with a purpose listed as domestic or domestic & stock were drilled.

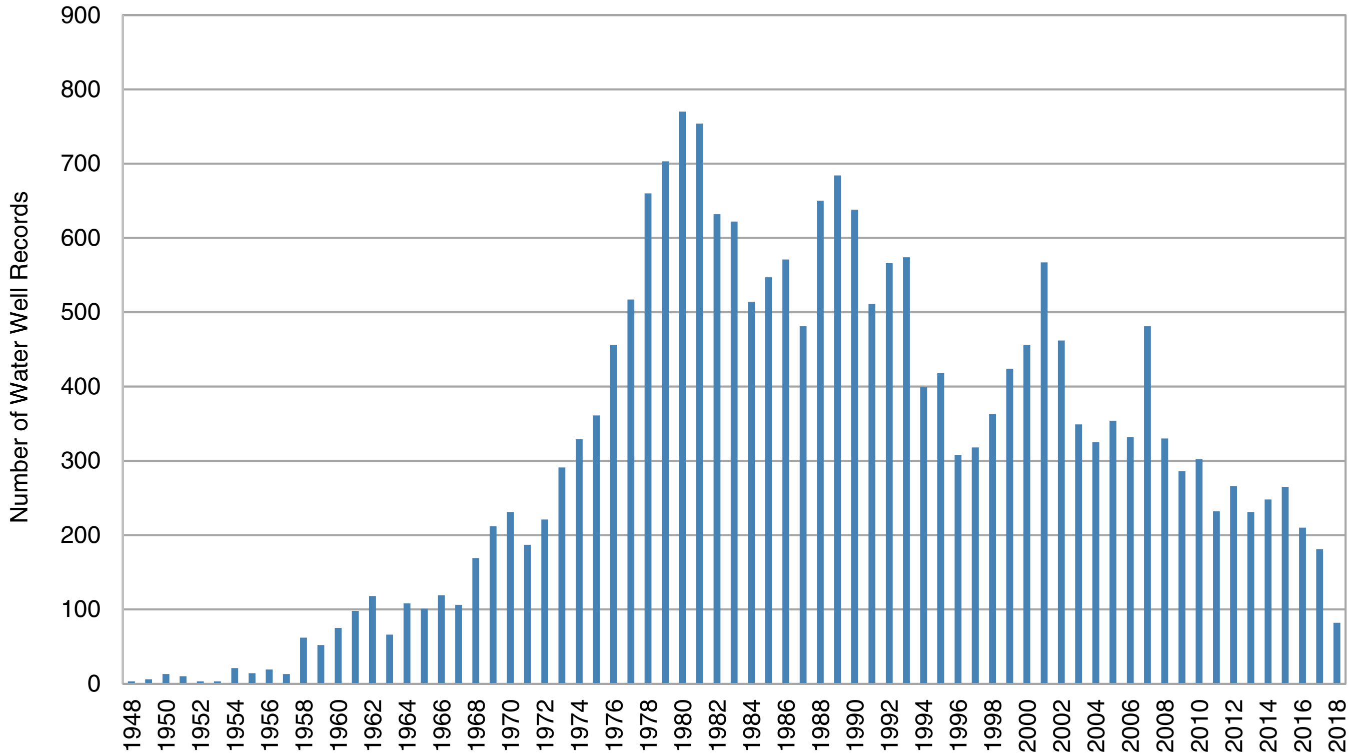


Figure 6. Drilling Dates for Existing Domestic and Domestic & Stock Water Wells

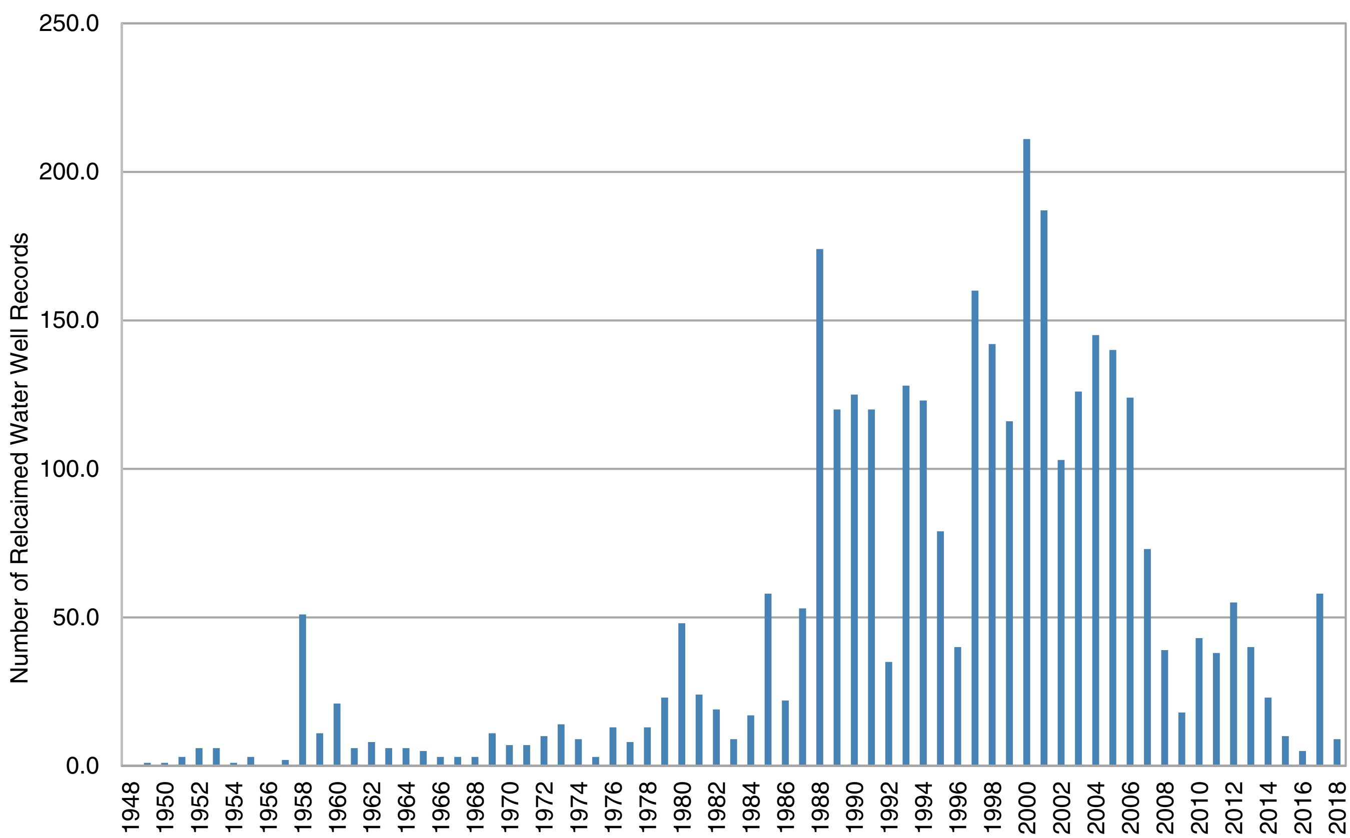


Figure 7. Drilling Dates for Reclaimed Domestic and Domestic & Stock Water Wells

The number of domestic and domestic & stock water wells exhibit a trend that is similar to the industrial water wells. There is a marked decline in recent decades of new domestic and domestic & stock water wells being drilled. Figure 6 and Figure 7 suggest that groundwater use for domestic and domestic & stock purposes in the UAR may have declined in recent years. However, because most of the domestic and domestic & stock water wells are not being reclaimed, the number of existing domestic and domestic & stock water wells within the UAR continues to rise each year, as shown in Figure 8. Because there is no system for reporting groundwater diversion by domestic or domestic & stock water wells, it is not possible to determine if groundwater use in the UAR is decreasing because fewer new water wells are being drilled, or if groundwater use is increasing because the existing number of water wells continues to rise.

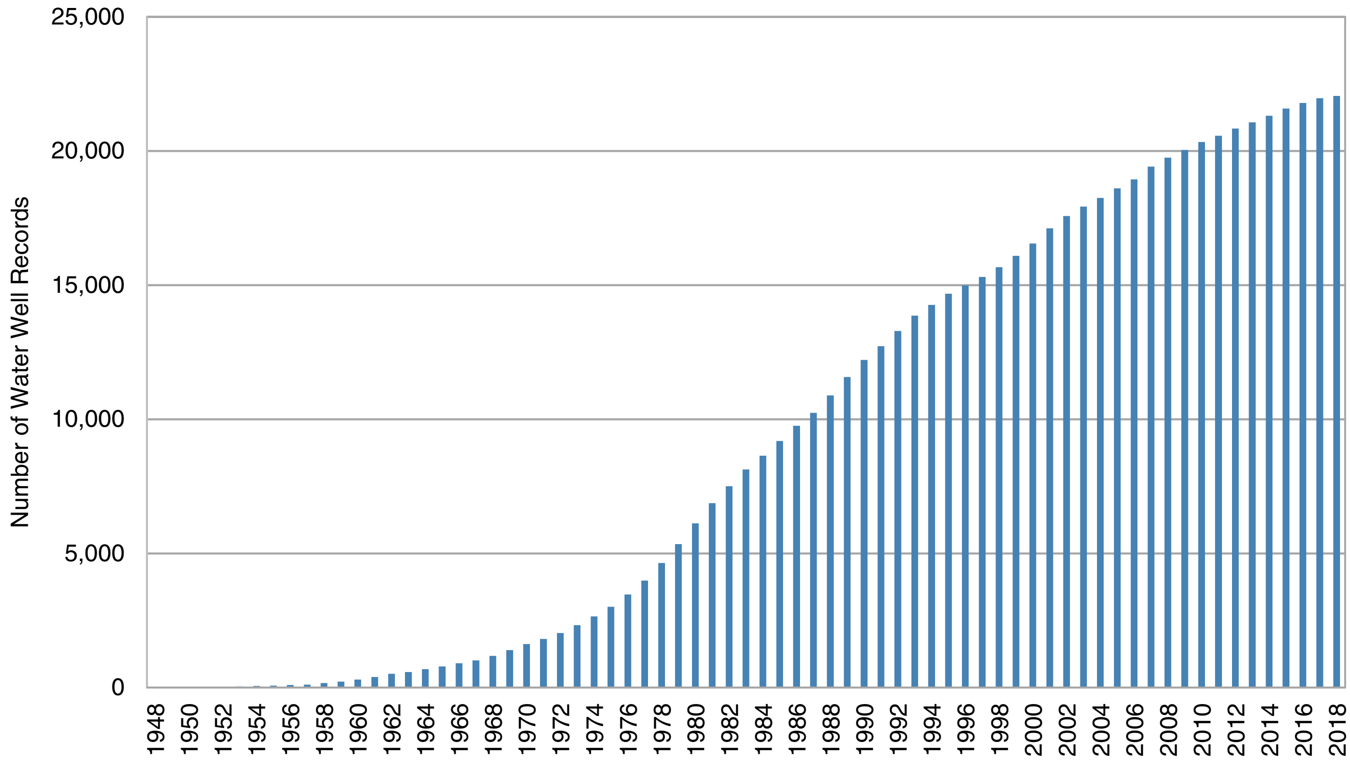


Figure 8. Number of Existing Domestic and Domestic & Stock Water Wells

3.4. Active Groundwater Authorizations

Within the UAR, there are five different types of groundwater authorizations, as shown in Table 5 on the following page. The groundwater authorizations are administered by the Province of Alberta.

Water Resources Act licences, which are the oldest licences in the UAR, do not have an expiry date. These licences were issued for industrial purposes up until the *Water Act* became law on January 1, 1999. The oldest active *Water Resources Act* licence within the UAR was issued on June 27, 1979. *Water Resources Act* interim licences also do not expire. These non-expiring licences represent approximately 49% of the total authorized diversion in the UAR.

There are two types of licences issued under the *Water Act*. Temporary diversion licences (TDLs), which are effective for periods of up to one year, are mainly intended for instances when the water requirements of licensees are temporary in nature or are for pilot projects. *Water Act* licences are effective for periods of up to 10 years and can be renewed indefinitely; these represent a more consistent demand on groundwater resources than TDLs.

Water Act registrations authorized traditional agricultural water users who have used water prior to the *Water Act* becoming law on January 1, 1999, to continue using water by registering their water use. The *Water Act* registration would be given a priority number dating back to the approximate time of first use. The registration process was meant to provide a fair mechanism of protecting traditional agricultural water users while at the same time minimizing the impact on existing licensed users. Applications for *Water Act* registrations were accepted from both landowners and licensees between January 1, 1999, and December 31, 2001. *Water Act* registrations for traditional agricultural use have no expiry date.

Table 5, Figure 9, and Figure 10 show a breakdown of the number of active authorizations and the annual groundwater volumes in the UAR by authorization type.

Authorization Type	Number of Authorizations	Annual Volume (m³/year)
Water Resources Act Licence	1,131	10,124,085
Water Resources Act Interim Licence	87	4,642,475
Water Act TDL	29	638,995
Water Act Licence	450	9,206,861
Water Act Registration	3,981	4,060,447
Total	5,678	28,672,863

Table 5. Active UAR Authorizations

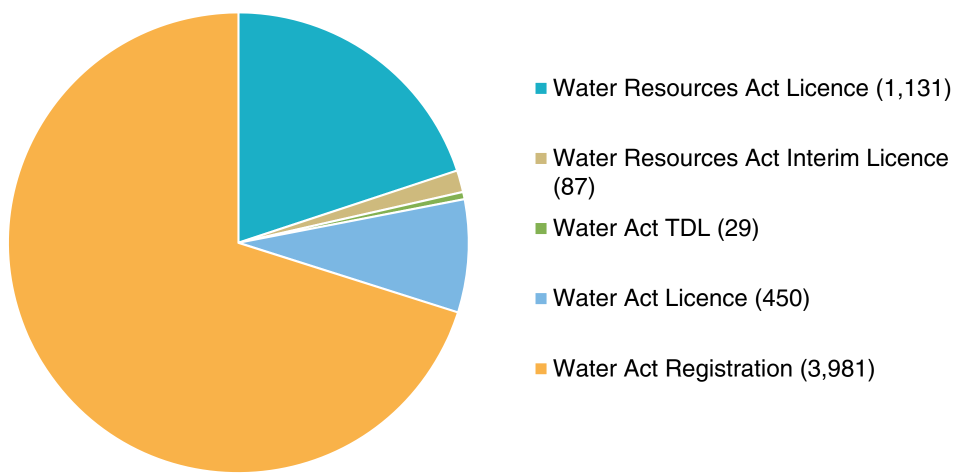


Figure 9. Number of Active Authorizations by Authorization Type

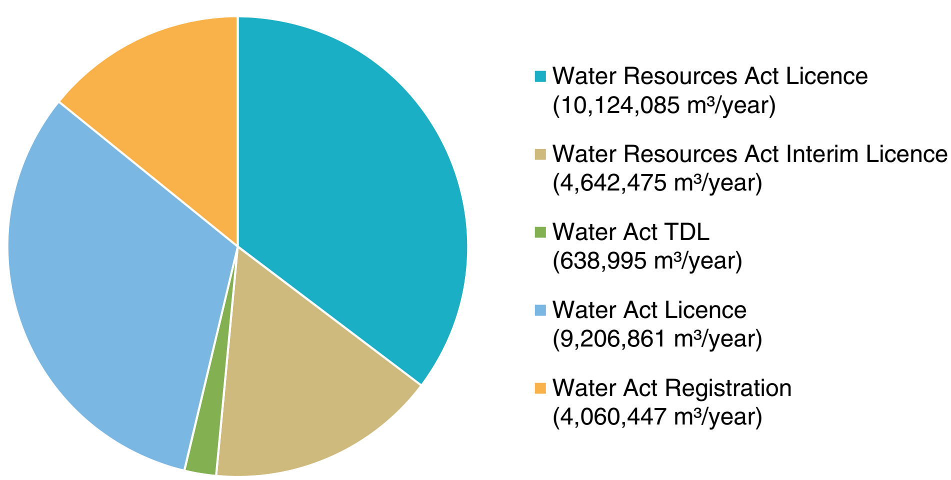


Figure 10. Active Authorized Groundwater Volumes by Authorization Type

The authorizations can be broadly grouped into three categories: Agricultural, Industrial, and Municipal. Agricultural authorizations include irrigation, feedlot, and all registrations. Industrial authorizations include mainly upstream oil and gas users, and aggregate producers to a lesser extent. Municipal authorizations include municipal water supplies, trailer parks, and golf courses.

Table 6 and Figure 11 outline the number of active authorizations and the annual groundwater volumes in the UAR by water-use category.

Water-Use Category	Number of Authorizations	Annual Volume (m³/year)
Agricultural	5,181	7,839,366
Industrial	353	14,672,720
Municipal	144	6,160,777
Total	5,678	28,672,863

Table 6. Active Groundwater Authorizations by Water-Use Category

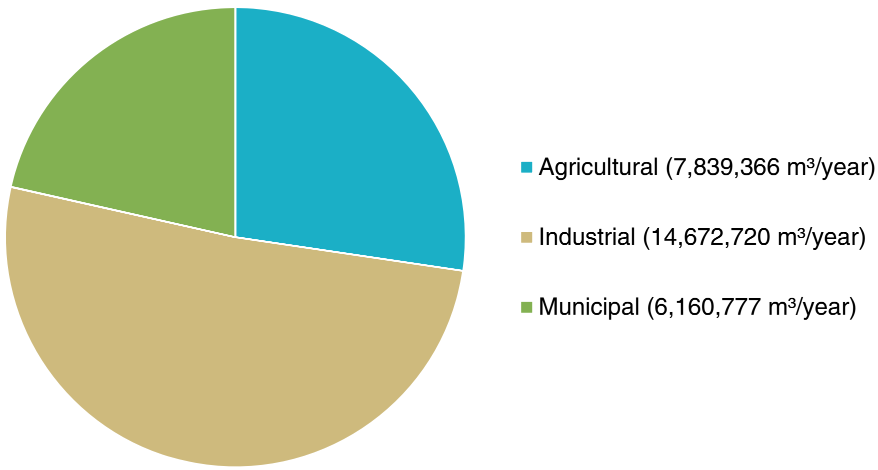


Figure 11. Active Annual Groundwater Volumes by Water-Use Category

The majority (95%) of the total groundwater volume allocated for municipal use in the UAR is held by ten entities and is summarized in Table 7.

Licensee	Number of Licences	Annual Authorized Volume (m³/year)
Town of Edson	7	2,919,722
Municipality of Jasper	1	1,600,000
Town of Mayerthorpe	3	341,205
Athabasca County	1	289,956
Municipal District of Yellowhead	3	266,430
Woodlands County	5	172,485
Village of Clyde	2	92,258
Westlock County	6	91,190
Lac Ste Anne County	1	55,500
Municipal District of Slave River	1	13,570
Total	30	5,842,316

Table 7. Major Municipal Groundwater Users (Active Authorizations)

The majority (84%) of the total groundwater volume allocated for industrial use in the UAR is held by 28 entities and is summarized in Table 8.

Licensee	Number of Authorizations	Annual Authorized Volume (m^3/year)
Cardinal River Coals Ltd	2	3,093,930
Coalspur Mines (Operations) Ltd.	1	2,679,500
Whitecourt Power Limited Partnership	1	956,700
Prairie Mines & Royalty ULC	9	750,732
Peyto Exploration & Development Corp.	10	732,614
West Fraser Mills Ltd.	7	716,315
Tolko Industries Ltd.	3	548,495
Suez Canada Waste Services Inc.	4	313,350
Whitecap Resources Inc.	2	308,425
Atco Power Canada Ltd.	0	300,000
Tourmaline Oil Corp.	9	205,195
Canlin Energy Corporation	1	178,850
Lexin Resources Ltd.	3	177,620
Semcams ULC	6	159,921
Vermilion Energy Inc.	3	155,320
Tervita Corporation	13	123,061
Accel Canada Holdings Limited	3	116,035
Bashaw Oil Corp.	1	98,185
Lehigh Hanson Materials Limited	3	97,804
Zargon Oil & Gas Ltd.	1	92,710
Keyera Energy Ltd.	6	91,955
Secure Energy Services Inc.	5	86,275
Tidewater Midstream and Infrastructure Ltd.	4	70,130
Canadian Natural Resources Limited	15	65,258
Insch Commodity Ltd.	1	56,210
Boulder Energy Ltd.	2	54,800
Weyerhaeuser Company Limited	2	51,810
BURNCO Rock Products Ltd.	1	50,000
Total	118	12,331,200

Table 8. Major Industrial Groundwater Users (Active Authorizations)

The agricultural authorizations are much smaller and are spread out over a large number of users. The largest agricultural licence in the UAR authorizes a diversion of 25,000 m^3/year.

3.5. Historical Trends

Groundwater authorizations dating back to 1980 were used to determine trends in groundwater demand within the UAR. Table 9 and Figure 12 show the total groundwater volumes authorized each year from 1980 through 2017.

Year	Number of Authorizations Issued	Authorized Volumes (m³/year)	Year	Number of Authorizations Issued	Authorized Volumes (m³/year)
1980	14	82,650	1999	20	426,414
1981	14	154,180	2000	80	490,883
1982	28	391,495	2001	202	677,532
1983	26	1,729,340	2002	2995	2,930,205
1984	29	2,643,413	2003	504	681,056
1985	95	5,512,446	2004	61	250,322
1986	40	2,343,998	2005	183	808,509
1987	33	1,198,640	2006	265	1,537,327
1988	44	405,165	2007	25	2,100,192
1989	176	668,540	2008	32	173,807
1990	161	2,631,288	2009	19	55,179
1991	169	1,502,793	2010	37	90,325
1992	115	544,112	2011	48	994,276
1993	97	4,481,203	2012	77	503,017
1994	174	4,777,376	2013	191	1,812,950
1995	147	1,146,112	2014	237	5,808,468
1996	35	743,520	2015	213	2,858,596
1997	24	8,636,815	2016	204	1,615,901
1998	25	2,842,657	2017	215	1,888,492

Table 9. Total Volume of Issued Groundwater Authorizations

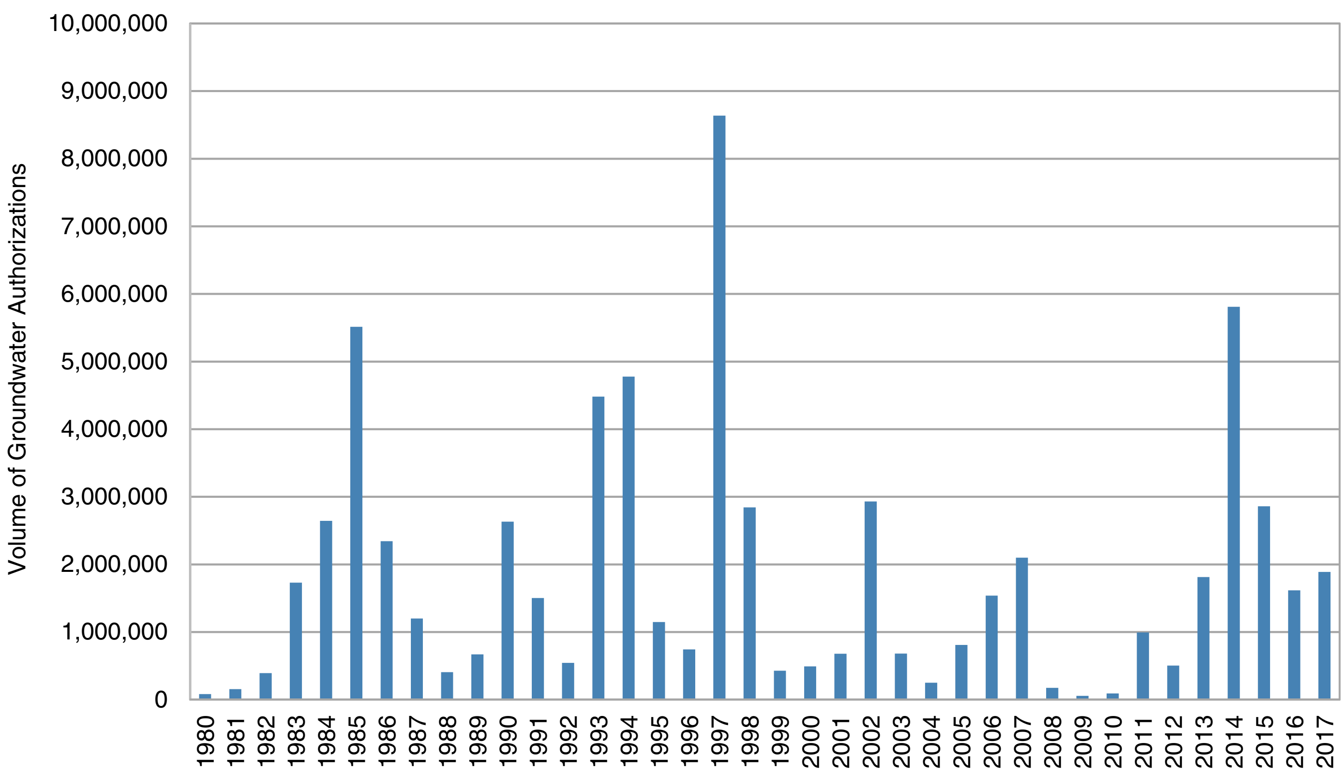


Figure 12. Total Annual Volume of Issued Groundwater Authorizations

Table 10 shows the volume of groundwater authorizations that were issued each year, the volume of groundwater authorizations that expired or were cancelled each year, and the change in the volume of groundwater authorized, in addition to a running total of the authorized volumes. As shown in the last column of Table 10, the total authorized groundwater volumes have slowly increased to over 29,000,000 m³/year in 2017.

Year	Volume of Authorizations Issued (m³/year)	Authorizations Expired or Cancelled Volume (m³/year)	Net Allocation (Gained or Lost, m³/year)	Total Authorized (m³/year)
1980	82,650	0	82,650	82,650
1981	154,180	0	154,180	236,830
1982	391,495	0	391,495	628,325
1983	1,729,340	0	1,729,340	2,357,665
1984	2,643,413	592,070	2,051,343	4,409,008
1985	5,512,446	0	5,512,446	9,921,454
1986	2,343,998	99,910	2,244,088	12,165,542
1987	1,198,640	200,780	997,860	13,163,402
1988	405,165	1,774,970	-1,369,805	11,793,597
1989	668,540	571,100	97,440	11,891,037
1990	2,631,288	3,327,940	-696,652	11,194,385
1991	1,502,793	2,389,260	-886,467	10,307,918
1992	544,112	160,350	383,762	10,691,680
1993	4,481,203	38,230	4,442,973	15,134,653
1994	4,777,376	40,700	4,736,676	19,871,329
1995	1,146,112	35,770	1,110,342	20,981,671
1996	743,520	3,014,630	-2,271,110	18,710,561
1997	8,636,815	60,430	8,576,385	27,286,947
1998	2,842,657	8,793,780	-5,951,124	21,335,823
1999	426,414	631,463	-205,049	21,130,774
2000	490,883	60,425	430,458	21,561,232
2001	677,532	70,856	606,676	22,167,908
2002	2,930,205	423,962	2,506,243	24,674,151
2003	681,056	147,724	533,332	25,207,483
2004	250,322	192,372	57,950	25,265,433
2005	808,509	1,065,060	-256,551	25,008,882
2006	1,537,327	272,864	1,264,463	26,273,345
2007	2,100,192	1,810,161	290,031	26,563,376
2008	173,807	3,110,911	-2,937,104	23,626,272
2009	55,179	342,985	-287,807	23,338,466
2010	90,325	429,750	-339,425	22,999,041
2011	994,276	238,515	755,761	23,754,802
2012	503,017	82,973	420,044	24,174,846
2013	1,812,950	852,962	959,988	25,134,834
2014	5,808,468	2,464,620	3,343,848	28,478,681
2015	2,858,596	2,673,129	185,467	28,664,148
2016	1,615,901	1,841,492	-225,591	28,438,557
2017	1,888,492	1,115,626	772,866	29,211,423

Table 10. Yearly Breakdown of Changes to Groundwater Authorizations

Figure 13 shows the net authorization volume gained or lost in each year. Figure 14 shows the total cumulative authorized groundwater volumes within the UAR.

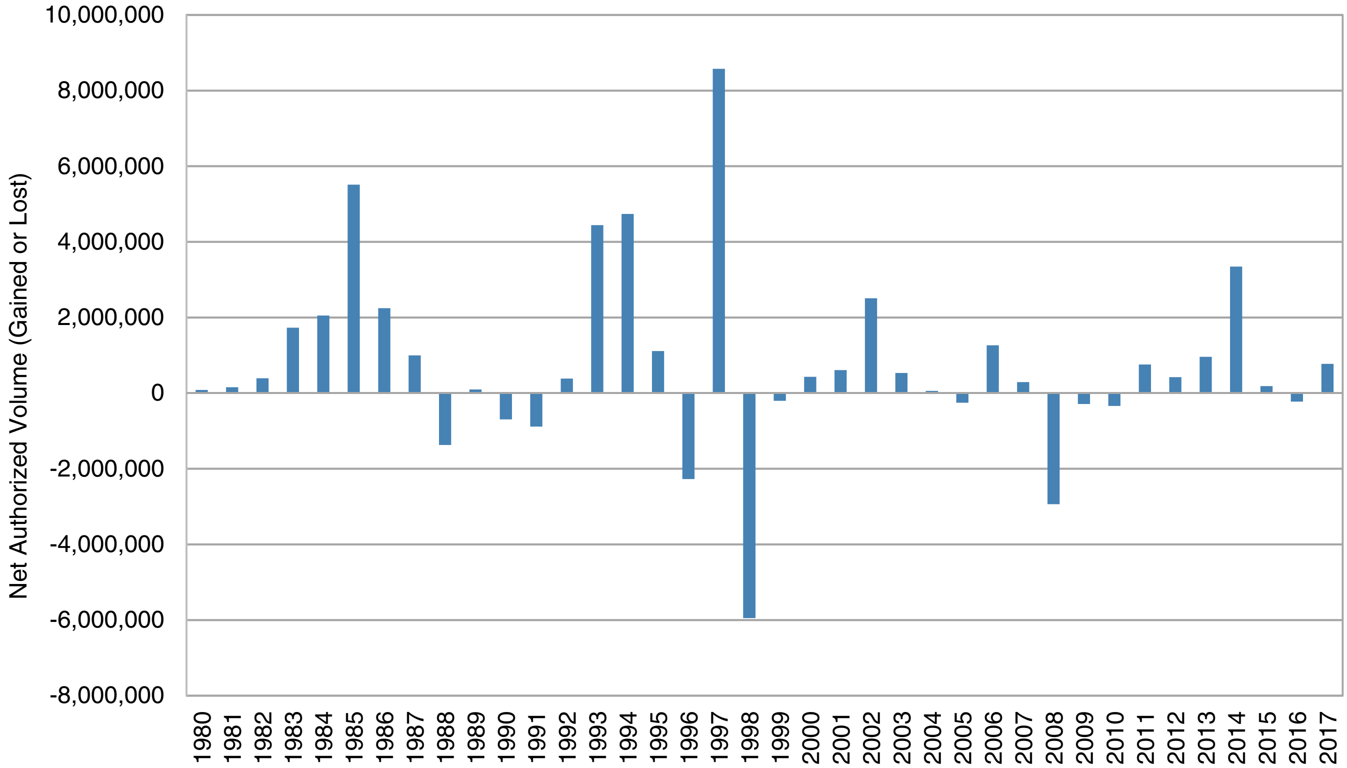


Figure 13. Net Authorized Volume (Gained or Lost)

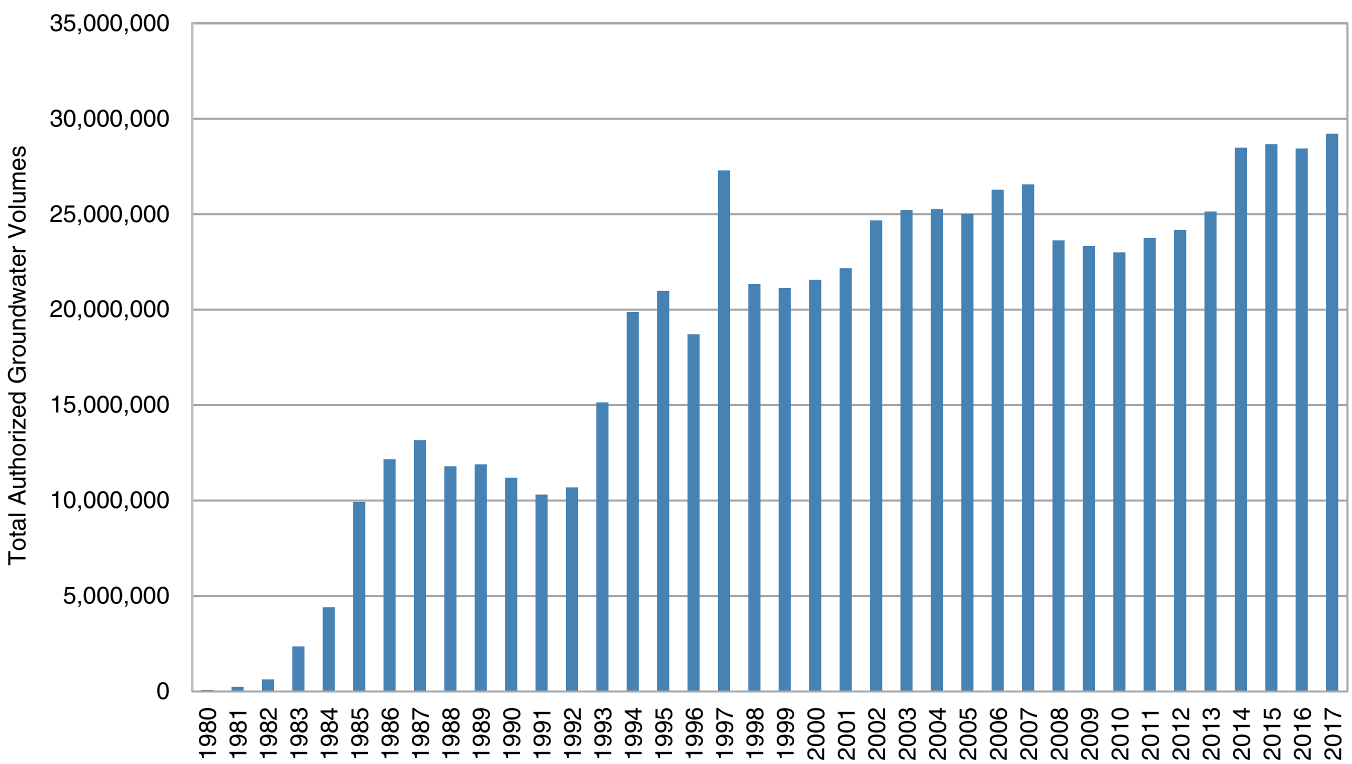


Figure 14. Total Cumulative Authorized Groundwater Volumes

3.6. Reported Data

AEP provided historical data that have been reported to the Water Use Reporting System (WURS) and are associated with all of the authorizations in the UAR with reported data. This includes more than 53,000 monthly entries for 674 authorizations. As with any manually entered data, there are some errors expected within the dataset. Any monthly entry that is greater than the annual total of the authorization was adjusted to the average monthly entry for that licence, excluding entries of zero. Using this methodology, 618 monthly entries were adjusted. There were several entries between 2010 and 2013 that were adjusted because the values were several orders of magnitude too large for the authorization. These errors could be simple typos or a confusion on the units entered (e.g. litres instead of cubic metres). Table 11 shows the raw and adjusted WURS data entered each year from 1987 through 2017, the total allocations, and the raw and adjusted WURS data as percentages of the total authorized. From this point forward, only the adjusted WURS data will be used in the present report.

Year	Total Authorized Volume (m³/year)	Raw WURS Entries (m³)	Reported Diversion as a Percentage of Authorized Diversion	Adjusted WURS Entries (m³)	Adjusted Reported Diversion as a Percentage of Authorized Diversion
1987	13,163,402	628,221	4.8%	594,387	4.5%
1988	11,793,597	807,949	6.9%	684,741	5.8%
1989	11,891,037	617,969	5.2%	569,253	4.8%
1990	11,194,385	1,677,459	15.0%	1,661,916	14.8%
1991	10,307,918	2,492,414	24.2%	2,377,866	23.1%
1992	10,691,680	3,004,113	28.1%	2,849,584	26.7%
1993	15,134,653	2,971,916	19.6%	2,961,998	19.6%
1994	19,871,329	631,953	3.2%	631,953	3.2%
1995	20,981,671	1,161,050	5.5%	1,161,050	5.5%
1996	18,710,561	2,938,768	15.7%	2,938,768	15.7%
1997	27,286,947	2,246,814	8.2%	2,246,814	8.2%
1998	21,335,823	666,791	3.1%	666,791	3.1%
1999	21,130,774	2,963,805	14.0%	2,775,178	13.1%
2000	21,561,232	3,077,606	14.3%	3,077,606	14.3%
2001	22,167,908	519,258	2.3%	519,258	2.3%
2002	24,674,151	2,610,711	10.6%	2,610,711	10.6%
2003	25,207,483	1,137,330	4.5%	1,037,777	4.1%
2004	25,265,433	811,517	3.2%	777,918	3.1%
2005	25,008,882	5,634,037	22.5%	5,111,628	20.4%
2006	26,273,345	6,445,561	24.5%	5,679,254	21.6%
2007	26,563,376	6,734,747	25.4%	6,026,536	22.7%
2008	23,626,272	5,900,302	25.0%	5,501,440	23.3%
2009	23,338,466	5,016,218	21.5%	4,413,915	18.9%
2010	22,999,041	7,239,992	31.5%	5,374,399	23.4%
2011	23,754,802	10,268,113	43.2%	5,207,192	21.9%
2012	24,174,846	11,225,790	46.4%	5,521,979	22.8%
2013	25,134,834	9,965,657	39.6%	5,578,025	22.2%
2014	28,478,681	6,714,396	23.6%	4,912,734	17.3%
2015	28,664,148	5,554,225	19.4%	3,907,923	13.6%
2016	28,438,557	5,956,883	20.9%	4,294,135	15.1%
2017	29,211,423	5,173,742	17.7%	4,089,352	14.0%

Table 11. WURS-Reported Diversions and Adjusted Diversions (1987 through 2017)

Figure 15 shows the total groundwater diversion reported to WURS each year from 1987 through 2017. The graph shows that the total reported groundwater diversion peaked in 2007 and has been slowly declining since then, with the reported diversion in each of 2015, 2016, and 2017 being approximately 4,000,000 cubic metres.

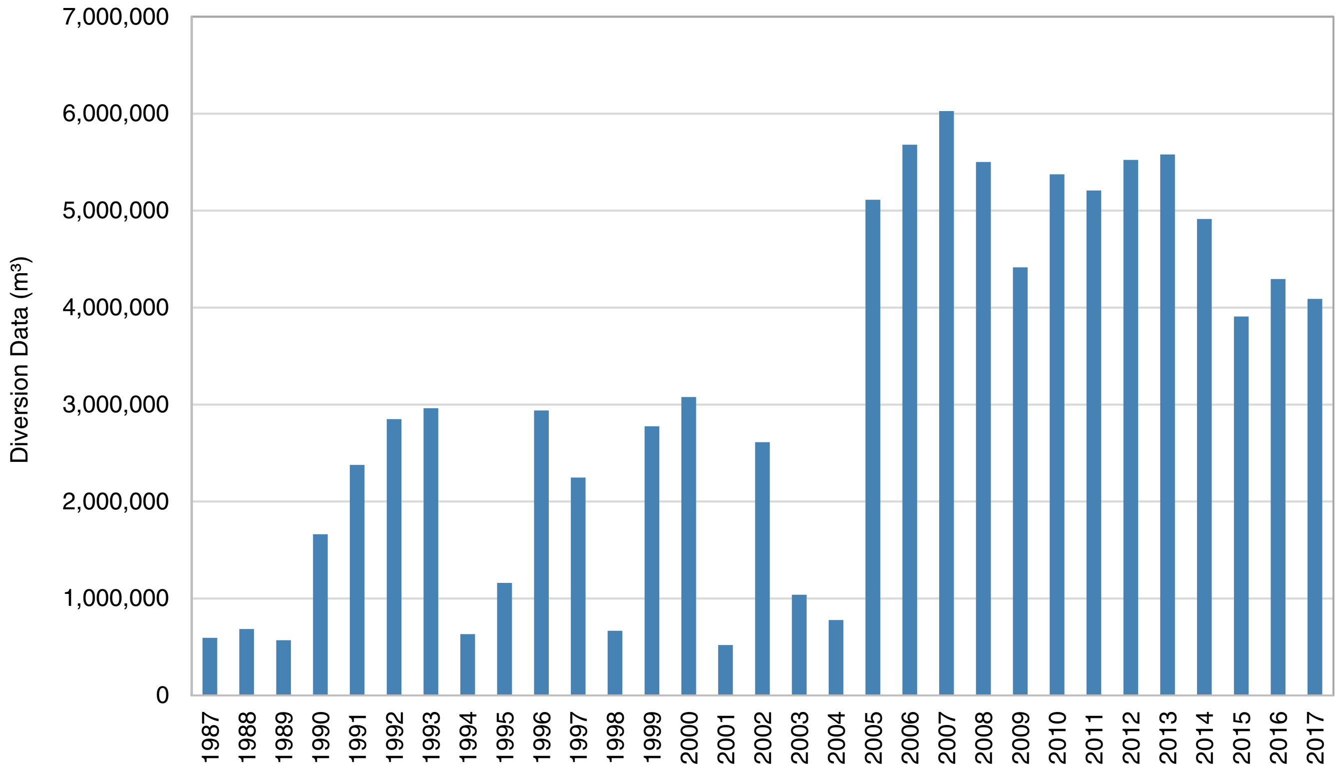


Figure 15. Groundwater Diversion Data Reported to WURS (1987 through 2017)

4. Geology of the UAR

4.1. Overview

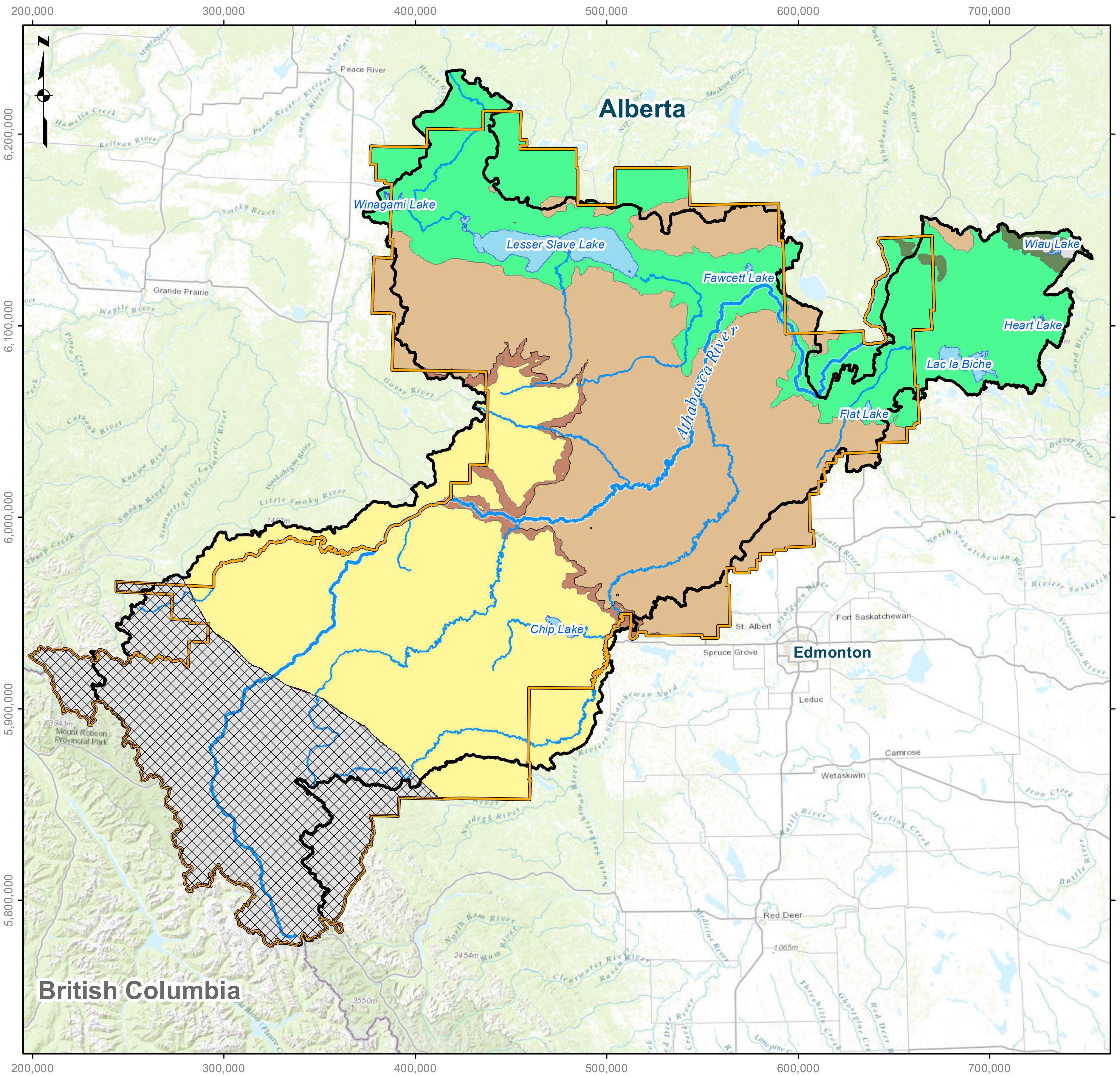
Within the UAR, there are five stratigraphic intervals defined by Branscombe, et al. (2018). All of the stratigraphic surfaces used in the present report are from Branscombe, et al. (2018), with the exception of the individual members of the Paskapoo Formation, which are from AGS Bulletin 066 (Lyster and Andriashek, 2012). No stratigraphic units are identified in the deformed belt that is within the southwestern corner of the UAR encompassing the foothills and mountainous regions of the UAR.

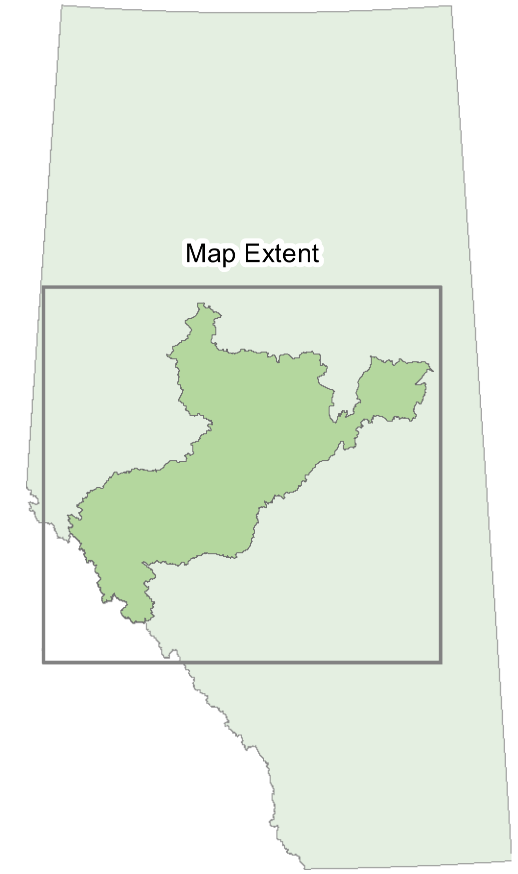
The stratigraphic intervals are defined below; each stratigraphic interval and its regional equivalents are considered as one geounit in the present report:

- Paskapoo Formation
- Scollard Formation
- Undifferentiated Horseshoe Canyon Formation/Wapiti Formation/St. Mary River Formation/Belly River Group/Bearpaw Formation Equivalent Interval (Wapiti Interval)
- Undifferentiated Lea Park Formation/Colorado Group/Smoky Group/Fort St. John Group Equivalent Interval (Lea Park Interval)
- Base of the Fish Scales Formation to Viking Formation/Bow Island Formation/Peace River Formation Equivalent Interval (Base of Fish Scales to Top of Viking Interval)

Although the Wapiti Interval and Lea Park Interval represent more than one formation, the names Wapiti and Lea Park will be used for simplicity.

Map 4 on the following page shows where each of the formations and intervals are expected to subcrop within the UAR; a geounit subcrops when it is the uppermost bedrock unit. The Paskapoo Formation and the Wapiti Interval are the most prevalent subcropping geounits within the UAR.





Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Wapiti Interval consists of undifferentiated Horseshoe Canyon Formation/Wapiti Formation/St. Mary River Formation/Belly River Group/Bearpaw Formation Equivalent (Branscombe, et al., 2018)

Lea Park Interval consists of undifferentiated Lea Park Formation/Colorado Group/Smoky Group/Fort St. John Group Equivalent Interval (Branscombe, et al., 2018)

Map 4. Geological Map per Branscombe, et al. (2018)

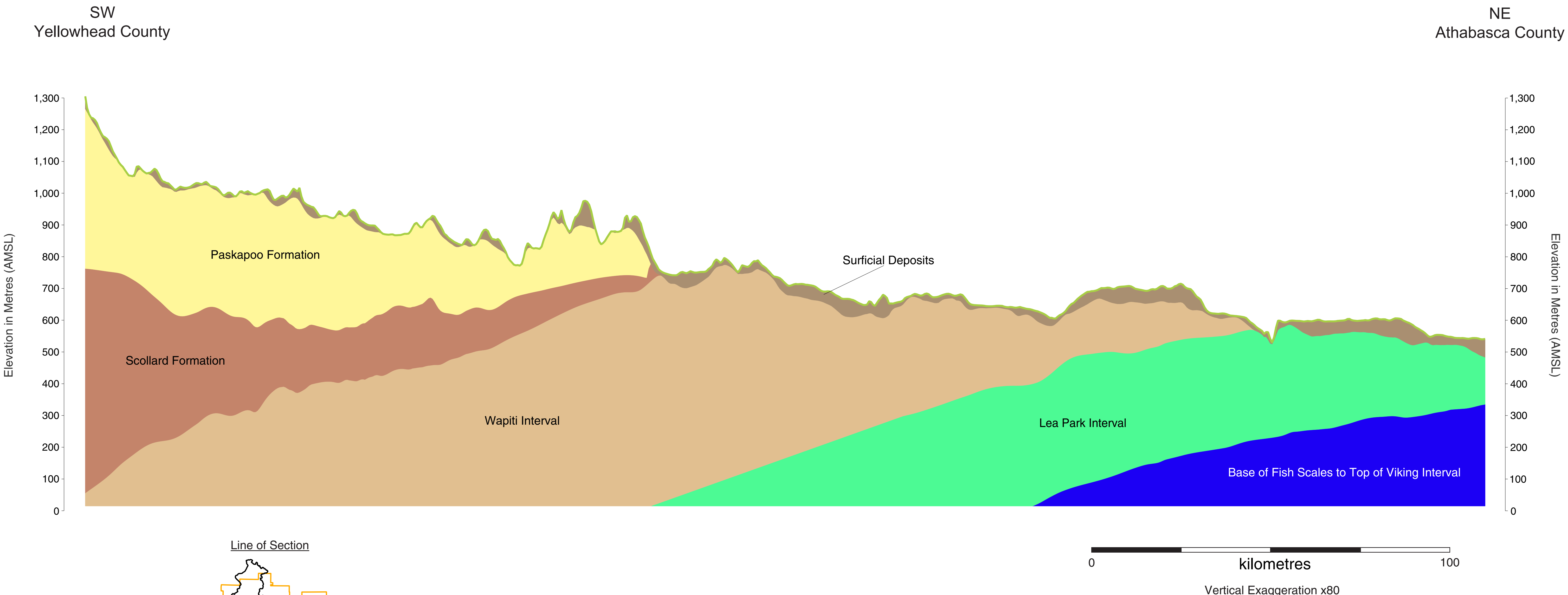
Table 12 shows the number of water well records that have enough details to be assigned to one formation or interval. The table also shows the average long-term yield (Q_{20}) of the water wells in each formation or interval. The surficial deposits, the Paskapoo Formation, and the Wapiti Interval are the most prolific aquifer systems in the UAR in terms of usage, with the Paskapoo Formation representing the highest long-term yields. The Paskapoo Formation is broken down into its individual members in Section 4.3.

Formation or Interval	Number of Records	Average Q_{20} (m^3/day)
Surficial Deposits	12,541	196
Paskapoo	12,214	209
Scollard	745	79
Wapiti	15,700	91
Lea Park	1,738	99
Base of Fish Scales to Top of Viking	1	Insufficient Data
Total	42,939	

Table 12. Water Well Records by Formation or Interval

The Base of Fish Scales to Top of Viking Interval is deeper than 150 metres BGL throughout the entire UAR. There is one water well completed in the Interval that is 248 metres deep. The Base of Fish Scales to Top of Viking Interval and all deeper geounits will not be evaluated in the present study due to a lack of data and the regulatory and logistical difficulties of drilling a water well to the required depth.

Figure 16 on the following page is a southwest–northeast cross-section from Yellowhead County to Athabasca County that shows the geounits that are present to an elevation of approximately 0 metres above mean sea level (AMSL). Figure 17 on Page 29 is a northwest–southeast cross-section from Big Lakes County to Lac St. Anne County that shows the geounits that are present to an elevation of approximately 0 metres AMSL. Geounits shown on the cross-sections are per Branscombe, et al. (2018).



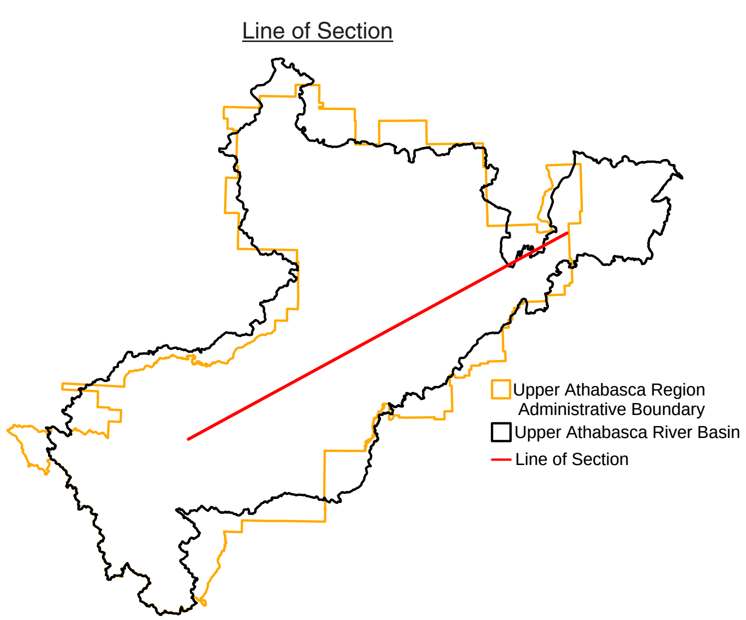


Figure 16. Southwest–Northeast Cross-Section (Yellowhead County to Athabasca County)

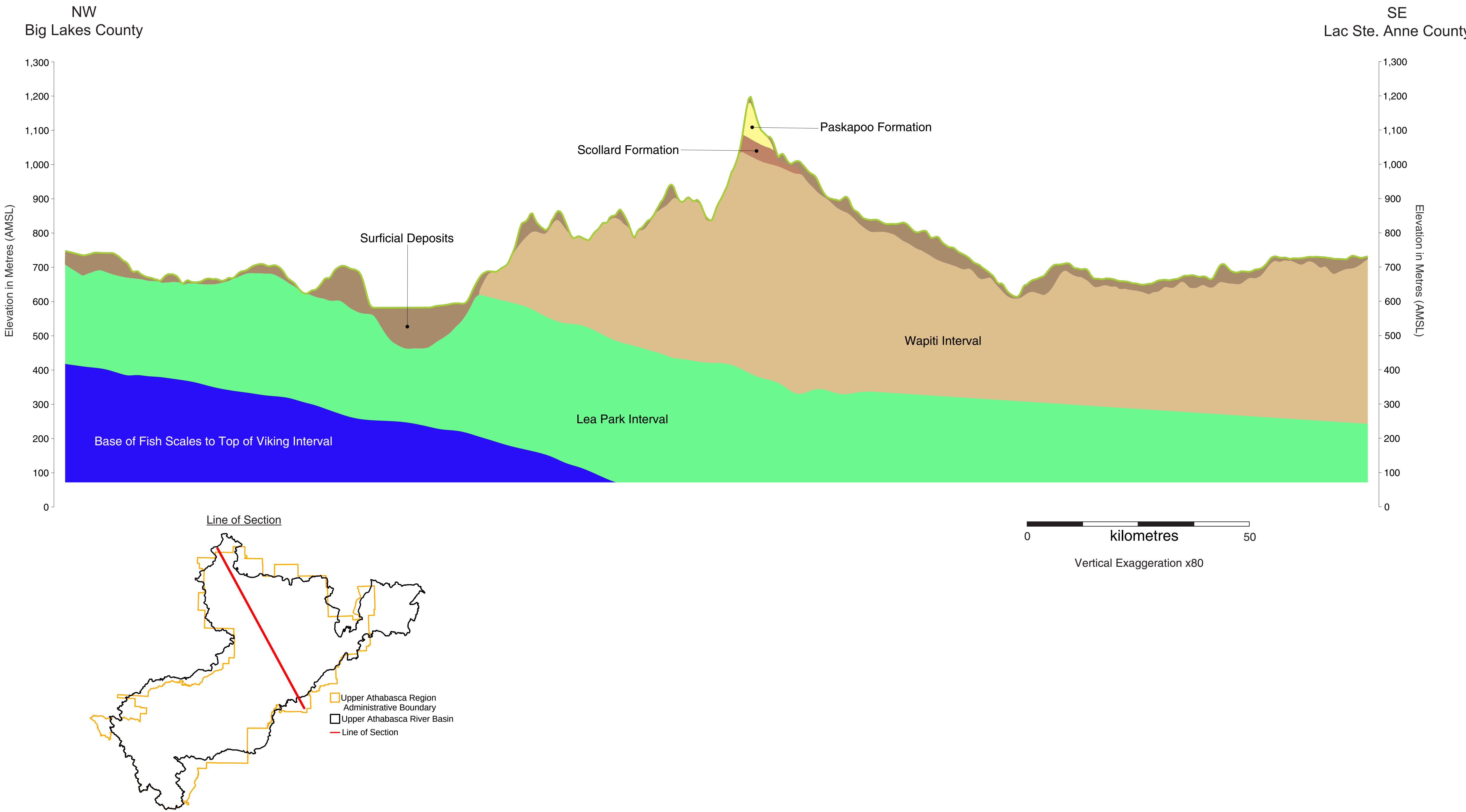


Figure 17. Northwest–Southeast Cross-Section (Big Lakes County to Lac Ste. Anne County)

4.2. Surficial Deposits

Within the UAR, the surficial deposits range in thickness from very thin to non-existent in most of the western half of the UAR to over 100 metres thick within a buried bedrock valley that runs west to east along the northern edge of the UAR. Map 5 shows the thickness of the surficial deposits throughout the UAR.

Map 6 shows the water wells completed in the surficial deposits in the UAR with enough information to calculate a long-term yield. The surficial deposits form important aquifers in the eastern portion of the UAR, especially for domestic and agricultural groundwater users. In this area of the UAR, the Wapiti and Lea Park intervals make up the uppermost bedrock, and both have relatively low yields. Map 7 shows contoured areas of long-term yields for water wells completed in the surficial deposits. While the surficial deposits are very thick and high-yielding along the northern edge of the UAR, there are relatively few water wells that are completed in the buried bedrock valley represented by the thick surficial deposits along the northern edge of the UAR.

Map 8 and Map 9 show the water wells completed in the surficial deposits that have available values for total dissolved solids (TDS) and hardness, respectively. Table 13 shows an overview of the available TDS and hardness results for groundwater samples from water wells completed in the surficial deposits. Table 14 shows the number of chemical analysis records that fit into the four categories of chemical hardness as defined by McGowan (2000). Most of the chemical analysis records are categorized as chemically very hard; it is likely that the groundwater samples that yielded hardness values of between 0 and 60 milligrams per litre (mg/L) were sampled after passing through a water softener.

Chemical Parameter	Number of Records	Maximum (mg/L)	Minimum (mg/L)	Average (mg/L)	Median (mg/L)
TDS	1,271	5,131	34	827	659
Hardness	1,261	2,640	1	365	311

Table 13. Surficial Deposits – TDS and Hardness Overview

Hardness (mg/L)	Number of Records
0 – 60 (Soft)	153
60 – 120 (Moderately Hard)	80
120 – 180 (Hard)	106
180+ (Very Hard)	922
Total	1,261

Table 14. Surficial Deposits – Hardness Categories

Map 10 shows the locations of authorized groundwater diversions from the surficial deposits. Within the UAR, there are 1,574 groundwater authorizations associated with water wells completed in surficial aquifers. These authorizations represent a total groundwater allocation of 7,757,235 m³/year. There are 4,196 domestic water wells and 1,856 domestic & stock water wells that are completed in the surficial deposits; these represent a protected allocation of 5,245,000 m³/year and 11,600,000 m³/year, respectively. The total of allocated and protected groundwater in the surficial deposits is 24,602,235 m³/year. This value is a minimum, as there are domestic and domestic & stock water wells that could not be assigned to a geounit due to insufficient or unreported completion intervals.

Table 15 shows the number and volume of groundwater authorizations associated with water wells completed in the surficial deposits by authorization type. Table 16 shows the number and volume of groundwater authorizations associated with water wells completed in the surficial deposits by water-use category. Figure 18, Figure 19, and Figure 20 show the number of groundwater authorizations by authorization type, the annual authorized groundwater volumes by authorization type, and the annual authorized groundwater volumes by water-use category, respectively, for the surficial deposits. Most of the licences authorizing groundwater diversion from the surficial deposits are for industrial purposes, with the majority of these being *Water Act* licences.

Authorization Type	Number of Authorizations	Annual Volume (m^3/year)
Water Resources Act Licence	217	2,538,921
Water Resources Act Interim Licence	24	408,847
Water Act TDL	3	52,925
Water Act Licence	135	3,555,524
Water Act Registration	1,195	1,201,018
Total	1,574	7,757,235

Table 15. Surficial Deposits – Groundwater Authorizations by Authorization Type

Water-Use Category	Number of Authorizations	Annual Volume (m^3/year)
Agricultural	1,439	1,756,317
Industrial	97	5,285,084
Municipal	38	715,834
Total	1,574	7,757,235

Table 16 .Surficial Deposits – Groundwater Authorizations by Water-Use Category

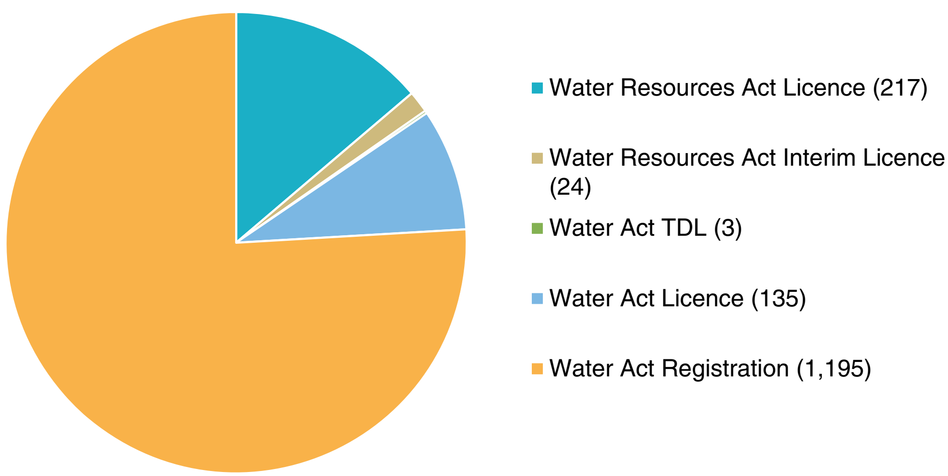


Figure 18. Surficial Deposits – Number of Groundwater Authorizations by Authorization Type

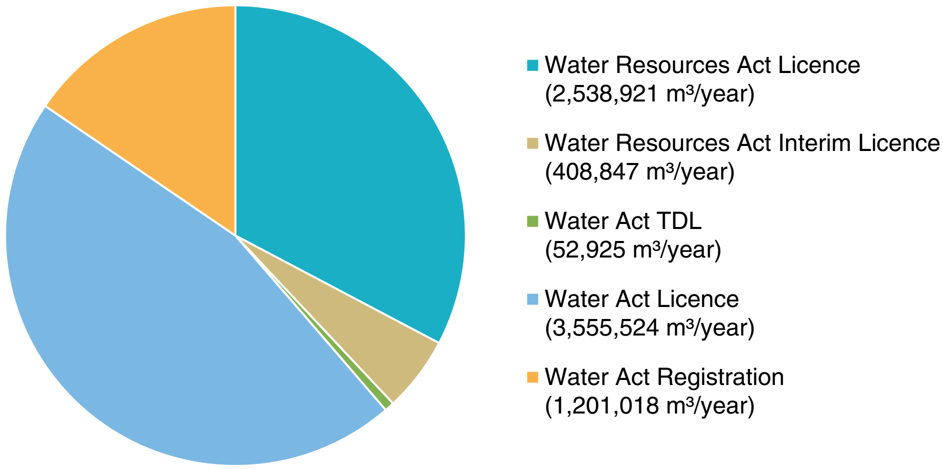


Figure 19. Surficial Deposits – Annual Authorized Groundwater Volumes by Authorization Type

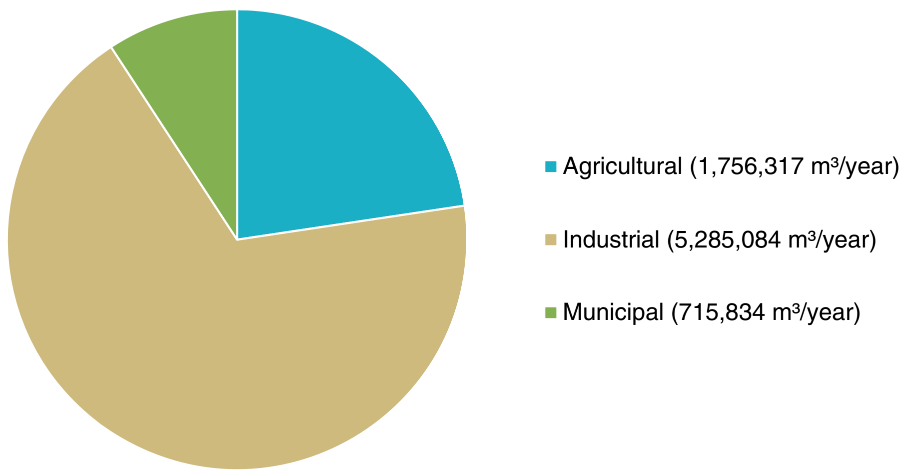
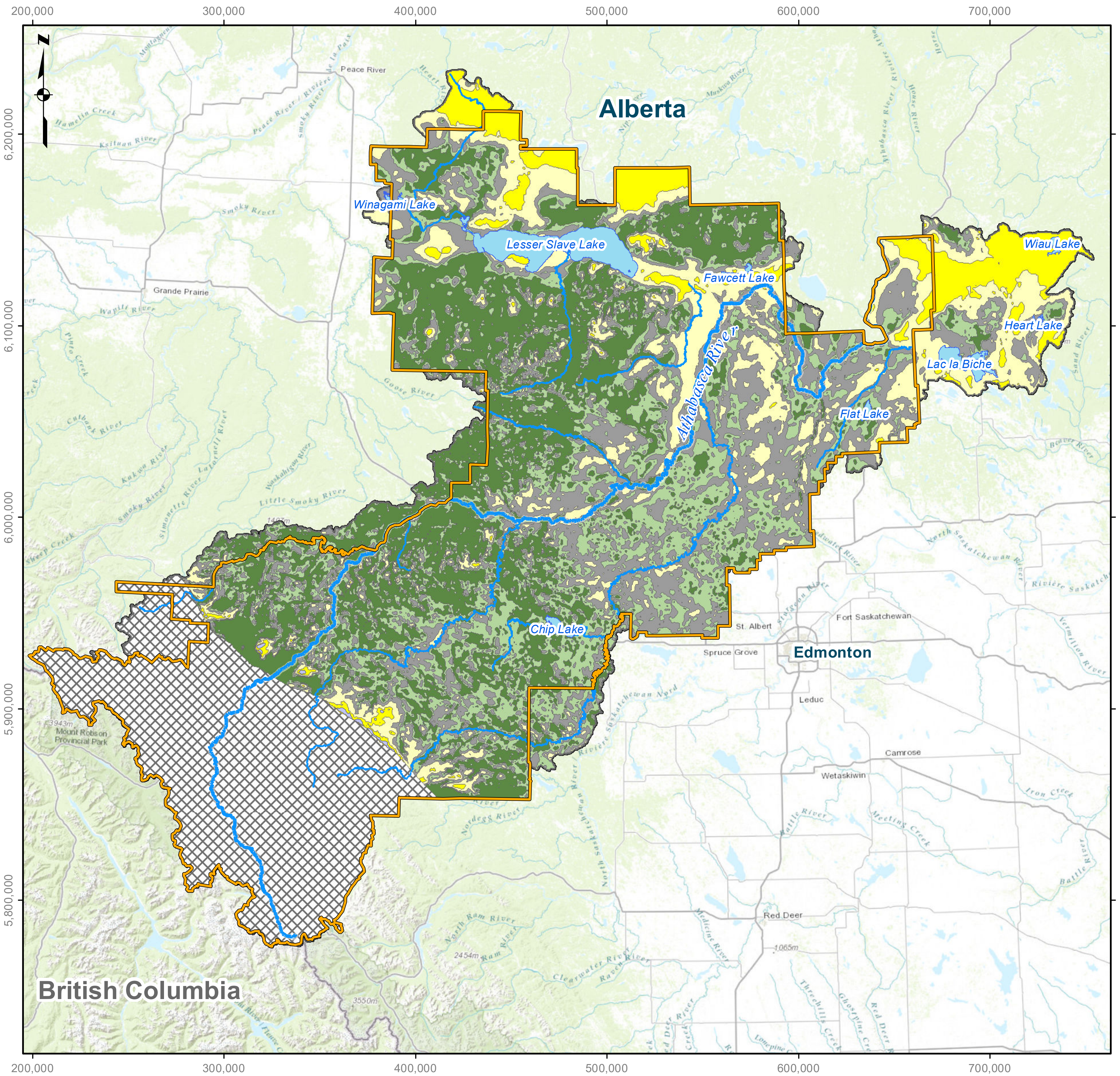
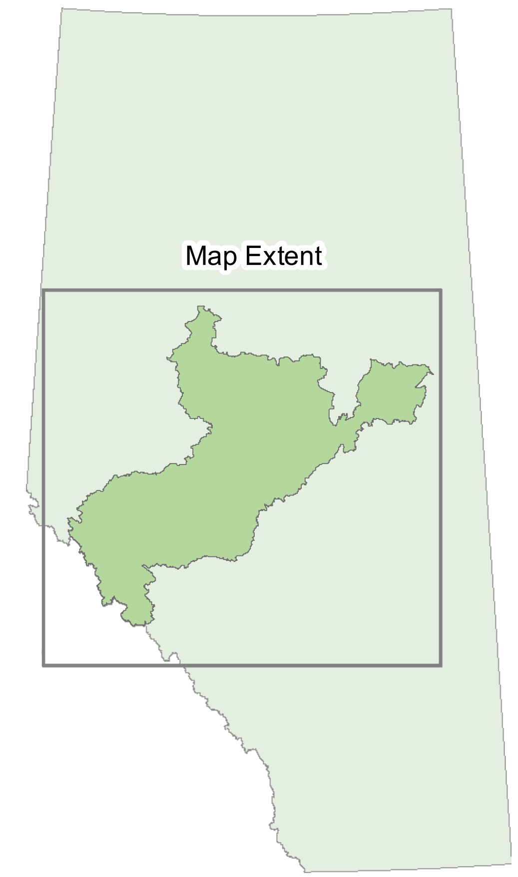


Figure 20. Surficial Deposits – Annual Authorized Groundwater Volumes by Water-Use Category





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt

Surficial Deposit Thickness (m)

- 0 - 10
- 10 - 25
- 25 - 50
- 50 - 100
- 100+

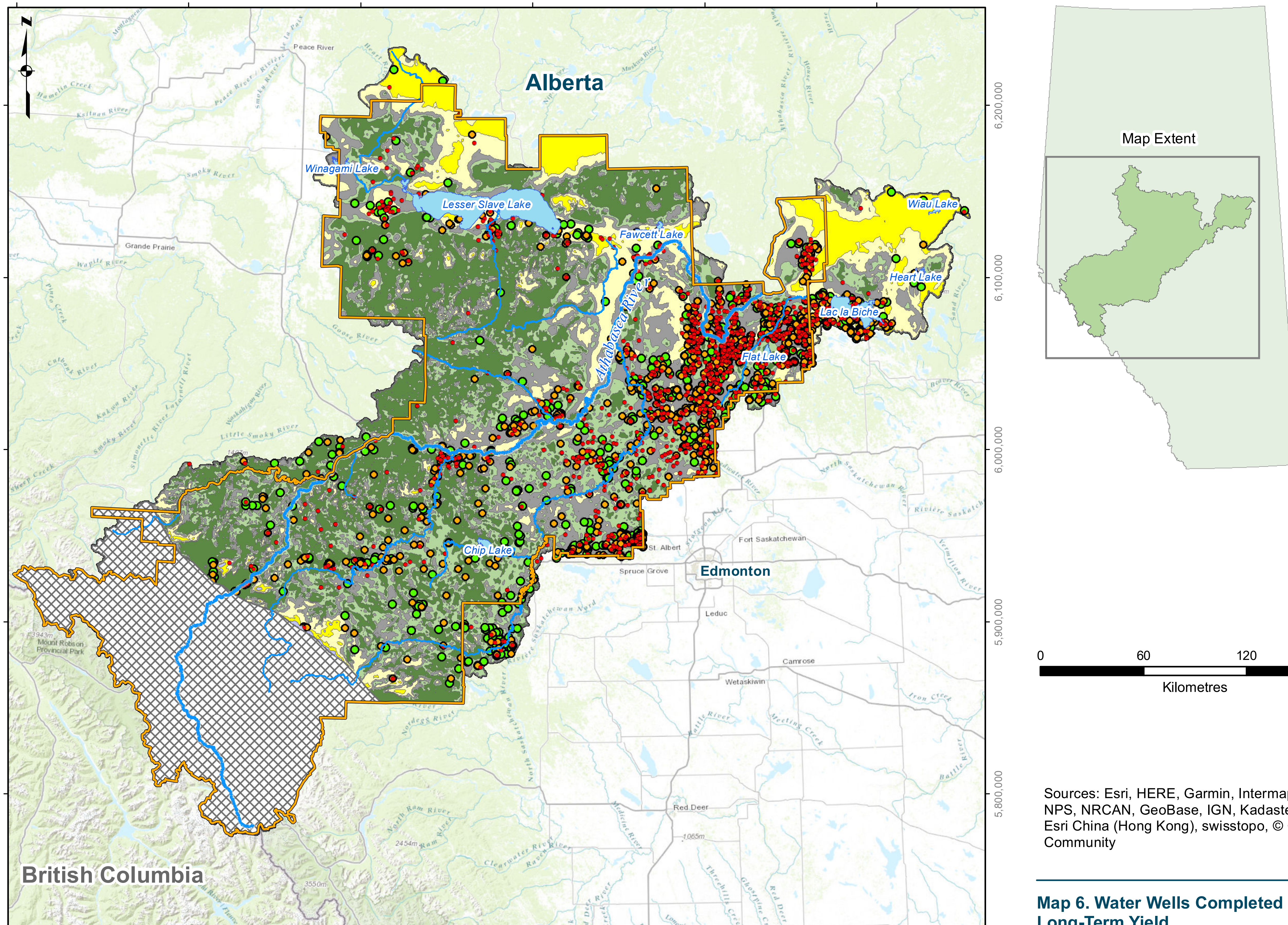
0 60 120 180

Kilometres

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 5. Thickness of the Surficial Deposits



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt

Surficial Deposit Thickness (m)

- 0 - 10
- 10 - 25
- 25 - 50
- 50 - 100
- 100+

Water Well with Long-Term Yield (m^3/day)

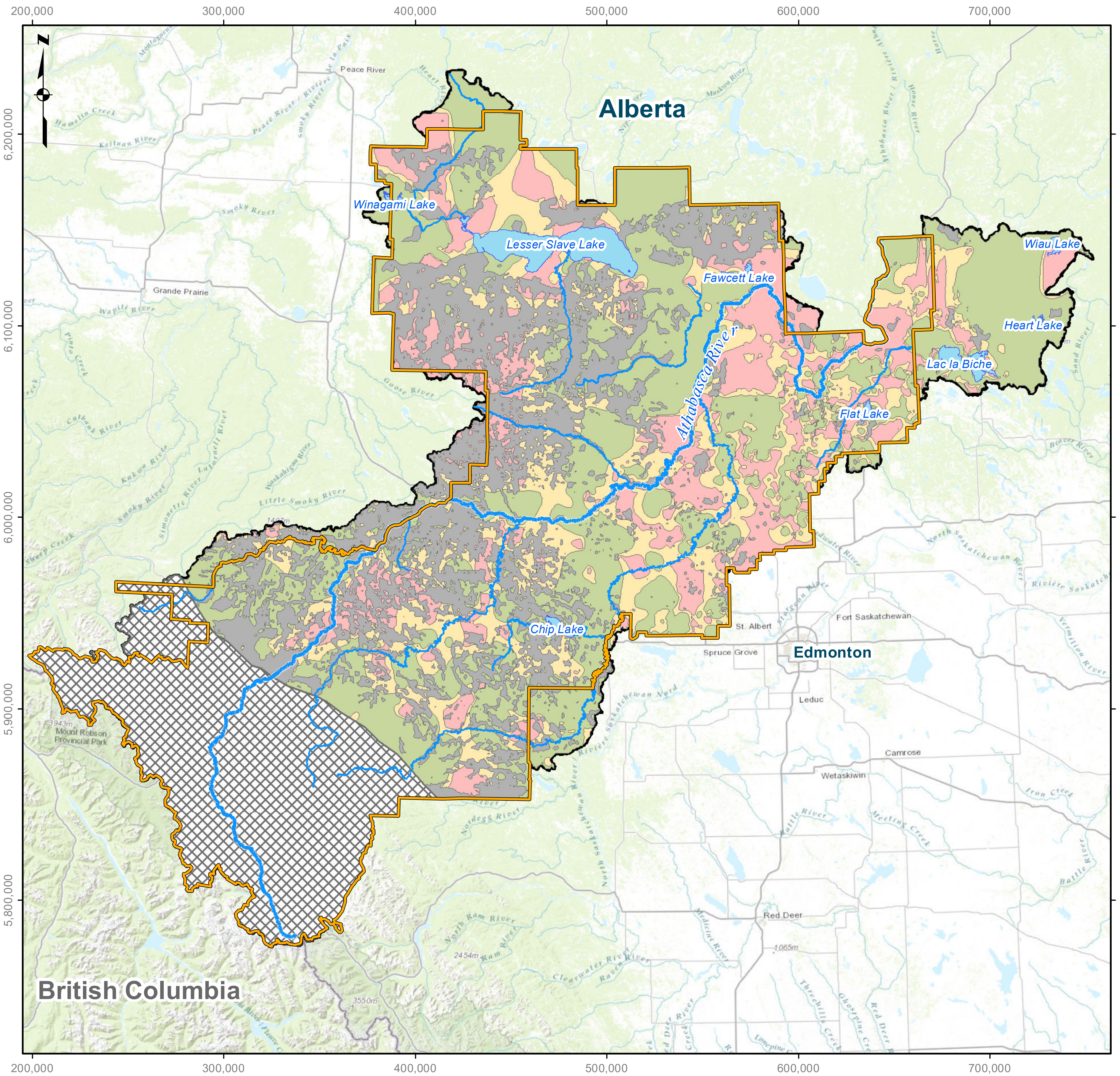
- 100+
- 25 - 100
- 0 - 25

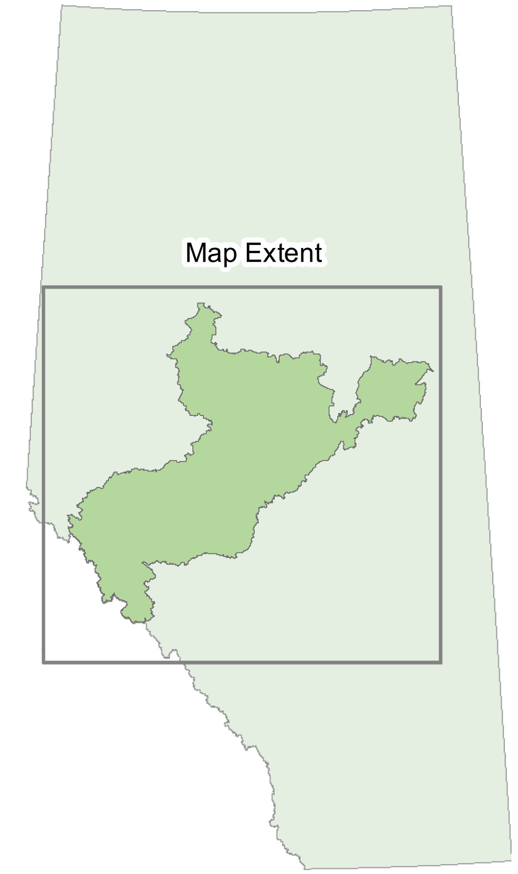
0 60 120 180

Kilometres

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 6. Water Wells Completed in the Surficial Deposits with Long-Term Yield



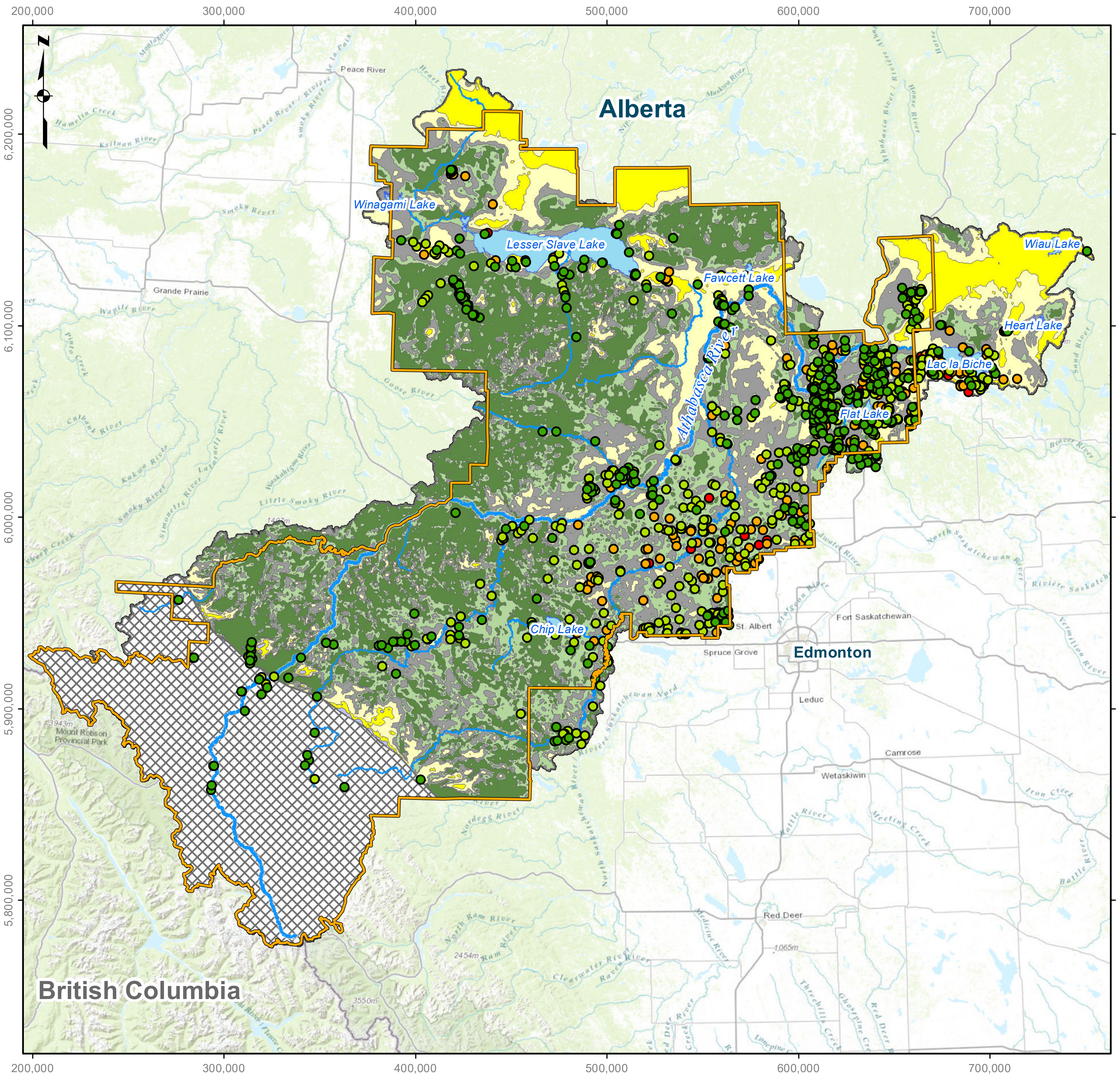


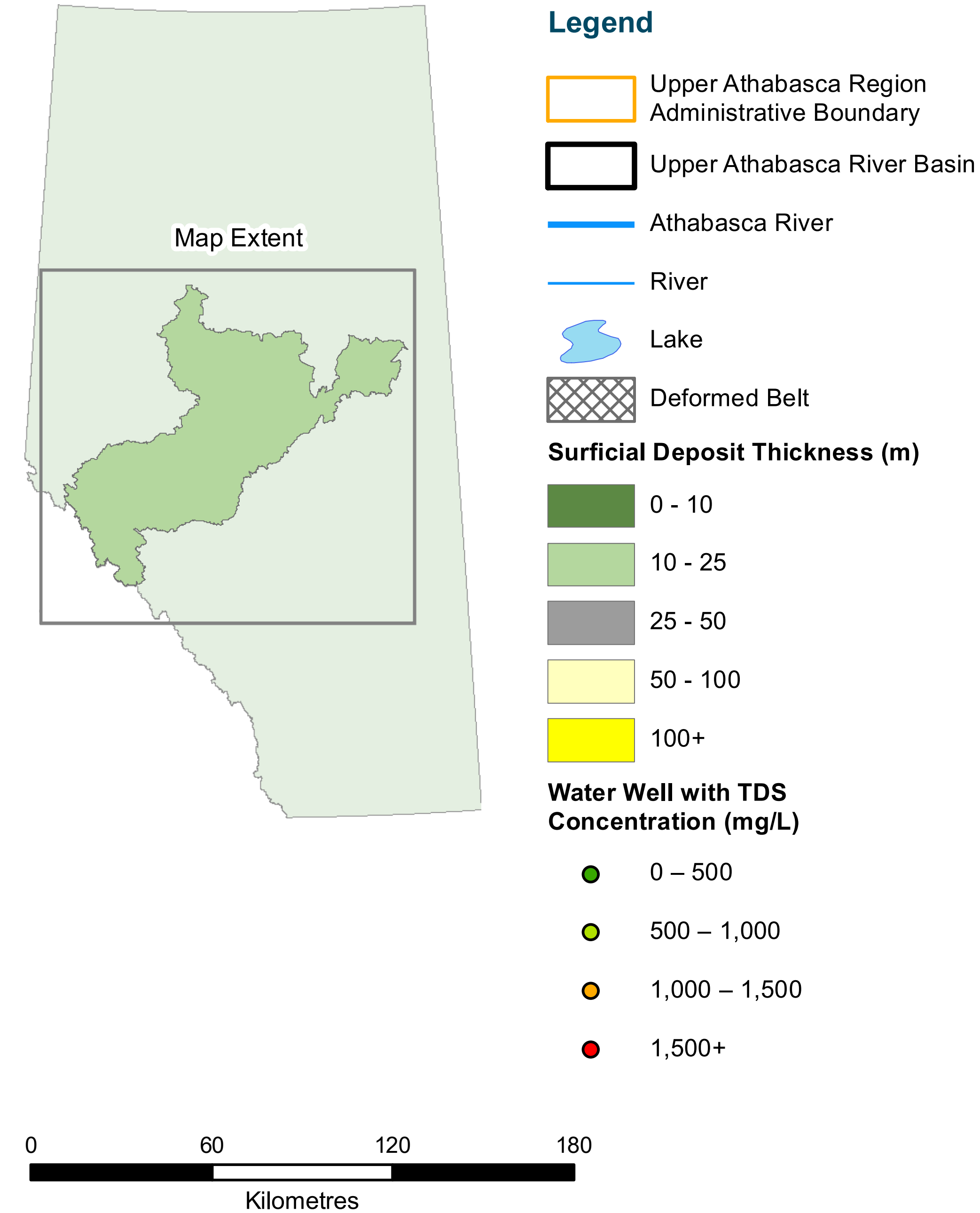
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the surficial deposits.

Branscombe, et al. (2018)

Map 7. Long-Term Water Well Yields Within the Surficial Deposits

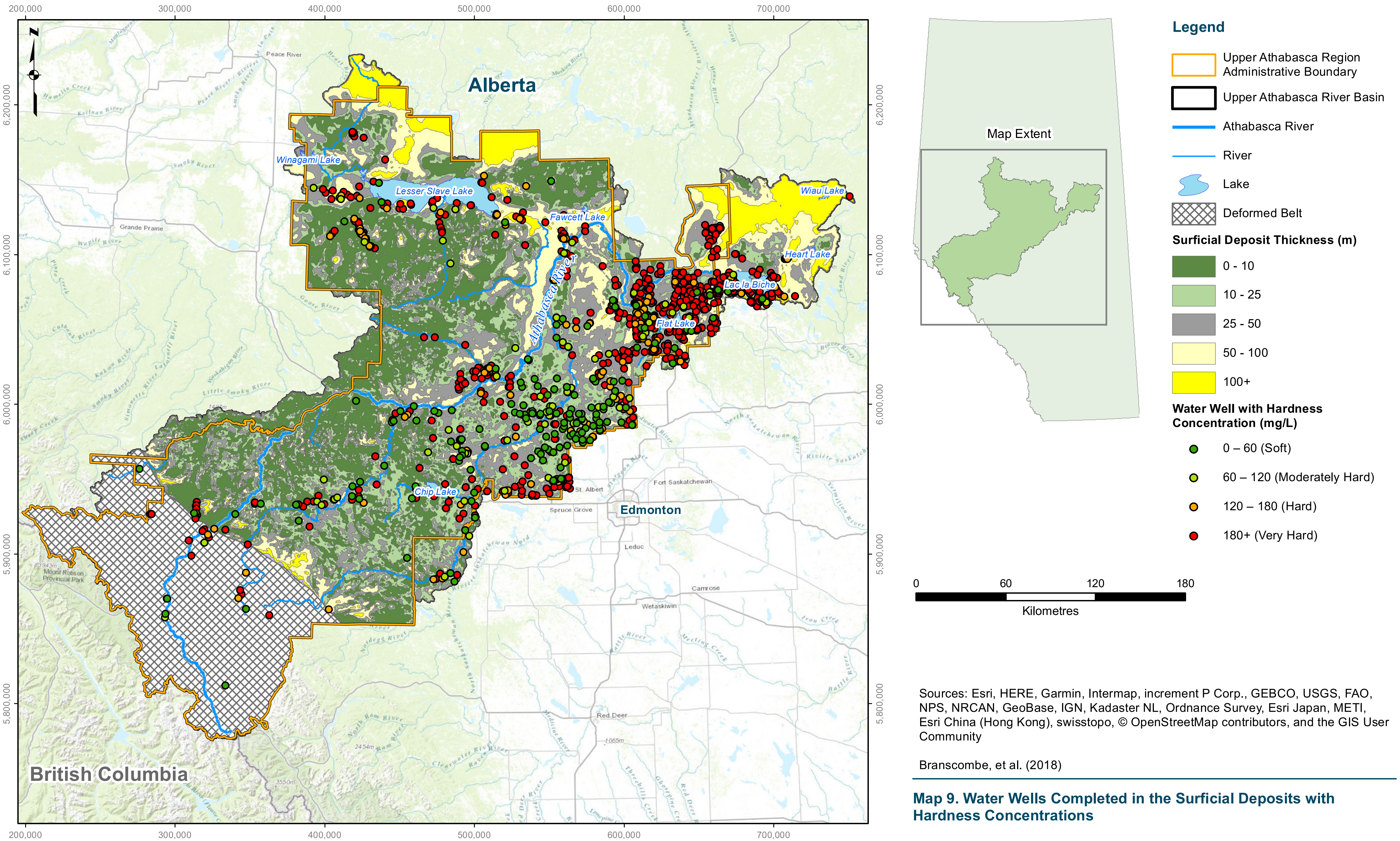




Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

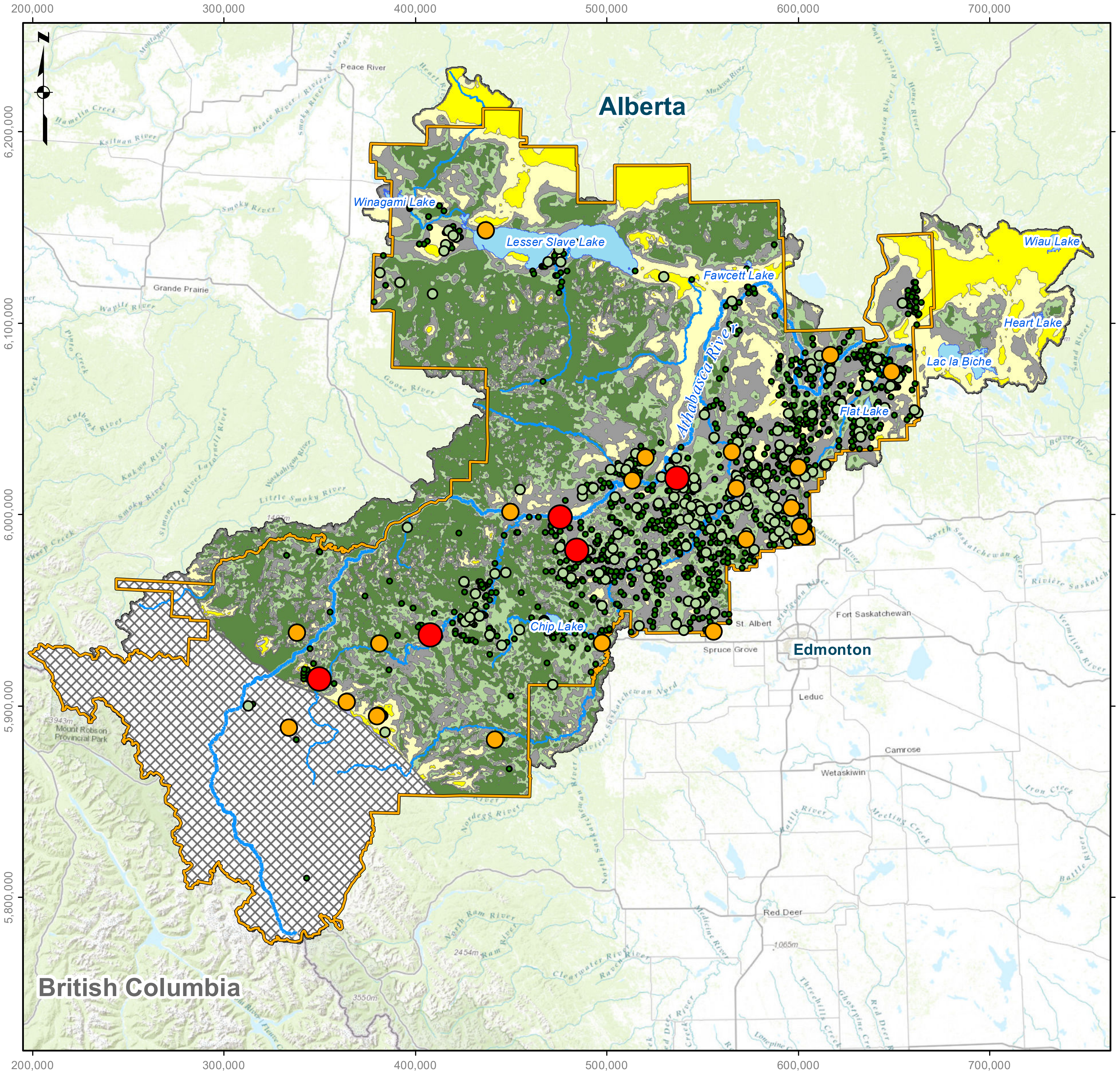
Map 8. Water Wells Completed in the Surficial Deposits with Total Dissolved Solids Concentrations

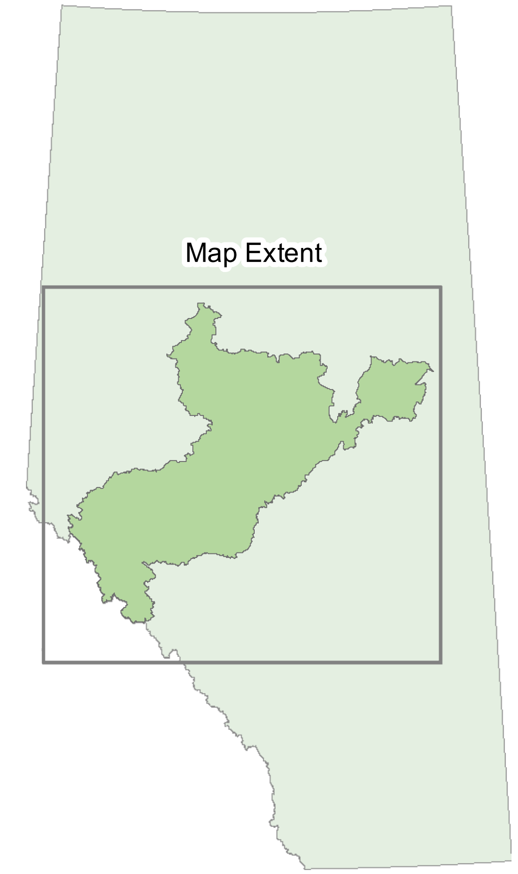


Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 9. Water Wells Completed in the Surficial Deposits with Hardness Concentrations





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt

Surficial Deposit Thickness (m)

- 0 - 10
- 10 - 25
- 25 - 50
- 50 - 100
- 100+

Authorization (m³/year)

- 0 – 2,500
- 2,500 – 10,000
- 10,000 – 100,000
- 100,000 +

0 60 120 180

Kilometres

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 10. Groundwater Authorizations in the Surficial Deposits

4.3. Paskapoo Formation

The Paskapoo Formation will first be considered as one geounit per the delineation created by Branscombe, et al. (2018), and then broken down into individual members using grid files prepared by Lyster and Andriashek (2012).

The Paskapoo Formation is geologically the youngest bedrock geounit in the UAR and therefore forms the top of the stratigraphic column for the bedrock in the UAR. The Formation is thickest in the southwestern portion of the UAR, thins to the northeast, and is entirely absent in the northeastern part of the UAR. Map 11 shows the extent of the Paskapoo Formation in the UAR, in addition to any areas where the Formation is deeper than 150 metres BGL in the UAR.

Map 12 shows the water wells completed in the Paskapoo Formation in the UAR with enough information to calculate a long-term yield. The map shows that the Paskapoo Formation forms an important aquifer system in the southwestern portion of the UAR. Map 13 shows contoured areas of long-term yields for water wells completed in the Paskapoo Formation.

Map 14 and Map 15 show the water wells completed in the Paskapoo Formation that have available values for TDS and hardness, respectively. Table 17 shows an overview of the available TDS and hardness results for groundwater samples from water wells completed in the Paskapoo Formation. Table 18 shows the number of chemical analysis records that fit into the four categories of chemical hardness as defined by McGowan (2000). Most of the chemical analysis records are categorized as chemically soft or very hard; it is likely that the groundwater samples that yielded hardness values of between 0 and 60 mg/L were sampled after passing through a water softener.

Chemical Parameter	Number of Records	Maximum (mg/L)	Minimum (mg/L)	Average (mg/L)	Median (mg/L)
TDS	739	1,633	109	549	525
Hardness	699	838	1	162	139

Table 17. Paskapoo Formation – TDS and Hardness Overview

Hardness (mg/L)	Number of Records
0 – 60 (Soft)	261
60 – 120 (Moderately Hard)	63
120 – 180 (Hard)	71
180+ (Very Hard)	304
Total	699

Table 18. Paskapoo Formation – Hardness Categories

Map 16 shows the locations of authorized groundwater diversions from the Paskapoo Formation. Within the UAR, there are 734 groundwater authorizations associated with water wells completed in the Paskapoo Formation; these authorizations represent a total groundwater allocation of 6,745,360 m^3/year. There are 3,734 domestic water wells and 616 domestic & stock water wells completed in the Paskapoo Formation; these represent a protected allocation of 4,667,500 m^3/year and 3,850,000 m^3/year, respectively. The total of allocated and protected groundwater in the Paskapoo Formation is 15,262,860 m^3/year. This value is a minimum, as there are domestic and domestic & stock water wells that could not be assigned to a geounit due to insufficient or unreported completion interval details.

Table 19 shows the number and volume of groundwater authorizations associated with water wells completed in the Paskapoo Formation by authorization type. Table 20 shows the number and volume of groundwater authorizations associated with water wells completed in the Paskapoo Formation by water-use category. Figure 21, Figure 22, and Figure 23 show the number of groundwater authorizations by authorization type, the annual authorized groundwater volumes by authorization type, and the annual authorized groundwater volumes by water-use category, respectively, for the Paskapoo Formation.

Authorization Type	Number of Authorizations	Annual Volume (m³/year)
Water Resources Act Licence	138	3,666,162
Water Resources Act Interim Licence	11	460,690
Water Act TDL	25	556,070
Water Act Licence	141	1,586,699
Water Act Registration	419	475,739
Total	734	6,745,360

Table 19. Paskapoo Formation – Groundwater Authorizations by Authorization Type

Water-Use Category	Number of Authorizations	Annual Volume (m³/year)
Agricultural	525	951,410
Industrial	170	2,700,861
Municipal	39	3,093,089
Total	734	6,745,360

Table 20. Paskapoo Formation – Groundwater Authorizations by Water-Use Category

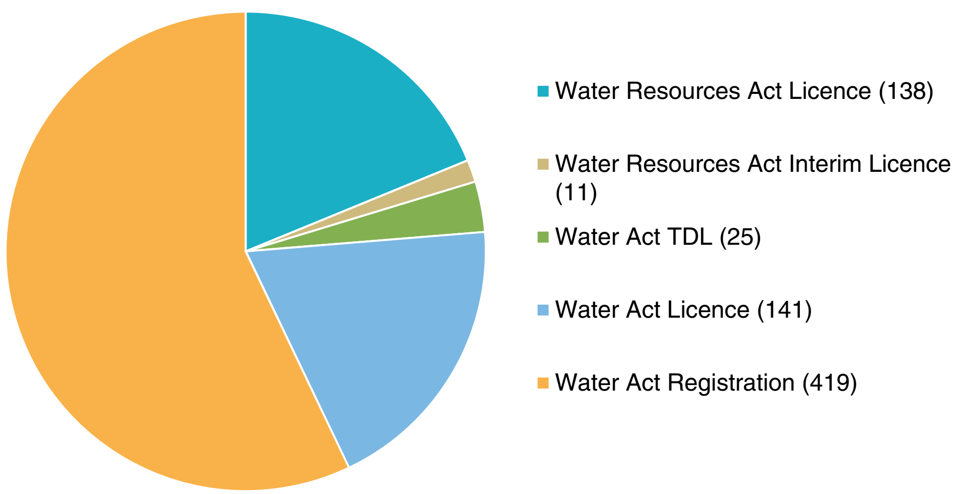


Figure 21. Paskapoo Formation – Number of Groundwater Authorizations by Authorization Type

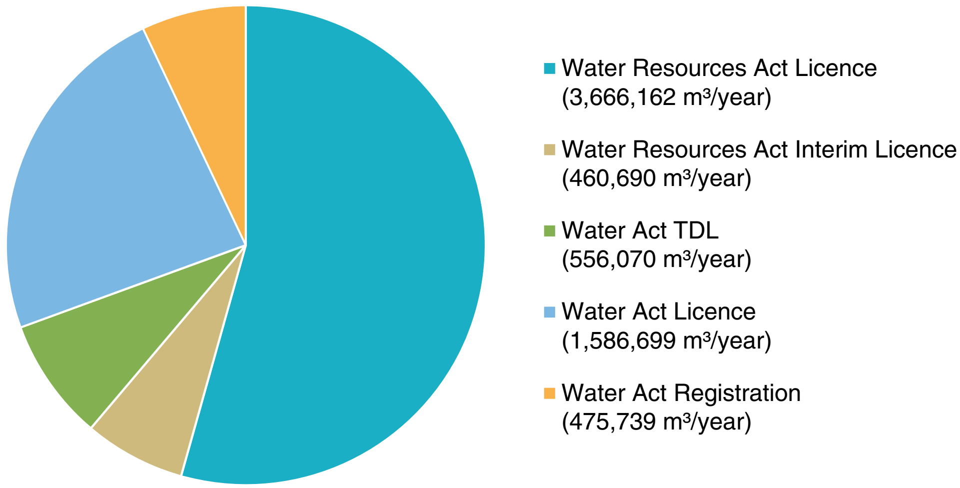


Figure 22. Paskapoo Formation – Annual Authorized Groundwater Volumes by Authorization Type

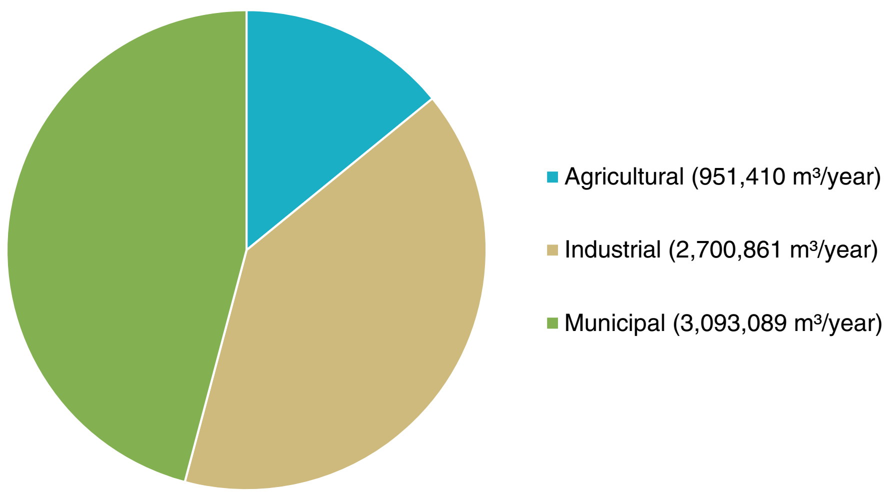
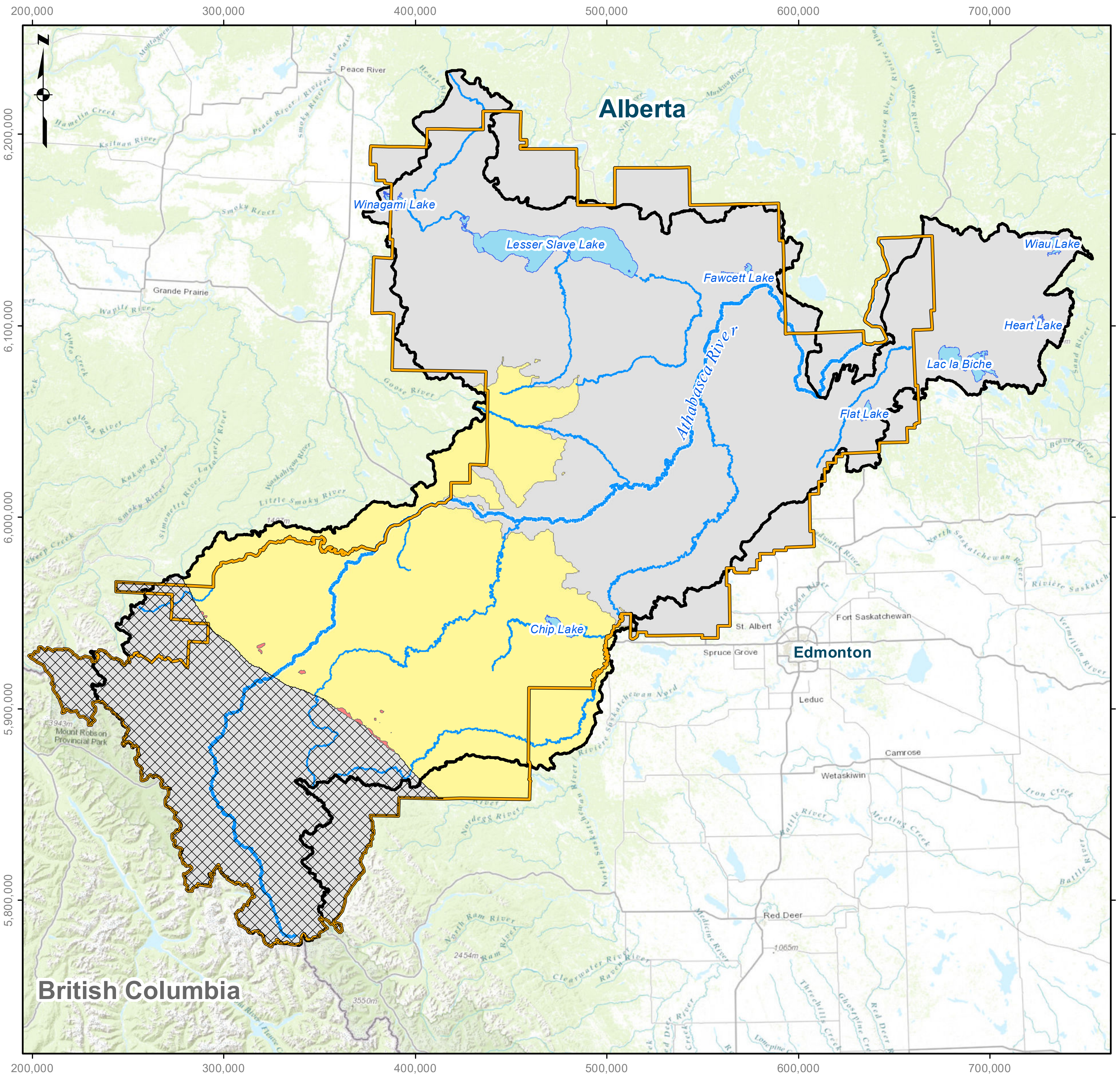
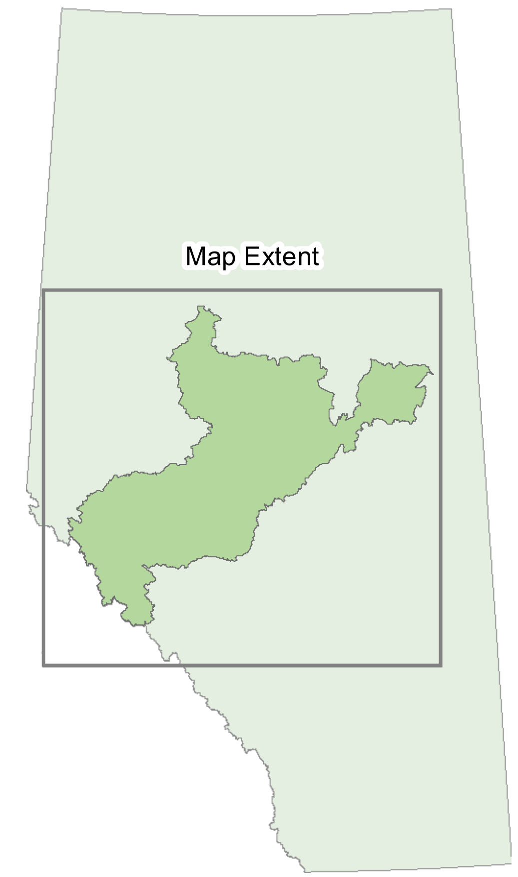


Figure 23. Paskapoo Formation – Annual Authorized Groundwater Volumes by Water-Use Category

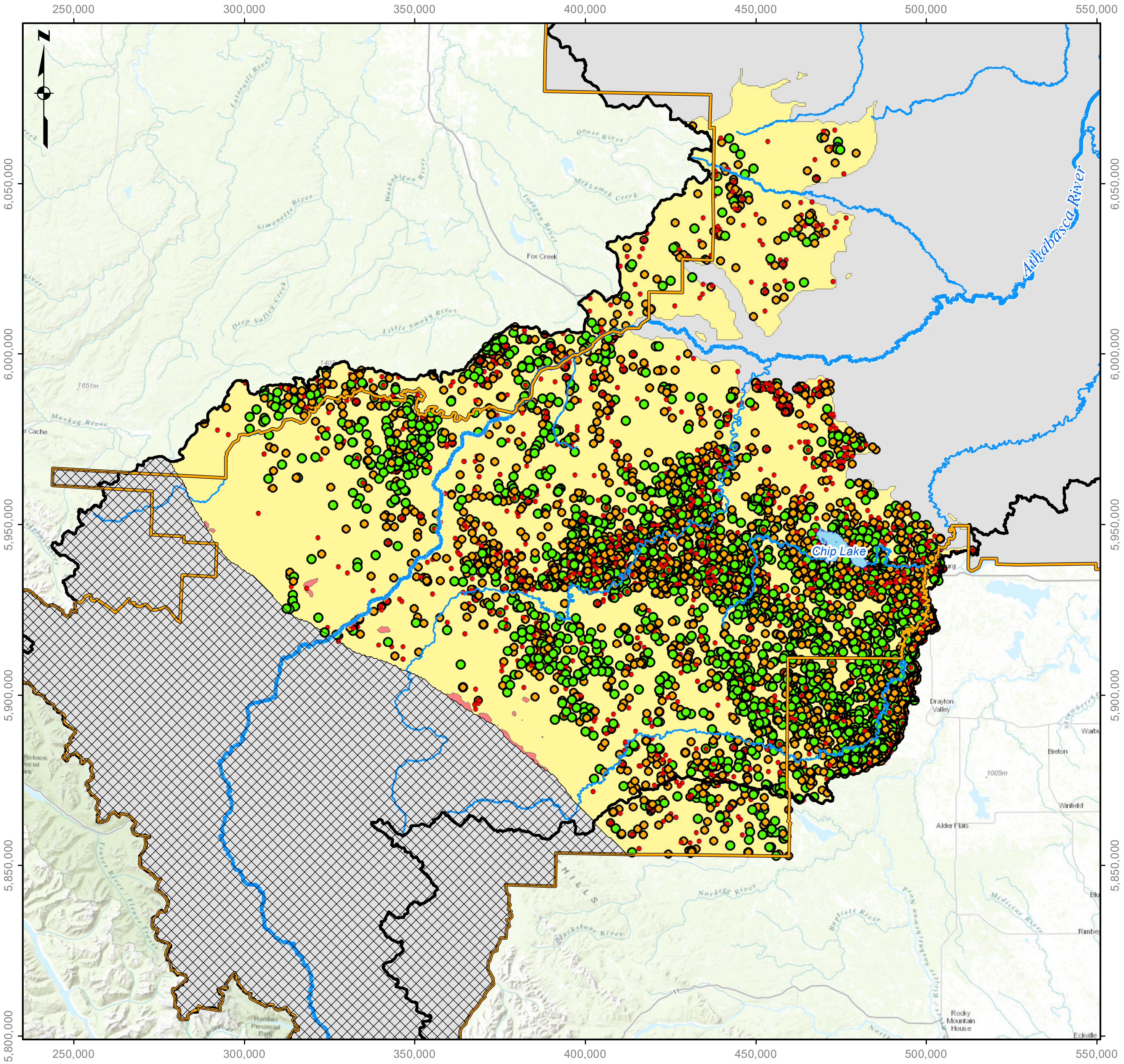


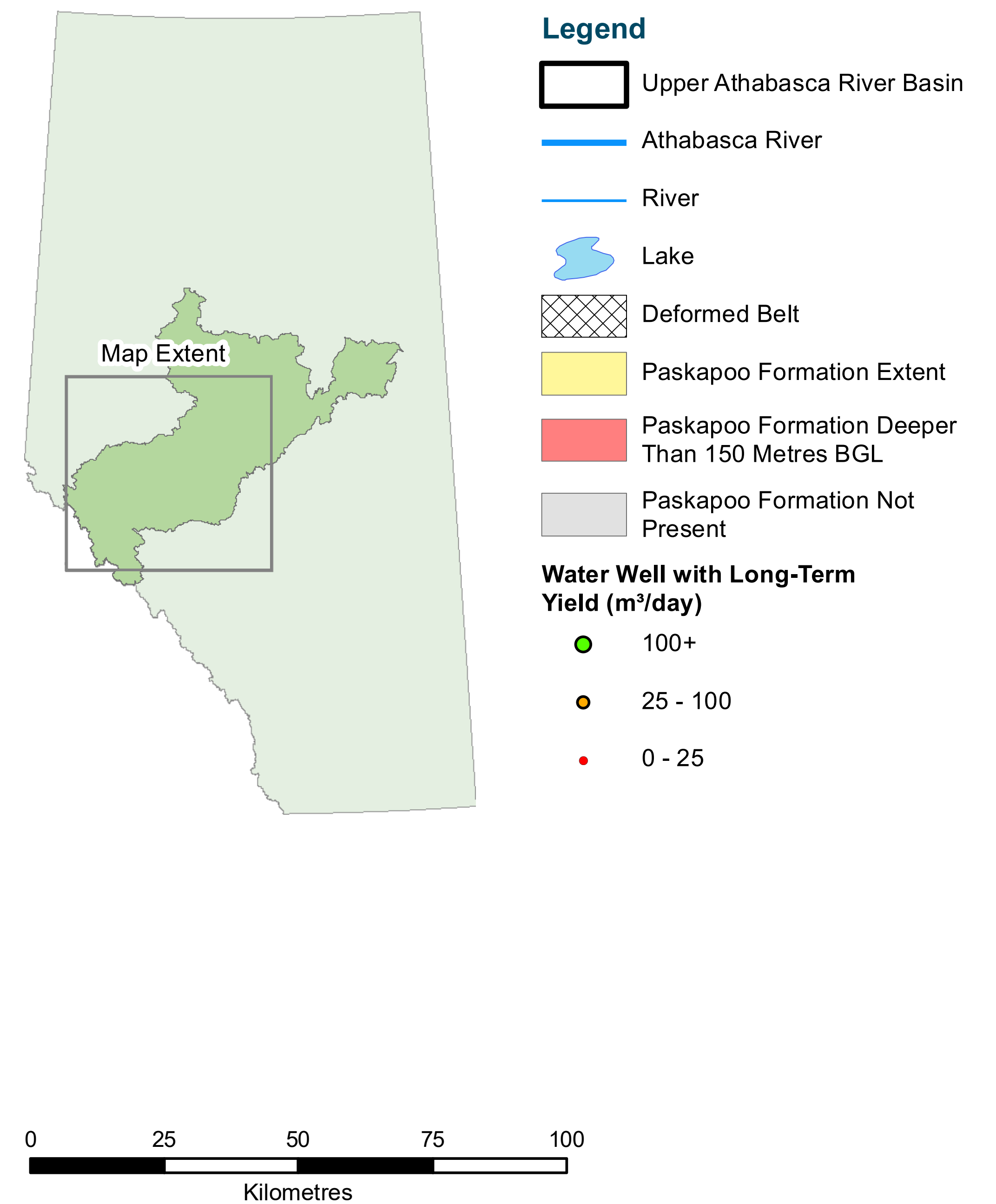


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 11. Extent of the Paskapoo Formation Within the UAR

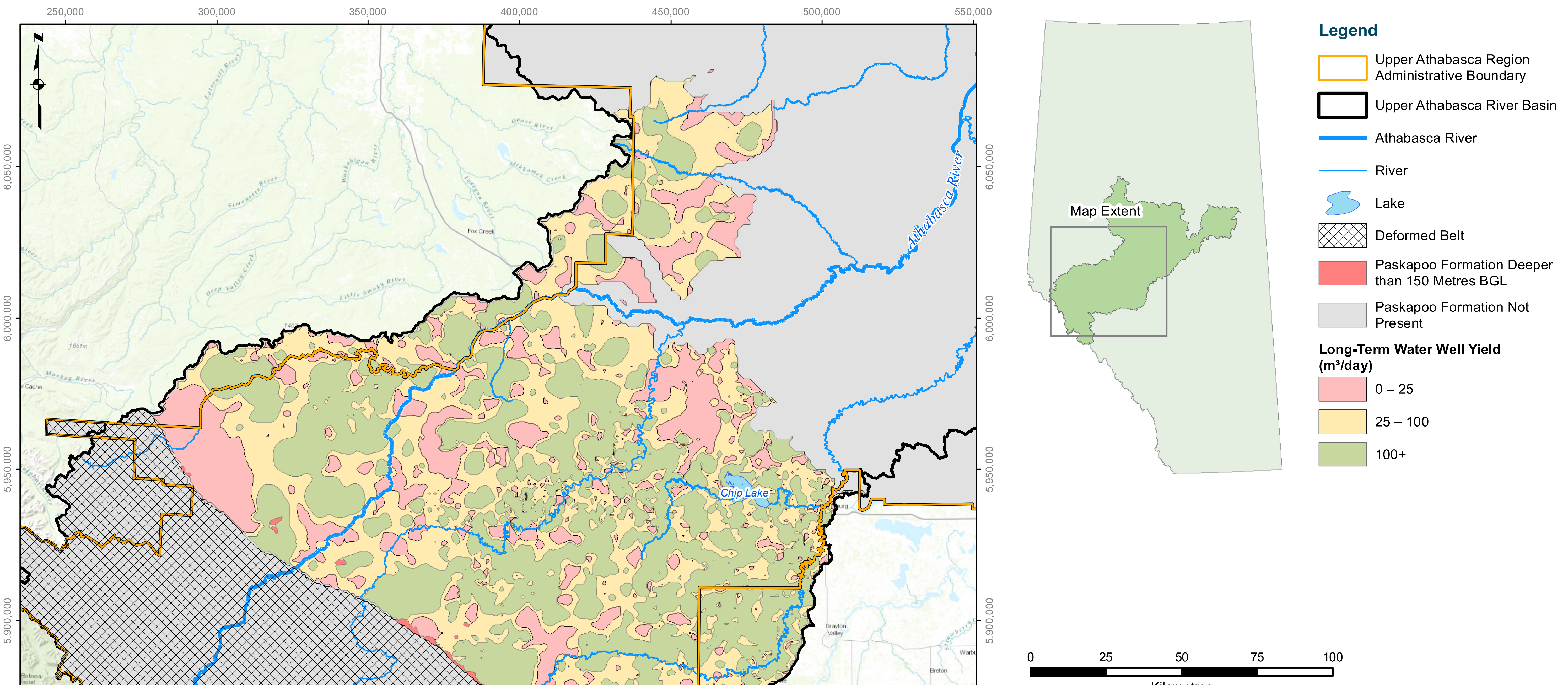




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 12. Water Wells Completed in the Paskapoo Formation with Long-Term Yield

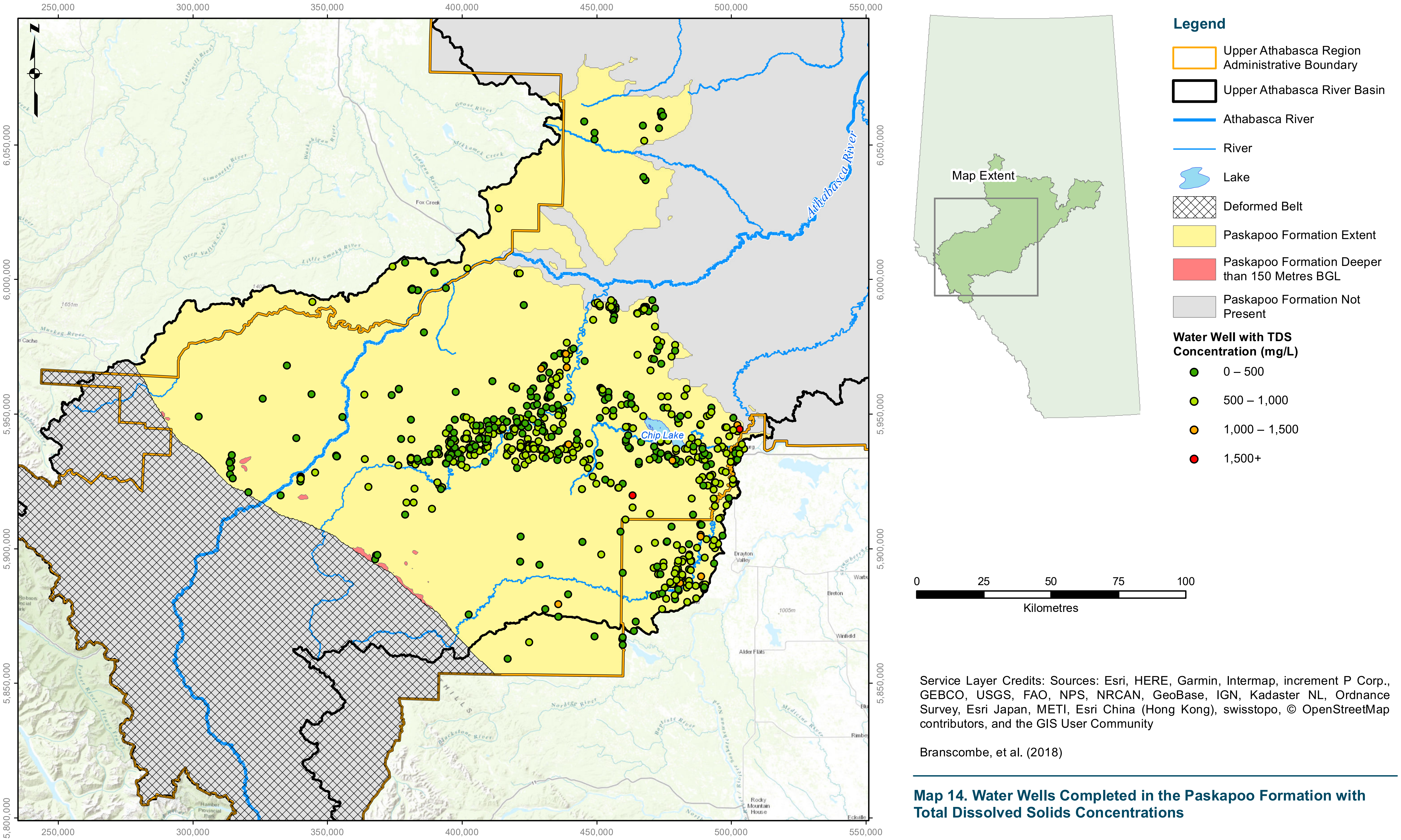


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Paskapoo Formation.

Branscombe, et al. (2018)

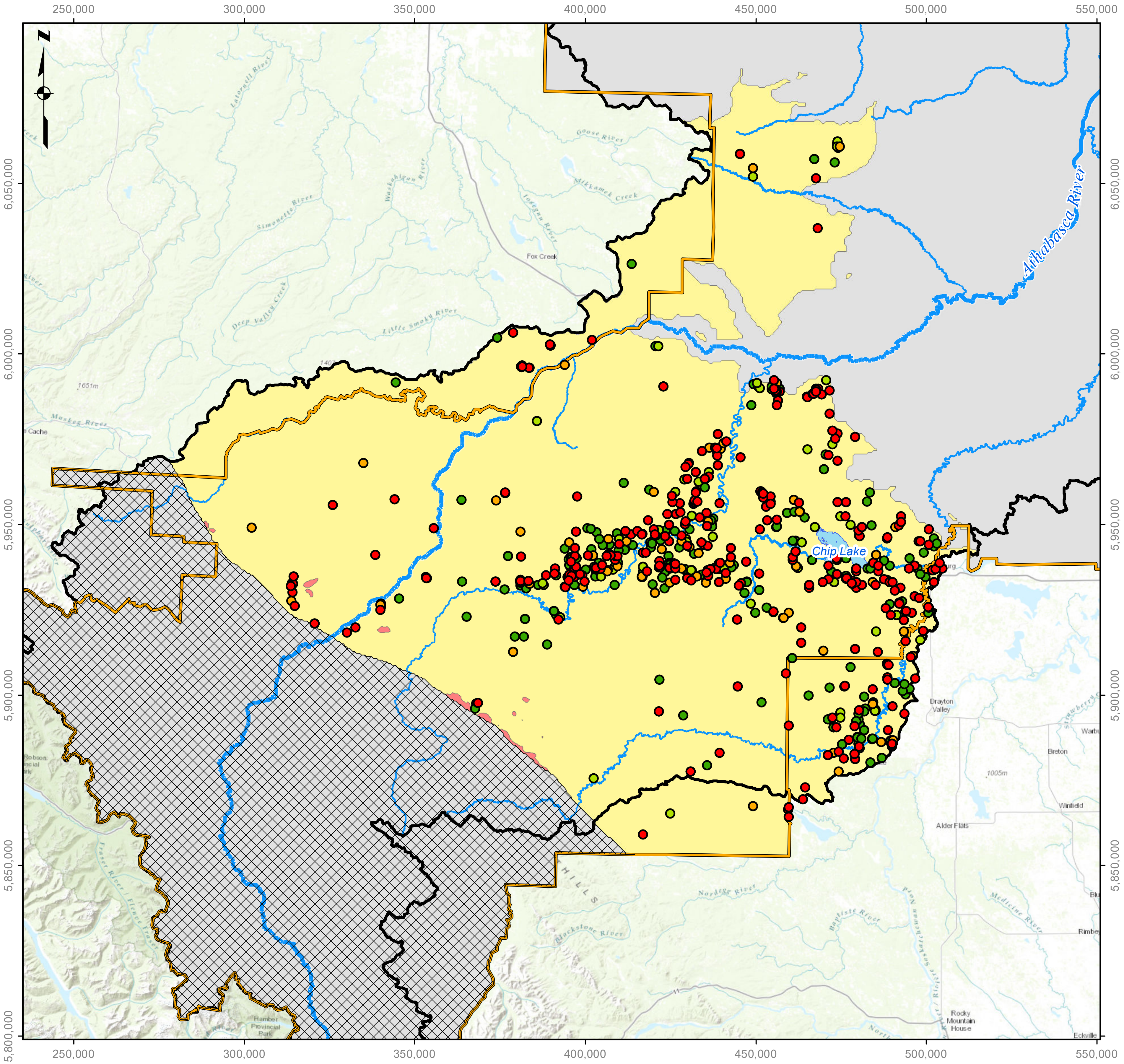
Map 13. Long-Term Water Well Yields Within the Paskapoo Formation



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 14. Water Wells Completed in the Paskapoo Formation with Total Dissolved Solids Concentrations



Legend

Upper Athabasca Region Administrative Boundary

Upper Athabasca River Basin

Athabasca River

River

Lake

Deformed Belt

Paskapoo Formation Extent

Paskapoo Formation Deeper Than 150 Metres BGL

Paskapoo Formation Not Present

Water Well with Hardness Concentration (mg/L)

- 0 – 60 (Soft)
- 60 – 120 (Moderately Hard)
- 120 – 180 (Hard)
- 180+ (Very Hard)

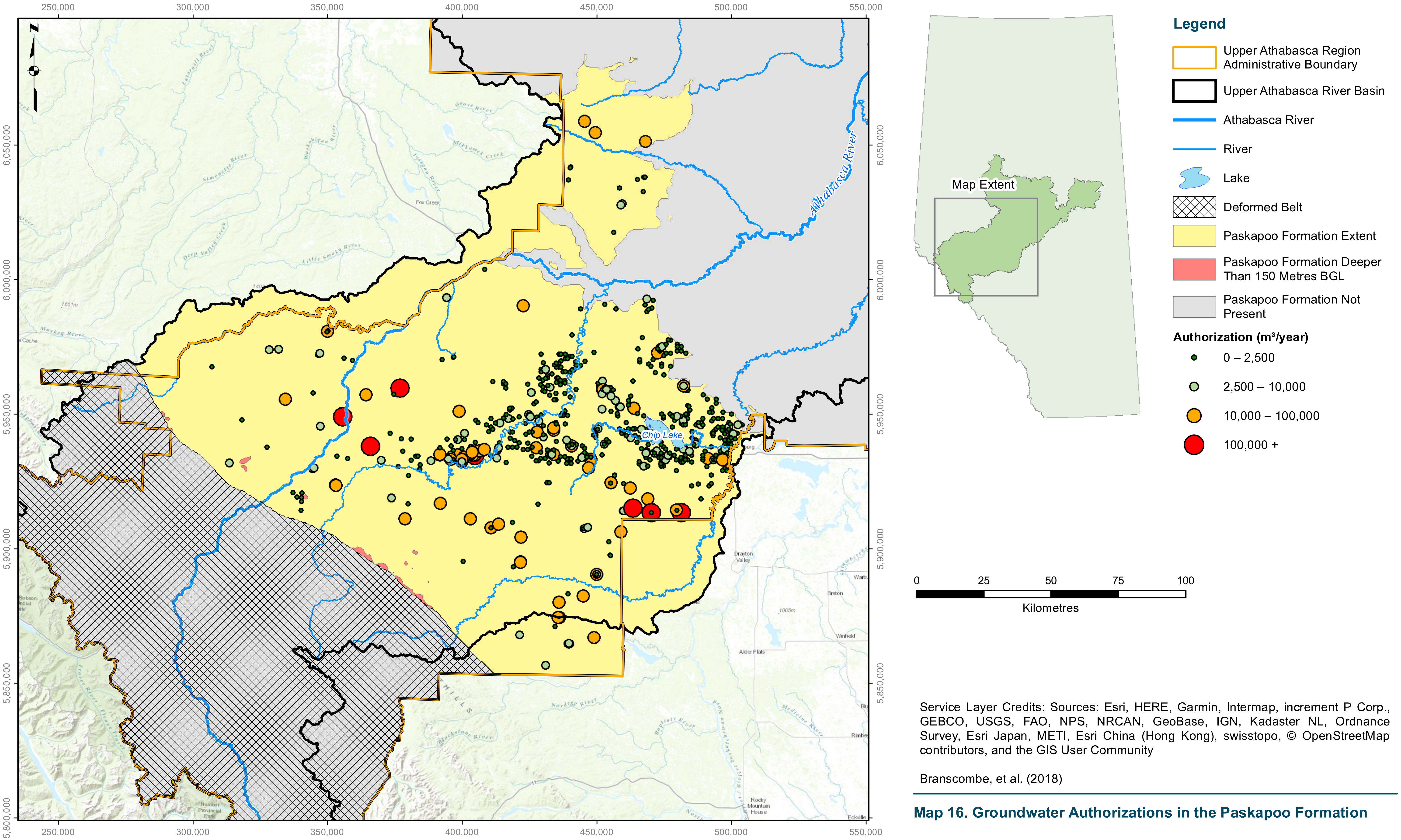
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 15. Water Wells Completed in the Paskapoo Formation with Hardness Concentrations



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 16. Groundwater Authorizations in the Paskapoo Formation

4.3.1. Dalehurst Member/Sunchild Aquifer

The individual members of the Paskapoo Formation as defined by Lyster and Andriashek (2012), from stratigraphically youngest to oldest, are the Sunchild Aquifer, the Lacombe Aquitard, and the Haynes Member; these members have been delineated within the UAR using grid files prepared by Lyster and Andriashek (2012). The methodology for identifying and delineating the Sunchild Aquifer is outlined in AGS Bulletin 066 (Lyster and Andriashek, 2012). Other sources in the literature name the Dalehurst Member as the uppermost member of the Paskapoo Formation, but since the grid files prepared by Lyster and Andriashek (2012) have been used for the present study, their terminology will be used in this report.

The Sunchild Aquifer is geologically the youngest constituent of the Paskapoo Formation and the youngest bedrock geounit in the UAR where it is present. Map 17 shows the extent of the Sunchild Aquifer in the UAR.

Map 18 shows the water wells completed in the Sunchild Aquifer in the UAR with enough information to calculate a long-term yield. The map shows that the Sunchild Aquifer is an important aquifer in the southwestern portion of the UAR. Map 19 shows contoured areas of long-term yields for water wells completed in the Sunchild Aquifer. The Sunchild Aquifer is very productive throughout its extent in the UAR.

Map 20 and Map 21 show the water wells completed in the Sunchild Aquifer that have available values for TDS and hardness, respectively. Table 21 shows an overview of the available TDS and hardness results for groundwater samples from water wells completed in the Sunchild Aquifer. Table 22 shows the number of chemical analysis records that fit into the four categories of chemical hardness as defined by McGowan (2000). Most of the chemical analysis records are categorized as chemically very hard; it is likely that the groundwater samples that yielded hardness values of between 0 and 60 mg/L were sampled after passing through a water softener.

Chemical Parameter	Number of Records	Maximum (mg/L)	Minimum (mg/L)	Average (mg/L)	Median (mg/L)
TDS	59	1,600	4	457	416
Hardness	60	450	3	178	206

Table 21. Sunchild Aquifer – TDS and Hardness Overview

Hardness (mg/L)	Number of Records
0 – 60 (Soft)	15
60 – 120 (Moderately Hard)	4
120 – 180 (Hard)	5
180+ (Very Hard)	36
Total	60

Table 22. Sunchild Aquifer – Hardness Categories

Map 22 shows the locations of authorized groundwater diversions from the Sunchild Aquifer. Within the UAR, there are 111 groundwater authorizations associated with water wells completed in the Sunchild Aquifer; these authorizations represent a total groundwater allocation of 1,695,619 m^3/year. There are 292 domestic water wells and 41 domestic & stock water wells completed in the Sunchild Aquifer; these represent a protected allocation of 365,000 m^3/year and 256,250 m^3/year, respectively. The total of allocated and protected groundwater in the Sunchild Aquifer is 2,316,869 m^3/year. This value is a minimum, as there are domestic and domestic & stock water wells that could not be assigned to a geounit due to insufficient or incomplete completion interval details.

Table 23 shows the number and volume of groundwater authorizations associated with water wells completed in the Sunchild Aquifer by authorization type. Table 24 shows the number and volume of groundwater authorizations associated with water wells completed in the Sunchild Aquifer by water-use category. Figure 24, Figure 25, and Figure 26 show the number of groundwater authorizations by authorization type, the annual authorized groundwater volumes by authorization type, and the annual authorized groundwater volumes by water-use category, respectively, for the Sunchild Aquifer.

Authorization Type	Number of Authorizations	Annual Volume (m^3/year)
Water Resources Act Licence	26	708,513
Water Resources Act Interim Licence	4	66,350
Water Act TDL	14	528,820
Water Act Licence	34	345,237
Water Act Registration	33	46,699
Total	111	1,695,619

Table 23. Sunchild Aquifer – Groundwater Authorizations by Authorization Type

Water-Use Category	Number of Authorizations	Annual Volume (m^3/year)
Agricultural	41	136,662
Industrial	68	1,496,540
Municipal	2	62,417
Total	111	1,695,619

Table 24. Sunchild Aquifer – Groundwater Authorizations by Water-Use Category

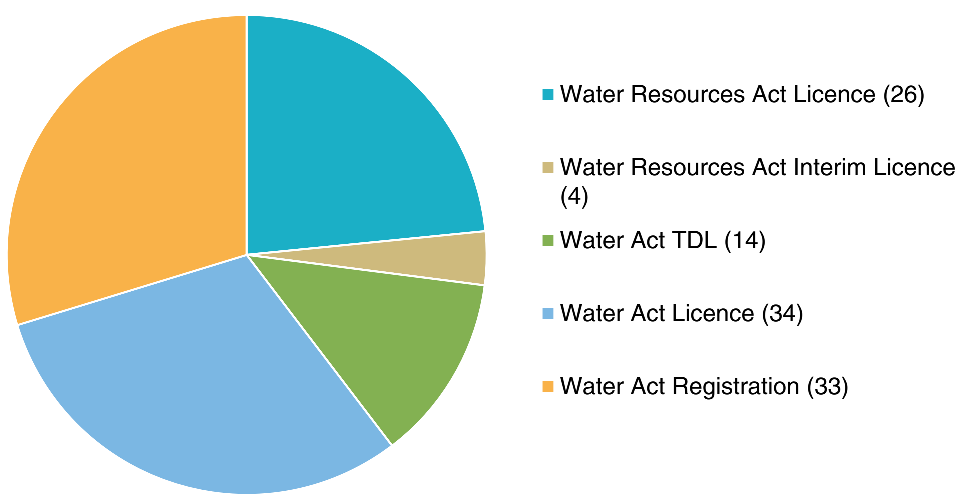


Figure 24. Sunchild Aquifer – Number of Groundwater Authorizations by Authorization Type

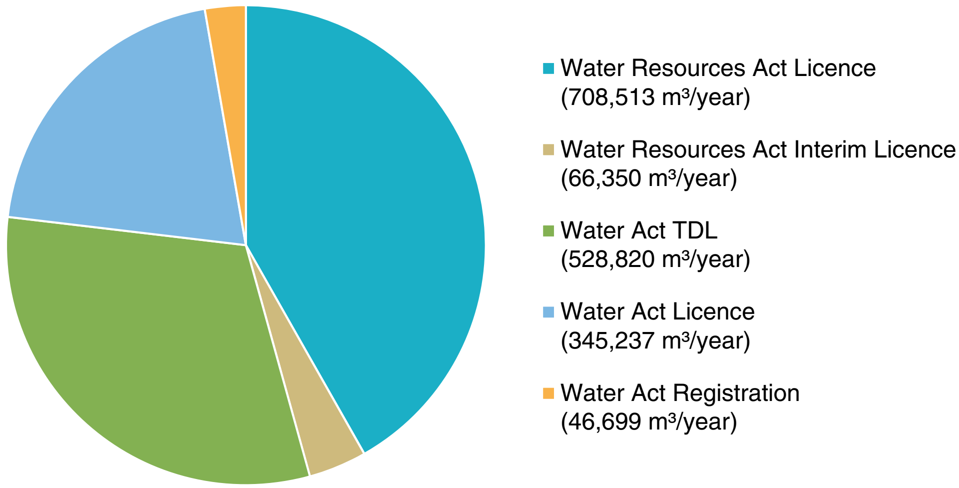


Figure 25. Sunchild Aquifer – Annual Authorized Groundwater Volumes by Authorization Type

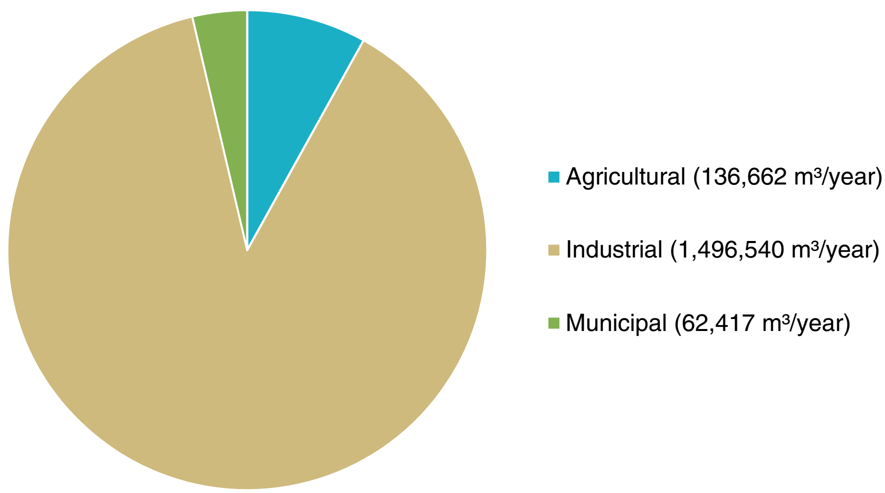
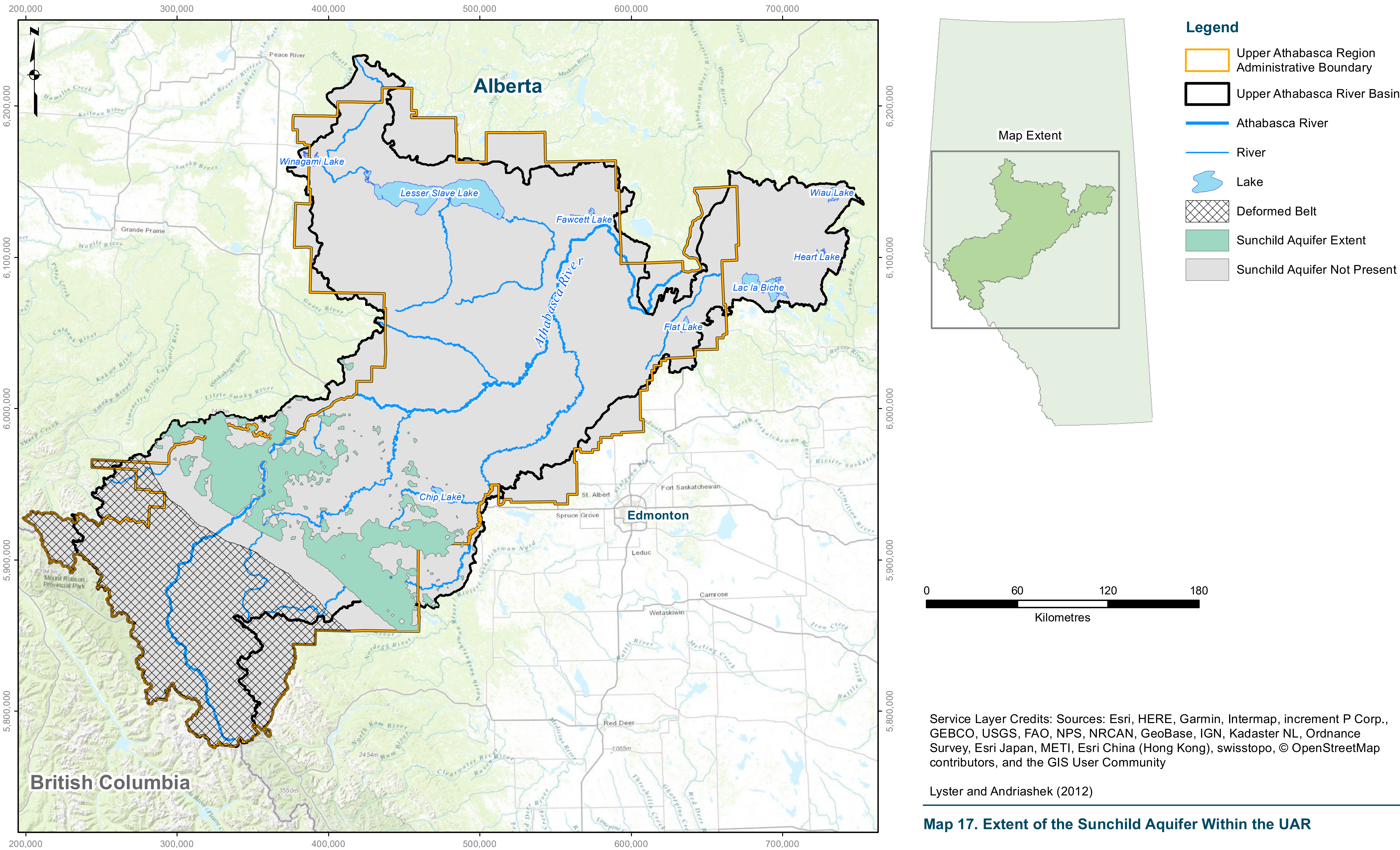


Figure 26. Sunchild Aquifer – Annual Authorized Groundwater Volumes by Water-Use Category



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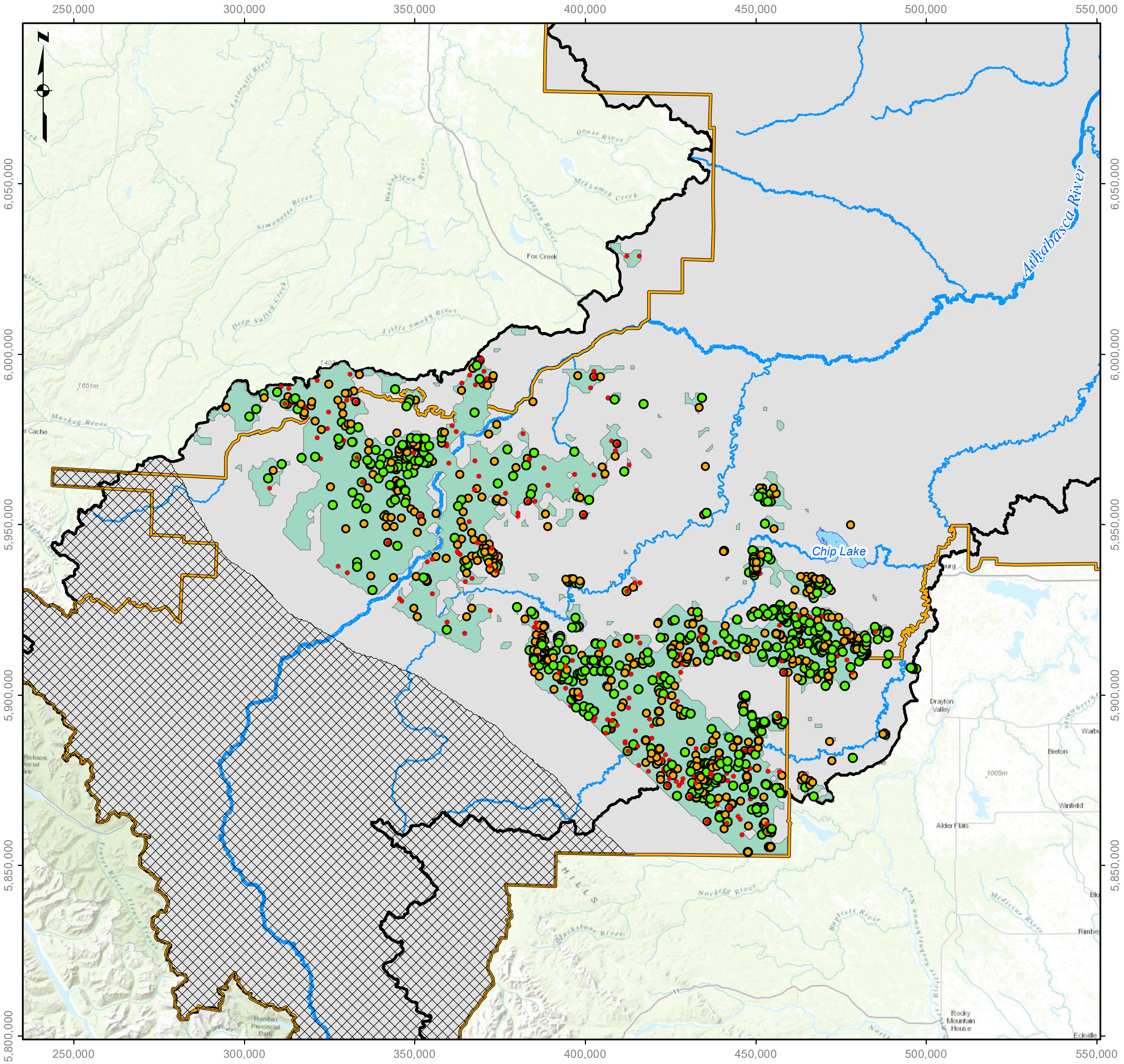
Lyster and Andriashek (2012)

Map 17. Extent of the Sunchild Aquifer Within the UAR



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Sunchild Aquifer Extent
- Sunchild Aquifer Not Present

Water Well with Long-Term Yield (m³/day)

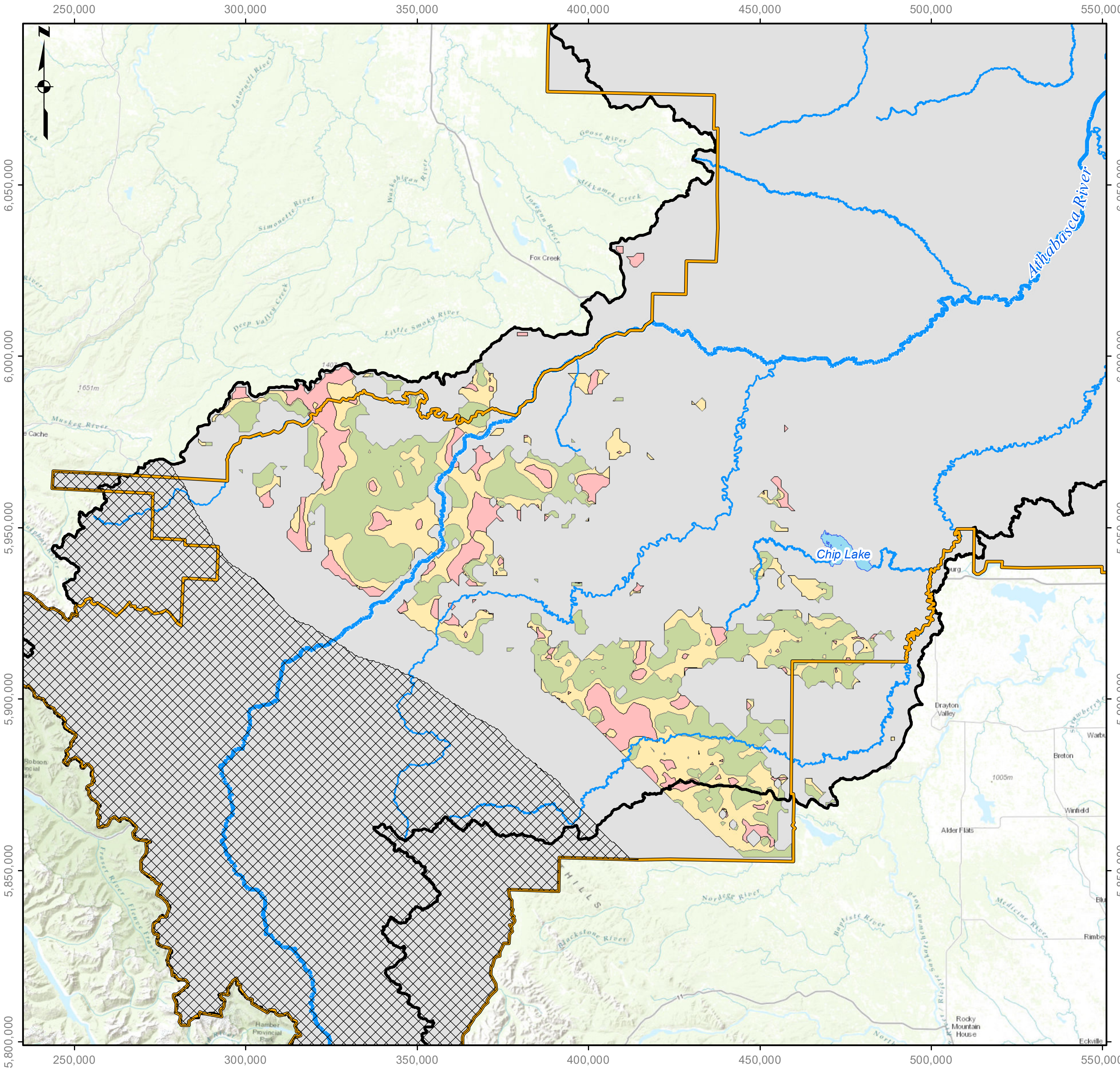
- 100+
- 25 - 100
- 0 - 25

0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 18. Water Wells Completed in the Sunchild Aquifer with Long-Term Yield



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Sunchild Aquifer Not Present

Long-Term Water Well Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+

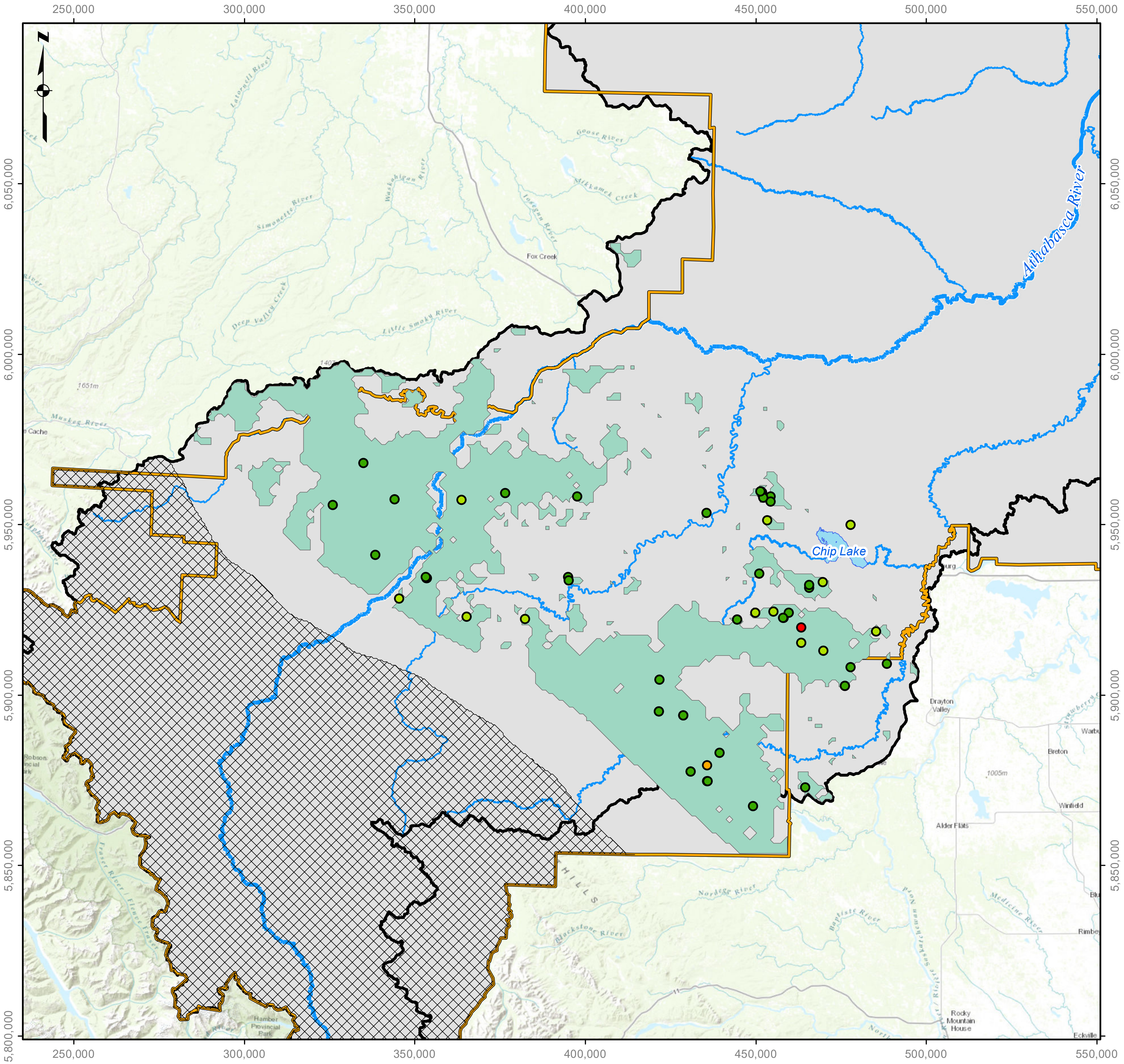
0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Sunchild Aquifer.

Lyster and Andriashek (2011)

Map 19. Long-Term Water Well Yields Within the Sunchild Aquifer



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Sunchild Aquifer Extent
- Sunchild Aquifer Not Present

Water Well with TDS Concentration (mg/L)

- 0 – 500
- 500 – 1,000
- 1,000 – 1,500
- 1,500+

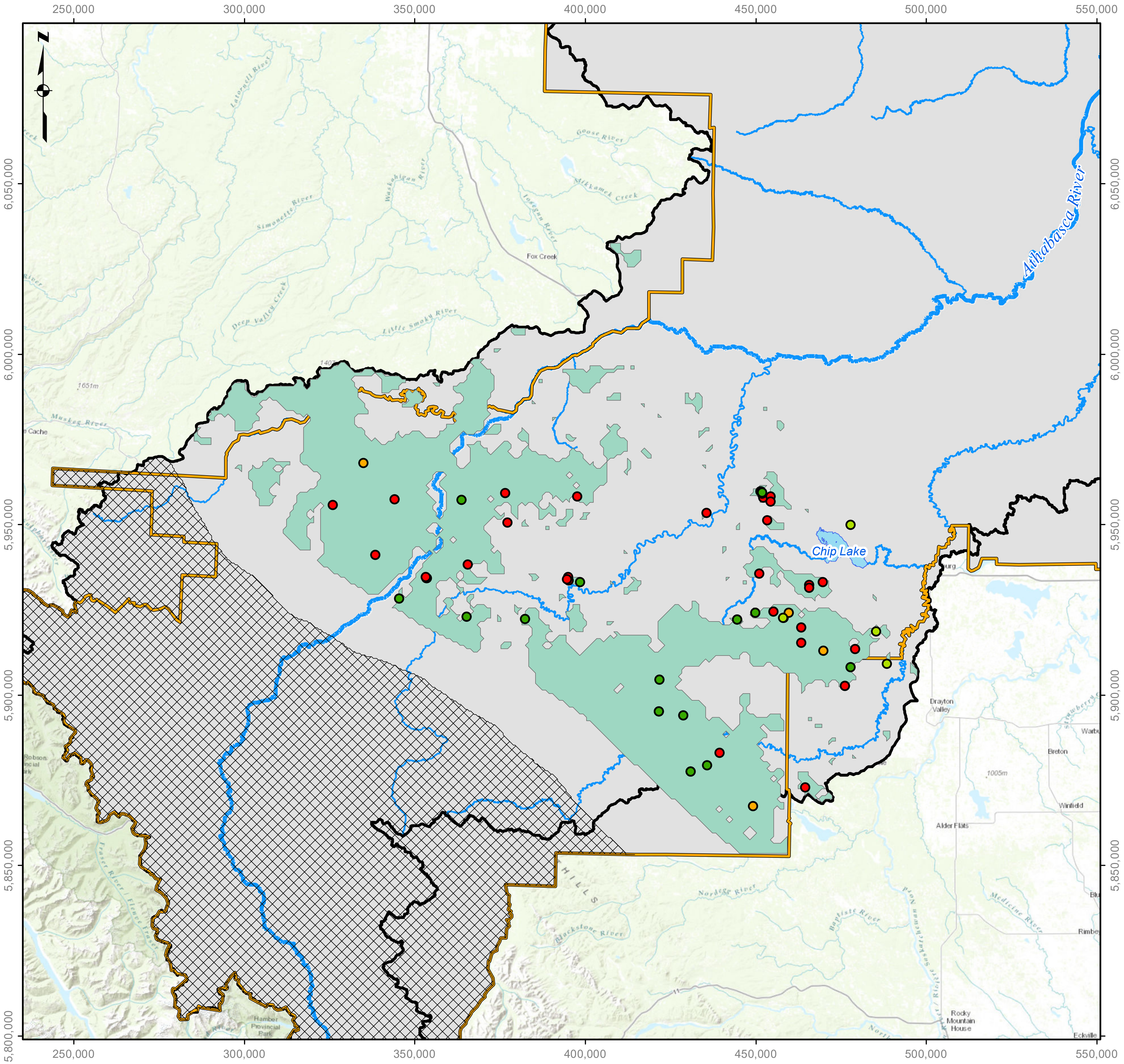
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 20. Water Wells Completed in the Sunchild Aquifer with Total Dissolved Solids Concentrations



Legend

Upper Athabasca Region Administrative Boundary

Upper Athabasca River Basin

Athabasca River

River

Lake

Deformed Belt

Sunchild Aquifer Extent

Sunchild Aquifer Not Present

Water Well with Hardness Concentration (mg/L)

0 – 60 (Soft)

60 – 120 (Moderately Hard)

120 – 180 (Hard)

180+ (Very Hard)

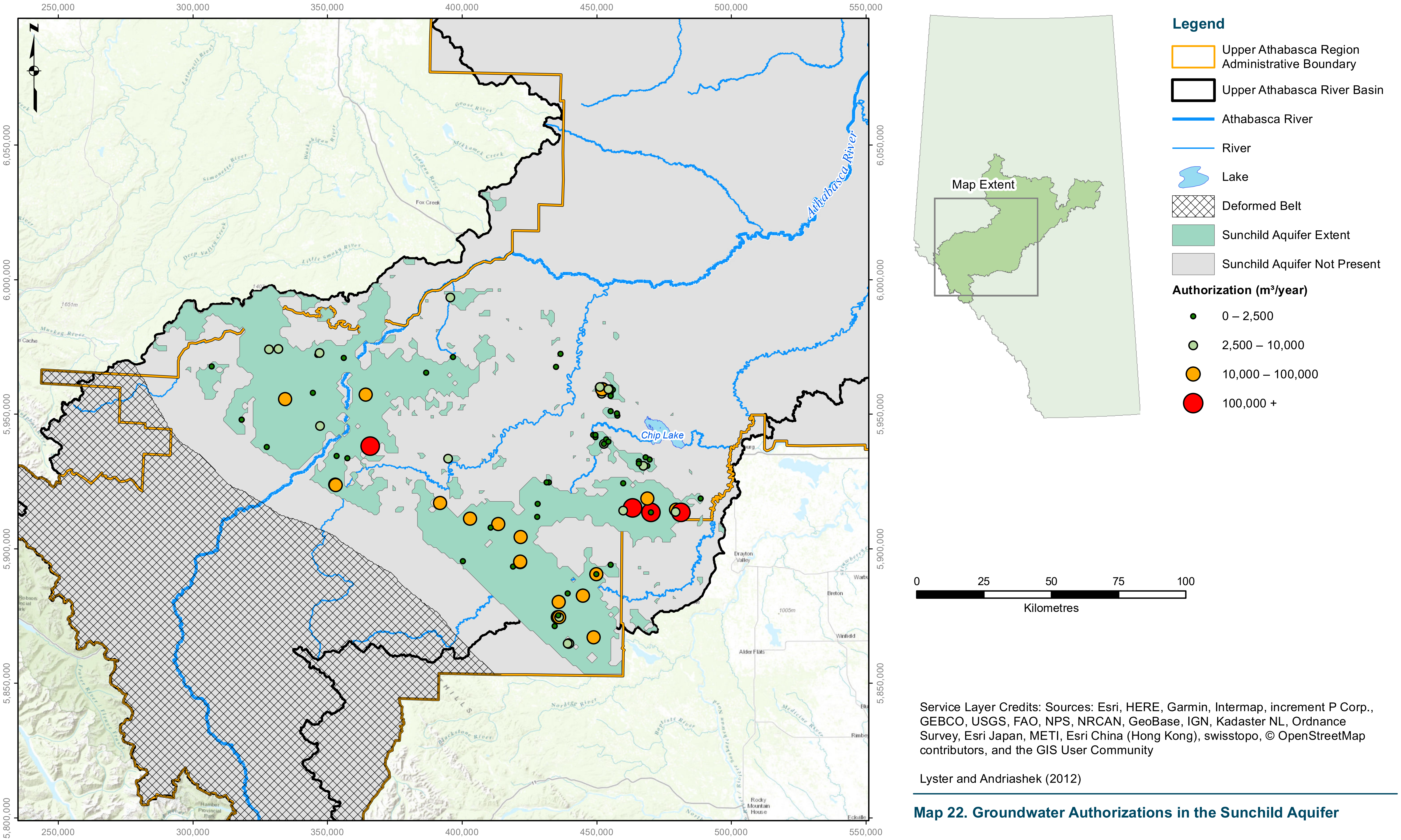
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 21. Water Wells Completed in the Sunchild Aquifer with Hardness Concentrations



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 22. Groundwater Authorizations in the Sunchild Aquifer

4.3.2. Lacombe Member

The individual members of the Paskapoo Formation (i.e. the Sunchild Aquifer, the Lacombe Aquitard, and the Haynes Member) have been delineated within the UAR using grid files prepared by Lyster and Andriashek (2012). The methodology for identifying and delineating the Lacombe Aquitard is outlined in AGS Bulletin 066 (Lyster and Andriashek, 2012). Although Lyster and Andriashek (2012) considered the Lacombe Member to be an aquitard, there are still a number of water wells and authorizations that are associated with the Lacombe Member in the UAR. The Lacombe Member is the middle unit of the Paskapoo Formation.

Map 23 shows the extent of the Lacombe Member in the UAR, in addition to any areas where the Lacombe Member is deeper than 150 metres BGL in the UAR. The Lacombe Member is deeper than 150 metres BGL in large portions along the southwestern extent of the Member. Throughout most of its extent, the Lacombe Member is not the uppermost bedrock geounit, but it is within 150 metres of ground level.

Map 24 shows the water wells completed in the Lacombe Member in the UAR with enough information to calculate a long-term yield. Map 25 shows contoured areas of long-term yields for water wells completed in the Lacombe Member in the areas where the Member is shallower than a depth of 150 metres BGL.

Map 26 and Map 27 show the water wells completed in the Lacombe Member that have available values for TDS and hardness, respectively. Table 25 shows an overview of the available TDS and hardness results for groundwater samples from water wells completed in the Lacombe Member. Table 26 shows the number of chemical analysis records that fit into the four categories of chemical hardness as defined by McGowan (2000). Most of the chemical analysis records are categorized as chemically soft or very hard; it is likely that the groundwater samples that yielded hardness values of between 0 and 60 mg/L were sampled after passing through a water softener.

Chemical Parameter	Number of Records	Maximum (mg/L)	Minimum (mg/L)	Average (mg/L)	Median (mg/L)
TDS	183	2764	158	545	526
Hardness	166	398	1	113	52

Table 25. Lacombe Member – TDS and Hardness Overview

Hardness (mg/L)	Number of Records
0 – 60 (Soft)	85
60 – 120 (Moderately Hard)	15
120 – 180 (Hard)	13
180+ (Very Hard)	53
Total	166

Table 26. Lacombe Member – Hardness Categories

Map 28 shows the locations of authorized groundwater diversions from the Lacombe Member. Within the UAR, there are 153 groundwater authorizations associated with water wells completed in the Lacombe Member; these authorizations represent a total groundwater allocation of 3,862,999 m^3/year. There are 881 domestic water wells and 56 domestic & stock water wells completed in the Lacombe Member; these represent a protected allocation of 1,101,250 m^3/year and 350,000 m^3/year, respectively. The total of allocated and protected groundwater in the Lacombe Member is 5,314,249 m^3/year. This value is a minimum, as there are domestic and domestic & stock water wells that could not be assigned to a geounit due to insufficient or unreported completion interval details.

A large number of small-volume registrations and domestic users rely on the Lacombe Member as a source of groundwater. The main user of the Lacombe Member is the Town of Edson, based on the grid files prepared by Lyster and Andriashek (2012). However, due to the thick sequence of sandstone reported for the aquifers in which the Town of Edson water source wells are completed, the water source wells could also be interpreted as being completed in the Dalehurst Member/Sunchild Aquifer of the Paskapoo Formation.

Table 27 shows the number and volume of groundwater authorizations associated with water wells completed in the Lacombe Member by authorization type. Table 28 shows the number and volume of groundwater authorizations associated with water wells completed in the Lacombe Member by water-use category. Figure 27, Figure 28, and Figure 29 show the number of groundwater authorizations by authorization type, the annual authorized groundwater volumes by authorization type, and the annual authorized groundwater volumes by water-use category, respectively, for the Lacombe Member.

Authorization Type	Number of Authorizations	Annual Volume (m^3/year)
Water Resources Act Licence	30	2,617,507
Water Resources Act Interim Licence	4	382,380
Water Act TDL	7	48,850
Water Act Licence	42	742,560
Water Act Registration	70	71,702
Total	153	3,862,999

Table 27. Lacombe Member – Groundwater Authorizations by Authorization Type

Water-Use Category	Number of Authorizations	Annual Volume (m^3/year)
Agricultural	73	153,655
Industrial	54	1,022,982
Municipal	26	2,686,362
Total	153	3,862,999

Table 28. Lacombe Member – Groundwater Authorizations by Water-Use Category

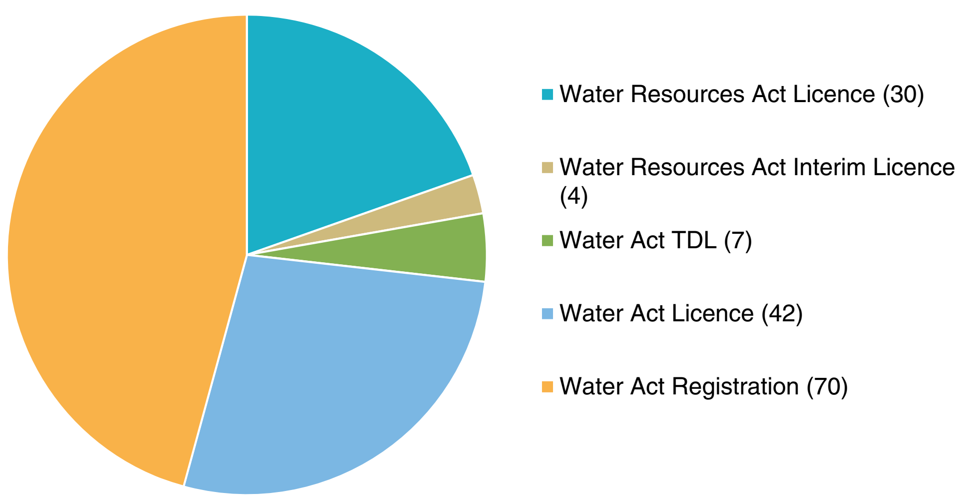


Figure 27. Lacombe Member – Groundwater Authorizations by Authorization Type

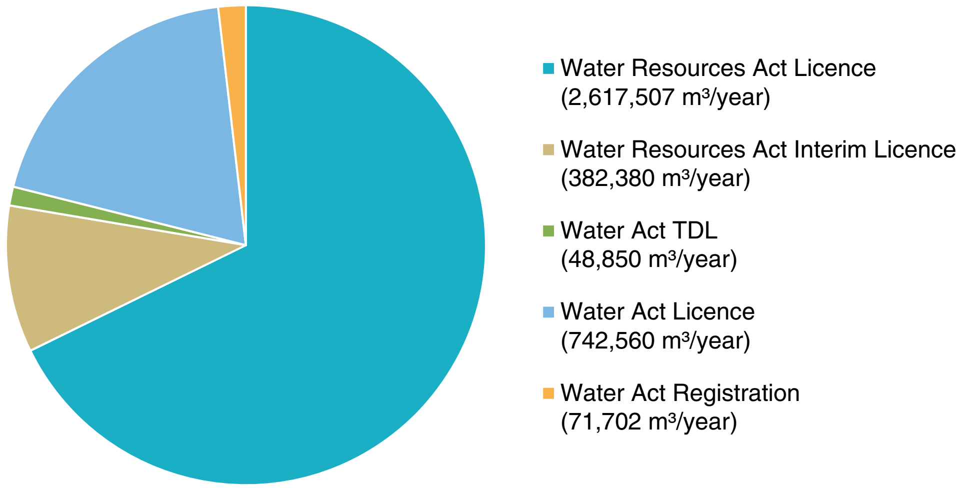


Figure 28. Lacombe Member – Annual Authorized Groundwater Volumes by Authorization Type

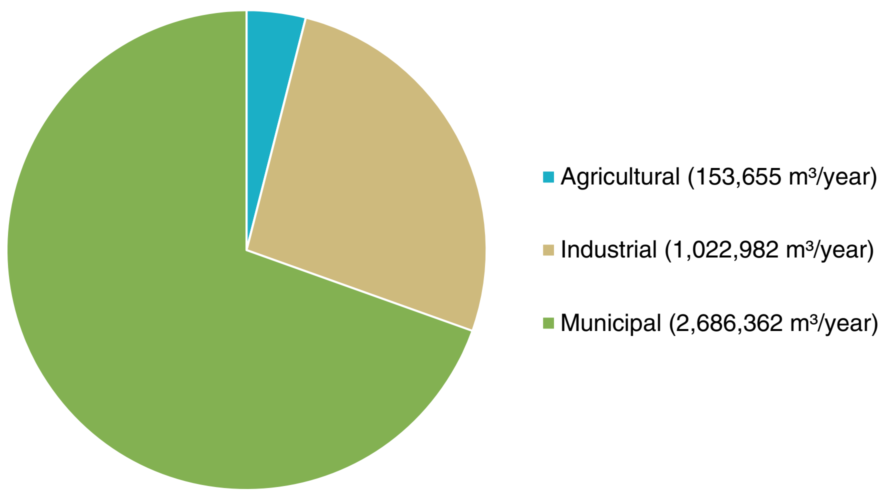
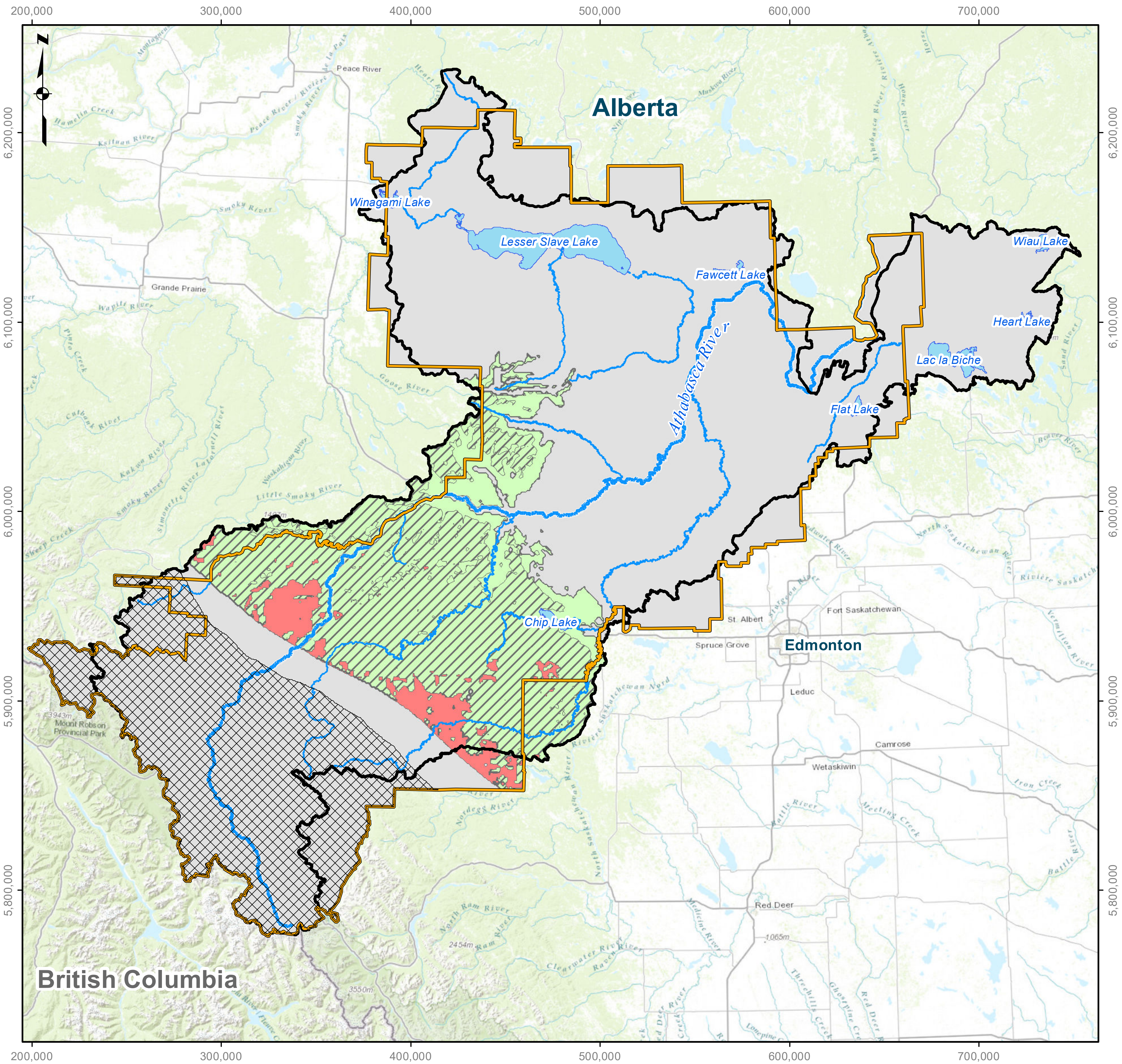
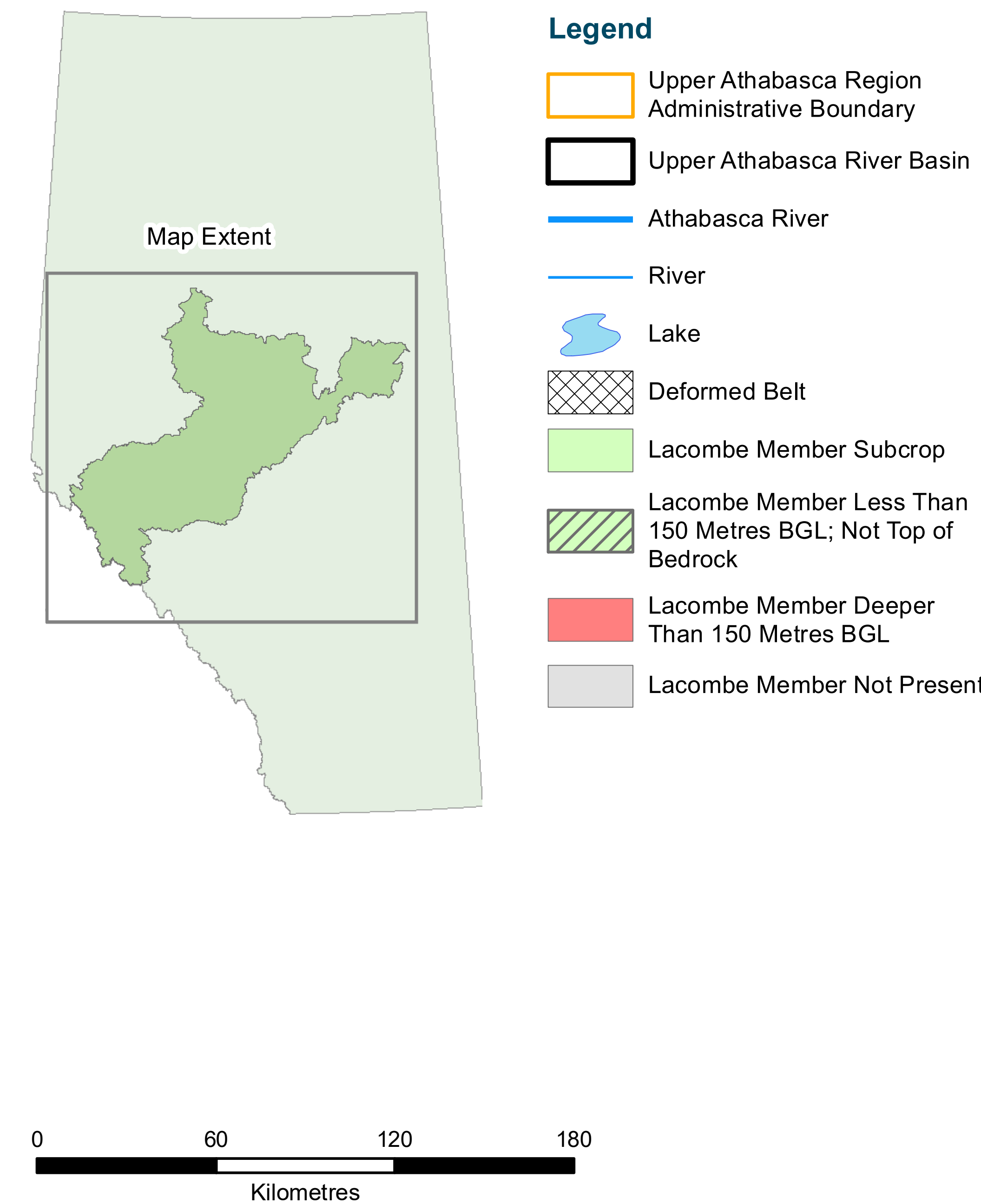


Figure 29. Lacombe Member – Annual Authorized Groundwater Volumes by Water-Use Category





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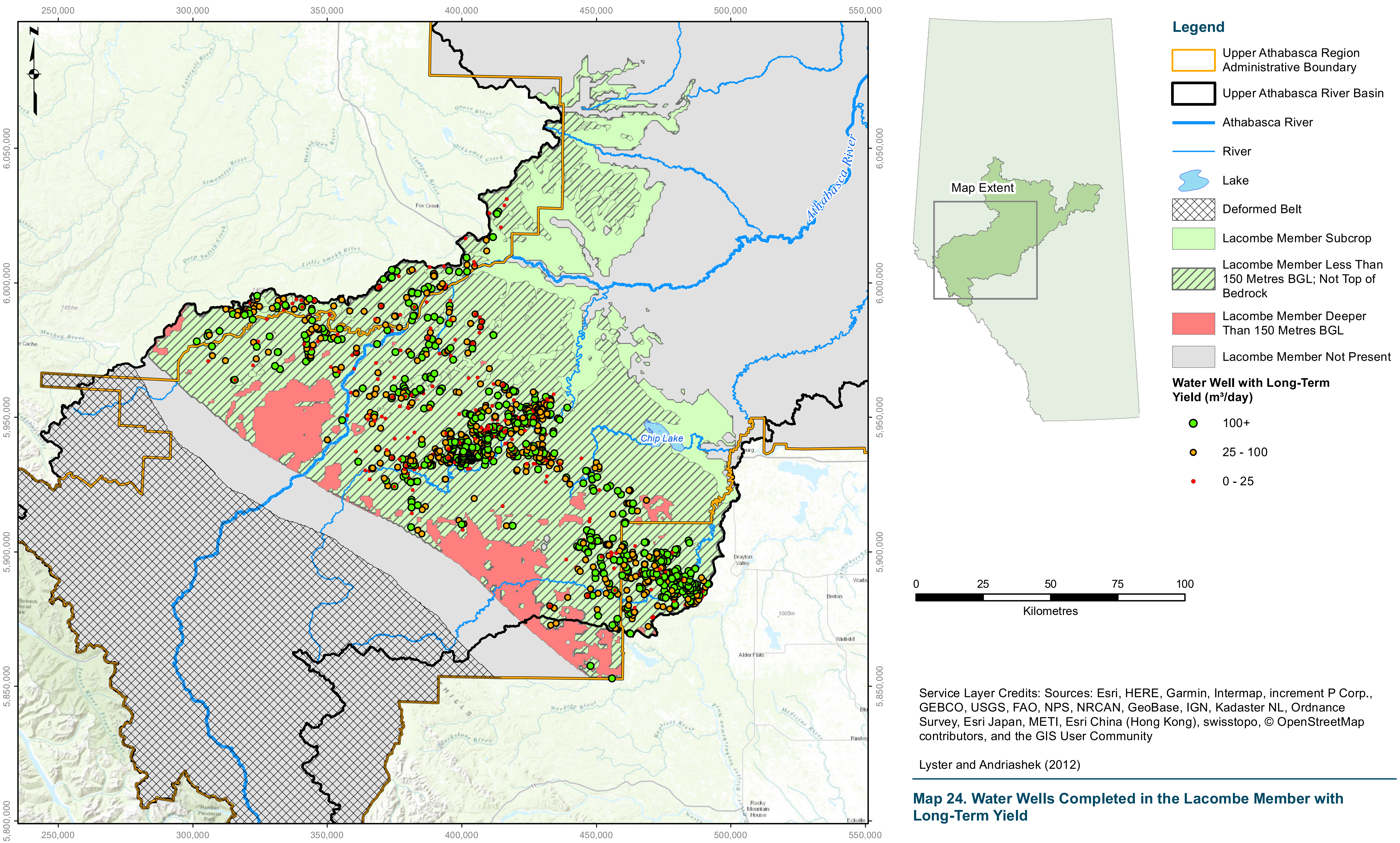
Lyster and Andriashek (2012)

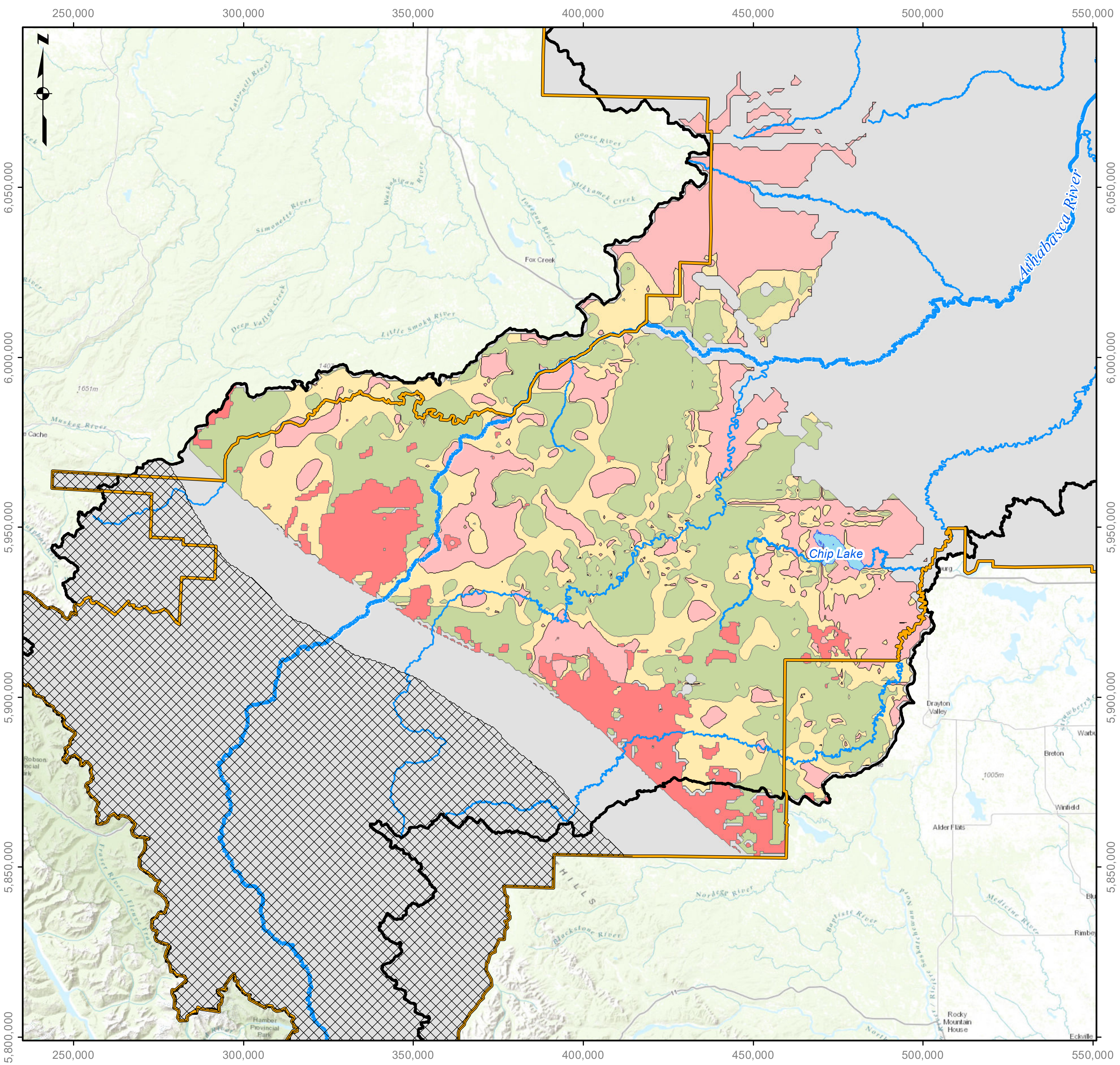
Map 23. Extent of the Lacombe Member Within the UAR



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 24. Water Wells Completed in the Lacombe Member with Long-Term Yield



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Lacombe Member Deeper Than 150 Metres BGL
- Lacombe Member Not Present

Long-Term Water Well Yield (m³/day)

- 0 – 25
- 25 – 100
- 100+

0 25 50 75 100

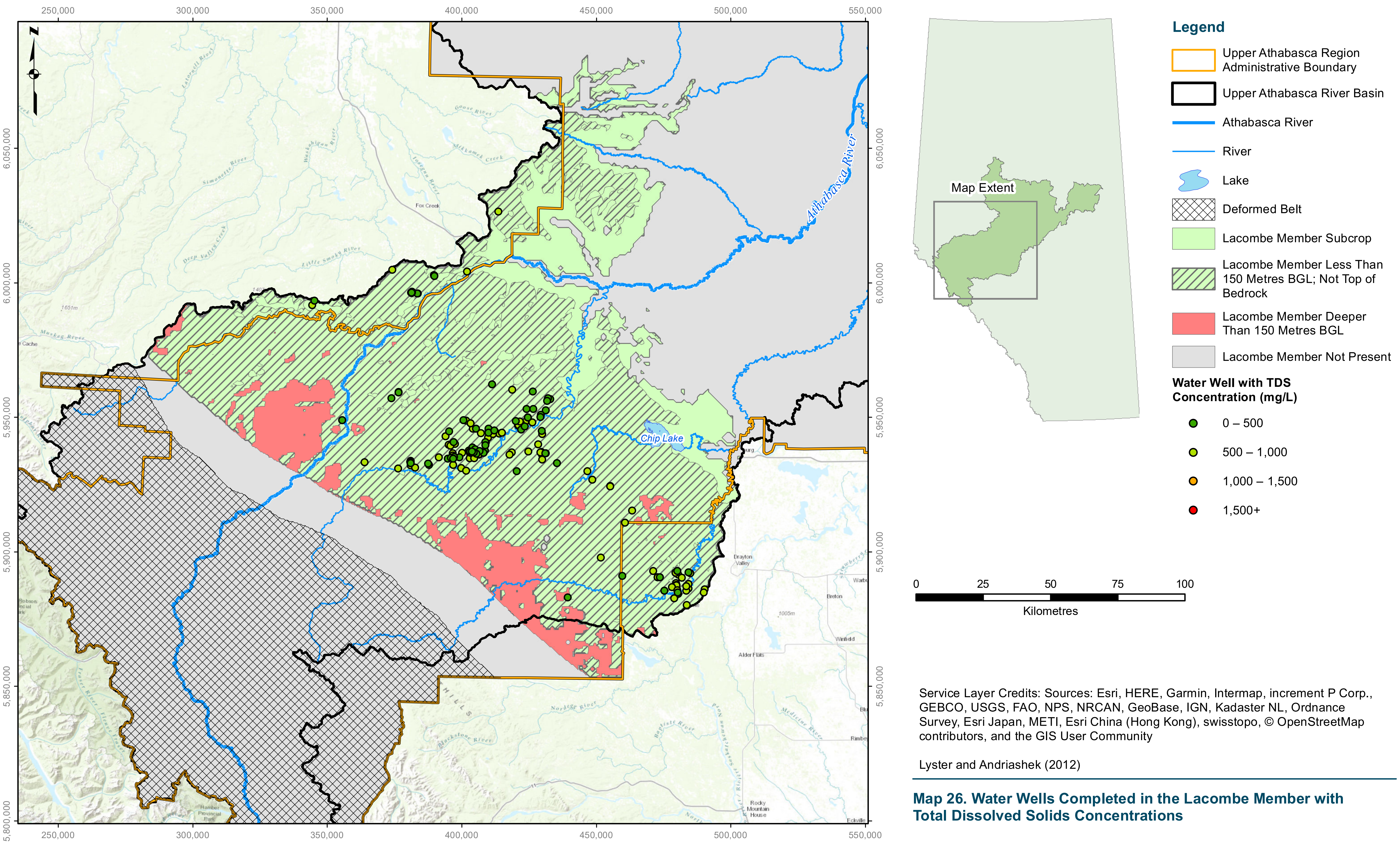
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Lacombe Member.

Lyster and Andriashek (2012)

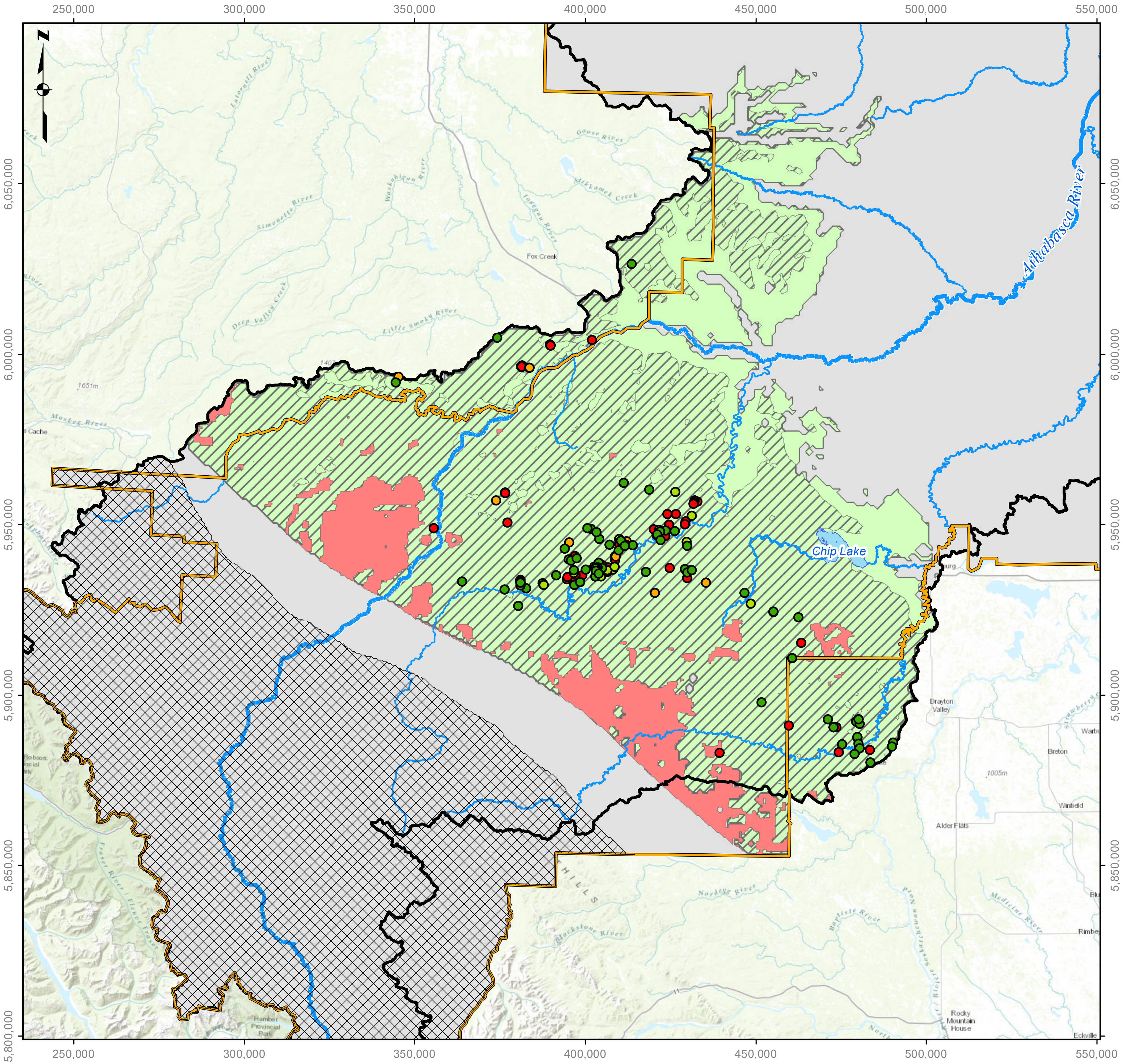
Map 25. Long-Term Water Well Yields Within the Lacombe Member

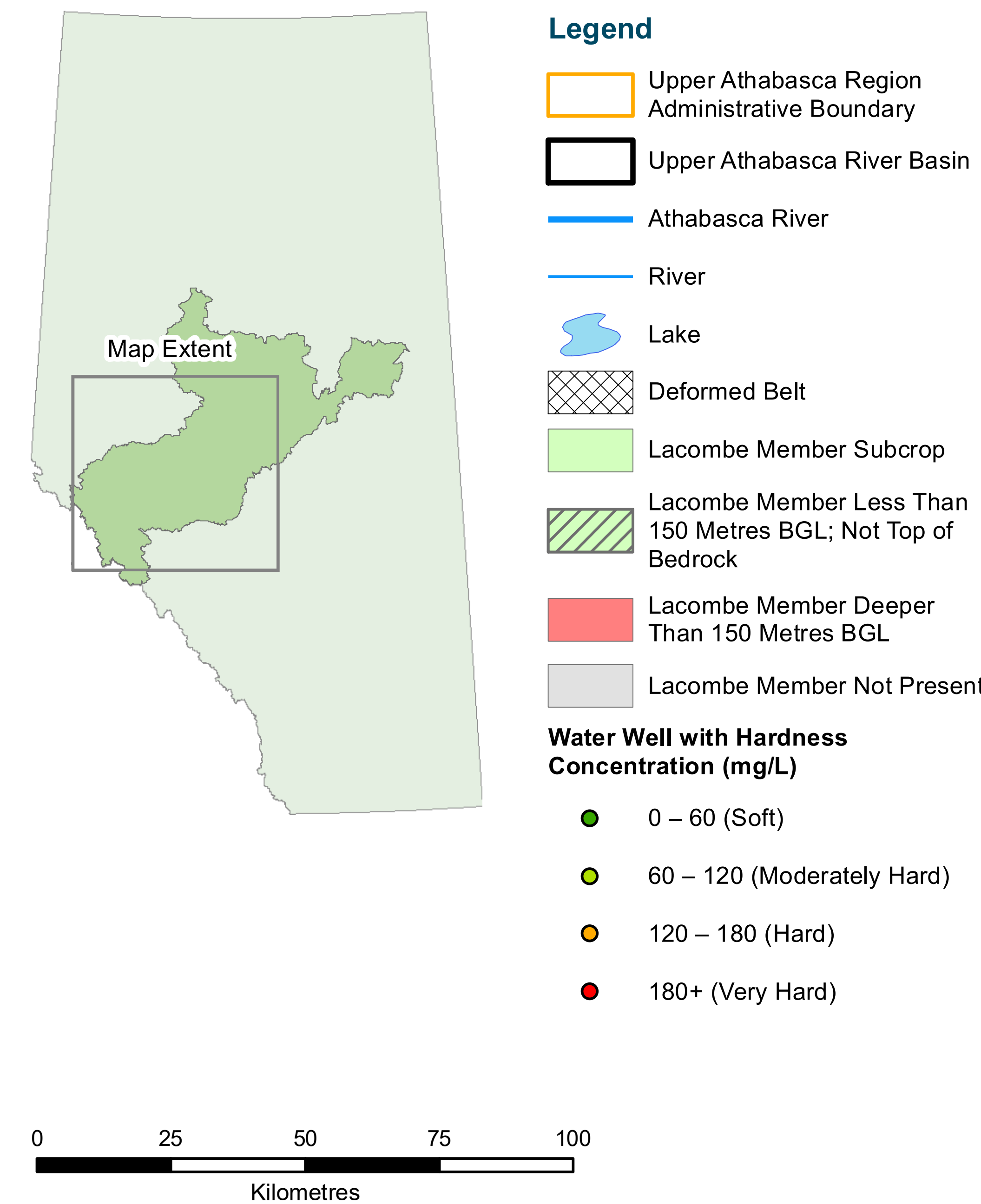


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 26. Water Wells Completed in the Lacombe Member with Total Dissolved Solids Concentrations

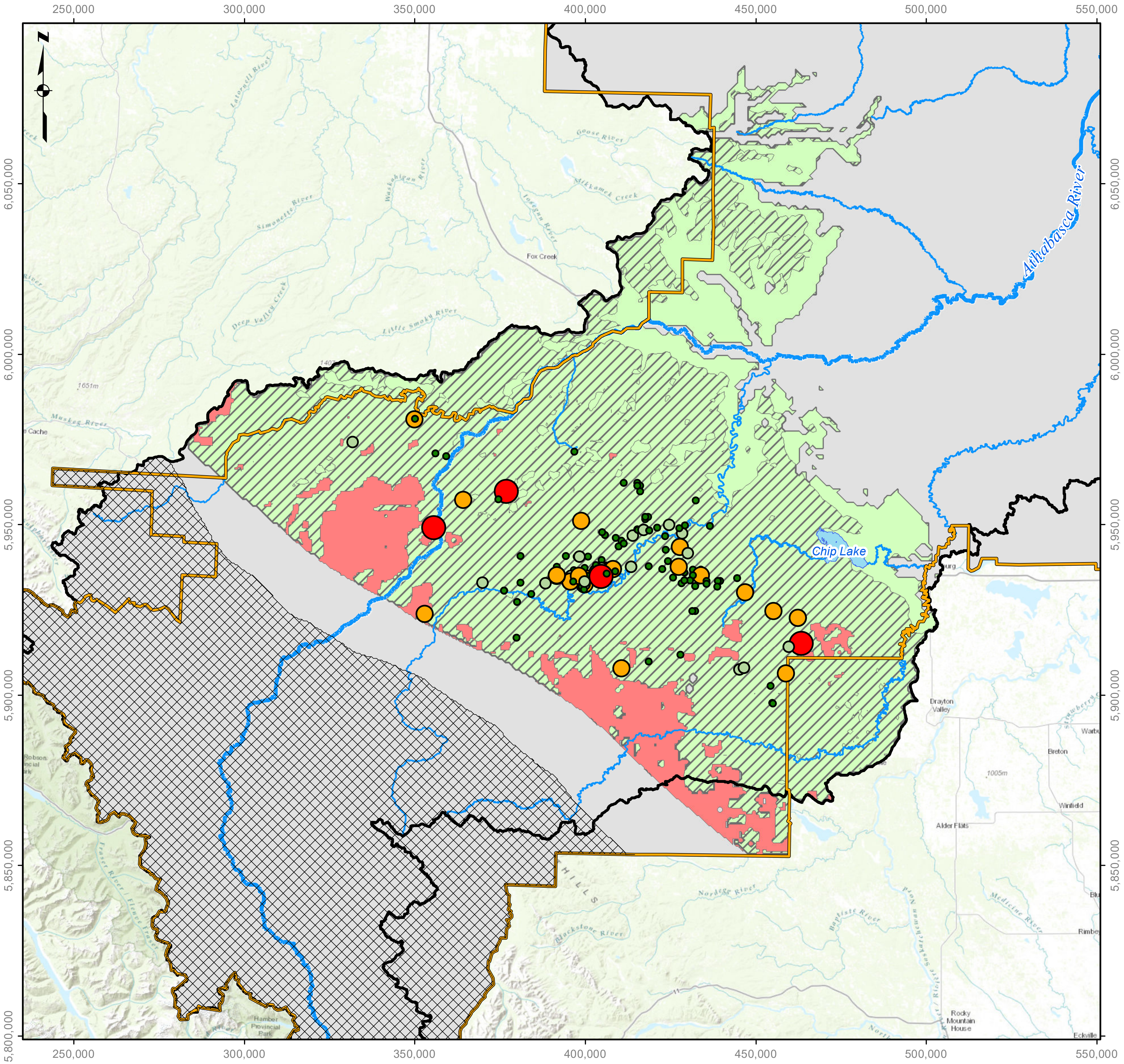




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 27. Water Wells Completed in the Lacombe Member with Hardness Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Lacombe Member Subcrop
- Lacombe Member Less Than 150 Metres BGL; Not Top of Bedrock
- Lacombe Member Deeper Than 150 Metres BGL
- Lacombe Member Not Present

Authorization (m^3/year)

- 0 – 2,500
- 2,500 – 10,000
- 10,000 – 100,000
- 100,000 +

0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 28. Groundwater Authorizations in the Lacombe Member

4.3.3. Haynes Member

The individual members of the Paskapoo Formation (i.e. the Sunchild Aquifer, the Lacombe Aquitard, and the Haynes Member) have been delineated within the UAR using grid files prepared by Lyster and Andriashek (2012). The methodology for identifying and delineating the Haynes Member is outlined in AGS Bulletin 066 (Lyster and Andriashek, 2012).

The Haynes Member is geologically the oldest constituent of the Paskapoo Formation and therefore forms the base of the geounit. Map 29 shows the extent of the Haynes Member in the UAR, in addition to any areas where the Member is deeper than 150 metres BGL in the UAR. The Haynes Member is deeper than 150 metres BGL in large portions of its extent in the UAR.

Map 30 shows the water wells completed in the Haynes Member in the UAR with enough information to calculate a long-term yield. Map 31 shows contoured areas of long-term yields for water wells completed in the Haynes Member in the areas where the Member is shallower than a depth of 150 metres BGL.

Map 32 and Map 33 show the water wells completed in the Haynes Member that have available values for TDS and hardness, respectively. Table 29 shows an overview of the available TDS and hardness results for groundwater samples from water wells completed in the Haynes Member. Table 30 shows the number of chemical analysis records that fit into the four categories of chemical hardness as defined by McGowan (2000). Most of the chemical analysis records are categorized as chemically very hard; it is likely that the groundwater samples that yielded hardness values of between 0 and 60 mg/L were sampled after passing through a water softener.

Chemical Parameter	Number of Records	Maximum (mg/L)	Minimum (mg/L)	Average (mg/L)	Median (mg/L)
TDS	24	923	286	534	492
Hardness	22	619	6	238	266

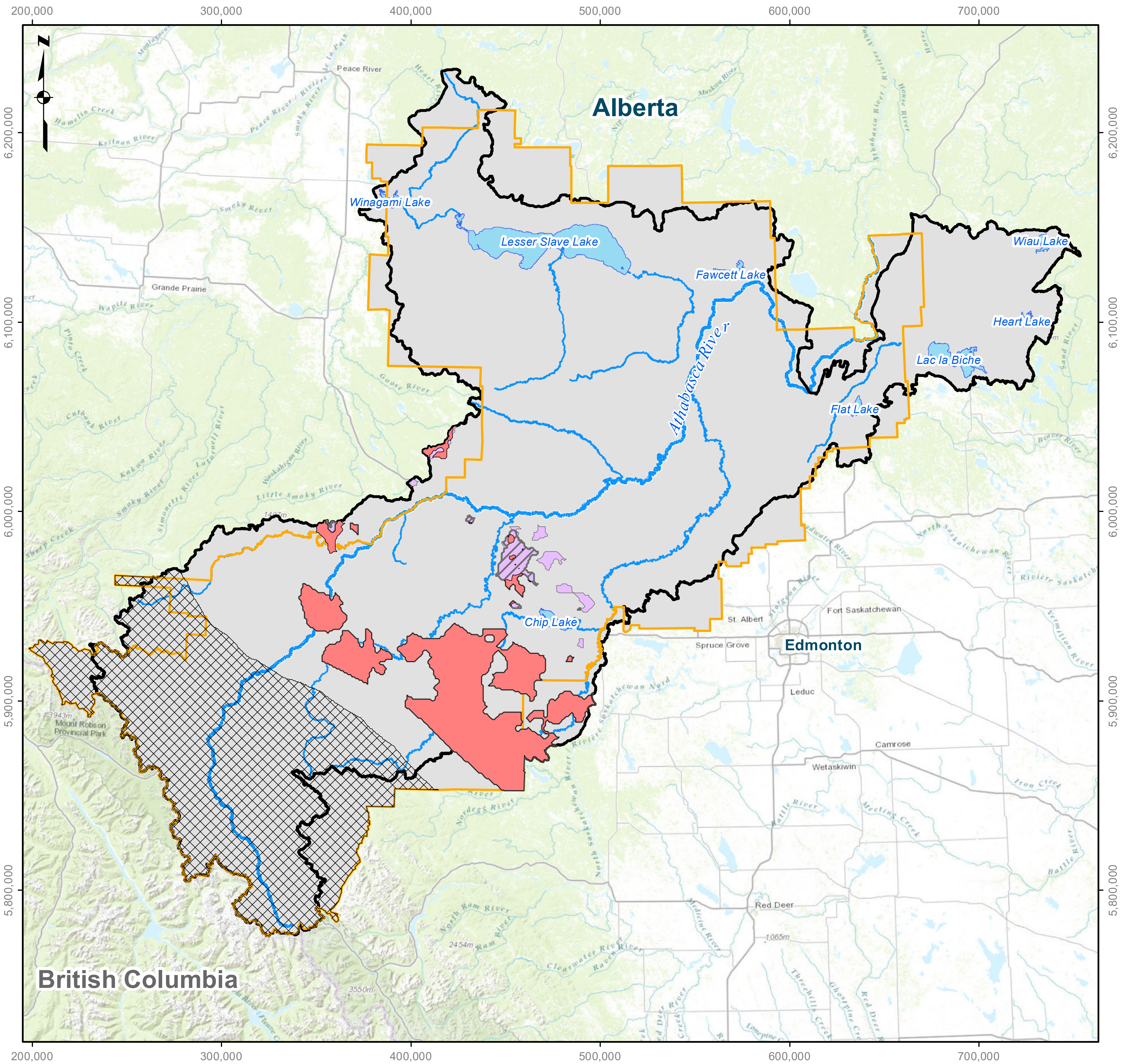
Table 29. Haynes Member – TDS and Hardness Overview

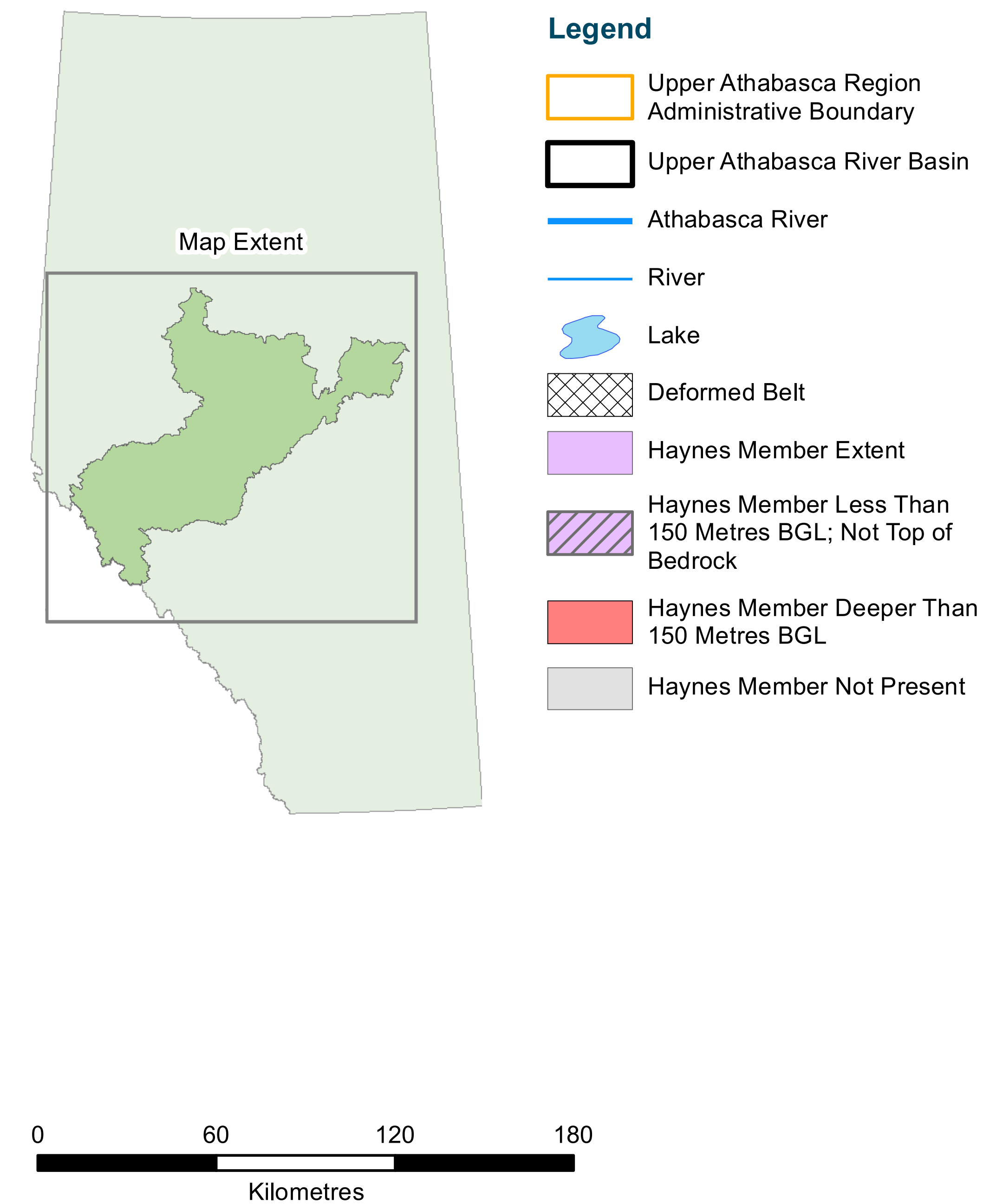
Hardness (mg/L)	Number of Records
0 – 60 (Soft)	7
60 – 120 (Moderately Hard)	1
120 – 180 (Hard)	0
180+ (Very Hard)	14
Total	22

Table 30. Haynes Member – Hardness Categories

Within the UAR, there are no groundwater authorizations associated with water wells completed in the Haynes Member. There are 129 domestic water wells and 50 domestic & stock water wells completed in the Haynes Member; these represent a protected allocation of 161,250 m^3/year and 312,500 m^3/year, respectively. The total of protected groundwater in the Haynes Member is 473,750 m^3/year. This value is a minimum, as there are domestic and domestic & stock water wells that could not be assigned to a geounit due to insufficient or unreported completion interval details.

The Haynes Member as defined by Lyster and Andriashek (2012) is not an important aquifer within the UAR, with relatively few water wells completed in the Member and no groundwater authorizations.





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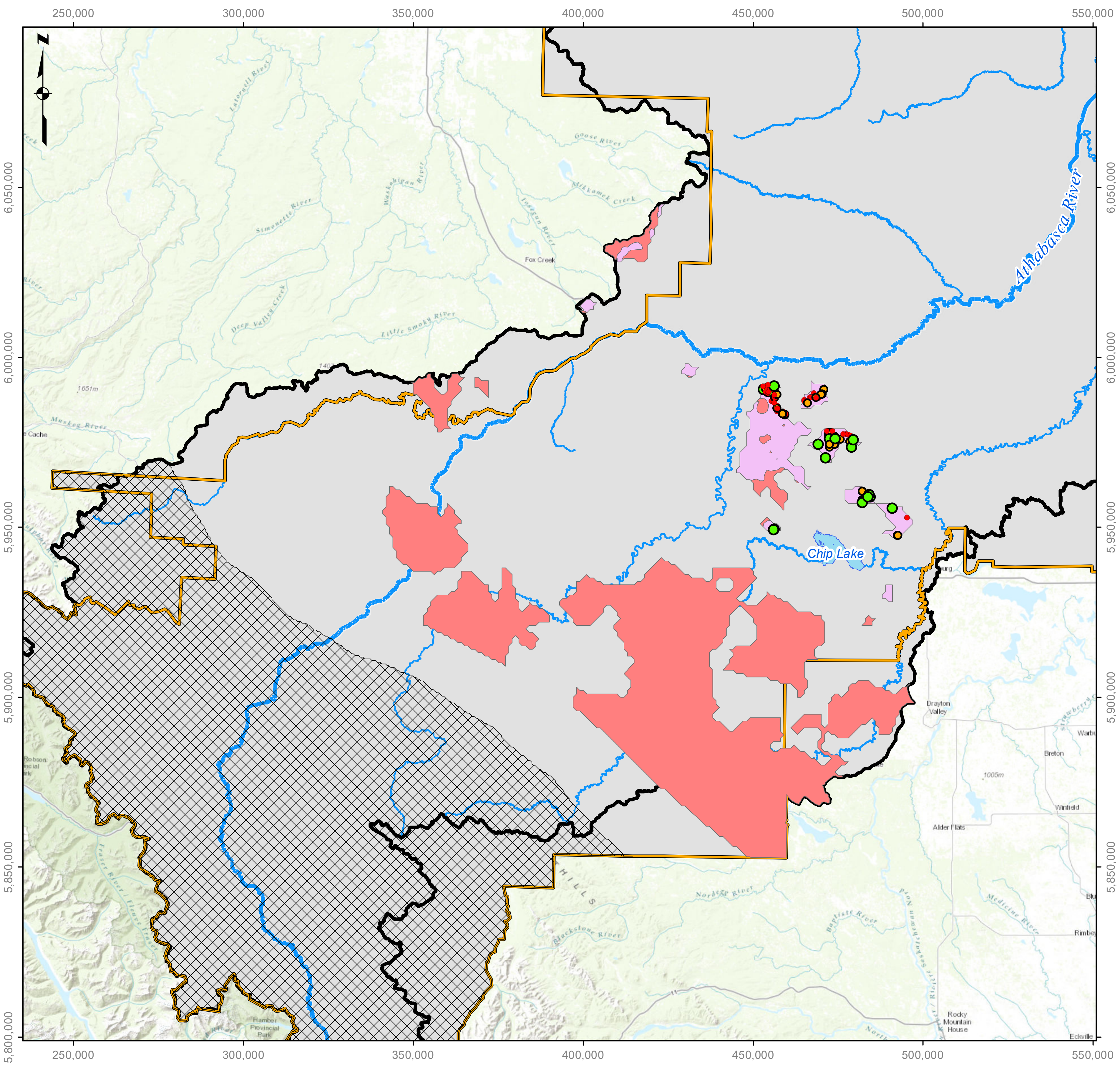
Lyster and Andriashek (2012)

Map 29. Extent of the Haynes Member Within the UAR

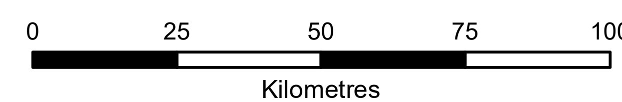


Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Haynes Member Extent
- Haynes Member Deeper Than 150 Metres BGL
- Haynes Member Not Present

Water Well with Long-Term Yield (m³/day)

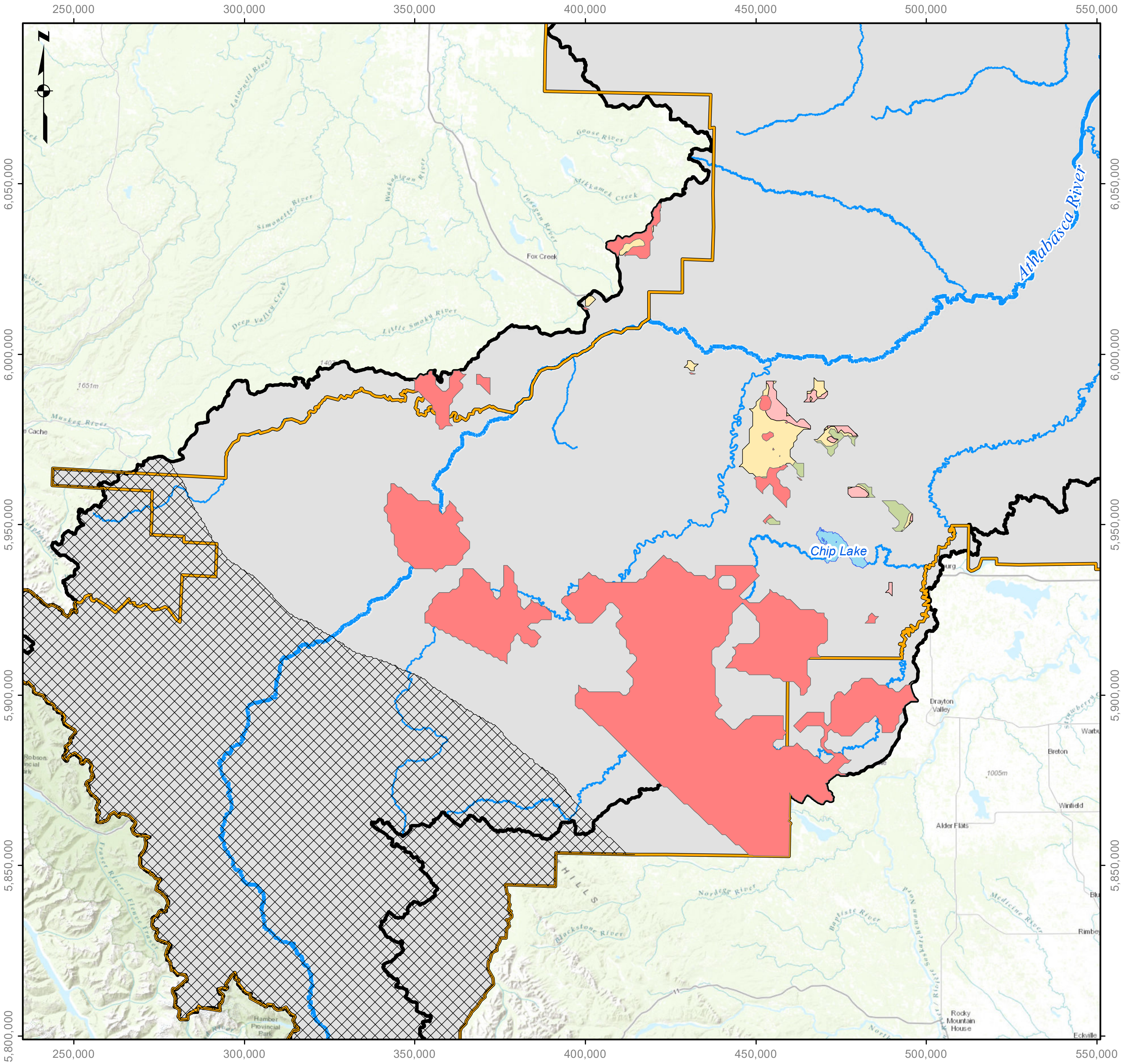
- 100+
- 25 - 100
- 0 - 25



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 30. Water Wells Completed in the Haynes Member with Long-Term Yield



Legend

- Upper Athabasca Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Haynes Member Deeper Than 150 Metres BGL
- Haynes Member Not Present

Long-Term Water Well Yield (m³/day)

- 0 – 25
- 25 – 100
- 100+

0 25 50 75 100

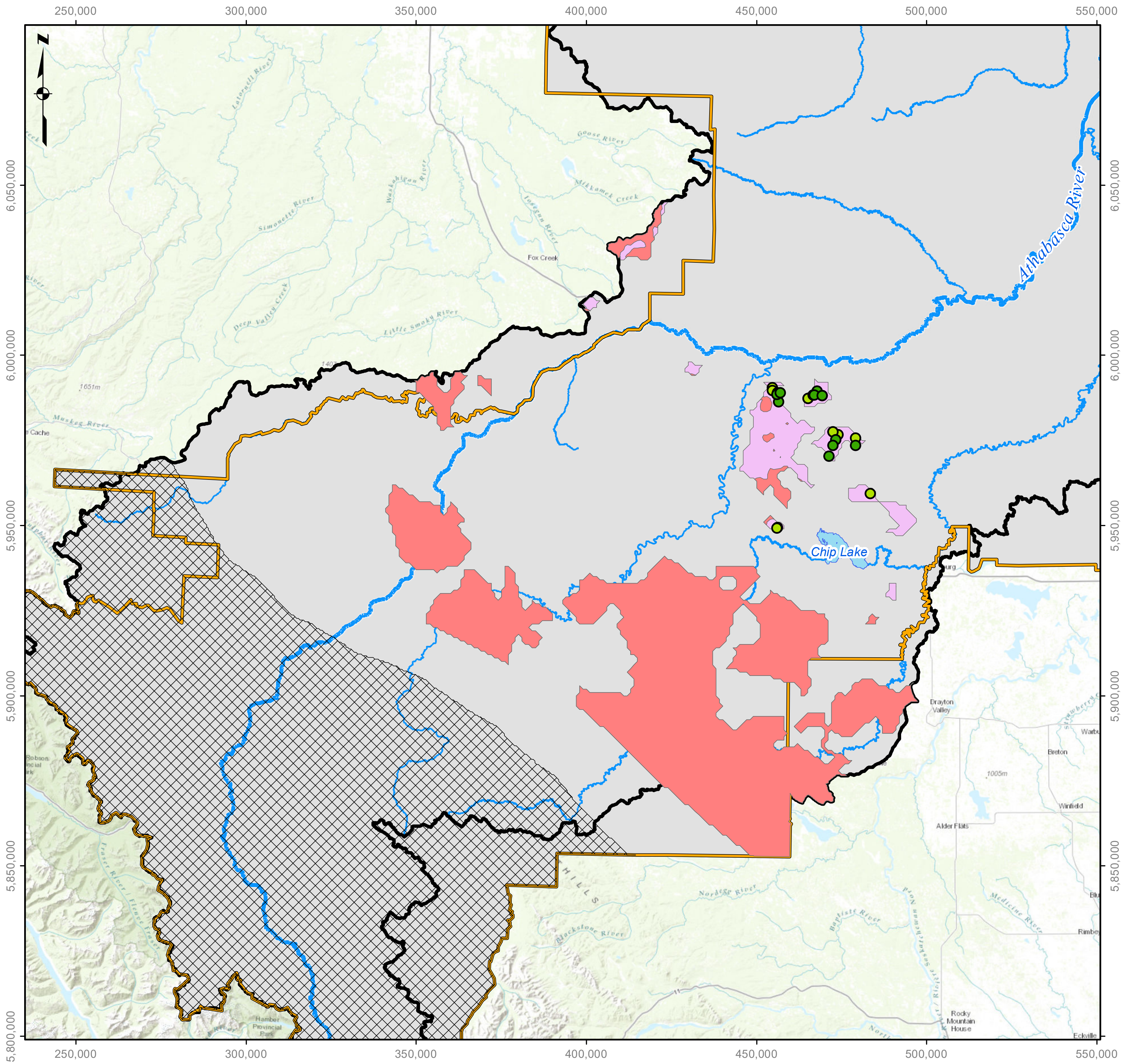
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Haynes Member.

Lyster and Andriashek (2012)

Map 31. Long-Term Water Well Yields Within the Haynes Member



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Haynes Member Extent
- Haynes Member Deeper Than 150 Metres BGL
- Haynes Member Not Present

Water Well with TDS Concentration (mg/L)

- 0 – 500
- 500 – 1,000
- 1,000 – 1,500
- 1,500+

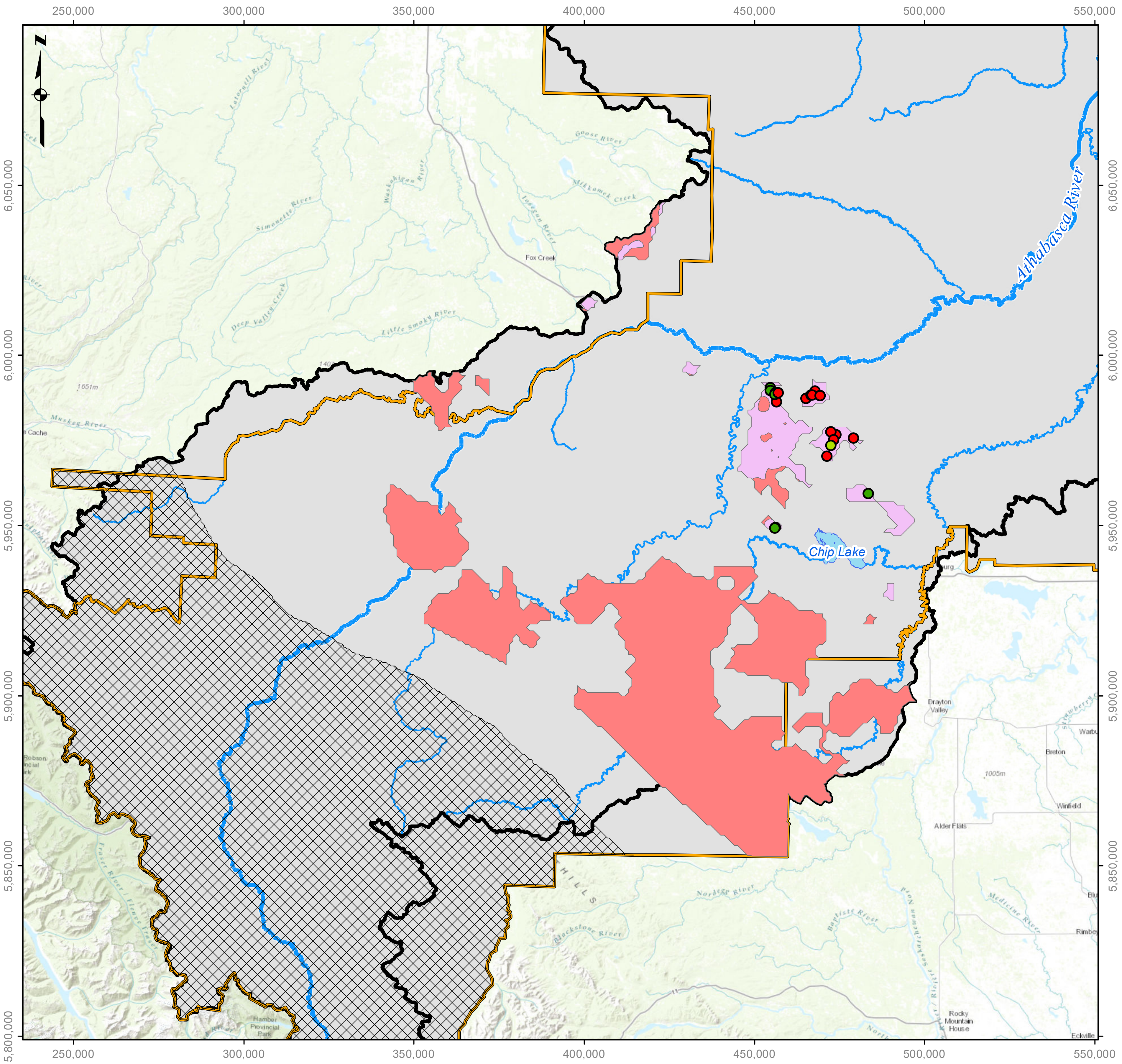
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 32. Water Wells Completed in the Haynes Member with Total Dissolved Solids Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Haynes Member Extent
- Haynes Member Deeper Than 150 Metres BGL
- Haynes Member Not Present

Water Well with Hardness Concentration (mg/L)

- 0 – 60 (Soft)
- 60 – 120 (Moderately Hard)
- 120 – 180 (Hard)
- 180+ (Very Hard)

0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 33. Water Wells Completed in the Haynes Member with Hardness Concentrations

4.4. Scollard Formation

The Scollard Formation is the second youngest bedrock geounit in the UAR, conformably underlies the Paskapoo Formation, and is relatively thin compared to the Paskapoo Formation. Map 34 shows the extent of the Scollard Formation in the UAR, in addition to any areas where the Scollard Formation is deeper than 150 metres BGL in the UAR. The Scollard Formation is deeper than 150 metres BGL in large portions of its extent in the southwestern portion of the UAR where it underlies the Paskapoo Formation.

Map 35 shows the water wells completed in the Scollard Formation in the UAR with enough information to calculate a long-term yield. Map 36 shows contoured areas of long-term yields for water wells completed in the Scollard Formation in the areas where the Formation is shallower than a depth of 150 metres BGL.

Map 37 and Map 38 show the water wells completed in the Scollard Formation that have available values for TDS and hardness, respectively. Table 31 shows an overview of the available TDS and hardness results for groundwater samples from water wells completed in the Scollard Formation. Table 32 shows the number of chemical analysis records that fit into the four categories of chemical hardness as defined by McGowan (2000). Most of the chemical analysis records are categorized as chemically soft; it is likely that the groundwater samples that yielded hardness values of between 0 and 60 mg/L were sampled after passing through a water softener.

Chemical Parameter	Number of Records	Maximum (mg/L)	Minimum (mg/L)	Average (mg/L)	Median (mg/L)
TDS	33	2,098	336	876	862
Hardness	30	341	3	66	30

Table 31. Scollard Formation – TDS and Hardness Overview

Hardness (mg/L)	Number of Records
0 – 60 (Soft)	22
60 – 120 (Moderately Hard)	2
120 – 180 (Hard)	2
180+ (Very Hard)	4
Total	30

Table 32. Scollard Formation – Hardness Categories

Map 39 shows the locations of authorized groundwater diversions from the Scollard Formation. Within the UAR, there are 75 groundwater authorizations associated with water wells completed in the Scollard Formation; these authorizations represent a total groundwater allocation of 253,544 m^3/year. There are 257 domestic water wells and 51 domestic & stock water wells completed in the Scollard Formation; these represent a protected allocation of 321,250 m^3/year and 318,750 m^3/year, respectively. The total of allocated and protected groundwater in the Scollard Formation is 893,544 m^3/year. This value is a minimum, as there are domestic and domestic & stock water wells that could not be assigned to a geounit due to insufficient or unreported completion interval details.

Table 33 shows the number and volume of groundwater authorizations associated with water wells completed in the Scollard Formation by authorization type. Table 34 shows the number and volume of groundwater authorizations associated with water wells completed in the Scollard Formation by water-use category. Figure 30, Figure 31, and Figure 32 show the number of groundwater authorizations by authorization type, the annual authorized groundwater volumes by authorization type, and the annual authorized groundwater volumes by water-use category, respectively, for the Scollard Formation.

Authorization Type	Number of Authorizations	Annual Volume (m^3/year)
Water Resources Act Licence	25	79,265
Water Resources Act Interim Licence	2	0
Water Act TDL	0	0
Water Act Licence	6	137,854
Water Act Registration	42	36,425
Total	75	253,544

Table 33. Scollard Formation – Groundwater Authorizations by Authorization Type

Water-Use Category	Number of Authorizations	Annual Volume (m^3/year)
Agricultural	63	98,666
Industrial	10	149,969
Municipal	2	4,909
Total	75	253,544

Table 34. Scollard Formation – Groundwater Authorizations by Water-Use Category

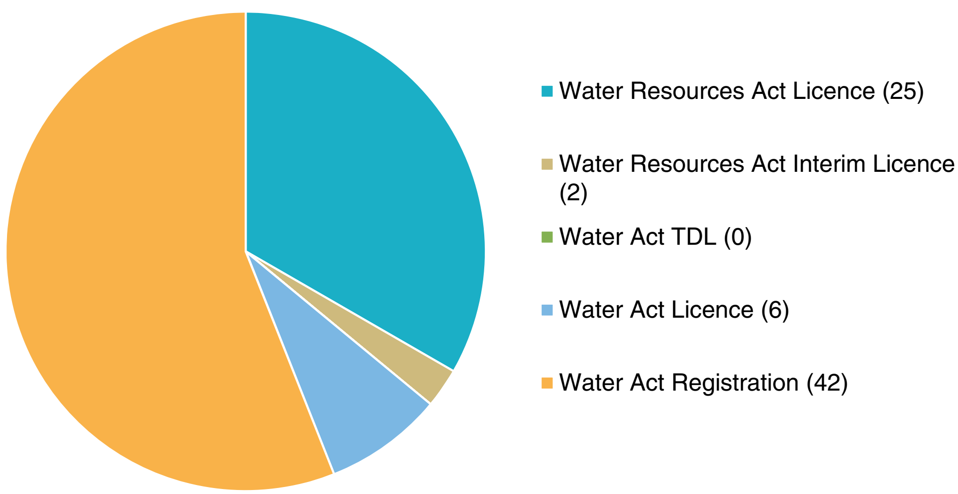


Figure 30. Scollard Formation – Number of Groundwater Authorizations by Authorization Type

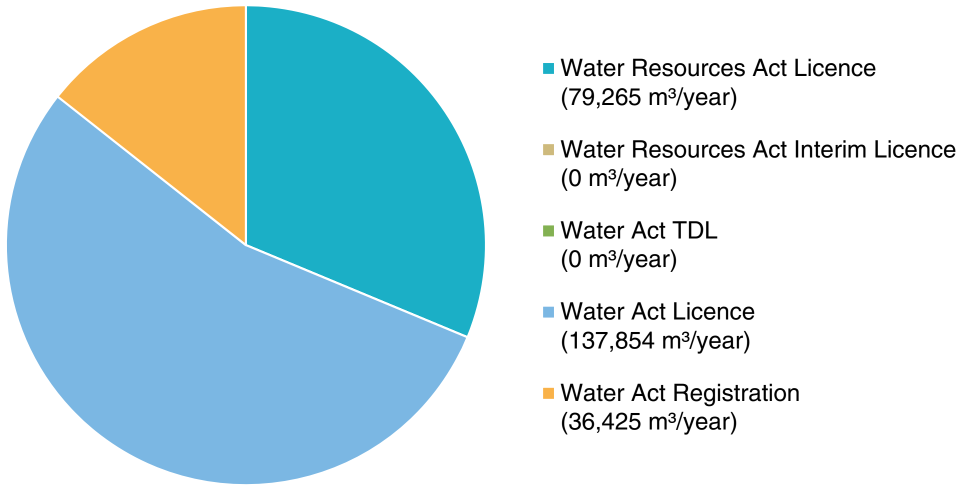


Figure 31. Scollard Formation – Annual Authorized Groundwater Volumes by Authorization Type

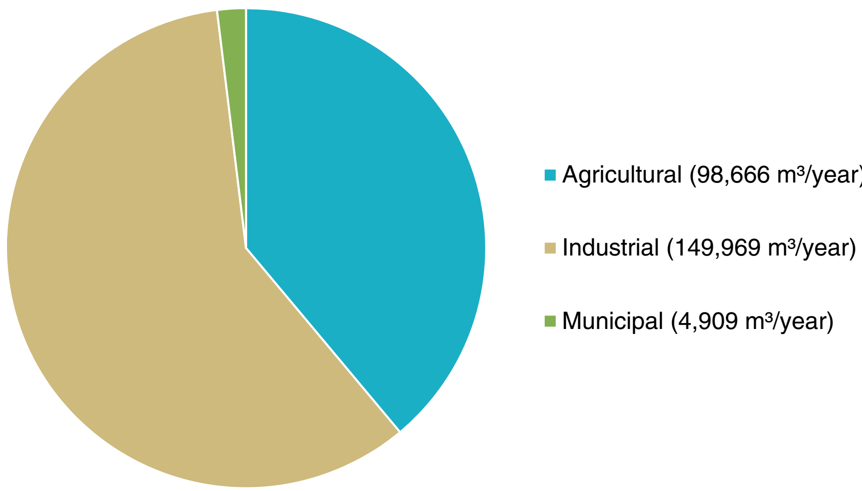
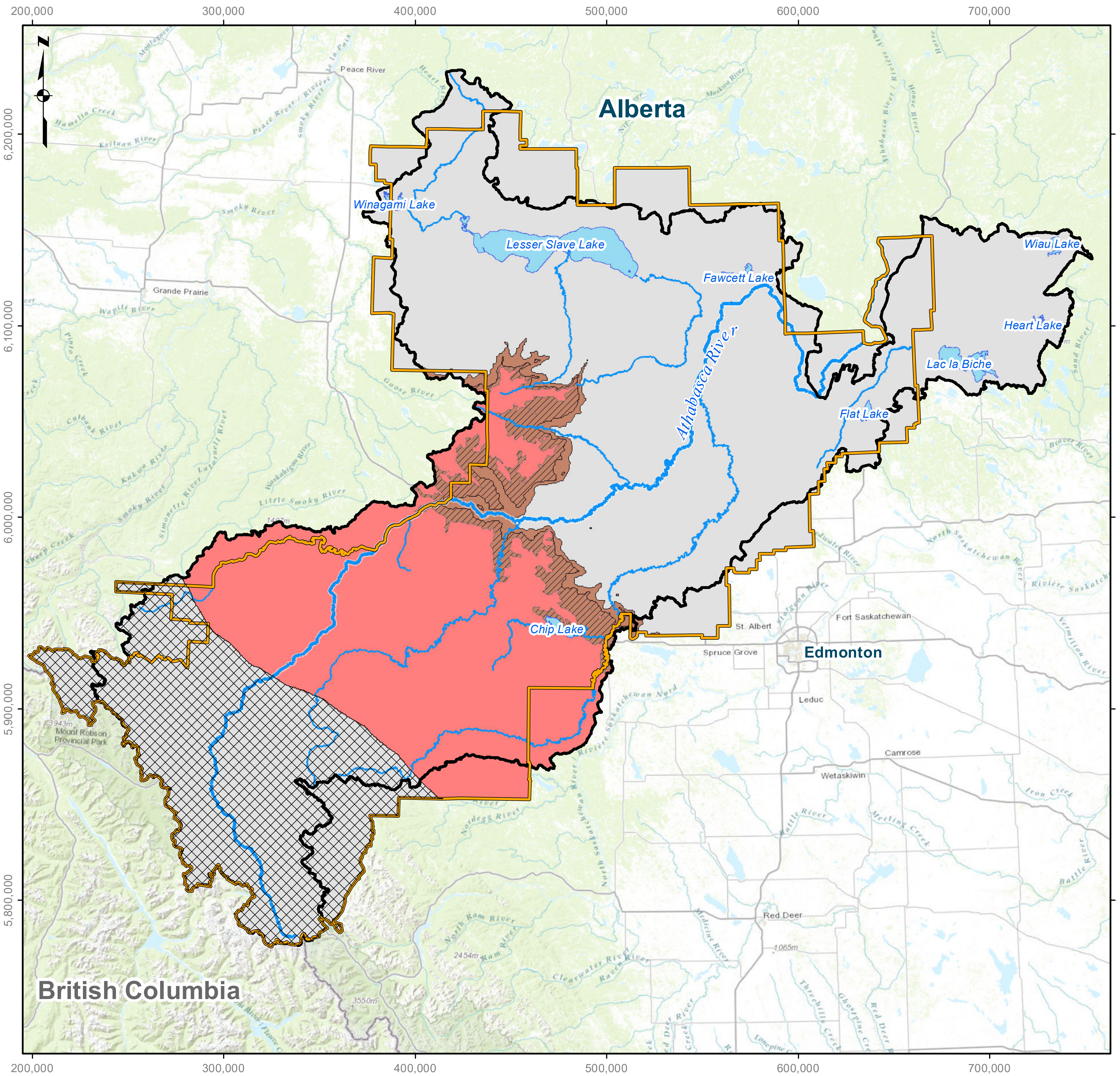
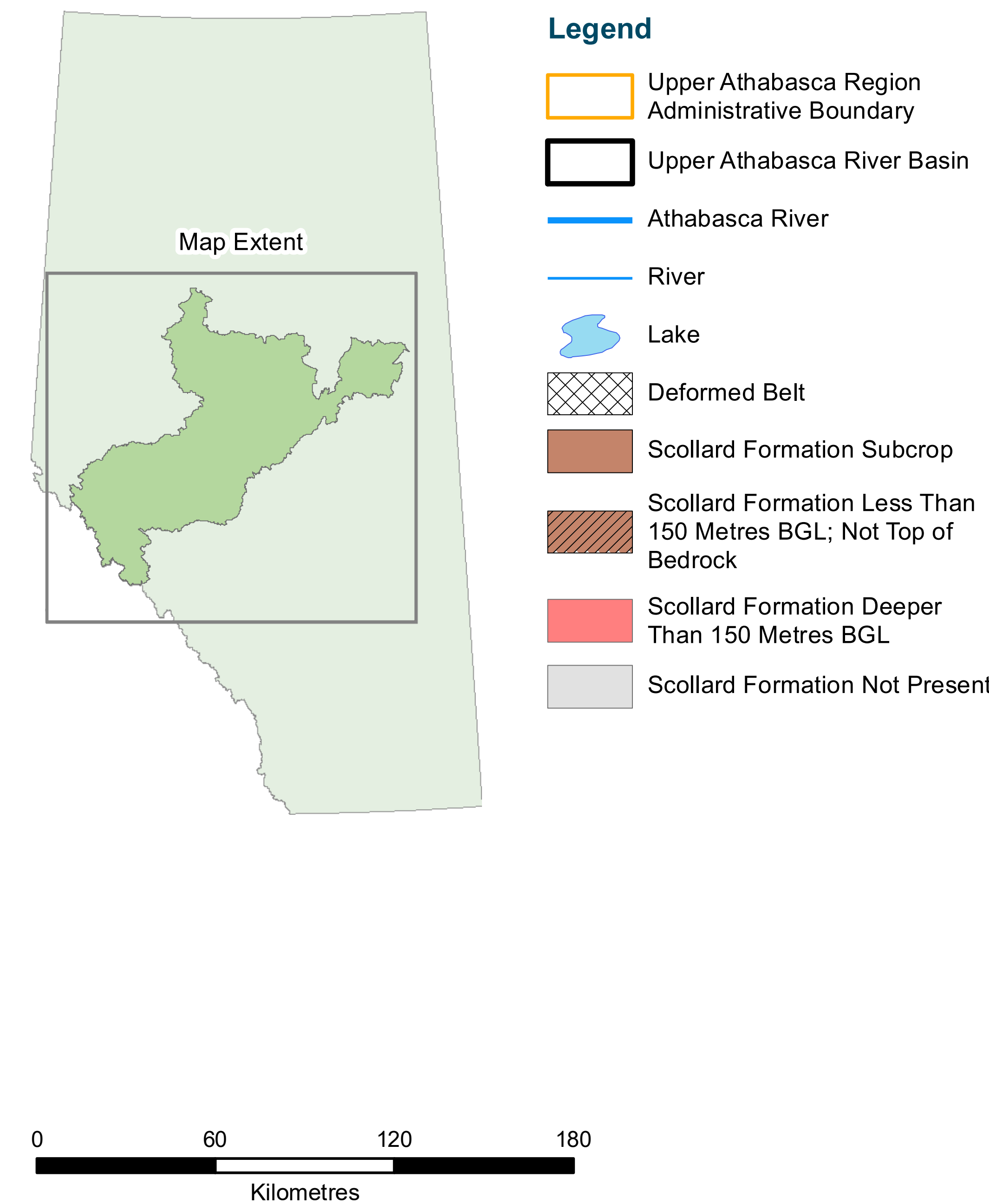


Figure 32. Scollard Formation – Annual Authorized Groundwater Volumes by Water-Use Category

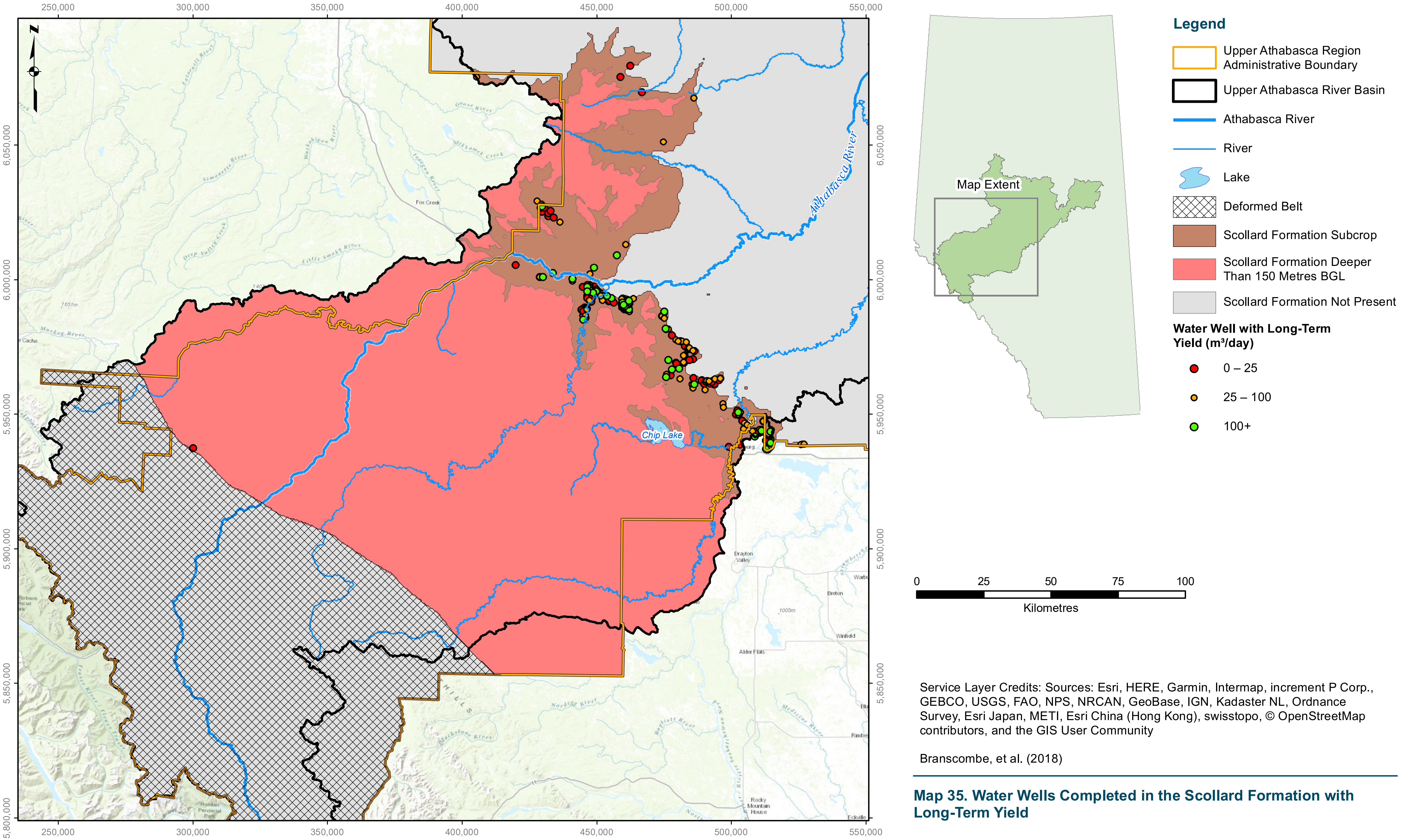




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 34. Extent of the Scollard Formation Within the UAR



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

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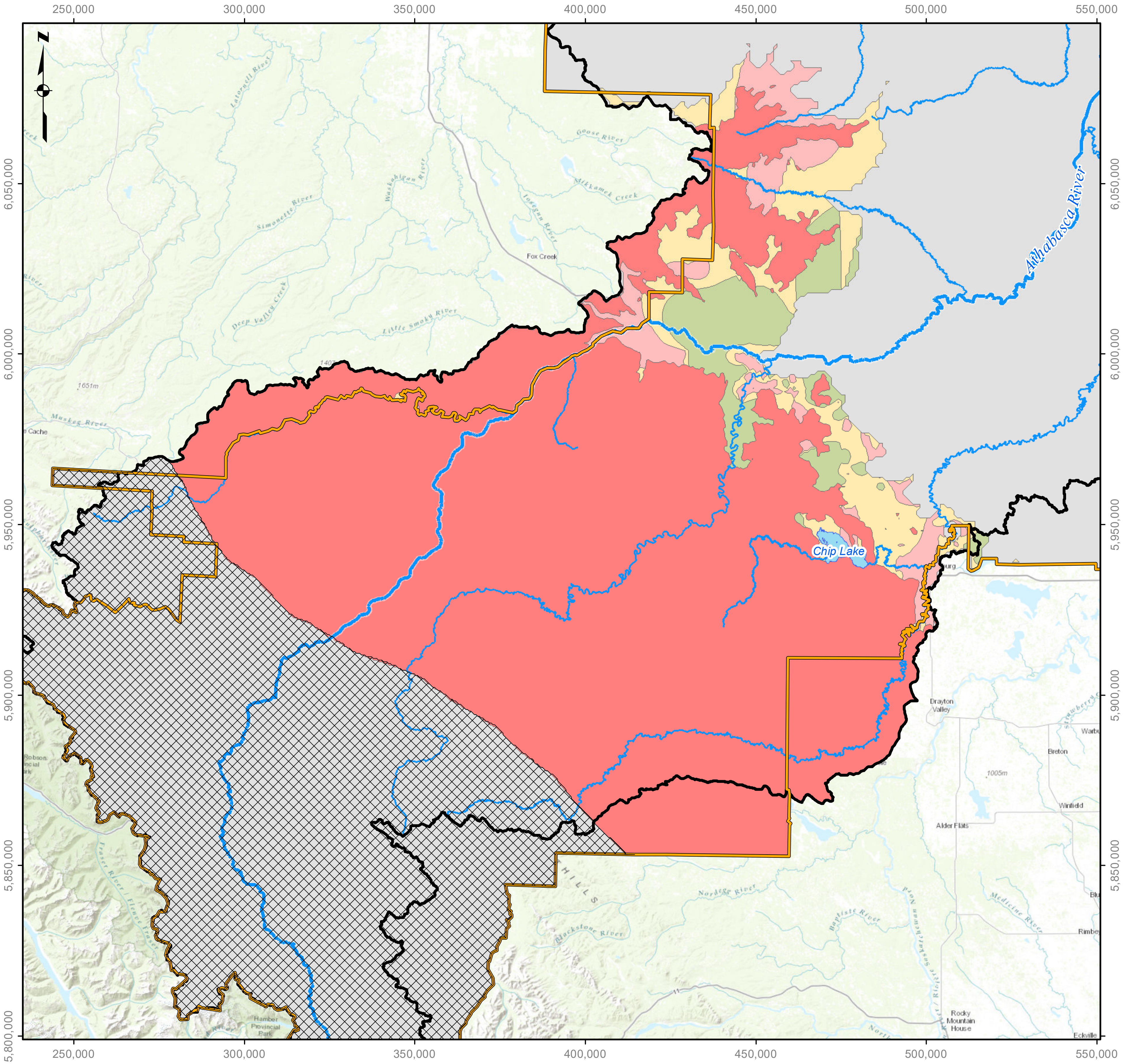
Map 35. Water Wells Completed in the Scollard Formation with Long-Term Yield



Legend

- Upper Athabasca Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Scollard Formation Deeper Than 150 Metres BGL
- Scollard Formation Not Present

Long-Term Water Well Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+

0 25 50 75 100

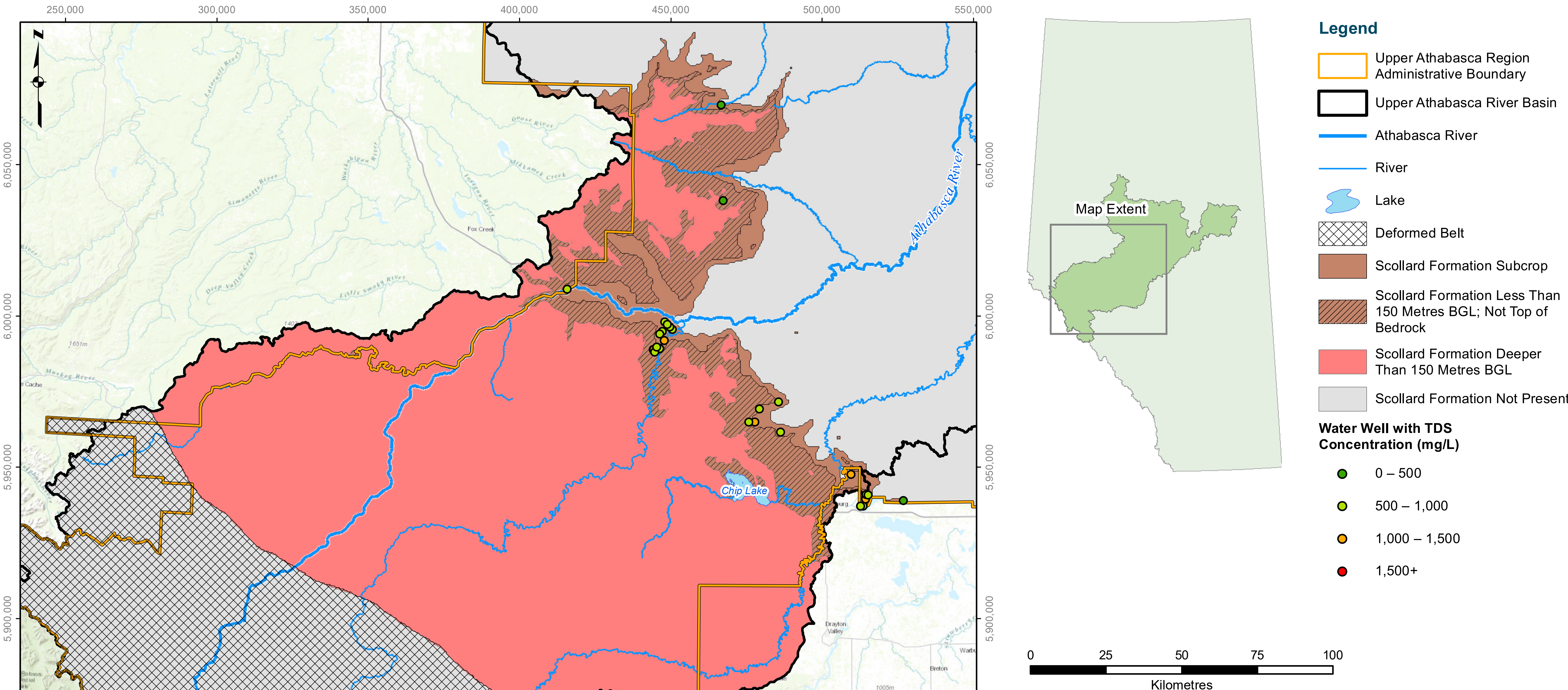
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Scollard Formation.

Branscombe, et al. (2018)

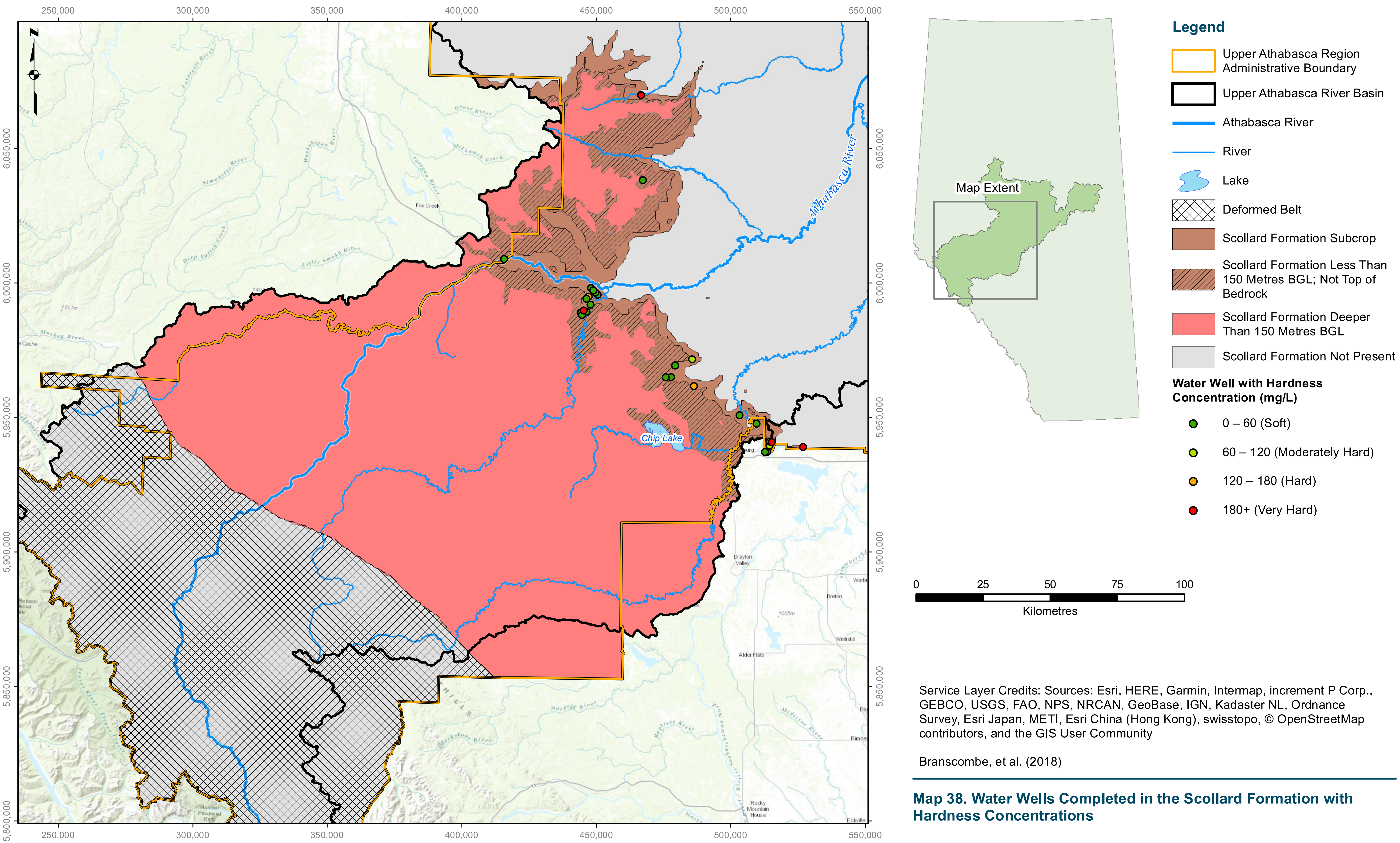
Map 36. Long-Term Water Well Yields Within the Scollard Formation



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

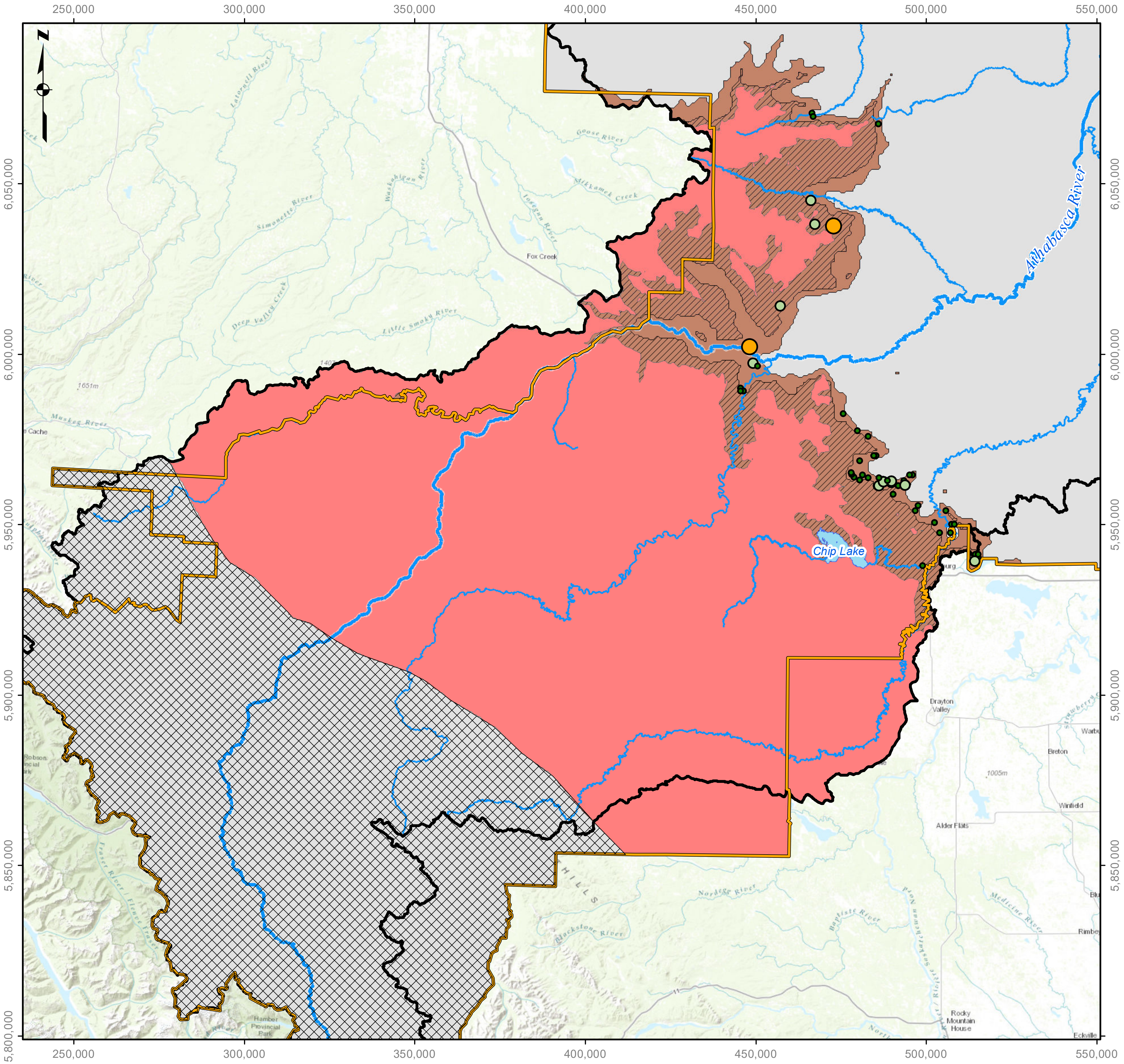
Map 37. Water Wells Completed in the Scollard Formation with Total Dissolved Solids Concentrations

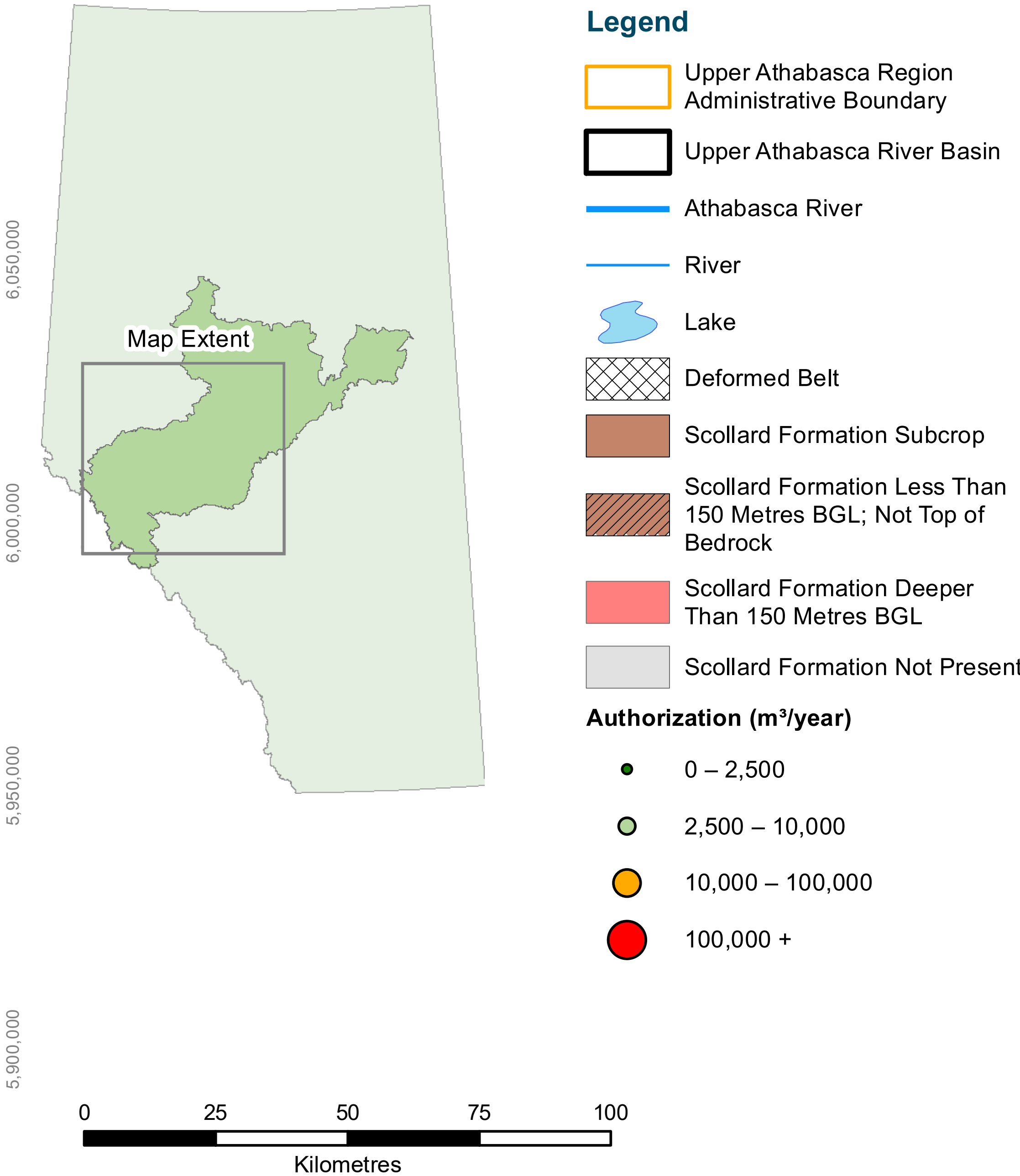


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 38. Water Wells Completed in the Scollard Formation with Hardness Concentrations





Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 39. Groundwater Authorizations in the Scollard Formation

4.5. Wapiti Interval

The Wapiti Interval is the third youngest bedrock geounit in the UAR and conformably underlies the Scollard Formation. Map 40 shows the extent of the Wapiti Interval in the UAR, in addition to any areas where the Wapiti Interval is deeper than 150 metres BGL in the UAR. The Wapiti Interval is deeper than 150 metres BGL in large portions of its extent in the southwestern portion of the UAR where it underlies the Scollard Formation and the Paskapoo Formation. The Wapiti Interval subcrops in much of the northern portion of the UAR.

Map 41 shows the water wells completed in the Wapiti Interval in the UAR with enough information to calculate a long-term yield. The map shows that the majority of water wells completed in the Wapiti Interval are situated in the east–central region of the UAR, closest to Edmonton. Map 42 shows contoured areas of long-term yields for water wells completed in the Wapiti Interval in the areas where the Interval is shallower than a depth of 150 metres BGL.

Map 43 and Map 44 show the water wells completed in the Wapiti Interval that have available values for TDS and hardness, respectively. Table 35 shows an overview of the available TDS and hardness results for groundwater samples from water wells completed in the Wapiti Interval. Table 36 shows the number of chemical analysis records that fit into the four categories of chemical hardness as defined by McGowan (2000). Most of the chemical analysis records are categorized as chemically soft or very hard; it is likely that the groundwater samples that yielded hardness values of between 0 and 60 mg/L were sampled after passing through a water softener.

Chemical Parameter	Number of Records	Maximum (mg/L)	Minimum (mg/L)	Average (mg/L)	Median (mg/L)
TDS	1,316	4,834	26	1,037	928
Hardness	1,210	1,212	1	97	33

Table 35. Wapiti Interval – TDS and Hardness Overview

Hardness (mg/L)	Number of Records
0 – 60 (Soft)	751
60 – 120 (Moderately Hard)	141
120 – 180 (Hard)	76
180+ (Very Hard)	242
Total	1,210

Table 36. Wapiti Interval – Hardness Categories

Map 45 shows the locations of authorized groundwater diversions from the Wapiti Interval. Within the UAR, there are 2,969 groundwater authorizations associated with water wells completed in the Wapiti Interval; these authorizations represent a total groundwater allocation of 6,546,281 m^3/year. There are 6,857 domestic water wells and 2,203 domestic & stock water wells completed in the Wapiti Interval; these represent a protected allocation of 8,571,250 m^3/year and 13,768,750 m^3/year, respectively. The total of allocated and protected groundwater in the Wapiti Interval is 28,886,281 m^3/year. This value is a minimum, as there are domestic and domestic & stock water wells that could not be assigned to a geounit due to insufficient or unreported completion interval details.

The Wapiti Interval in general is not a high-yielding aquifer and therefore is not an important aquifer for many industrial users in northwestern half of the UAR. However, it is an important aquifer for low-volume agricultural authorizations and domestic users.

Table 37 shows the number and volume of groundwater authorizations associated with water wells completed in the Wapiti Interval by authorization type. Table 38 shows the number and volume of groundwater authorizations associated with water wells completed in the Wapiti Interval by water-use category. Figure 33, Figure 34, and Figure 35 show the number of groundwater authorizations by authorization type, the annual authorized groundwater volumes by authorization type, and the annual authorized groundwater volumes by water-use category, respectively, for the Wapiti Interval.

Authorization Type	Number of Authorizations	Annual Volume (m³/year)
Water Resources Act Licence	689	2,816,583
Water Resources Act Interim Licence	37	588,228
Water Act TDL	0	0
Water Act Licence	120	1,014,232
Water Act Registration	2,123	2,127,237
Total	2,969	6,546,281

Table 37. Wapiti Interval – Groundwater Authorizations by Authorization Type

Water-Use Category	Number of Authorizations	Annual Volume (m³/year)
Agricultural	2,881	4,582,550
Industrial	40	1,315,861
Municipal	48	647,870
Total	2,969	6,546,281

Table 38. Wapiti Interval – Groundwater Authorizations by Water-Use Category

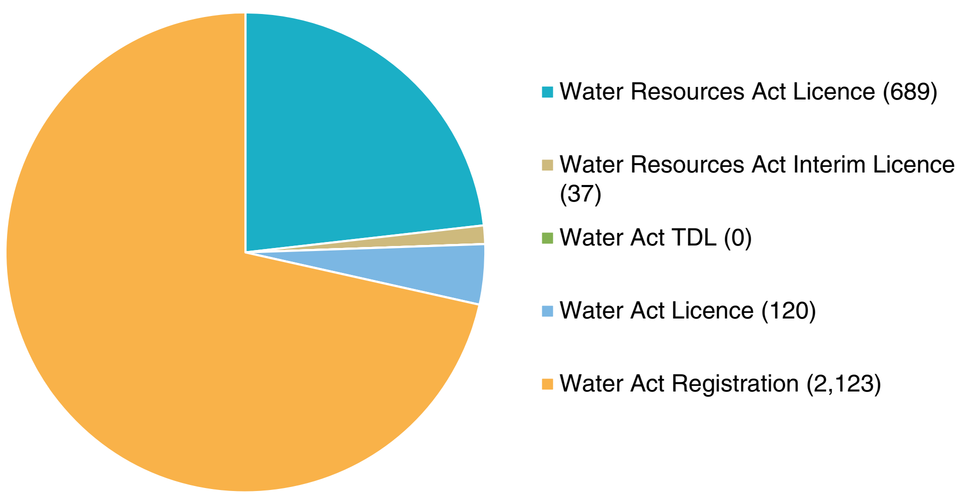


Figure 33. Wapiti Interval – Number of Groundwater Authorizations by Authorization Type

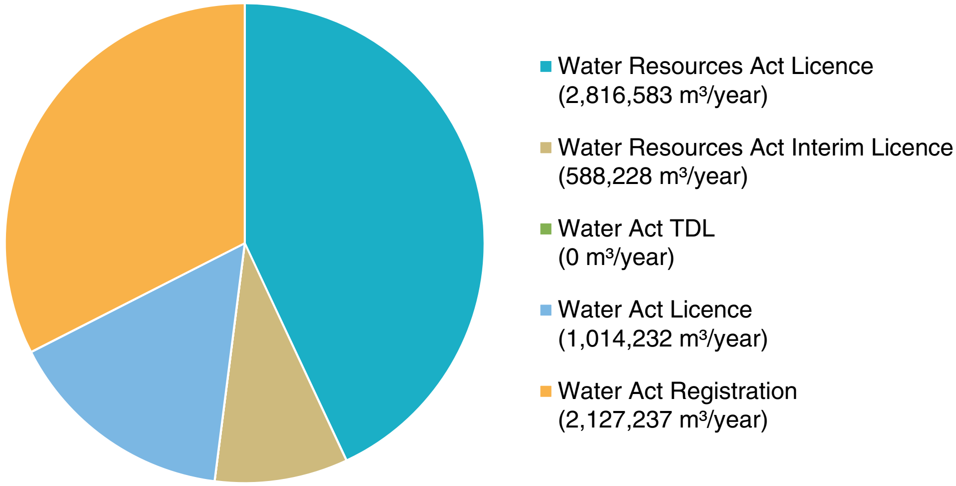


Figure 34. Wapiti Interval – Annual Authorized Groundwater Volumes by Authorization Type

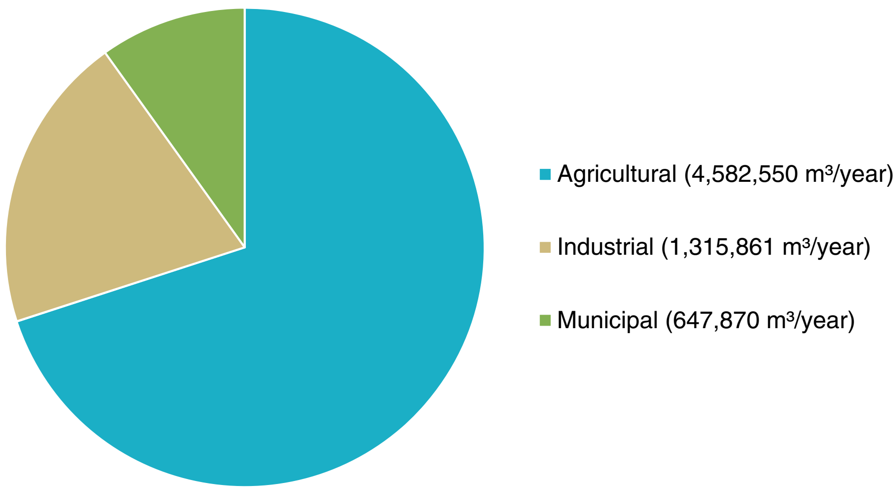
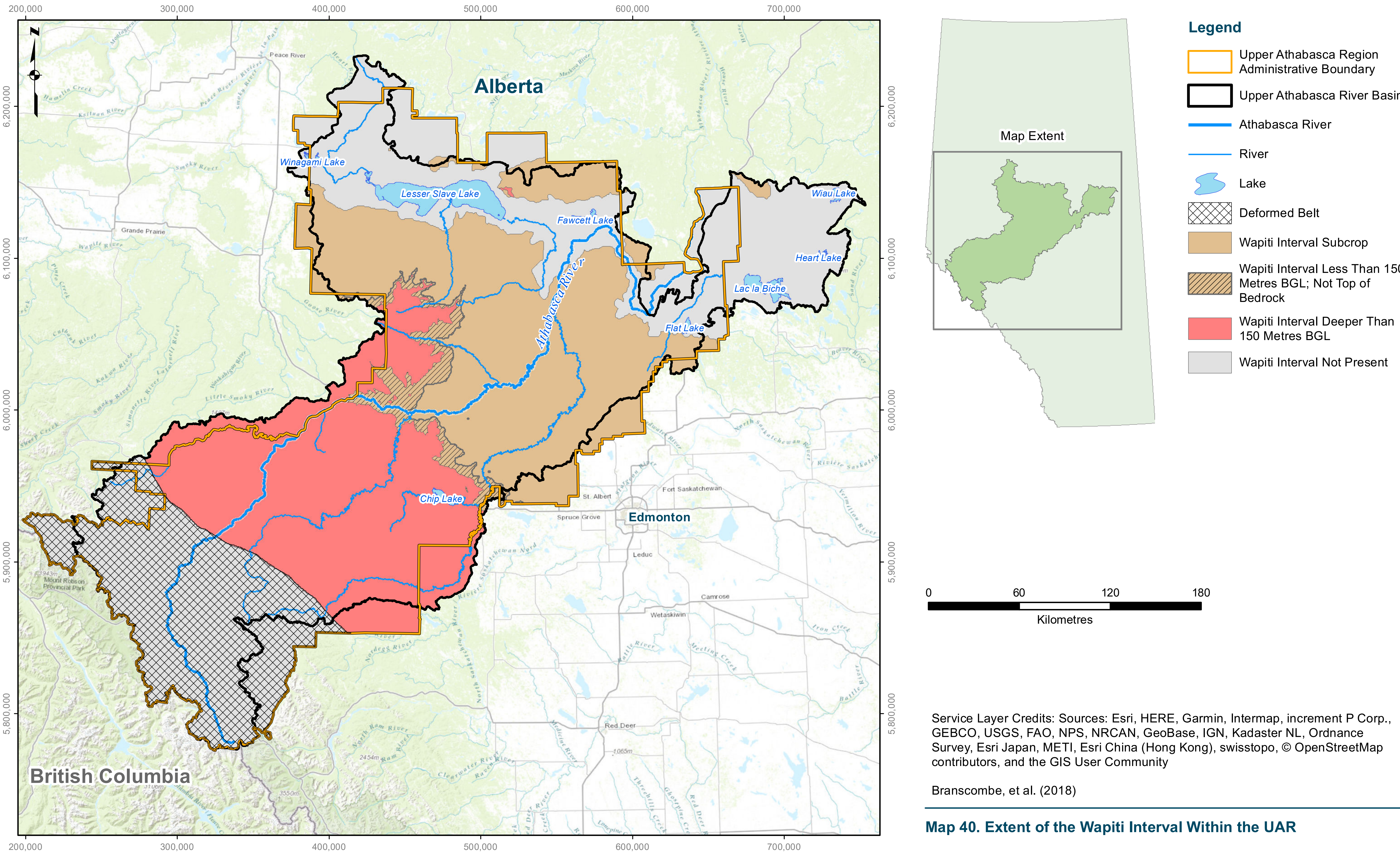


Figure 35. Wapiti Interval – Annual Authorized Groundwater Volumes by Water-Use Category



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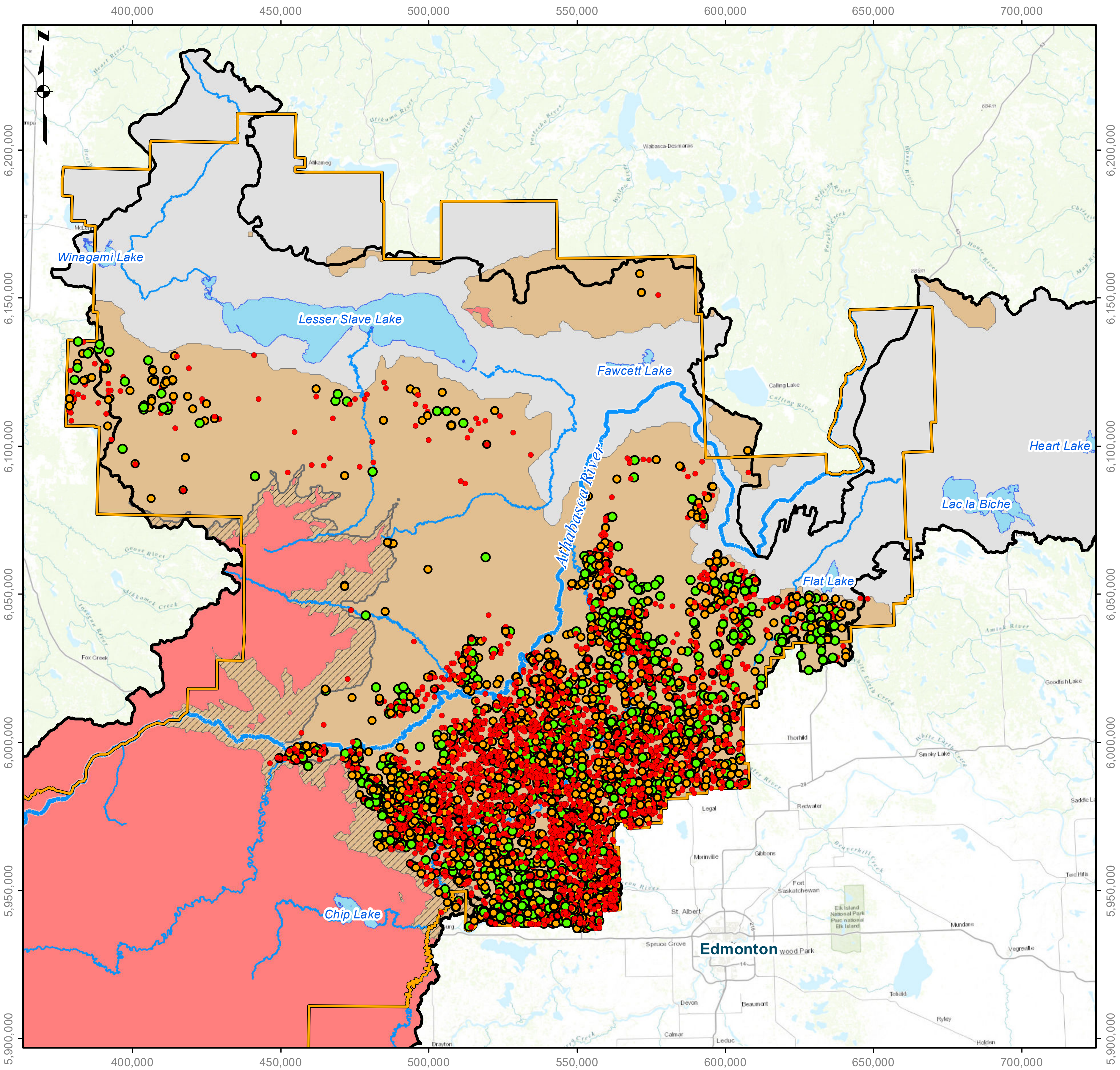
Map 40. Extent of the Wapiti Interval Within the UAR

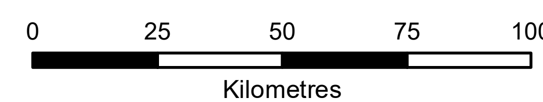


Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Wapiti Interval Subcrop
- Wapiti Interval Less Than 150 Metres BGL; Not Top of Bedrock
- Wapiti Interval Deeper Than 150 Metres BGL
- Wapiti Interval Not Present

Water Well with Long-Term Yield (m^3/day)

- 100+
- 25 - 100
- 0 - 25



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

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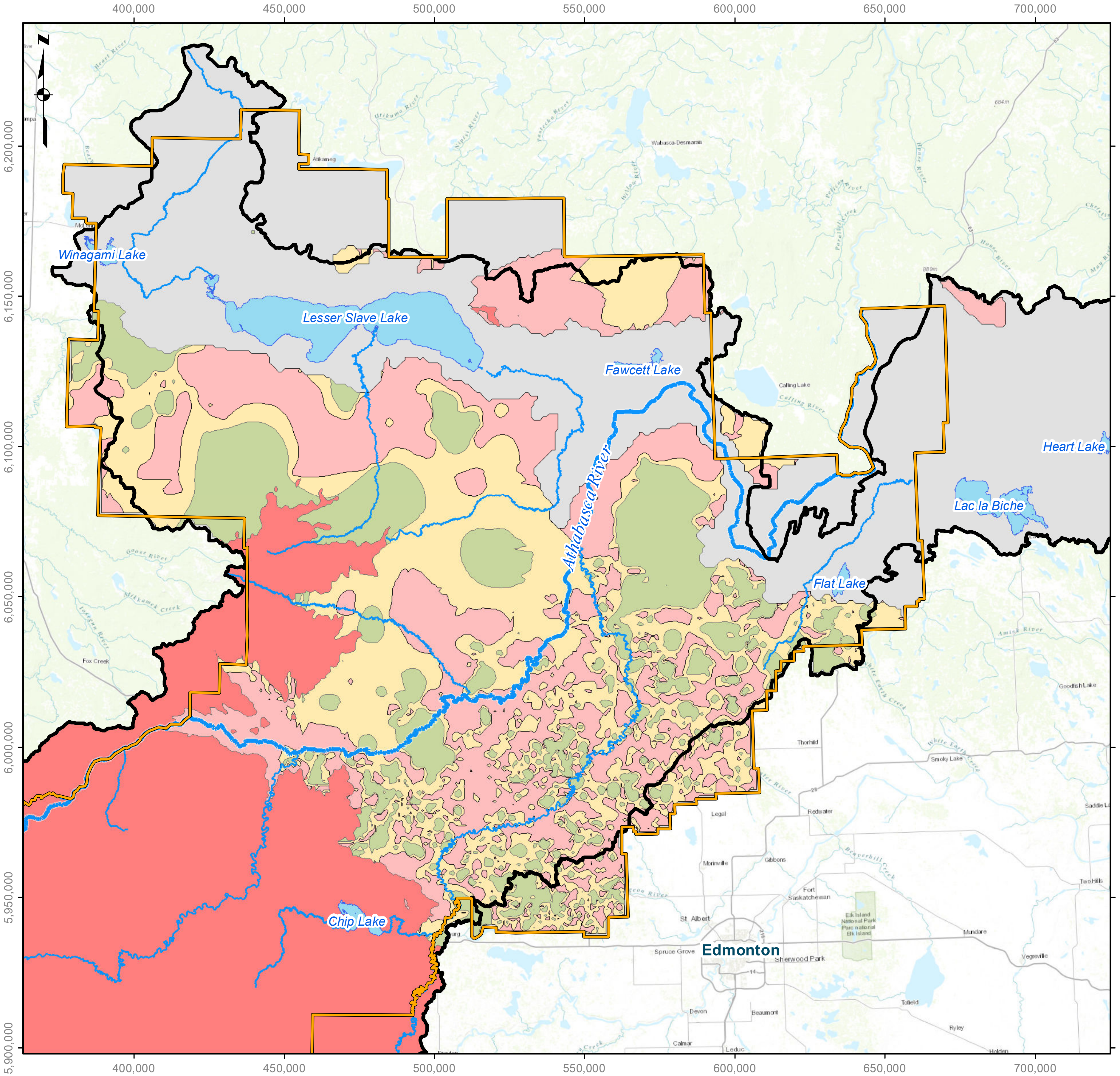
Map 41. Water Wells Completed in the Wapiti Interval with Long-Term Yield



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Wapiti Interval Deeper Than 150 Metres BGL
- Wapiti Interval Not Present

Long-Term Water Well Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+

0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Wapiti Interval.

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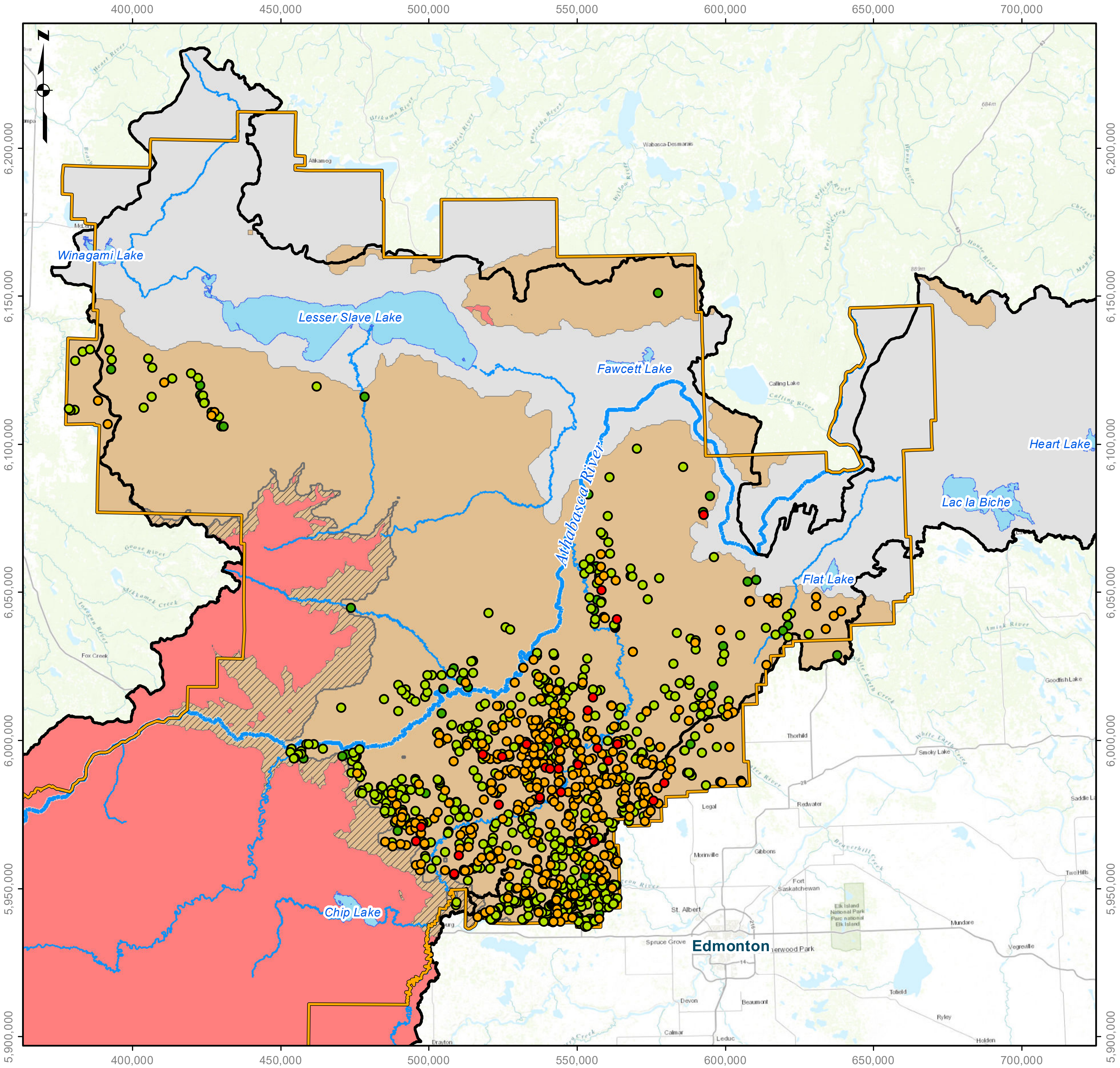
Map 42. Long-Term Water Well Yields Within the Wapiti Interval



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Wapiti Interval Subcrop
- Wapiti Interval Less Than 150 Metres BGL; Not Top of Bedrock
- Wapiti Interval Deeper Than 150 Metres BGL
- Wapiti Interval Not Present

Water Well with TDS Concentration (mg/L)

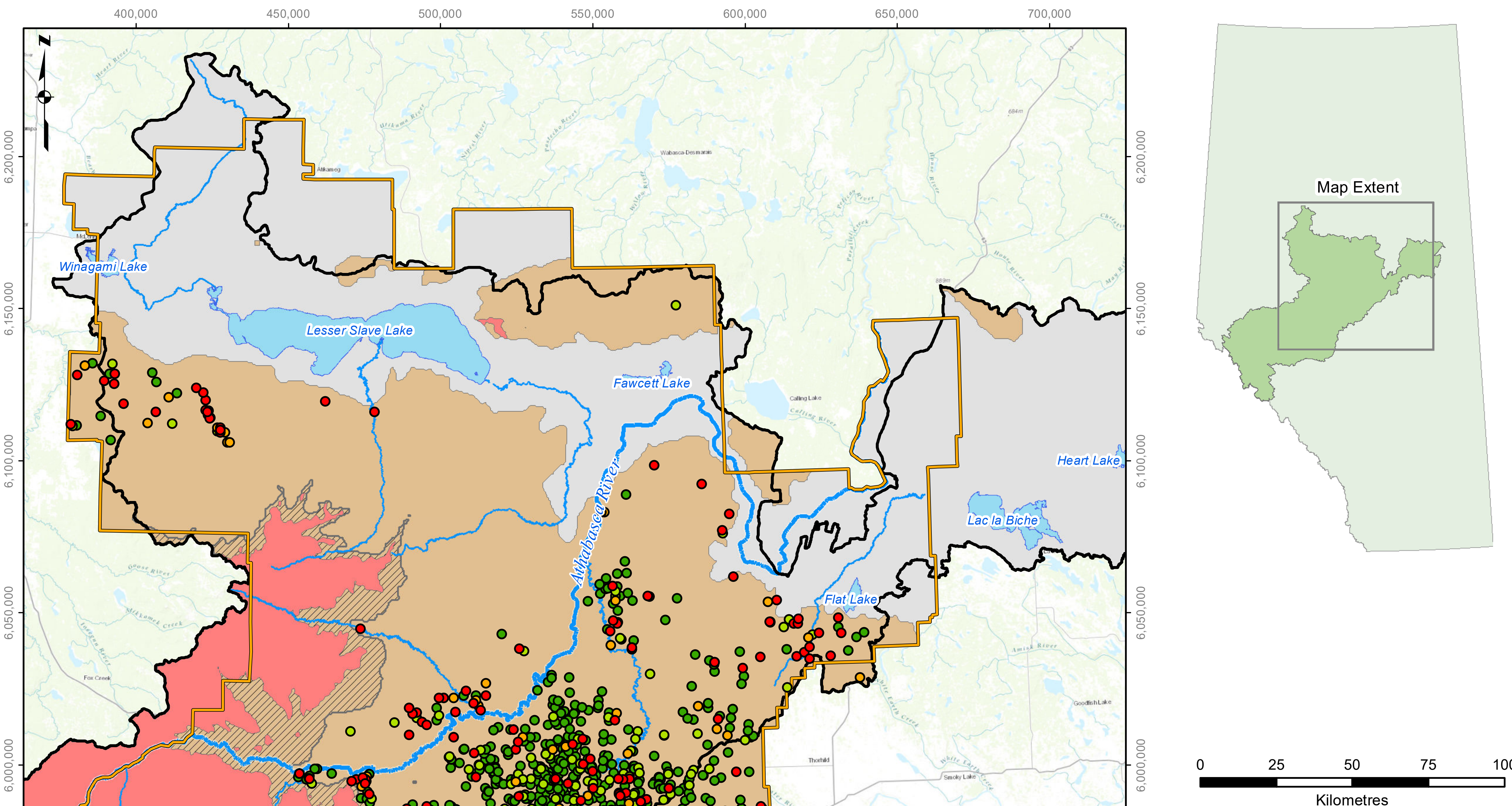
- 0 – 500
- 500 – 1,000
- 1,000 – 1,500
- 1,500+

0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

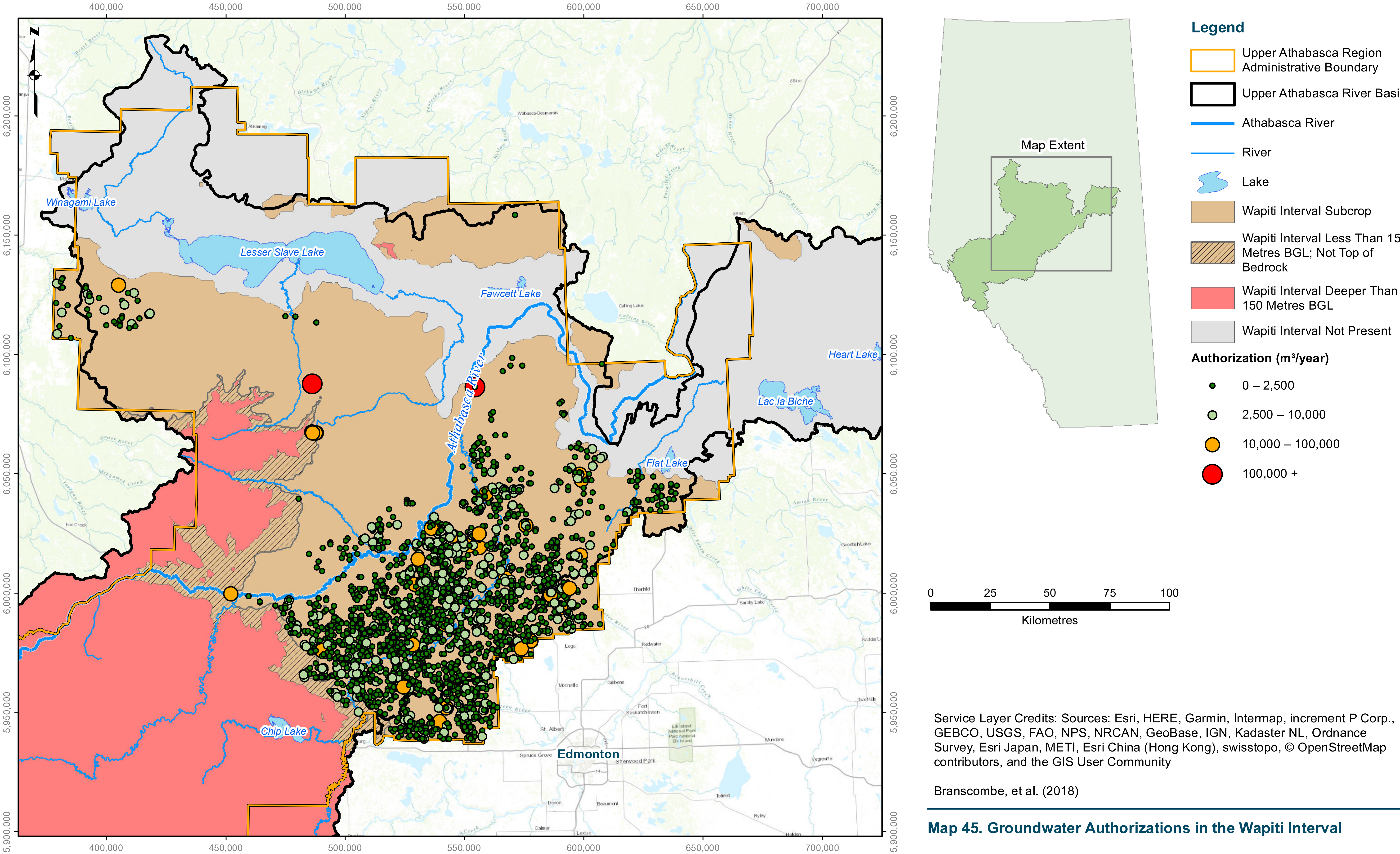
Map 43. Water Wells Completed in the Wapiti Interval with Total Dissolved Solids Concentrations



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 44. Water Wells Completed in the Wapiti Interval with Hardness Concentrations



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

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Map 45. Groundwater Authorizations in the Wapiti Interval

4.6. Lea Park Interval

The Lea Park Interval is the fourth youngest bedrock geounit in the UAR and conformably underlies the Wapiti Interval. The Lea Park Interval is also the oldest interval evaluated in the present study.

Map 46 shows the extent of the Lea Park Interval in the UAR, in addition to any areas where the Lea Park Interval is deeper than 150 metres BGL in the UAR. The Lea Park Interval is deeper than 150 metres BGL in large areas throughout most of the UAR where it underlies the Wapiti Interval, the Scollard Formation, and the Paskapoo Formation. The Lea Park Interval subcrops in the northern portion of the UAR.

Map 47 shows the water wells completed in the Lea Park Interval in the UAR with enough information to calculate a long-term yield. The map shows that the majority of water wells completed in the Lea Park Interval are completed in the northeastern region of the UAR, close to the Athabasca River and near Flat Lake. Map 48 shows contoured areas of long-term yields for water wells completed in the Lea Park Interval in the areas where the Interval is shallower than a depth of 150 metres BGL.

Map 49 and Map 50 show the water wells completed in the Lea Park Interval that have available values for TDS and hardness, respectively. Table 39 shows an overview of the available TDS and hardness results for groundwater samples from water wells completed in the Lea Park Interval. Table 40 shows the number of chemical analysis records that fit into the four categories of chemical hardness as defined by McGowan (2000). Most of the chemical analysis records are categorized as chemically very hard; it is likely that the groundwater samples that yielded hardness values of between 0 and 60 mg/L were sampled after passing through a water softener.

Chemical Parameter	Number of Records	Maximum (mg/L)	Minimum (mg/L)	Average (mg/L)	Median (mg/L)
TDS	88	3,219	281	946	789
Hardness	87	1,762	8	269	253

Table 39. Lea Park Interval – TDS and Hardness Overview

Hardness (mg/L)	Number of Records
0 – 60 (Soft)	8
60 – 120 (Moderately Hard)	15
120 – 180 (Hard)	10
180+ (Very Hard)	54
Total	87

Table 40. Lea Park Interval – Hardness Categories

Map 51 shows the locations of authorized groundwater diversions from the Lea Park Interval. Within the UAR, there are 43 groundwater authorizations associated with water wells completed in the Lea Park Interval; these authorizations represent a total groundwater allocation of 819,129 m³/year. There are 625 domestic water wells and 134 domestic & stock water wells completed in the Lea Park Interval; these represent a protected allocation of 781,250 m³/year and 837,500 m³/year, respectively. The total of allocated and protected groundwater in the Lea Park Interval is 2,437,879 m³/year. This value is a minimum, as there are domestic and domestic & stock water wells that could not be assigned to a geounit due to insufficient or unreported completion interval details.

The Lea Park Interval in general is not a very important aquifer within the UAR, as there are relatively few authorized or protected users diverting groundwater from the Interval in the UAR.

Table 41 shows the number and volume of groundwater authorizations associated with water wells completed in the Lea Park Interval by authorization type. Table 42 shows the number and volume of groundwater authorizations associated with water wells completed in the Lea Park Interval by water-use category. Figure 36, Figure 37, and Figure 38 show the number of groundwater authorizations by authorization type, the annual authorized groundwater volumes by type, and the annual authorized groundwater volumes by water-use category, respectively, for the Lea Park Interval.

Authorization Type	Number of Authorizations	Annual Volume (m^3/year)
Water Resources Act Licence	3	7,400
Water Resources Act Interim Licence	2	66,230
Water Act TDL	0	0
Water Act Licence	22	728,257
Water Act Registration	16	17,242
Total	43	819,129

Table 41. Lea Park Interval – Groundwater Authorizations by Authorization Type

Water-Use Category	Number of Authorizations	Annual Volume (m^3/year)
Agricultural	33	96,203
Industrial	10	722,926
Municipal	0	0
Total	43	819,129

Table 42. Lea Park Interval – Groundwater Authorizations by Water-Use Category

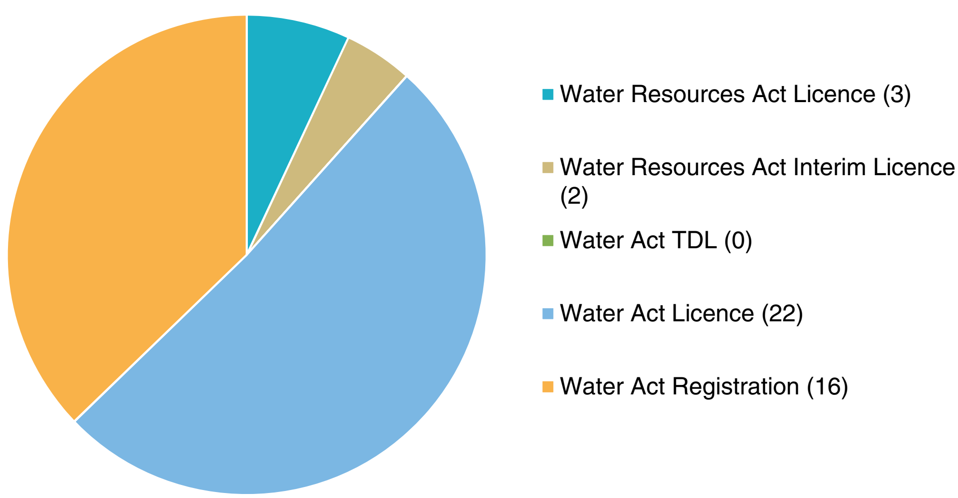


Figure 36. Lea Park Interval – Number of Groundwater Authorizations by Authorization Type

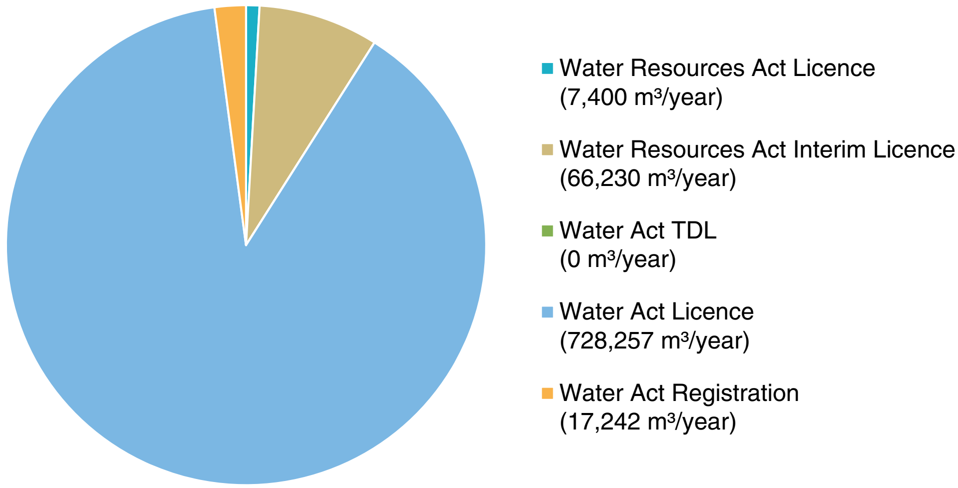


Figure 37. Lea Park Interval – Annual Authorized Groundwater Volumes by Authorization Type

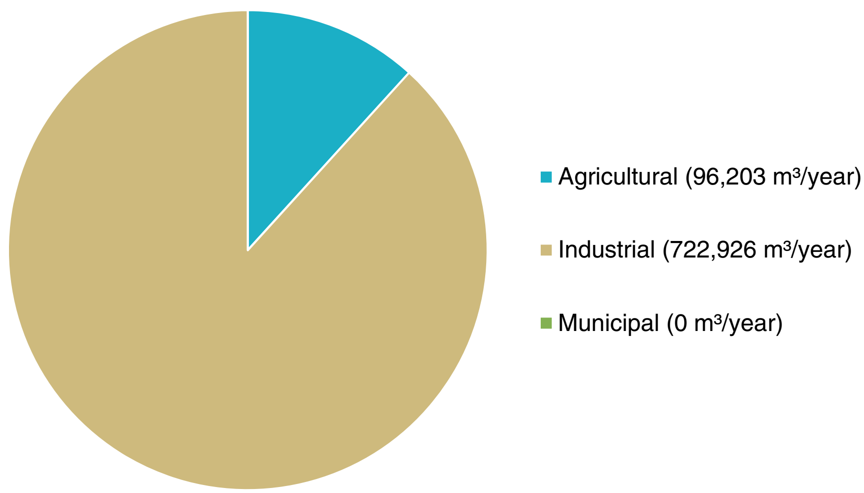
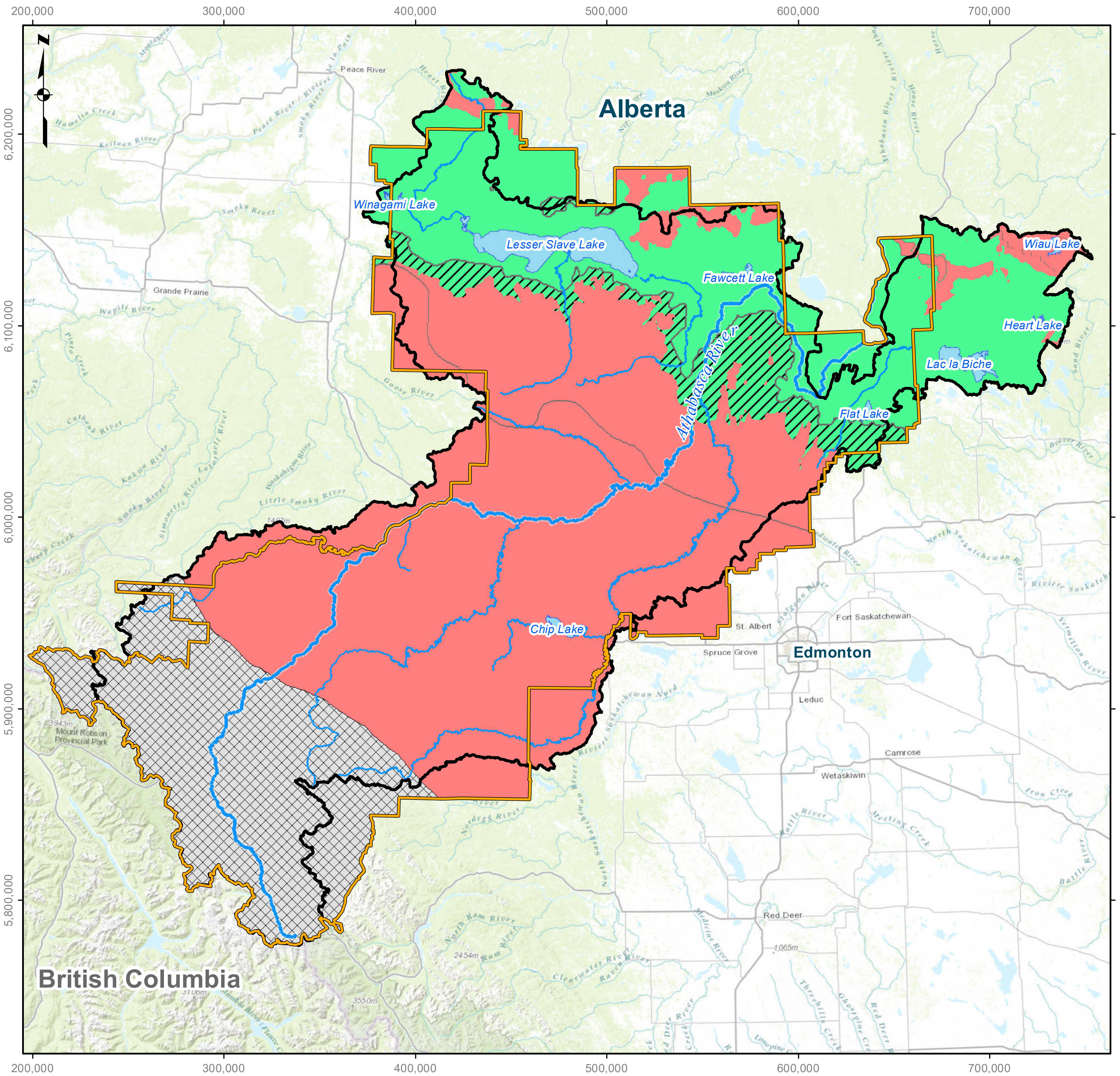
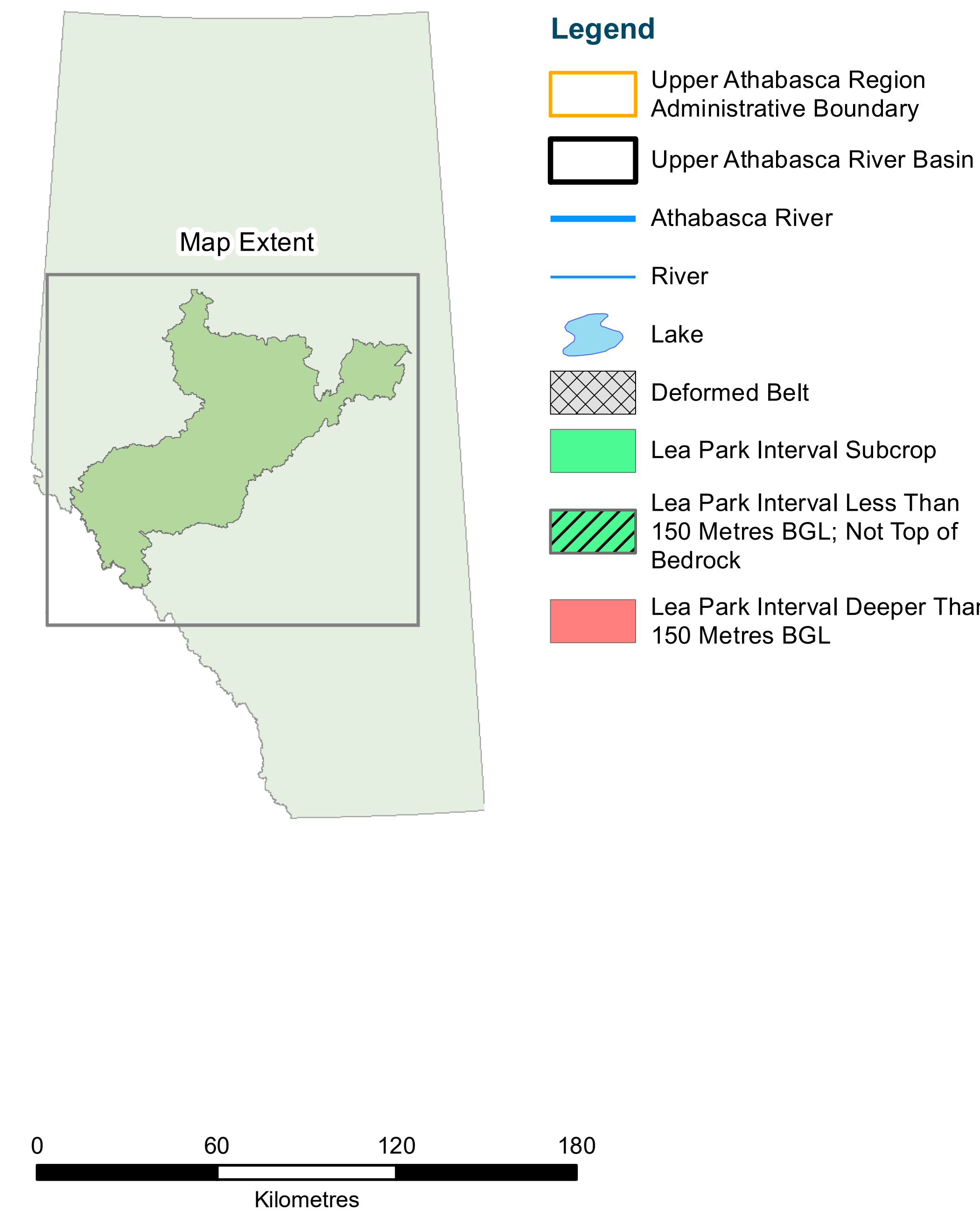


Figure 38. Lea Park Interval – Annual Authorized Groundwater Volumes by Water-Use Category





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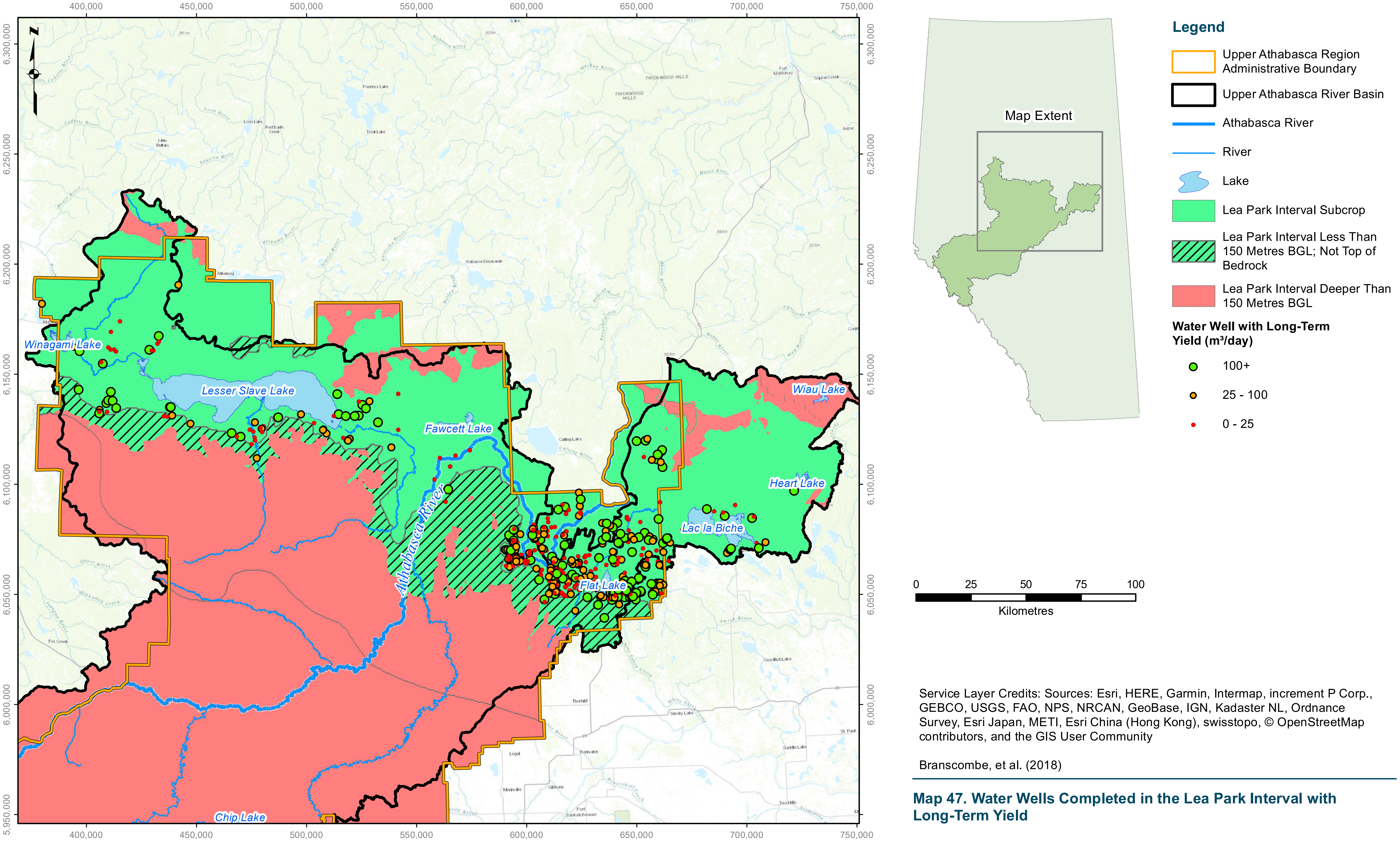
Map 46. Extent of the Lea Park Interval Within the UAR



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

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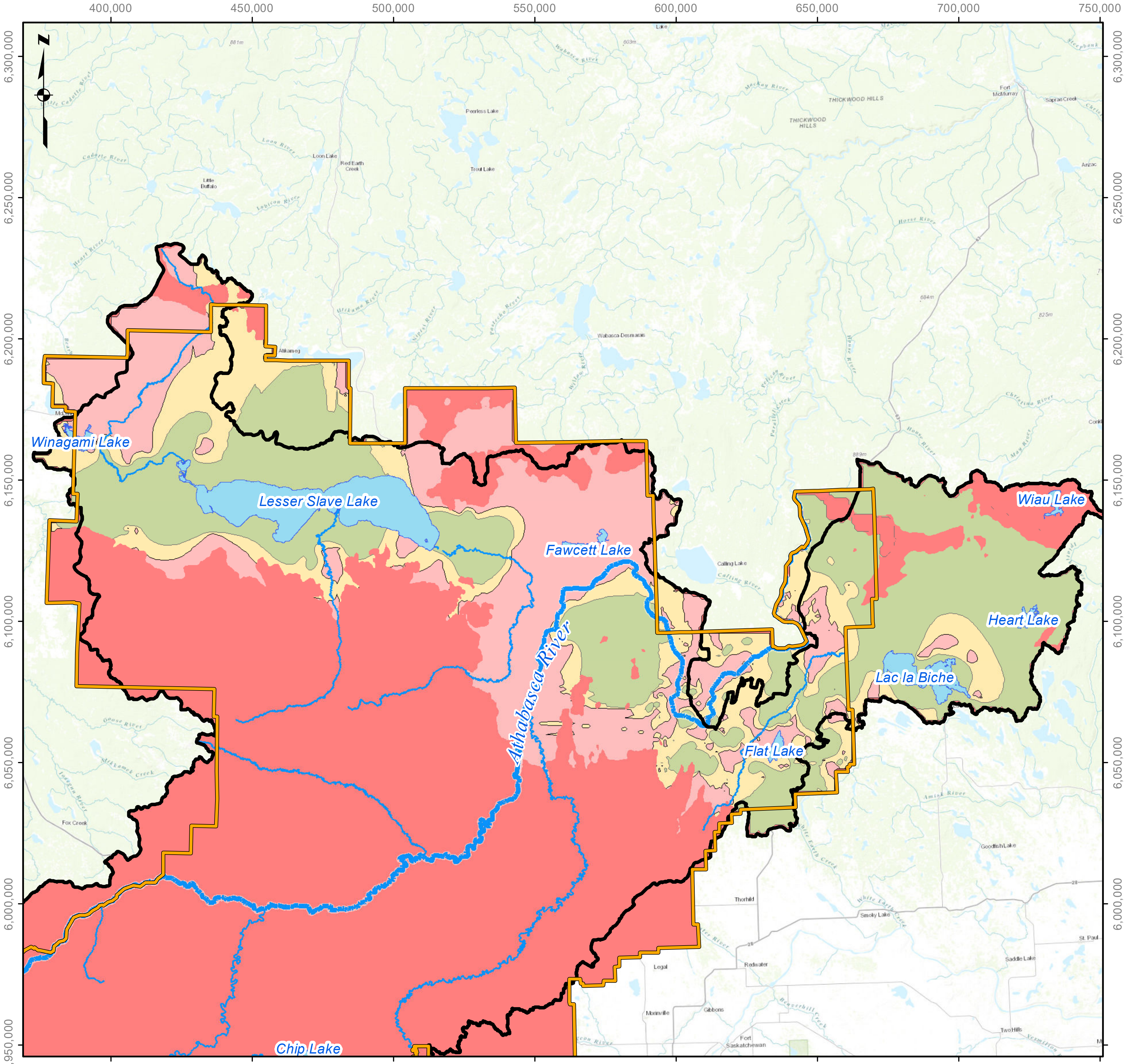
Map 47. Water Wells Completed in the Lea Park Interval with Long-Term Yield

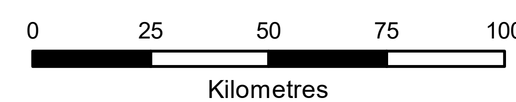


Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Lea Park Interval Deeper Than 150 Metres BGL

Long-Term Water Well Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+



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Long-term yield data are contoured from water wells completed in the Lea Park Interval.

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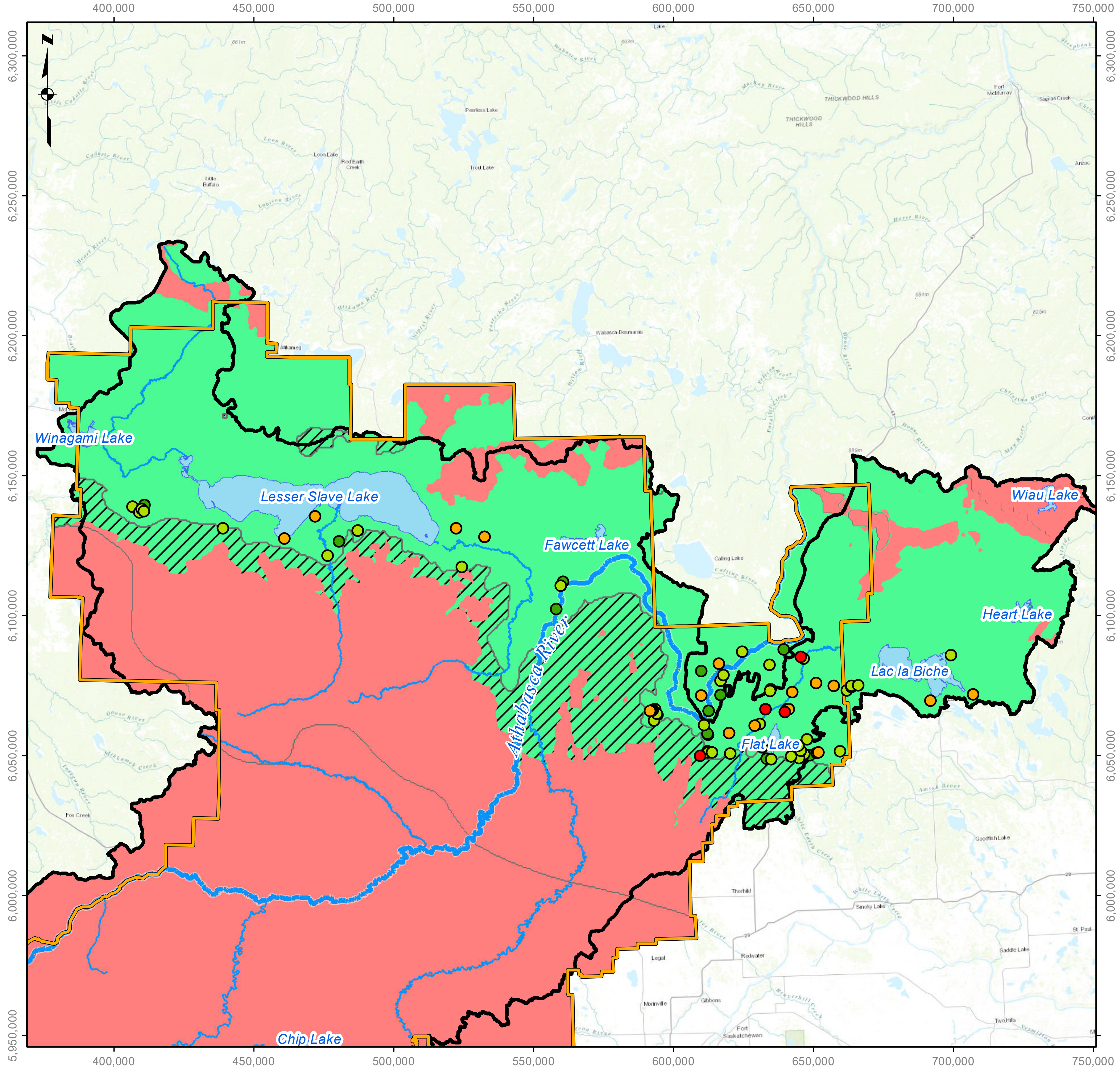
Map 48. Long-Term Water Well Yields Within the Lea Park Interval



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Lea Park Interval Subcrop
- Lea Park Interval Less Than 150 Metres BGL; Not Top of Bedrock
- Lea Park Interval Deeper Than 150 Metres BGL

Water Well with TDS Concentration (mg/L)

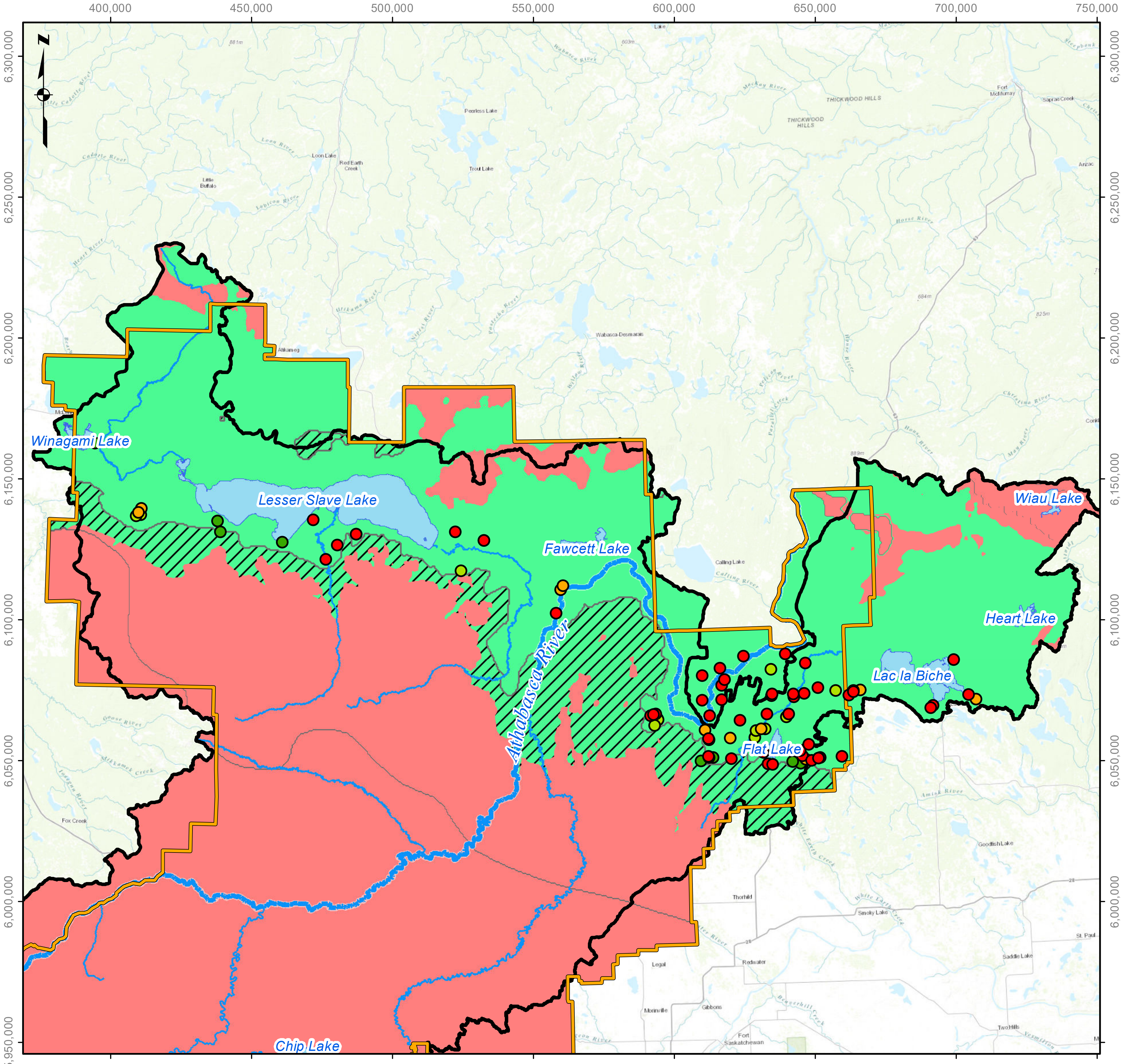
- 0 – 500
- 500 – 1,000
- 1,000 – 1,500
- 1,500+

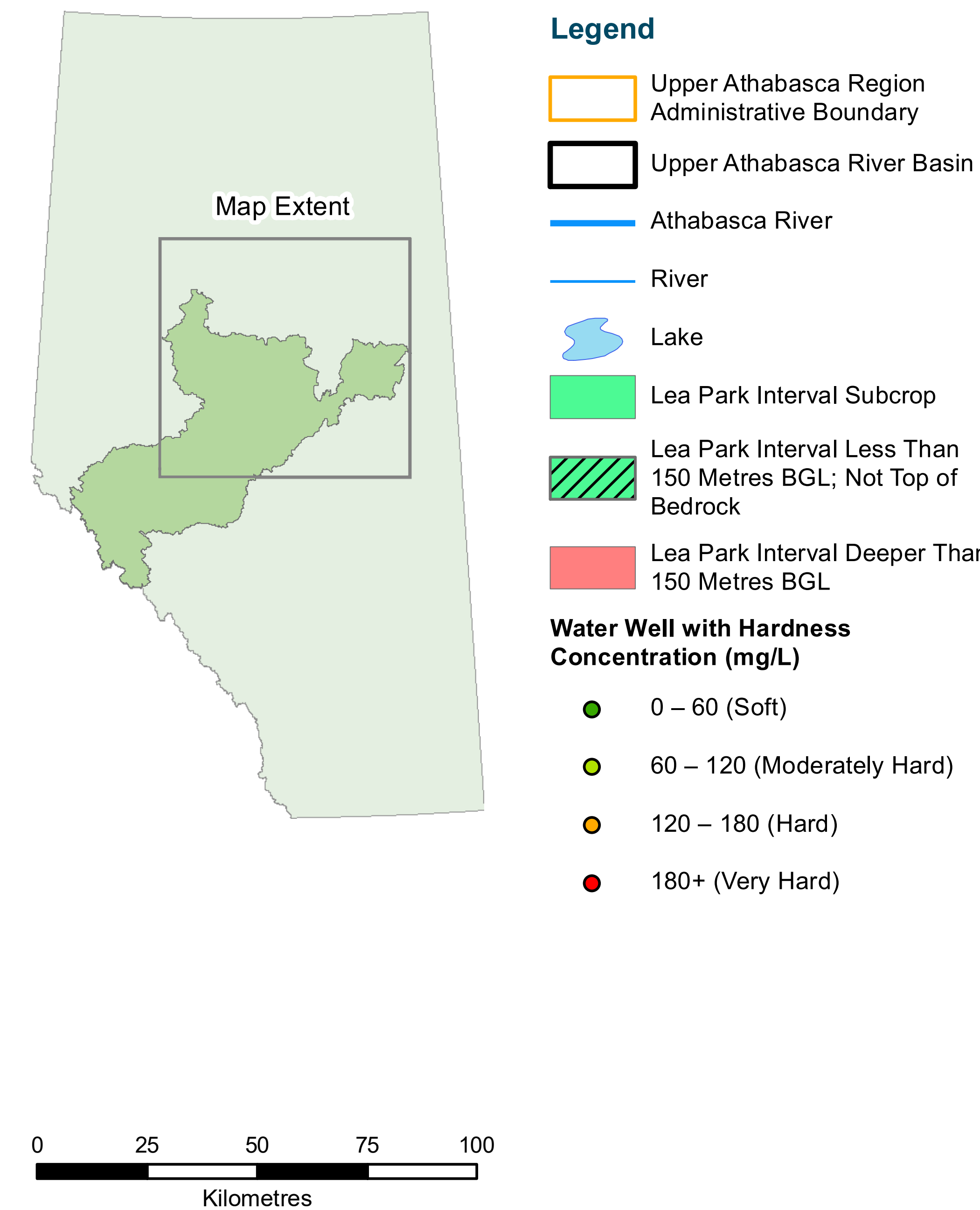
0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 49. Water Wells Completed in the Lea Park Interval with Total Dissolved Solids Concentrations





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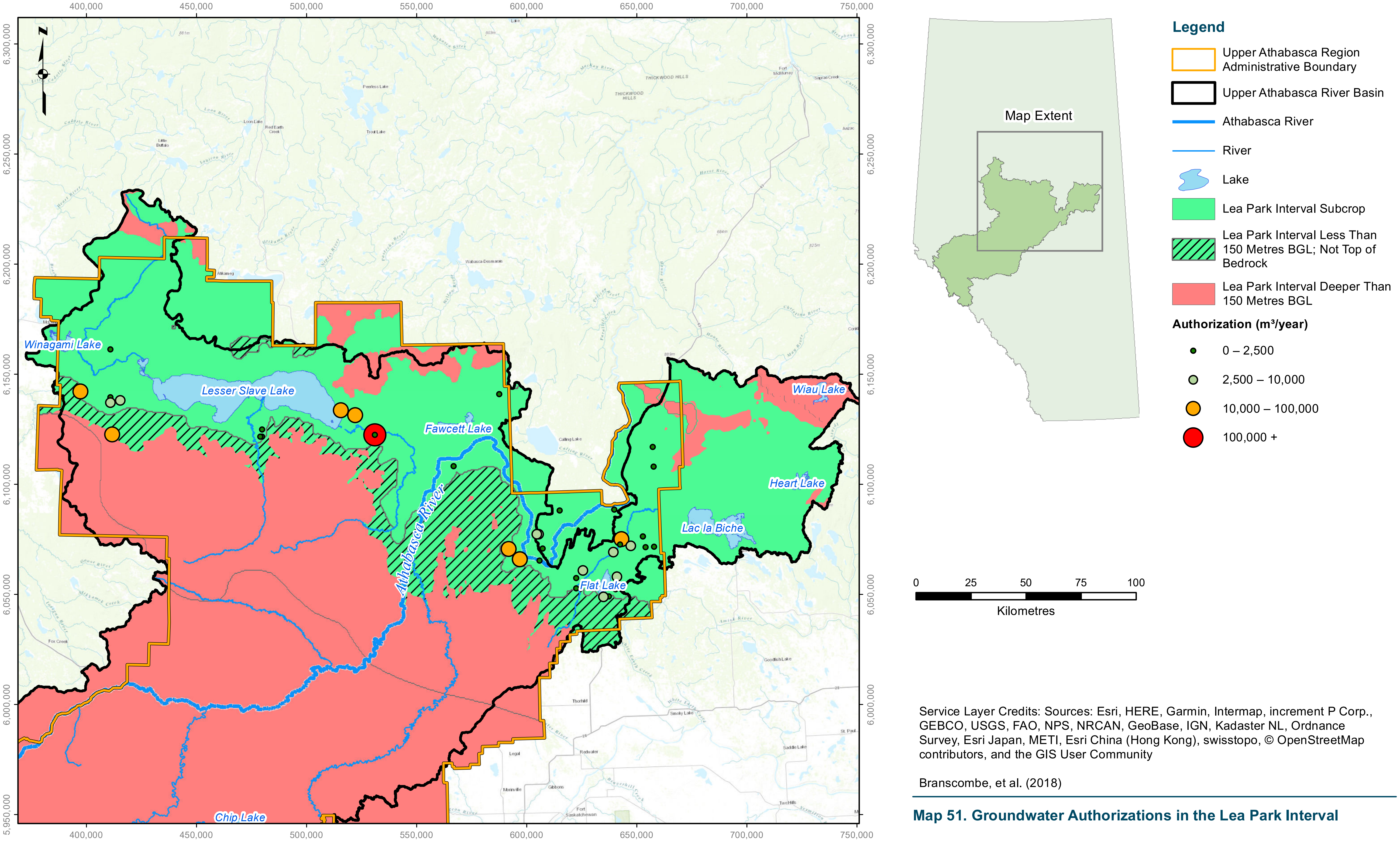
Branscombe, et al. (2018)

Map 50. Water Wells Completed in the Lea Park Interval with Hardness Concentrations



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Branscombe, et al. (2018)

Map 51. Groundwater Authorizations in the Lea Park Interval

5. Groundwater Budget

5.1. Overview

The primary component of a groundwater budget is groundwater recharge. However, there is no method to directly measure groundwater recharge, and indirect methods over a large area are subject to many variables that cannot be directly measured. In the present report, values for groundwater recharge are calculated based on average regional values for precipitation, actual evapotranspiration, and runoff. As a result, there is a high degree of uncertainty in the values calculated for groundwater recharge; also, the calculations would not be useful in determining the variability in groundwater recharge that could be expected to occur under varying climatic conditions.

In the present report, the process used to calculate groundwater recharge includes recharge that enters a groundwater-flow system and discharges both to a stream as baseflow and to evapotranspiration; no attempt was made to consider the portion of groundwater that flows between WMUs or the groundwater that will enter deeper groundwater-flow systems. These latter variables were not considered, in part because of time and budget restrictions, and in part because the volume of groundwater involved would be considerably less than the groundwater discharge to either baseflow or evapotranspiration.

5.2. Estimating Groundwater Recharge

The Government of Alberta (2013) provides the results of the Morton Complementary Relationship Areal Evapotranspiration (CRAE) Model for Alberta. The water balance includes precipitation (P), runoff (R), groundwater recharge (G), and aerial evapotranspiration (AET) in the following equation:

$$AET = P-R-G$$

Hubbert's (1940) theory of groundwater flow had the total groundwater discharging as baseflow in a basin. Tóth (1963), in the theoretic analysis of groundwater flow, demonstrated that in a homogeneous basin, half the basin would be an area of groundwater recharge and half the basin would be an area of groundwater discharge; therefore, not all groundwater discharges as baseflow in a homogeneous basin. Freeze and Witherspoon (1967) used computer modelling to show the effects of inhomogeneity and anisotropicity on groundwater flow in a basin. The results of the modelling showed that while inhomogeneity and anisotropicity do result in a recharge area that is larger than one half the basin, the groundwater discharge is not confined to streams as baseflow. The results of Freeze and Witherspoon (1967) are supported by field observations where groundwater discharge is observed as springs, soapholes, flowing shot holes, flowing water wells, and also the presence of groundwater-deposited salts at locations that are removed from any stream.

Therefore, total groundwater recharge (Gwt) will leave the groundwater system as both baseflow (Gwb) and evapotranspiration (Gwet) in the following equation:

$$Gwt = Gwb + Gwet$$

With the rearrangement of the aerial evapotranspiration equation, G = AET-P-R, the relationship can be used to determine the total groundwater recharge (Gwt). The precipitation can be measured at discrete points and reasonably extrapolated between the measuring points. The runoff can be measured with a reasonable degree of accuracy and averaged over the area of a basin. The determination of aerial evapotranspiration is much like precipitation in that it can be measured at discrete locations; however, unlike precipitation, extrapolation of the results between measuring sites is more difficult.

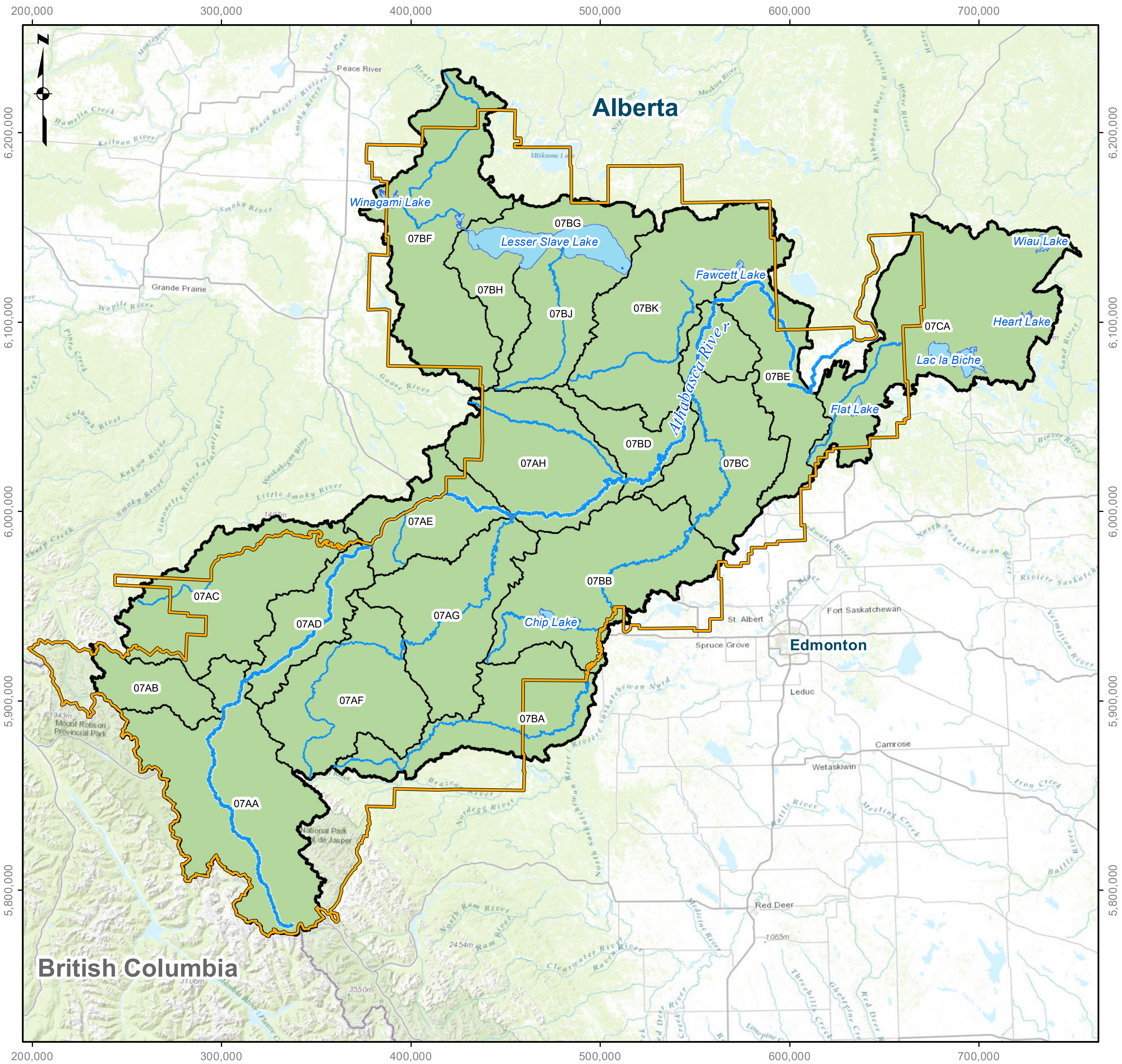
To solve for total groundwater recharge, it is necessary to obtain values for aerial evapotranspiration, precipitation, and groundwater recharge. Aerial evapotranspiration is considered to be the amount of water lost to evapotranspiration from the soil-plant continuum by an actively growing plant or crop. This value in Alberta is less than the potential evapotranspiration. The Government of Alberta (2013) provides a map for aerial evapotranspiration showing the spatial distribution of mean annual evapotranspiration losses over Alberta for 1980 through 2009, normalized by a corresponding mean value for Alberta of 364 millimetres per year.

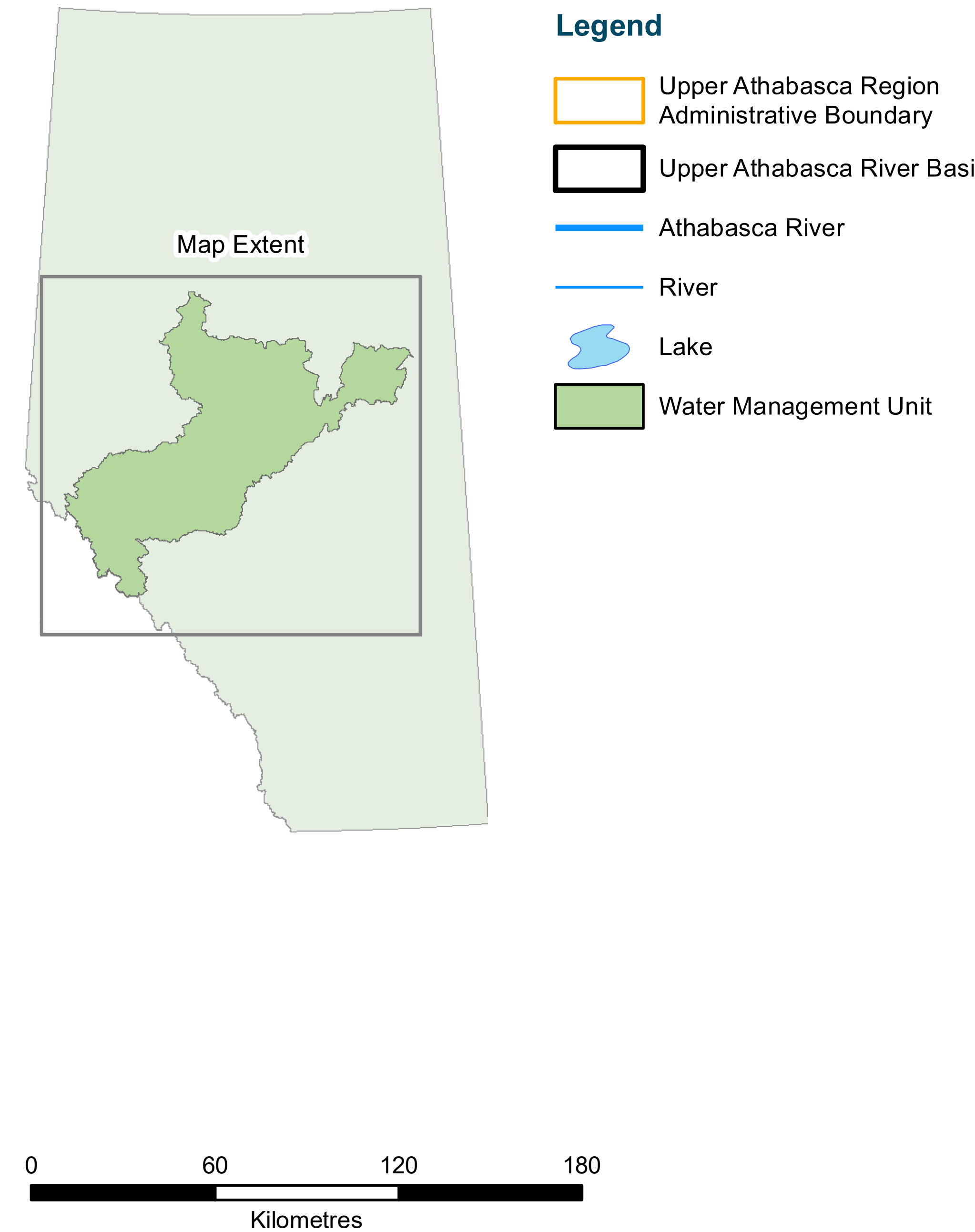
A map providing precipitation for the UAR is available from the Government of Alberta (2017). The map is based on precipitation from 1970 through 2000.

A map providing runoff for Alberta is available from the Government of Canada (Cole, 2013). The map provides average annual runoff in Canada from 1971 through 2013, and the 70% probability of exceedance results are used for mapping available runoff. The map is prepared from Statistics Canada's Water Yield Model and is intended for reference or mapping purposes.

The data provided by the above maps can be used to obtain values for precipitation, runoff, and aerial evapotranspiration over a large area. The maps can be converted into grids using Surfer, a Golden Software program.

There are 19 WMUs that fall entirely within the UAR. Each WMU is associated with a gauge station on a major river in the WMU that represents the pour point of the WMU, and measures all runoff and baseflow leaving that WMU. Map 52 shows the 19 WMUs within the UAR.





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Map 52. Water Management Units Within the UAR

5.3. Results

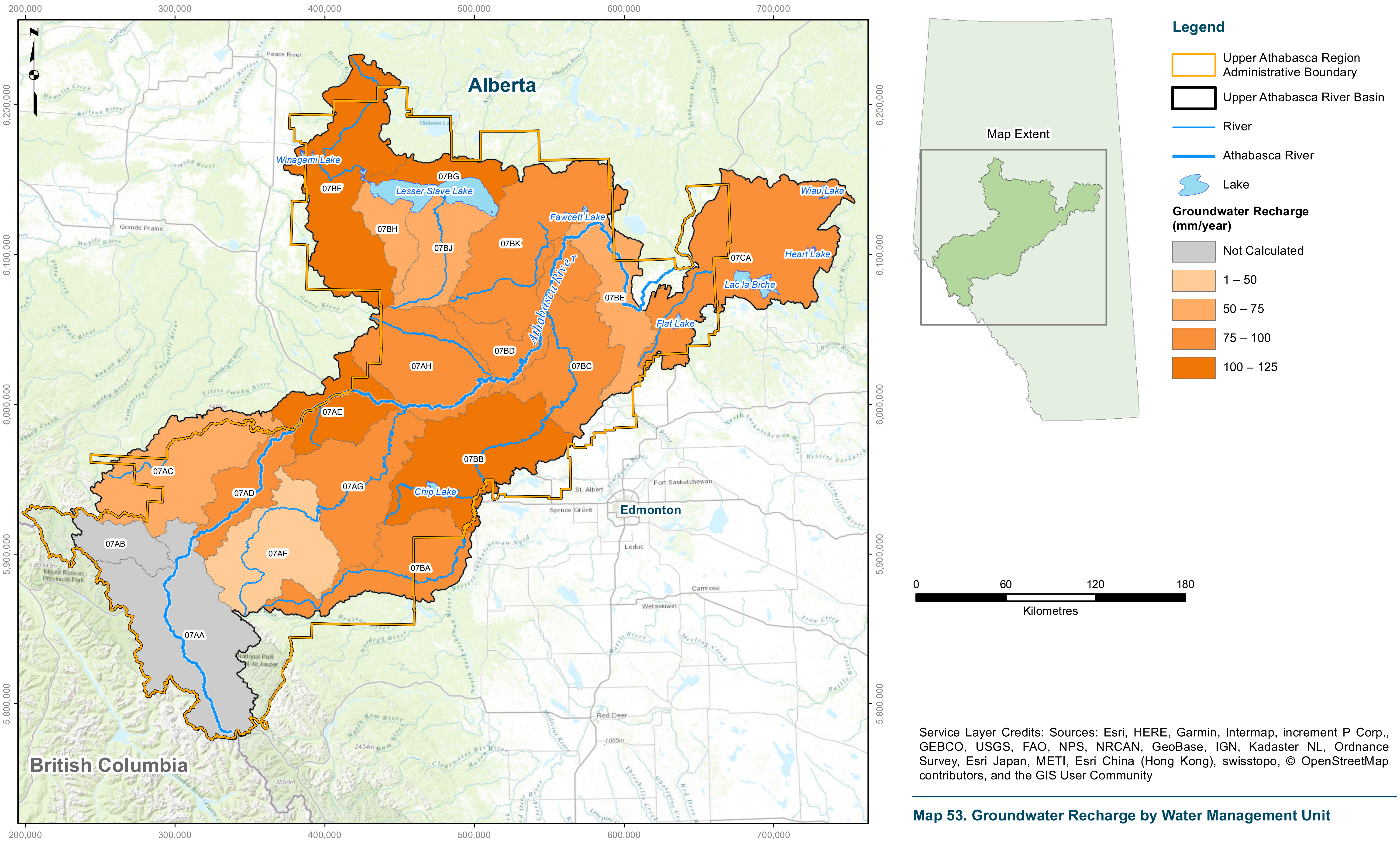
The maps for aerial evapotranspiration and precipitation (Government of Alberta, 2013; Government of Alberta, 2017), and the map for runoff (Cole, 2013) were used to obtain values for the present UAR project. The aerial evapotranspiration map shows that the aerial evapotranspiration values in the UAR vary from 340 to 405 millimetres per year (mm/year). The precipitation map shows that the annual precipitation in the UAR varies from more than 600 millimetres (mm) in the western part of the UAR to less than 500 mm in northern parts of the UAR. The map for the 70th percentile for runoff shows that the runoff in the UAR varies from less than 10 to more than 150 mm/year.

For the present project, the pertinent parts of the maps referenced above were converted to contour maps using Surfer and grids were created for each of the 19 WMUs in the UAR. The grids were then used to determine the total quantity of aerial evapotranspiration, precipitation, and runoff in each WMU; the WMUS are shown on Map 52. These data provided a value for total groundwater recharge in each WMU and the results are shown in Table 43. For WMU 07AA and WMU 07AB, the total groundwater recharge is a negative value and for the remaining WMUs, the total groundwater recharge varies from 151×10^6 to 740×10^6 m³/year. The two WMUs with negative values are both entirely within the mountains.

Region Designation	WMU Designation	Values in Millions of Cubic Metres per Year			
		AET	P	R	Gwt=P-R-AET
Mountains	07AA	Insufficient Data			
	07AB	Insufficient Data			
	07AC	2,034	3,377	1,022	320
Paskapoo and Scollard	07AD	893	1,412	315	204
	07AE	1,124	1,725	272	329
	07AF	1,883	2,917	806	229
	07AG	1,894	2,763	423	446
	07BA	1,640	2,468	446	382
Paskapoo and Wapiti	07AH	1,815	2,714	440	458
	07BB	2,452	3,365	243	670
Wapiti and Lea Park - Thick Surficial Deposits	07BC	1,520	1,975	113	342
	07BD	1,176	1,606	166	264
	07BE	1,189	1,515	118	209
Wapiti and Lea Park - Thin Surficial Deposits	07BF	2,434	3,601	464	702
	07BG	736	1,086	136	213
	07BH	601	929	177	151
	07BJ	1,204	1,855	412	238
	07BK	2,488	3,622	498	636
	07CA	3,183	4,255	332	740
Lake	07BO	Lesser Slave Lake			

Table 43. Total Groundwater Recharge by Water Management Unit

Map 53 shows the millimetres of groundwater recharge per year for each of the 19 WMUs in the UAR. The map shows that no groundwater recharge was calculated for the two WMUs in the mountains. For the remaining 17 WMUs, 2 WMUs have less than 60 mm/year of groundwater recharge, and the remaining 15 WMUs have between 68 and 114 mm/year of groundwater recharge.



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Map 53. Groundwater Recharge by Water Management Unit

Because the total groundwater recharge includes both baseflow and losses to evapotranspiration, an understanding of how much groundwater discharge is associated with each component is helpful in understanding the amount of groundwater that is available for exploitation. However, there is no way to directly measure baseflow or losses to evapotranspiration. An estimate of baseflow has been obtained by many different methods throughout the world, but no method works under all conditions. One time of the year in Alberta when baseflow can be observed is during the winter months (typically November to March when ice is present on a stream) and typically the volume of baseflow decreases through the winter. The issue becomes how to extrapolate baseflow through the remainder of the year. The decrease of baseflow through the winter corresponds to lowering water levels in the aquifer(s) contributing to baseflow.

In Alberta, the groundwater level has a seasonal fluctuation that has been observed at many locations where groundwater level monitoring occurs. The water level in an aquifer rises in late-spring/early-summer and then declines until late-spring/early-summer of the following year. Figure 39 is a hydrograph of the daily median water level for 11 years for the AEP Tricreek Observation Water Well No. 7B. The graph shows that the average of the median water levels (4.92 metres) intersects the median water level close to November 30th. However, stream flows in April are already affected by overland flow. With this observation, the stream flow on November 30th could be considered the average for the year, and the estimated total baseflow would be the November 30th flow multiplied by the number of days in the year.

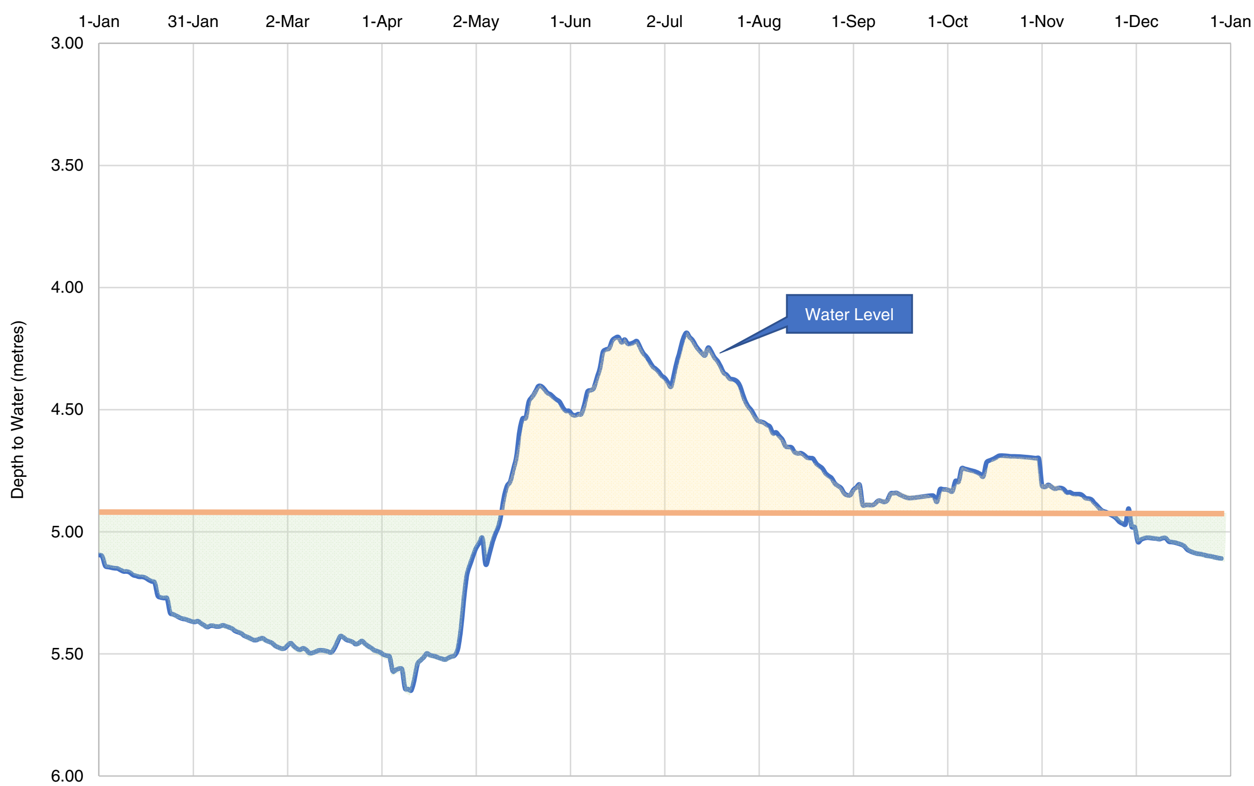


Figure 39. Hydrograph – AEP Tricreek Observation Water Well No. 7B (1969 through 1979)

One issue with using the November 30th flow is that when the stream flow is measured seasonally, measurements stop before November 30th. However, if the stream flow on October 31st and up to two other times during the winter months is available, the readings can be approximated by a second-order polynomial equation, and the November 30th flow can be calculated, as shown in Figure 40 on the following page; for the 19 WMUs, stream-flow values for five WMUs were calculated. In Table 44 on the following page, the November 30th readings that were calculated for the five WMUs using second-order polynomial equations are shown in red. Baseflow values for the four WMUs that are not in the mountains vary between 39 and 225 million m^3/year.

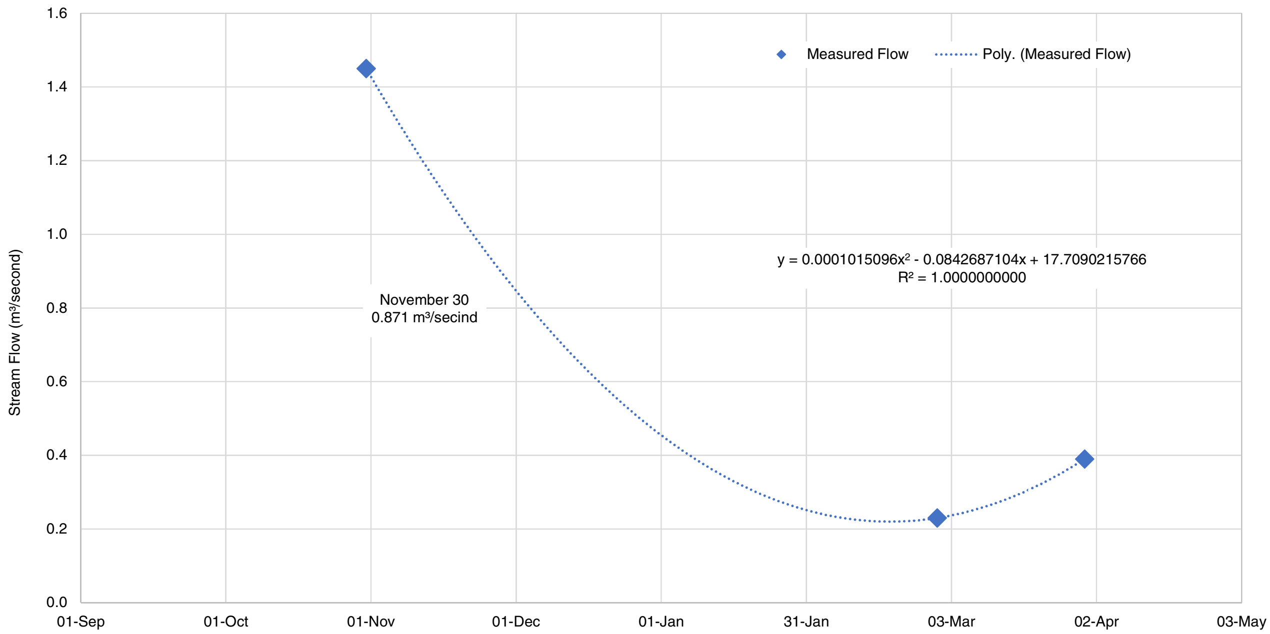


Figure 40. Baseflow Estimation from 2nd-Order Polynomial Equation (Gauging Station 07BH003)

Region Designation	WMU Designation	Values in Millions of Cubic Metres per Year			Gwb/P	Gwet/P	Gwt (mm/m²)
		Gwt=P-R-AET	Gwb	Gwet			
Mountains	07AA	Insufficient Data					
	07AB	Insufficient Data					
	07AC	320	436	-116	13%	-	56
Paskapoo and Scollard	07AD	204	185	18	13%	1%	86
	07AE	329	225	104	13%	6%	114
	07AF	229	217	12	7%	0.4%	47
	07AG	446	215	231	8%	8%	94
	07BA	382	193	189	8%	8%	92
Paskapoo and Wapiti	07AH	458	136	323	5%	12%	97
	07BB	670	171	499	5%	15%	107
Wapiti and Lea Park - Thick Surficial Deposits	07BC	342	43	299	2%	15%	87
	07BD	264	89	174	6%	11%	87
	07BE	209	90	119	6%	8%	68
Wapiti and Lea Park - Thin Surficial Deposits	07BF	702	50	653	1%	18%	103
	07BG	213	39	174	4%	16%	110
	07BH	151	53	98	6%	10%	93
	07BJ	238	68	171	4%	9%	75
	07BK	636	138	498	4%	14%	98
	07CA	740	79	660	2%	16%	85
Lake	07BO	Lesser Slave Lake					

Values in red are for baseflow estimated using second-order polynomial equations
mm/m² – millimetres per metre squared

Table 44. Total Groundwater Recharge by Water Management Unit (in mm/m²)

When the baseflow is determined using the November 30th flow multiplied by 365 to provide a value for Gwb and used in the basin analysis, a value for groundwater evapotranspiration losses can be calculated. The analysis results in values for groundwater evapotranspiration losses being calculated for 16 of the 19 WMUs. The analysis indicates that evapotranspiration losses range from 0.4% of precipitation in WMU 07AF to a maximum of 18% for WMU 07BF.

When comparing the groundwater recharge in Table 44 with the baseflow determined by Hatfield Consultants (2018), there is only one WMU (07BF) for which the Hatfield baseflow is less.

The average of the baseflow for the 16 WMUs as a percentage of precipitation is 6% and the average of the evapotranspiration losses as a percentage of precipitation is 11%. This ratio equates to 35% of the total groundwater recharge ending up as baseflow and 65% of the groundwater recharge being lost to evapotranspiration.

5.3.1. Comparison to Previous Work

A previous study by Klassen and Smerdon (2018) calculated baseflow for water units that are smaller in area than the WMUs used in the present report. Also, Klassen and Smerdon (2018) covered only a part of the UAR. Because the water units do not correspond to WMUs, it is not possible to directly compare the baseflow results determined by Klassen and Smerdon (2018) with the calculated baseflow results from the present report.

Table 45 compares the baseflow for ten WMUs, expressed as millimetres per year of recharge, where at least partial results are available from Klassen and Smerdon (2018). In the table, the Klassen and Smerdon (2018) results are presented in two columns: the "Average" column shows the average baseflow for water units that intersect a particular WMU, and the "Maximum" column shows the maximum baseflow for water units that intersect a particular WMU. For all WMUs except 07BC, the baseflow values calculated as part of the present study are larger than the baseflow values calculated by Klassen and Smerdon (2018). In areas where the upper bedrock is the Paskapoo and Scollard formations and where there are thick surficial deposits, the results are comparable. However, in areas where the upper bedrock is the Paskapoo Formation and Wapiti Interval, the values for baseflow can differ by an order of magnitude.

Region Designation	WMU Designation	Baseflow Values in mm/year of Recharge		
		Klassen and Smerdon (2018)		Present Report Findings
		Average	Maximum	
Paskapoo and Scollard	07AD	51	51	78
	07AE	51	51	78
	07AF	16	21	44
	07AG	12	22	45
	07BA	13	17	46
Paskapoo and Wapiti	07AH	2	4	29
	07BB	1	3	27
Wapiti and Lea Park - Thick Surficial Deposits	07BC	12	21	11
	07BD	21	21	29
	07BE	21	21	29

Table 45. Comparison of Baseflow Calculation Results

There can be no comparison of groundwater recharge values because Klassen and Smerdon (2018) only considered baseflow, not evapotranspiration losses. Consequently, groundwater recharge values in the present report will be larger than the values determined in the Klassen and Smerdon (2018) study.

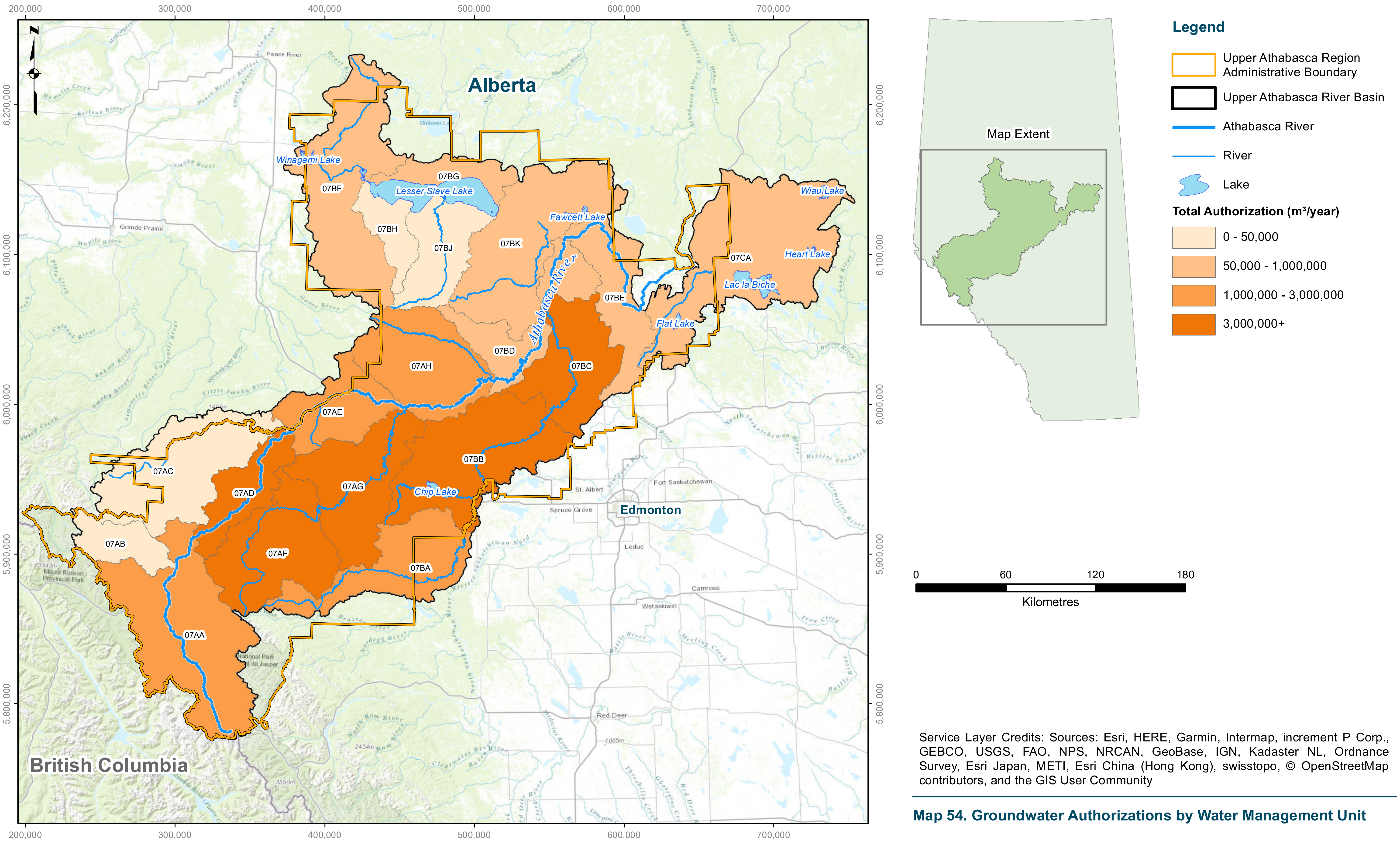
5.4. Allocations by Water Management Unit

Groundwater recharge estimated in the previous section was done on the basis of water management units because a value for baseflow is required and the stream flow at the pour point of each WMU is needed to estimate baseflow.

To make a comparison of groundwater recharge to the volume of groundwater allocated in the UAR, a value for both the volume of protected groundwater diversion from domestic and domestic & stock water wells and groundwater authorizations were determined for each WMU and summarized in Table 46; these are displayed on Map 54 and Map 55.

WMU	Number of Authorizations	Licensed Annual Volume (m^3/year)	Number of Domestic Water Wells	Protected Domestic Diversion (m^3/year)	Number of Domestic & Stock Water Wells	Protected Domestic & Stock Diversion (m^3/year)	Total Allocated Volume (m^3/year)
07AA	17	1,714,593	126	157,500	5	31,250	1,903,343
07AB	1	7,178	2	2,500	0	0	9,678
07AC	13	42,405	117	146,250	1	6,250	194,905
07AD	57	3,049,152	554	692,500	7	43,750	3,785,402
07AE	14	1,141,034	115	143,750	8	50,000	1,334,784
07AF	51	4,035,722	835	1,043,750	17	106,250	5,185,722
07AG	375	3,903,707	3,537	4,421,250	353	2,206,250	10,531,207
07BA	60	1,636,150	563	703,750	87	543,750	2,883,650
07AH	177	1,225,590	554	692,500	113	706,250	2,624,340
07BB	2,054	3,609,418	5,058	6,322,500	1,617	10,106,250	20,038,168
07BC	1,097	3,586,921	2,318	2,897,500	826	5,162,500	11,646,921
07BD	163	285,977	398	497,500	121	756,250	1,539,727
07BE	331	784,217	2,574	3,217,500	429	2,681,250	6,682,967
07BF	93	312,196	409	511,250	102	637,500	1,460,946
07BG	3	51,509	69	86,250	0	0	137,759
07BH	3	8,688	71	88,750	7	43,750	141,188
07BJ	43	44,863	258	322,500	19	118,750	486,113
07BK	30	945,868	199	248,750	12	75,000	1,269,618
07CA	13	42,405	1,813	2,266,250	715	4,468,750	6,777,405

Table 46. Total Groundwater Allocation in Each Water Management Unit



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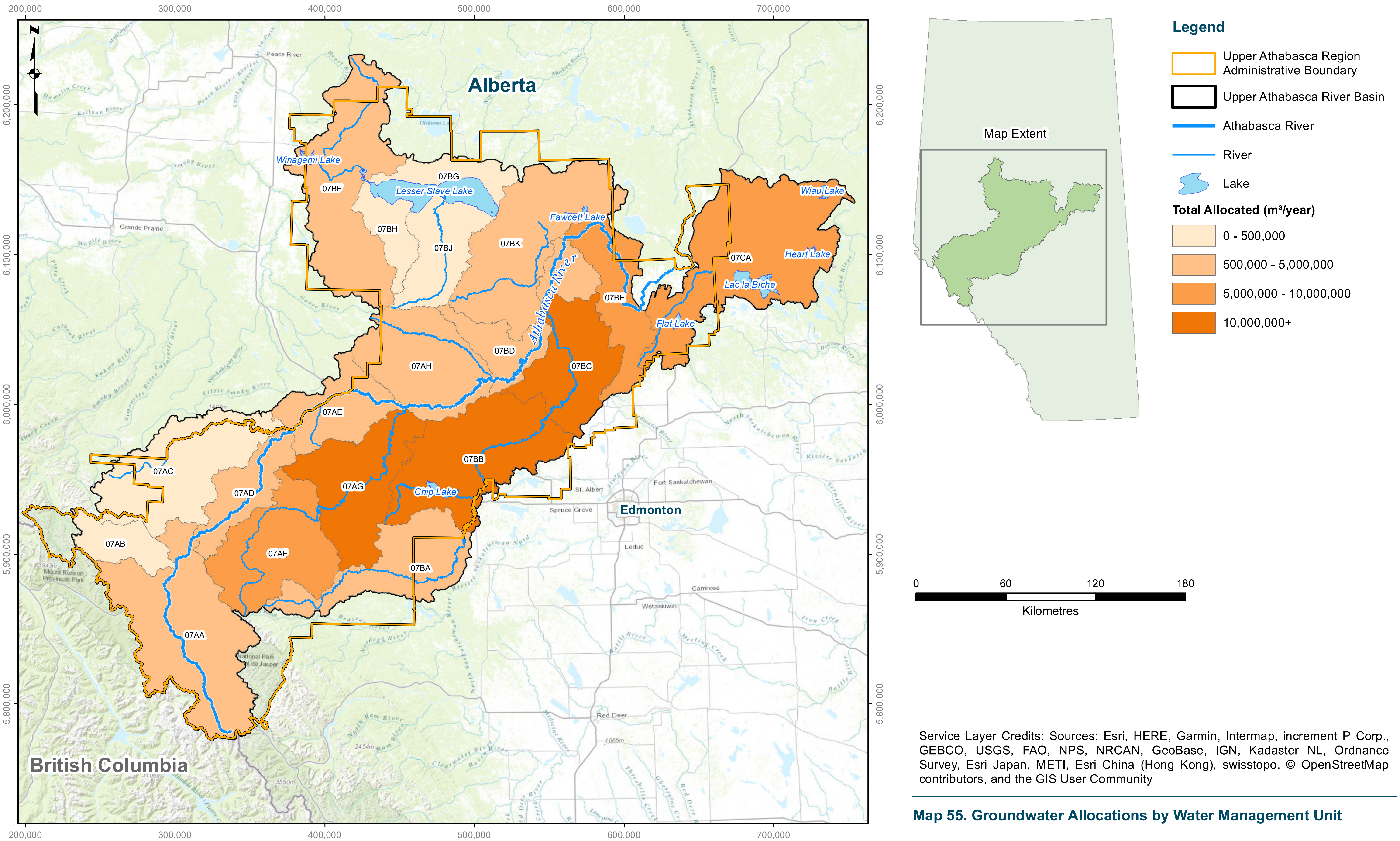
Map 54. Groundwater Authorizations by Water Management Unit



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Map 55. Groundwater Allocations by Water Management Unit

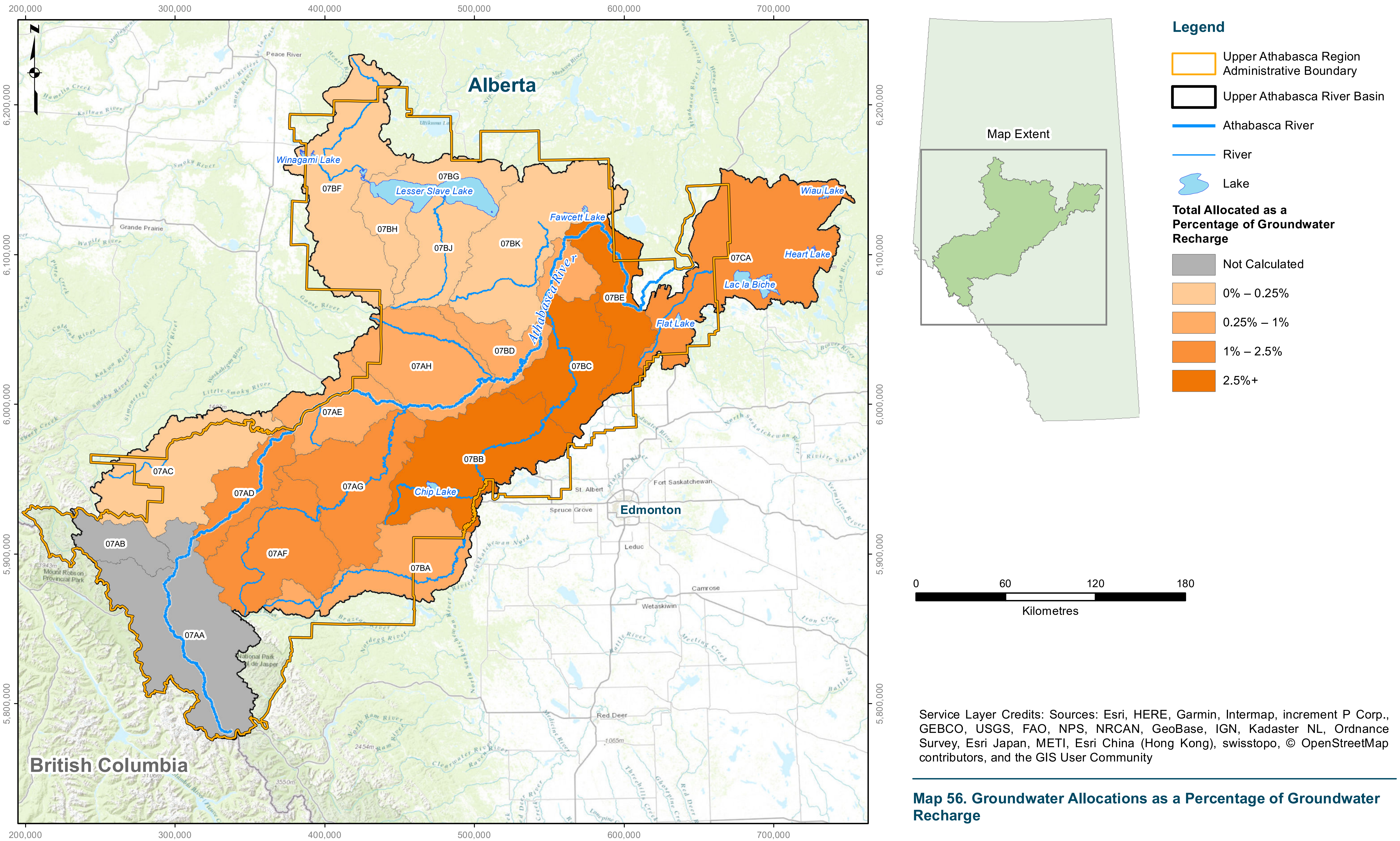
The total groundwater volumes currently allocated and the groundwater recharge for each WMU are compared in Table 47 and also displayed on Map 56. WMU 07BE has the highest groundwater allocation with respect to groundwater recharge within the UAR at 3.6%.

This report will not attempt to quantify what percentage of groundwater recharge should be authorized for diversion. Further study is required in this area to determine how much diversion as a percentage of recharge could be diverted before aquatic habitats and vegetation such as wetlands would be affected by the loss of groundwater in the hydrologic cycle.

Region Designation	WMU Designation	Groundwater Recharge (Million m³/year)	Total Allocated (Million m³/year)	Percentage Currently Allocated
Mountains	07AA	-	-	-
	07AB	-	-	-
	07AC	320	0.2	0.1%
Paskapoo and Scollard	07AD	204	3.8	1.9%
	07AE	329	1.3	0.4%
	07AF	229	5.2	2.3%
	07AG	446	10.6	2.4%
	07BA	382	2.9	0.8%
Paskapoo and Wapiti	07AH	458	2.6	0.6%
	07BB	670	20.0	3.0%
Wapiti and Lea Park - Thick Surficial Deposits	07BC	342	11.9	3.5%
	07BD	264	1.6	0.6%
	07BE	209	7.6	3.6%
Wapiti and Lea Park - Thin Surficial Deposits	07BF	702	1.7	0.2%
	07BG	213	0.2	0.1%
	07BH	151	0.2	0.1%
	07BJ	238	0.5	0.2%
	07BK	636	1.3	0.2%
	07CA	740	7.8	1.1%

Table 47. Groundwater Recharge Compared to Total Allocation in Each Water Management Unit

As shown on Map 56, the WMUs with the highest allocation as a percentage of recharge are 07BB, 07BC, and 07BE; these WMUs are along the eastern edge of the UAR in which most of the groundwater is being diverted from the surficial deposits and the Wapiti Interval.



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Map 56. Groundwater Allocations as a Percentage of Groundwater Recharge

5.5. Reported Diversion and Estimated Diversion by Water Management Unit

Table 49 on the following page shows the reported diversion to WURS for each WMU from 1987 through 2017; this table only includes data submitted to WURS and no estimation of domestic or domestic & stock water wells. While the protected volume for each domestic water well is 1,250 m^3/year (approximately 3.4 m^3/day), the average household will actually use far less groundwater than that. To estimate the actual volume of domestic groundwater diverted in the UAR, an average of 251 litres per person per day was used (Government of Canada, 2017) along with an average of 2.6 people per household (Government of Canada, 2018) to come up with an estimate of 238.2 m^3/year for each domestic water well. The domestic & stock water wells were estimated to use half of their protected volume of 6,250 m^3/year. Table 48 below shows the 2017 reported groundwater diversion for the authorizations and the 2017 estimated groundwater diversion for the domestic and the domestic & stock water wells for each WMU. The 2017 total groundwater diversion is less than half of the total allocated volume for all the WMUs and is significantly less in some WMUs.

WMU	2017 Reported Diversion (m^3)	2017 Estimated Domestic Diversion (m^3)	2017 Estimated Domestic & Stock Diversion (m^3)	2017 Total Diversion (m^3)	Total Allocated Volume (m^3/year)	Percentage of Allocation Used
07AA	0	30,013	15,604	68,680	1,903,343	3.6%
07AB	234,486	476	0	476	9,678	4.9%
07AC	10,214	27,869	3,121	72,380	194,905	37.1%
07AD	94,889	131,962	28,087	310,943	3,785,402	8.2%
07AE	11,899	27,393	24,966	64,258	1,334,784	4.8%
07AF	511,914	198,896	53,053	666,862	5,185,722	12.9%
07AG	521,558	842,510	1,154,678	2,192,306	10,531,207	20.8%
07BA	769,363	134,106	280,868	922,744	2,883,650	32.0%
07AH	281,369	131,962	365,128	613,917	2,624,340	23.4%
07BB	426,591	1,204,811	5,255,343	7,622,508	20,038,168	38.0%
07BC	509,685	552,145	2,690,087	3,322,090	11,646,921	28.5%
07BD	0	94,803	393,215	488,028	1,539,727	31.7%
07BE	25,567	613,124	1,591,583	2,215,749	6,682,967	33.2%
07BF	26,330	97,423	424,422	547,099	1,460,946	37.4%
07BG	6,152	16,436	0	16,436	137,759	11.9%
07BH	0	16,912	28,087	44,999	141,188	31.9%
07BJ	0	61,455	59,294	120,769	486,113	24.8%
07BK	435,941	47,402	37,449	333,286	1,269,618	26.3%
07CA	32,743	431,855	2,574,619	3,027,714	6,777,405	44.7%

Table 48. Allocation and Diversion by Water Management Unit

Year	07AA	07AB	07AC	07AD	07AE	07AF	07AG	07BA	07AH	07BB	07BC	07BD	07BE	07BF	07BG	07BH	07BJ	07BK	07CA
1987	0	0	1,351	85,589	0	38,218	0	110,682	141,283	147,451	0	46,278	14,364	0	6,449	0	0	2,723	0
1988	0	0	169	95,150	0	135,236	31,128	32,682	210,692	28,327	0	57,550	12,593	0	0	0	0	76,910	0
1989	0	0	0	84,884	0	143,628	0	145,313	45,749	9,339	0	31,628	18,156	0	0	0	0	68,163	0
1990	0	0	0	107,839	0	335,155	35,730	145,151	89,607	305,869	0	72,737	343,295	0	16,673	0	0	175,351	0
1991	0	0	0	90,273	0	325,087	43,357	105,597	83,095	1,418,600	0	28,754	42,087	0	0	0	0	201,100	3,479
1992	0	0	0	105,462	9,523	68,776	20,305	1,750,178	121,075	633,774	0	18,475	18,961	0	5,333	0	0	84,891	0
1993	0	0	0	47,948	10,690	3,593	18,006	571,519	127,045	1,762,625	0	16,841	306,042	0	742	0	0	60,586	4,232
1994	0	0	0	3,902	12,585	0	20,980	95,775	118,483	266,814	0	19,996	18,336	0	0	0	0	43,833	0
1995	0	0	795	4,905	14,346	0	1,951	58,378	147,402	831,069	0	18,327	19,156	0	0	0	0	0	0
1996	0	0	0	3,418	12,572	440,724	0	0	140,589	1,320,870	0	52,617	756,666	0	0	0	0	211,235	0
1997	0	0	0	4,654	0	223,978	0	97,865	131,195	1,589,388	0	0	181,329	0	0	0	0	18,405	0
1998	0	0	0	5,451	0	356,529	0	2,979	92,000	209,832	0	0	0	0	0	0	0	0	0
1999	0	0	0	4,301	0	299,449	0	507,975	135,671	1,181,257	0	0	646,526	0	0	0	0	0	0
2000	0	0	0	32,700	0	274,360	0	1,359,106	50,842	969,933	0	37,178	315,454	0	0	0	0	0	0
2001	0	0	0	31,541	11,076	233,535	0	12,007	60,918	102,799	0	20,918	8,054	0	6,866	0	10,784	0	0
2002	0	0	2,901	32,844	12,864	247,032	0	234,766	30,943	1,008,775	290	19,453	933,553	0	10,190	0	77,101	0	0
2003	0	0	3,427	26,100	12,752	21,131	0	67,798	107,211	742,289	294	28,745	9,272	0	10,106	0	7,079	0	0
2004	0	0	0	7,014	0	18,478	208	72,295	113,721	509,396	0	17,141	0	0	0	0	8,452	0	0
2005	0	0	29,794	51,612	51,532	58,289	269,111	301,865	996,045	1,416,637	318,100	0	1,447,562	13,729	8,674	0	81,704	41,079	4,184
2006	0	0	782	45,932	43,669	1,359,296	293,610	360,887	948,954	2,177,860	189,962	0	38,580	17,719	8,193	0	95,000	65,642	5,206
2007	0	0	4,159	32,571	19,406	1,504,071	361,992	526,490	728,756	2,264,707	364,350	6,752	42,140	33,722	12,237	0	56,165	50,460	0
2008	0	0	0	38,865	17,644	1,305,717	450,760	494,921	741,239	2,026,844	278,706	0	30,172	29,056	12,120	0	5,811	44,686	43
2009	7,046	0	56,124	45,218	19,751	1,210,689	659,913	617,034	681,033	674,820	330,254	0	188	50,009	10,059	0	1,443	38,028	8
2010	8,457	0	0	46,688	20,149	588,270	1,323,248	1,045,429	726,821	781,991	715,061	0	6,735	44,003	8,020	0	7	33,652	7,706
2011	5,533	0	2,569	45,805	5,166	361,238	1,395,564	951,405	902,766	740,389	646,930	0	31,460	15,498	6,153	0	0	44,032	12,156
2012	8,202	0	2,289	50,210	8,039	72,390	1,917,035	958,435	905,452	594,678	669,345	0	18,436	55,987	6,723	0	0	163,081	21,480
2013	7,765	0	111,461	79,469	3,456	353,116	1,278,102	1,030,519	700,524	740,380	799,455	0	21,688	5,639	7,710	0	0	293,421	17,158
2014	186,186	0	293,610	10,062	14,547	353,802	821,430	1,047,208	498,638	573,749	821,214	0	23,532	7,716	7,612	0	0	70,749	16,258
2015	224,498	0	8,766	4,998	2,777	417,686	674,142	826,145	326,219	518,720	669,513	0	29,460	8,867	5,754	0	0	72,656	12,912
2016	243,823	0	9,025	150,053	3,247	352,751	604,356	878,192	271,576	370,347	725,780	0	23,998	20,096	5,951	0	313	385,388	16,204
2017	0	234,486	10,214	94,889	11,899	511,914	521,558	769,363	281,369	426,591	509,685	0	25,567	26,330	6,152	0	0	435,941	32,743

Table 49. Historical Diversion Data by Water Management Unit

Table 50 shows the total estimated groundwater diversion in 2017 compared with the amount of groundwater recharge.

Region Designation	WMU Designation	Groundwater Recharge (Million m³/year)	2017 Diversion (Million m³)	Percentage of Recharge Used in 2017
Mountains	07AA	-	-	-
	07AB	-	-	-
	07AC	320	0.1	0.0%
Paskapoo and Scollard	07AD	204	0.3	0.2%
	07AE	329	0.1	0.0%
	07AF	229	0.7	0.3%
	07AG	446	2.2	0.5%
	07BA	382	0.9	0.2%
Paskapoo and Wapiti	07AH	458	0.6	0.1%
	07BB	670	7.6	1.1%
Wapiti and Lea Park – Thick Surficial Deposits	07BC	342	3.3	1.0%
	07BD	264	0.5	0.2%
	07BE	209	2.2	1.1%
Wapiti and Lea Park – Thin Surficial Deposits	07BF	702	0.5	0.1%
	07BG	213	0.0	0.0%
	07BH	151	0.0	0.0%
	07BJ	238	0.1	0.0%
	07BK	636	0.3	0.0%
	07CA	740	3.0	0.4%

Table 50. 2017 Groundwater Diversion as a Percentage of Groundwater Recharge

The water wells that are completed in WMUs 07BB, 07BC, and 07BE diverted the highest percentage of groundwater recharge in 2017; these water wells are along the eastern edge of the WMU in which most of the groundwater is being diverted from the surficial deposits and the Wapiti Interval.

6. Data Gaps and Areas for Further Study

Further work is required to understand the groundwater diversion allocations and groundwater recharge in areas of WMUs 07BB, 07BC, and 07AG, especially along the eastern borders of these WMUs, where most of the allocations are located. These areas are the most at risk for negative impacts on aquifers or ecosystems caused by over-diversion within the UAR, and localized areas of highly concentrated groundwater allocations should be reviewed in more detail.

Older licences associated with the *Water Resources Act* should also be reviewed in more detail because they do not expire; therefore, it is likely a large number of these licences are no longer in use, but their allocations are still considered active. These older licences may conflate the allocated groundwater diversion volumes and the actual volume of groundwater that might be needed in an area, which could make it difficult to determine the state of groundwater resources in the UAR in the future.

There is a large degree of uncertainty in the assumptions used to calculate groundwater recharge in the UAR. A range of groundwater recharge values could be calculated using a variety of assumptions for values such as runoff, precipitation, and evapotranspiration. Varying methods for calculating baseflow could also be determined and used. Using a variety of assumptions and methods to calculate groundwater recharge would provide a range of values that would better represent the uncertainty of groundwater recharge in the UAR.

Further work in localized areas would need to be done to determine how much groundwater diversion as a portion of groundwater recharge would have an effect on local ecosystems

7. Conclusions

Within the Upper Athabasca Region, a total of approximately 76,000,000 cubic metres of groundwater is allocated, which includes both authorized groundwater diversions in addition to protected groundwater volumes associated with domestic water wells and domestic & stock water wells.

The drilling of new water wells, including industrial, domestic, domestic & stock, and municipal, has been declining within the UAR since 2000. The total authorized groundwater diversion volumes have also been declining since approximately 2006; this decline may be masked because of a large number of licences that do not expire, which contribute to the total authorized volume but may not have been used in decades. Reported groundwater usage peaked in 2007 and has slowly declined since then for the last several years, levelling off at about 4,000,000 cubic metres of groundwater diversion per year. The majority of the groundwater authorizations within the UAR are for industrial purposes (approximately 50% of the total authorized volume); the remaining authorized volume is evenly split between agricultural and municipal purposes. Based on the trend of new water wells being drilled, additional licences being issued, and the overall trend of water use being reported, it appears that groundwater demand within the UAR is flat or in decline.

There are four main bedrock geounits that constitute aquifers within the UAR; the surficial deposits represent a high-yielding and highly utilized aquifer in much of the UAR. Table 51 summarizes the geounits in the UAR and how they relate to the groundwater resource.

Formation or Interval	Number of Records	Average Q_{20} (m^3/day)	Total Authorized Diversion (m^3/year)	Total Protected Diversion (m^3/year)
Surficial	12,541	196	7,757,234	16,791,460
Paskapoo	12,214	209	6,745,360	8,478,658
Scollard	745	79	253,544	1,050,142
Wapiti	15,700	91	6,636,125	24,879,240
Lea Park	1,738	99	19,050	2,452,946

Table 51. Summary of Geounits Within the UAR

The surficial deposits, the Paskapoo Formation, and the Wapiti Interval are the most important aquifers within the UAR.

The amount of groundwater recharge was estimated for each Water Management Unit and compared to the allocated volume (protected and authorized), the estimated domestic use, and diversion data reported to the Water Use Reporting System.

Table 52 on the following page shows that the WMUs within the UAR that have the most allocations and diversion as a percentage of recharge are 07BB, 07BC, and 07BE; these WMUs represent the Wapiti interval and the surficial deposit aquifers.

Region Designation	WMU Designation	Groundwater Recharge (Million m³/year)	Total Allocated (Million m³/year)	Percent Currently Allocated	2017 Diversion (Million m³)	Percentage of Recharge Used in 2017
Mountains	07AA	-	-	-	-	-
	07AB	-	-	-	-	-
	07AC	320	0.2	0.1%	0.07	0.0%
Paskapoo and Scollard	07AD	204	3.8	1.9%	0.30	0.1%
	07AE	329	1.3	0.4%	0.06	0.0%
	07AF	229	5.2	2.3%	0.67	0.3%
	07AG	446	10.6	2.4%	2.19	0.5%
	07BA	382	2.9	0.8%	0.92	0.2%
Paskapoo and Wapiti	07AH	458	2.6	0.6%	0.61	0.1%
	07BB	670	20.0	3.0%	7.62	1.1%
Wapiti and Lea Park – Thick Surficial Deposits	07BC	342	11.9	3.5%	3.32	1.0%
	07BD	264	1.6	0.6%	0.49	0.2%
	07BE	209	7.6	3.6%	2.22	1.1%
Wapiti and Lea Park – Thin Surficial Deposits	07BF	702	1.7	0.2%	0.55	0.1%
	07BG	213	0.2	0.1%	0.01	0.0%
	07BH	151	0.2	0.1%	0.04	0.0%
	07BJ	238	0.5	0.2%	0.12	0.1%
	07BK	636	1.3	0.2%	0.33	0.1%
	07CA	740	7.8	1.1%	3.03	0.4%

Table 52. Percentage of Recharge Used and Allocated

It is unlikely that the current allocations on a regional scale would represent a negative impact on these aquifer systems or the ecosystem in the UAR; on a local scale, large groundwater diversions could represent a higher percentage of groundwater recharge and could have an impact on these aquifers or the ecosystems in the UAR.

Further study is needed to determine what percentage of groundwater recharge should be allowed for future groundwater diversions.

8. Bibliography

Barnes, R. G. 1977. Hydrogeology of the Mount Robson-Wapiti Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1976-05. Available at: http://ags.aer.ca/publications/ESR_1976_05.html

Barnes, R. G. 1978. Hydrogeology of the Brazeau-Canoe River Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1977-05. Available at: http://ags.aer.ca/publications/ESR_1977_05.html

Bibby, R. 1974. Hydrogeology of the Edmonton Area (Northwest Segment), Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1974-10. Available at: http://ags.aer.ca/publications/ESR_1974_10.html

Borneuf, D. M. 1973. Hydrogeology of the Tawatinaw Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1972-11. Available at: http://ags.aer.ca/publications/ESR_1972_11.html

Borneuf, D. M. 1980. Hydrogeology of the Winagami Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1979-03. Available at: http://ags.aer.ca/publications/ESR_1979_03.html

Borneuf, D. M. 1981. Hydrogeology of the Peace River Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1981-02. Available at: http://ags.aer.ca/publications/ESR_1981_02.html

Branscombe, P., K. E. MacCormack, and M. Babakhani. 2018. 3D Provincial Geological Framework Model of Alberta, Version 1 – Methodology. Alberta Energy Regulator. AER/AGS Open File Report 2017-09. Available at: https://ags.aer.ca/publications/OFR_2017_09.html

Ceroici, W. J. 1979. Hydrogeology of the Peerless Lake Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1979-05. Available at: http://ags.aer.ca/publications/ESR_1979_05.html

Cole, A. 2013. Annual Unit Runoff in Canada. Government of Canada. Agriculture and Agri-Food Canada. 100 pp.

Freeze, R. A., and P. A. Witherspoon. 1967. Theoretical Analysis of Regional Groundwater Flow. Effect of Water-Table Configuration and Subsurface Permeability Variation. Water Resources Research. Vol. 3, No. 2, pp. 623–634.

Government of Alberta. 2006. Water Conservation and Allocation Guideline for Oilfield Injection. Alberta Environment and Parks. Available at: https://open.alberta.ca/publications/0778531447

Government of Alberta. 2011. Alberta Environment Guide to Groundwater Authorization. Alberta Environment and Parks. Available at: https://open.alberta.ca/publications/5612701

Government of Alberta. 2013. Evaporation and Evapotranspiration in Alberta. Alberta Environment and Sustainable Resource Development. 283 pp.

Government of Alberta. 2017. Annual Total Precipitation of Alberta, 1971 to 2000. Alberta Agriculture and Forestry. Retrieved from: https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6434/$FILE/onl_s_1_twp_annual_normals_19712000.gif

Government of Canada. 2017. Residential Water Use in Canada. Retrieved from Environment and Climate Change Canada: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/residential-water-use.html

Government of Canada. 2018. Census Profile, 2016 Census. Alberta and Canada. Retrieved from Statistics Canada: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/Page.cfm?Lang=E&Geo1=PR&Code1=48&Geo2=&Code2=&Data=Count&SearchText=Alberta&SearchType=Begins&SearchPR=01&B1=All&GeoLevel=PR&GeoCode=48

Hatfield Consultants. 2018. Upper Athabasca Region Water Supply and Allocation Study – Final Report. Report No. AEP8990. Prepared for Alberta Environment and Parks.

Hubbert, M. K. 1940. The Theory of Groundwater Motion. Journal of Geology. Vol. 48, No. 8, Part 1 (November–December), pp. 785–944.

Klassen, J., and B. D. Smerdon. 2018. First-Order Groundwater Availability Assessment for Central Alberta. Alberta Energy Regulator/Alberta Geological Survey. AER/AGS Open File Report 2017-07. 28 pp.

Lyster, S., and L. D. Andriashek. 2012. Geostatistical Rendering of the Architecture of Hydrostratigraphic Units within the Paskapoo Formation, Central Alberta. Bulletin 066. Alberta Geological Survey. Available at: https://ags.aer.ca/publications/BUL_066.html

McGowan, W. 2000. Water Processing: Residential, Commercial, Light-Industrial. Third Edition. Lisle, IL. Water Quality Association.

Ozoray, G. F. 1972. Hydrogeology of the Wabamun Lake Area, Alberta. Research Council of Alberta. RCA/AGS Earth Sciences Report 1972-08. Available at: http://ags.aer.ca/publications/ESR_1972_08.html

Ozoray, G. F. 1974. Hydrogeology of the Waterways-Winefred Lake Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1974-02. Available at: http://ags.aer.ca/publications/ESR_1974_02.html

Ozoray, G. F., and A. T. Lytviak. 1980. Hydrogeology of the Pelican-Algar Lake Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1980-01. Available at: http://ags.aer.ca/publications/ESR_1980_01.html

Ozoray, G. F., E. I. Wallick, and A. T. Lytviak. 1980. Hydrogeology of the Sand River Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1979-01. Available at: http://ags.aer.ca/publications/ESR_1979_01.html

Province of Alberta. *Water Act*. Revised Statutes of Alberta 2000. Chapter W-3. Current as of December 17, 2014. Office Consolidation. © Alberta Queen's Printer.

Province of Alberta. *Water Act*. Water (Ministerial) Regulation. Alberta Regulation 205/1998 (with amendments up to and including Alberta Regulation 185/2015). © Alberta Queen's Printer.

Province of Alberta. *Environmental Protection and Enhancement Act*. Potable Water Regulation. Alberta Regulation 277/2013 (with amendments up to and including Alberta Regulation 63/2015). © Alberta Queen's Printer.

Tokarsky, O. 1971. Hydrogeology of the Rocky Mountain House Area, Alberta. Research Council of Alberta. RCA/AGS Earth Sciences Report 1971-03. Available at: http://ags.aer.ca/publications/ESR_1971_03.html

Tokarsky, O. 1977a. Hydrogeology of the Iosegun Lake Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1976-02. Available at: http://ags.aer.ca/publications/ESR_1976_02.html

Tokarsky, O. 1977b. Hydrogeology of the Whitecourt Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report ESR 1976-03. Available at: http://ags.aer.ca/publications/ESR_1976_03.html

Tóth, J. 1963. A Theoretical Analysis of Groundwater Flow in Small Drainage Basins. Journal of Geophysical Research. Vol. 68, No. 16, pp. 4795–4812.

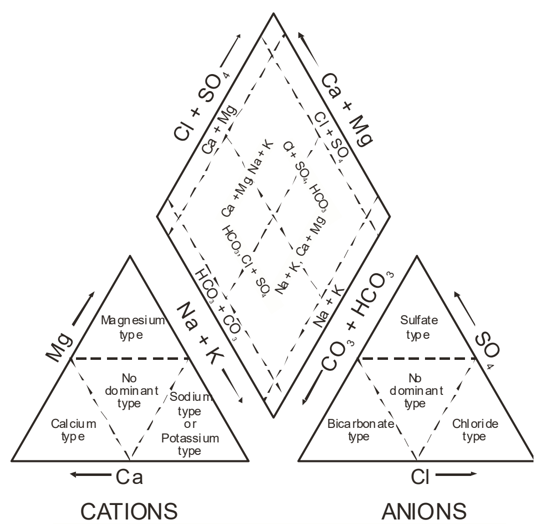
Vogwill, R. I. J. 1978. Hydrogeology of the Lesser Slave Lake Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1977-01. Available at: http://ags.aer.ca/publications/ESR_1977_01.html

Vogwill, R. I. J. 1983. Hydrogeology of the Edson Area, Alberta. Alberta Research Council. ARC/AGS Earth Sciences Report 1979-07. Available at: http://ags.aer.ca/publications/ESR_1979_07.html

9. Supplementary Information

9.1. Glossary of Terms

aesthetic objective	Health Canada aesthetic quality guidelines addressing parameters that may affect consumer acceptance of drinking water, such as taste, odour and colour
aquifer	a formation, group of formations or part of a formation that contains saturated permeable rocks capable of transmitting groundwater to water wells or springs in economical quantities
aquitard	a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer
available drawdown	in a confined aquifer, the distance between the non-pumping water level and the top of the aquifer in an unconfined aquifer (water table aquifer), two thirds of the saturated thickness of the aquifer and water level within 5 metres of the top of the aquifer
base of groundwater protection	the depth below which groundwater is expected to have a total dissolved solids concentration of more than 4,000 milligrams per litre
geounit	a geologic unit categorized by a similarity in geological feature(s) such as stratigraphic interval, depositional environment or hydrogeological properties
hydraulic conductivity	the rate of flow of water through a unit cross-section under a unit hydraulic gradient; units are length/time
maximum acceptable concentration	the highest level of chemical substances determined by Health Canada to be allowable in drinking water supplies; these substances are generally only a concern if exposure above guideline levels occurs over an extended time
Piper tri-linear diagram	a method to show the composition of water based on major cation and anion composition. This diagram allows groupings or trends in the chemical-quality data to be identified. In Alberta, surface water and shallow groundwater are typically a Ca+Mg-HCO3-type water, upper bedrock groundwaters are Na+K-HCO3-type water and deep groundwaters are a Na+K-Cl-type water.
storativity	the volume of water released from storage by a confined aquifer per unit surface area of aquifer per unit decline in hydraulic head (dimensionless)
surficial deposits	all sediments above the bedrock surface



till	a sediment deposited directly by a glacier that is unsorted and consisting of any grain size ranging from clay to boulders
transmissivity	the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient; a measure of the ease with which groundwater can move through the aquifer effective transmissivity: the value determined from late pumping and/or late recovery water-level data from an aquifer test aquifer transmissivity: the value determined by multiplying the hydraulic conductivity of an aquifer by the thickness of the aquifer
yield	a regional analysis term referring to the rate at which a properly completed water well could be pumped, if fully penetrating the aquifer long-term yield: based on effective transmissivity sustainable yield: based on aquifer parameters determined from long-term water-level and groundwater diversion monitoring

9.2. Glossary of Commonly Used Abbreviations, Acronyms, and Symbols

AEP	Alberta Environment and Parks
AER	Alberta Energy Regulator
AMSL	above mean sea level
AO	aesthetic objective
AOI	area of interest
AOS	area of study
AT	aquifer test
BGL	below ground level
BGWP	base of groundwater protection
BTOC	below top of casing
DEM	digital elevation model
DST	drill-stem test
GCDWQ–ST	Guidelines for Canadian Drinking Water Quality – Summary Table
GPS	global positioning system receiver
GWUDI	groundwater under the direct influence of surface water
km	kilometre(s)
km^2	square kilometre(s)
Lpm	litre(s) per minute
Lpm/metre	litre(s) per minute per metre
LSD	legal subdivision
m	metre(s)
m^2	metre(s) squared
m^2/day	metre(s) squared per day
m^3	cubic metre(s)
m^3/day	cubic metre(s) per day
m^3/year	cubic metre(s) per year

MAC	maximum acceptable concentration
mg/L	milligram(s) per litre
mm	millimetre(s)
mm/m²	millimetre(s) per metre squared
mm/year	millimetre(s) per year
MSL	mineral surface lease
NAD83	North American Datum of 1983
NPWL	non-pumping water level
Obs WW	observation water well
TDL	temporary diversion licence
TDS	total dissolved solids
TGWC	The Groundwater Centre (www.tgwc.com)
UAR	Upper Athabasca Region Administrative Boundary
VE	vertical exaggeration
WSW	water source well
WTH	water test hole
W(u)	well function $s = \frac{Q}{4\pi T} \int_{r^2 S/4Tt}^{\infty} \frac{e^{-u}}{u} du$, where $u = r^2 S / 4Tt$
WURS	Water Use Reporting System
WW	water well

Appendix A – Book of Maps

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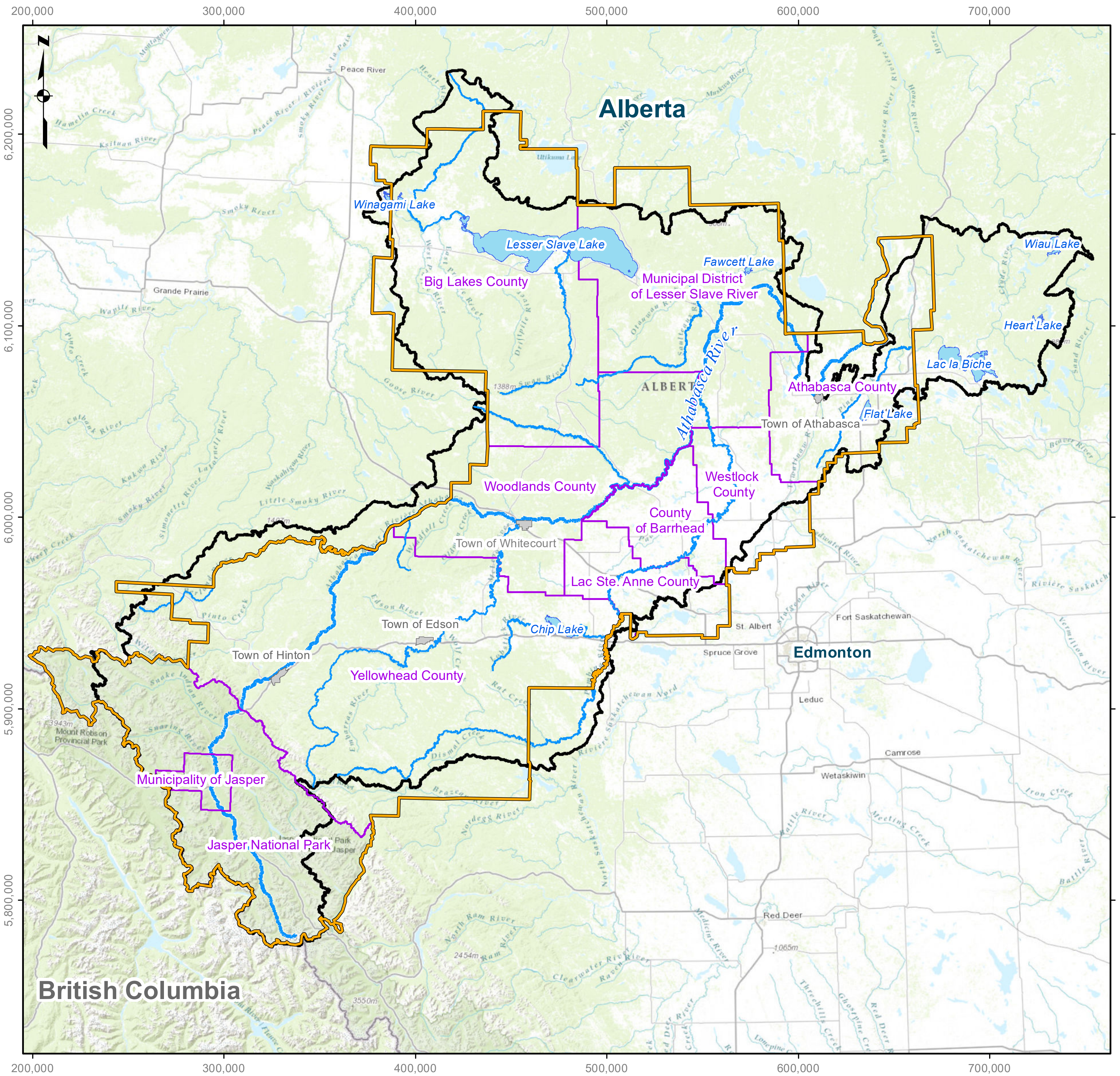
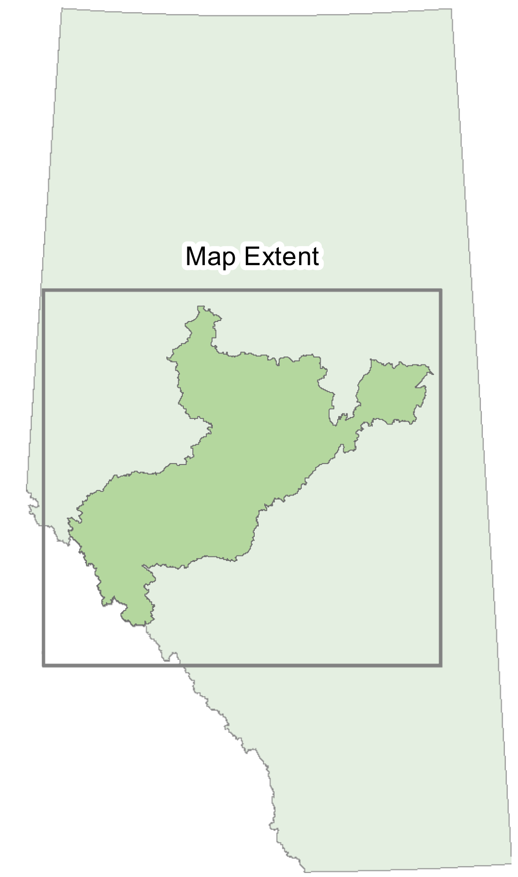




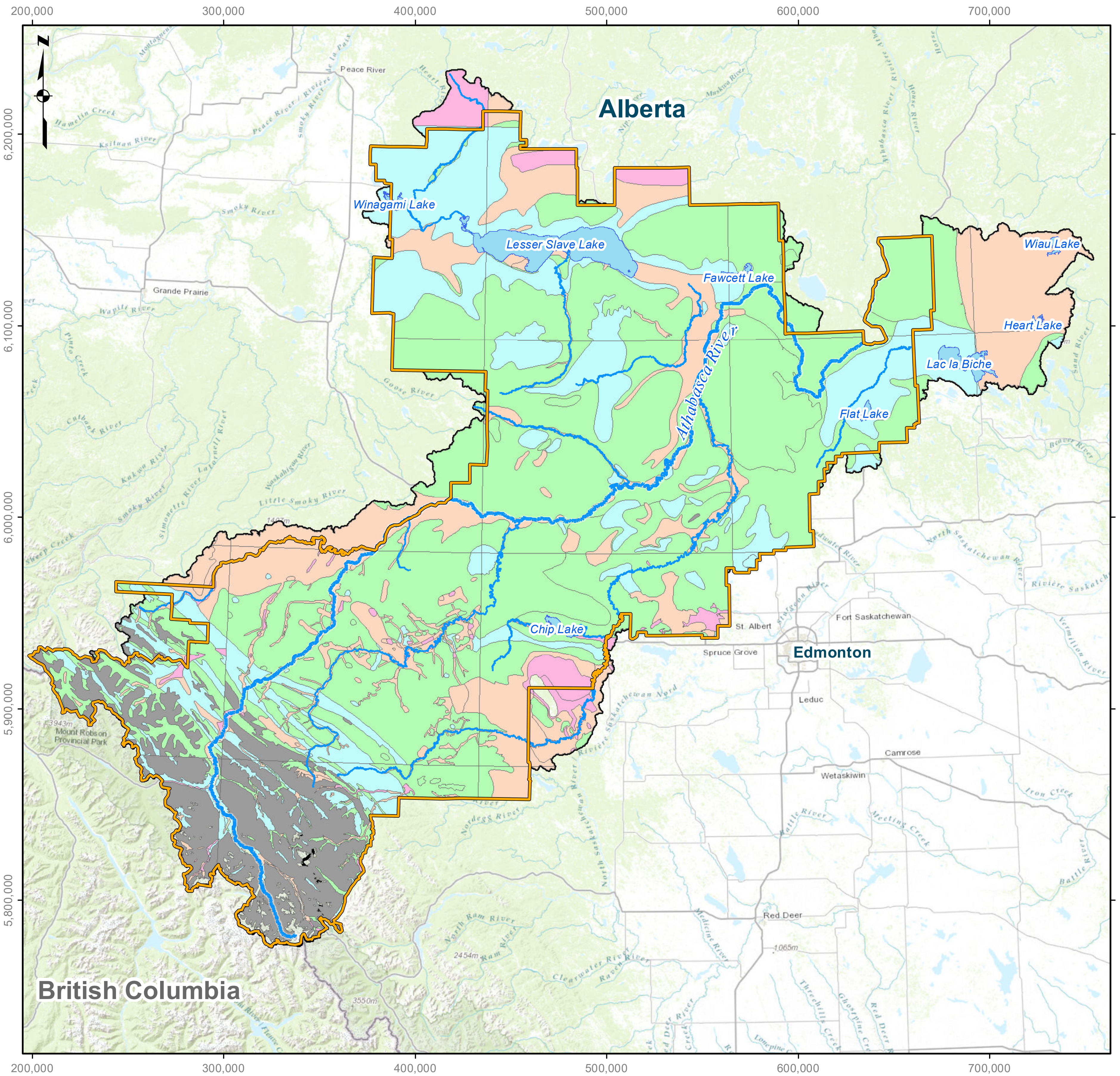
Legend

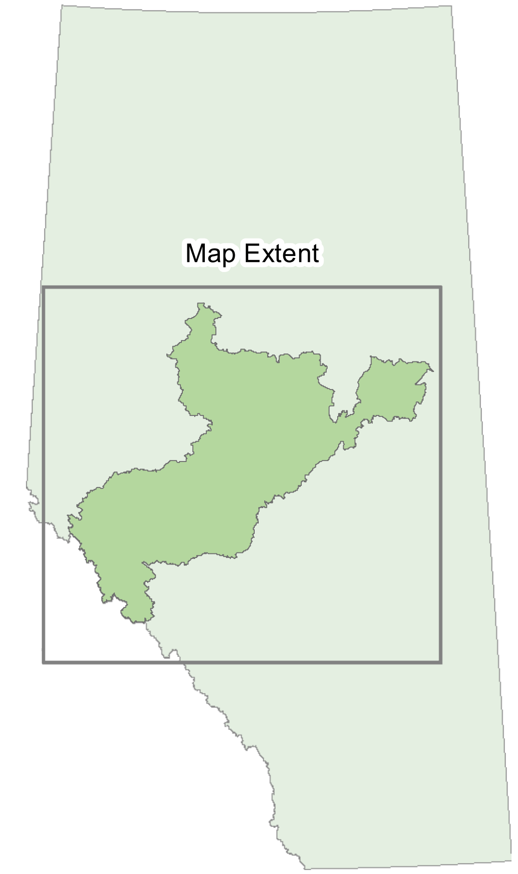
- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- County/Municipal District
- Athabasca River
- River
- Lake

0 60 120 180
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 1. Index Map





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake

AGS Determined Long-Term Yield (m³/day)

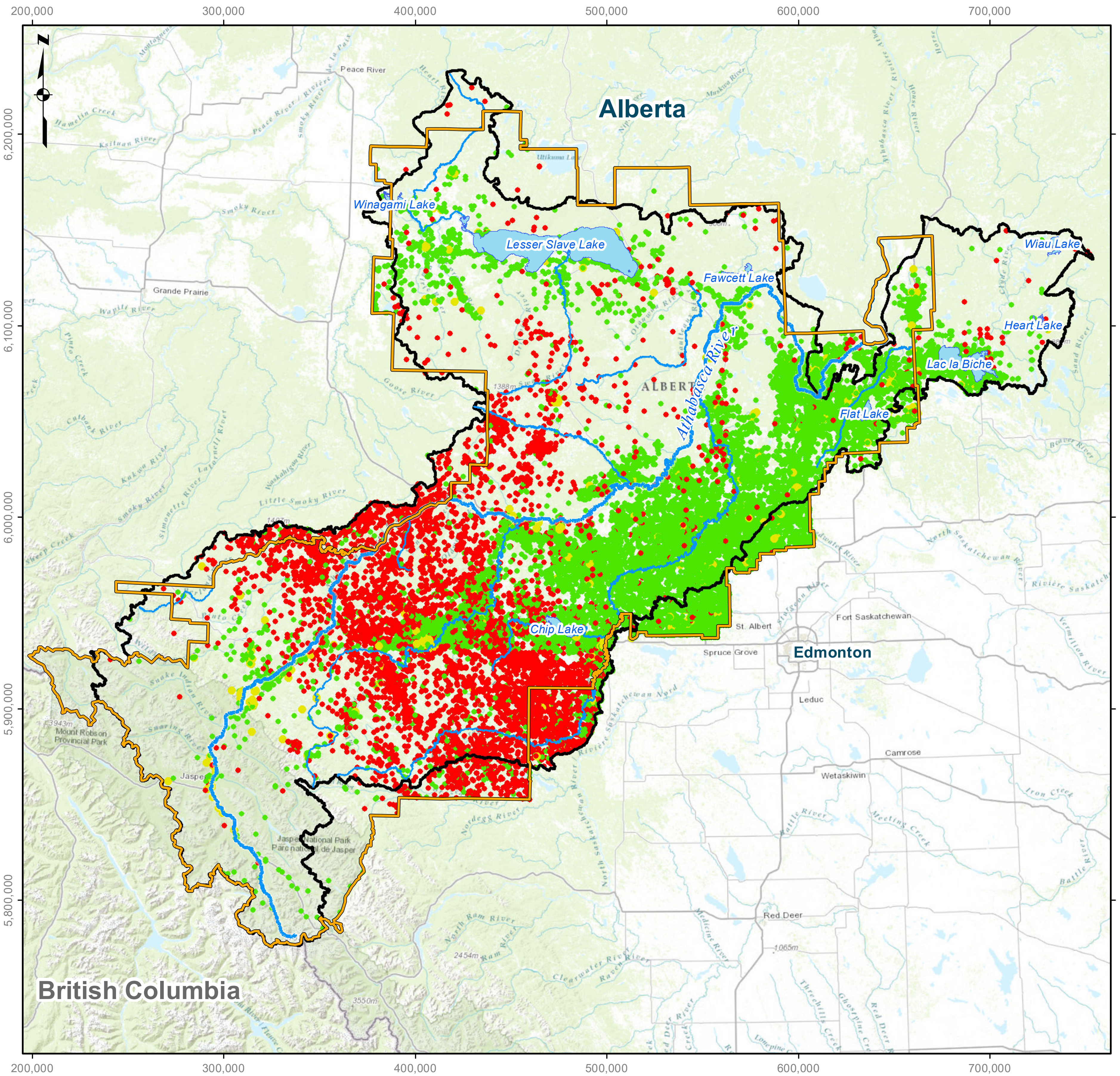
- 1- 5
- 30 - 160
- 160 - 650
- 650 - 3,300
- Unknown

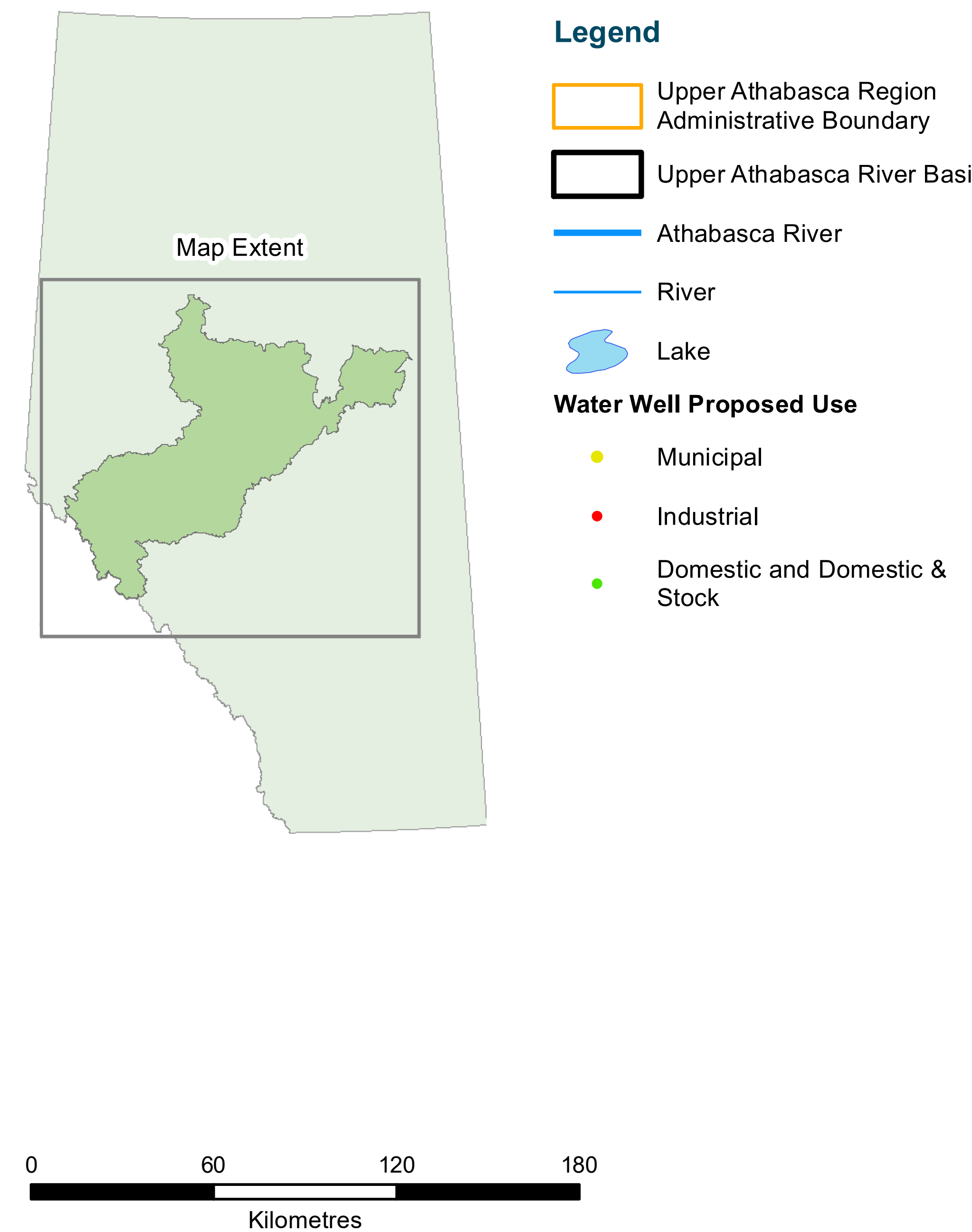
0 60 120 180
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

(Barnes, 1977; Barnes, 1978; Bibby, 1974; Borneuf, 1973; Borneuf, 1980, Borneuf, 1981; Ceroici, 1979; Ozoray, 1972; Ozoray, 1974; Ozoray and Lytviak, 1980; Ozoray, et al., 1980; Tokarsky, 1971; Tokarsky, 1977a; Tokarsky, 1977b; Vogwill, 1978; Vogwill, 1983)

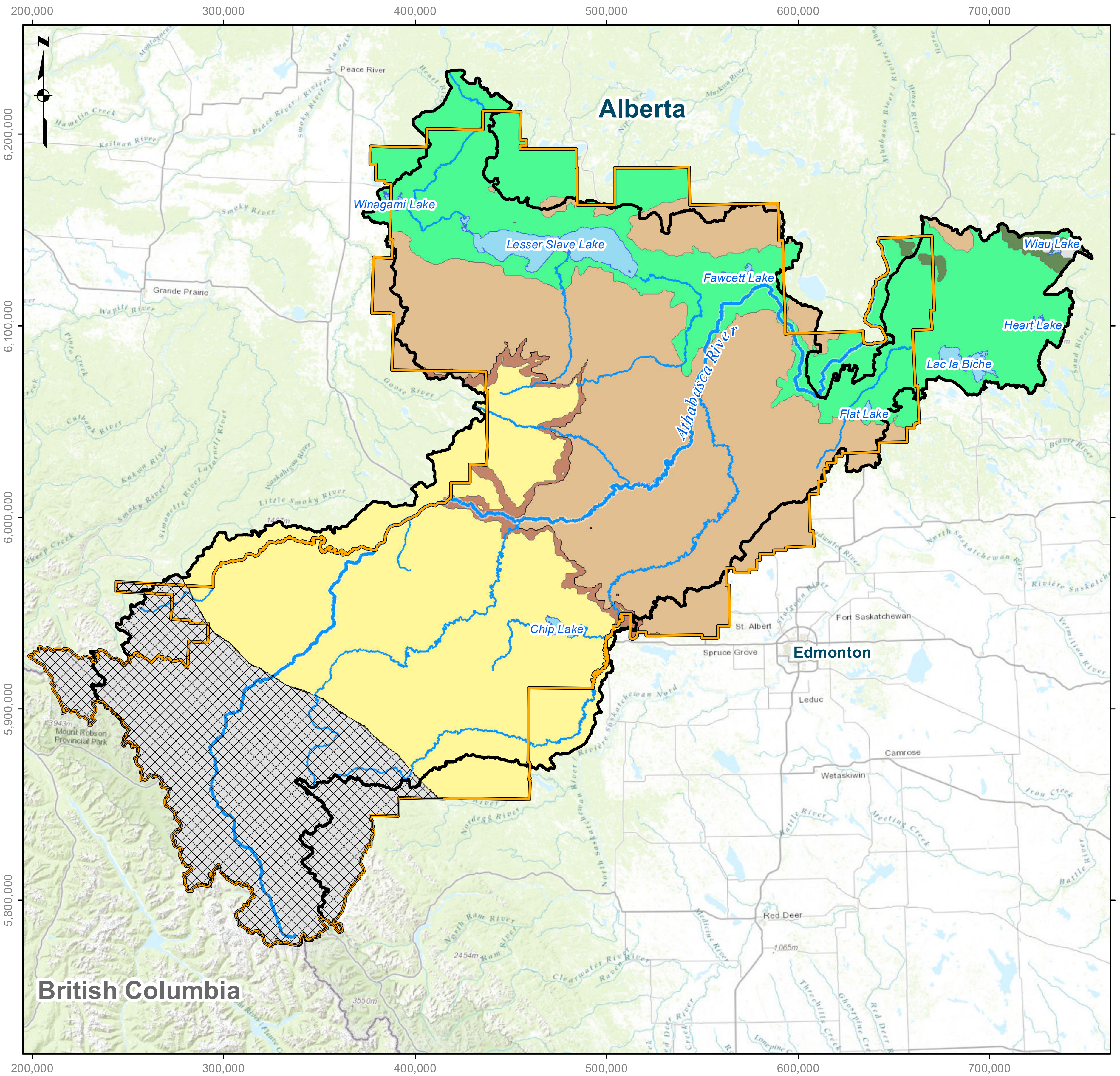
Map 2. Long-Term Water Well Yields Within the UAR

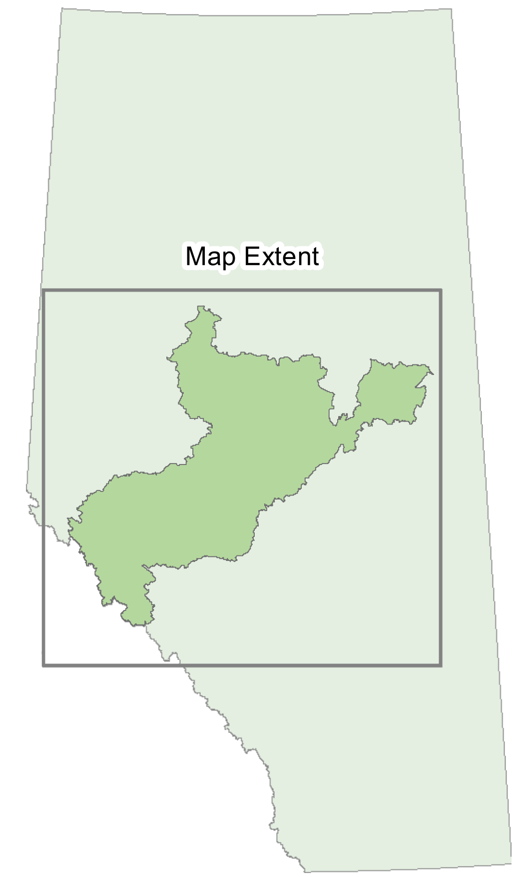




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 3. Water Wells Completed Within the UAR





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Paskapoo Formation Subcrop
- Scollard Formation Subcrop
- Wapiti Interval Subcrop
- Lea Park Interval Subcrop
- Base of Fish Scales to Top of Viking Interval Subcrop

0 60 120 180

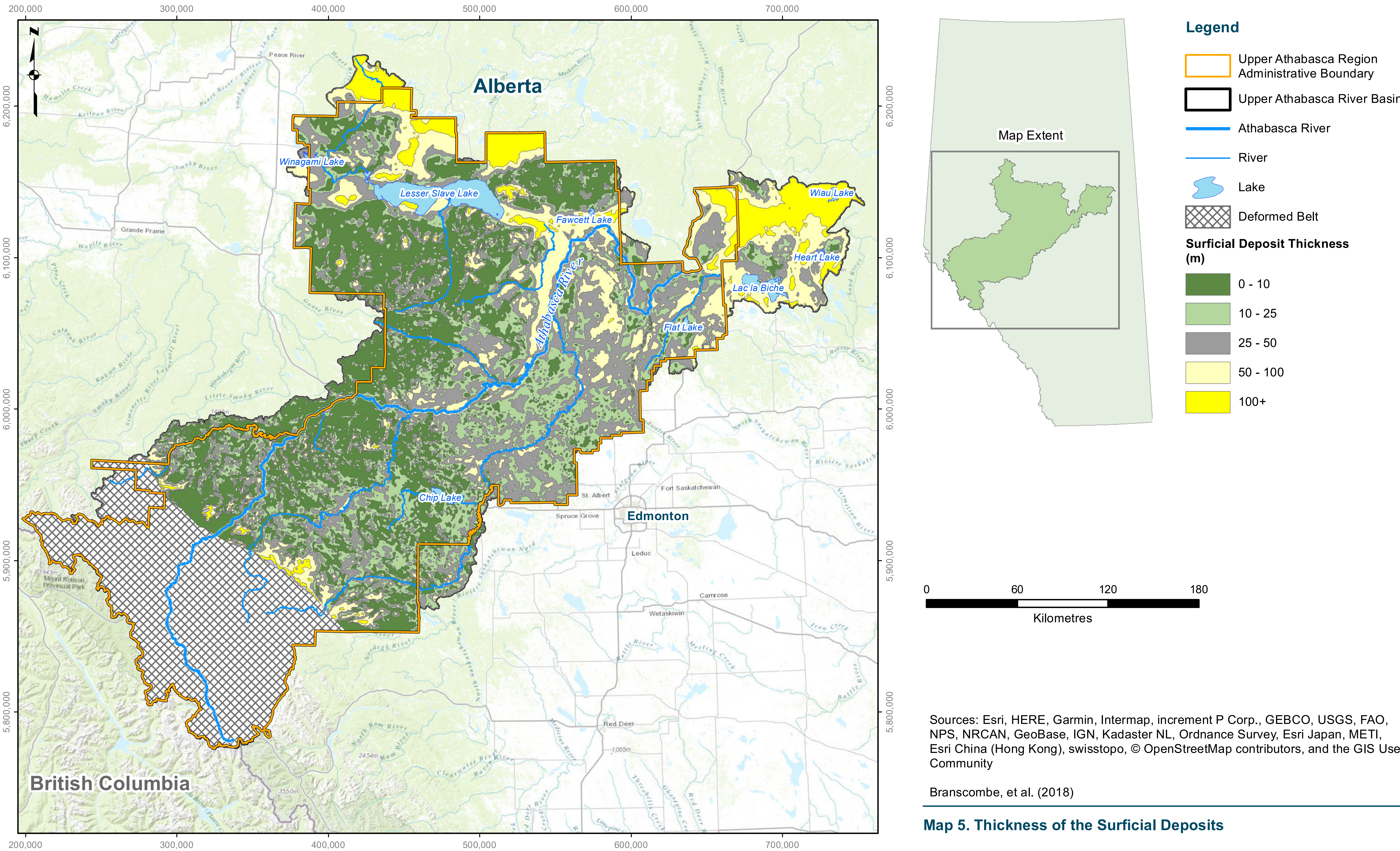
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Wapiti Interval consists of undifferentiated Horseshoe Canyon Formation/Wapiti Formation/St. Mary River Formation/Belly River Group/Bearpaw Formation Equivalent (Branscombe, et al., 2018)

Lea Park Interval consists of undifferentiated Lea Park Formation/Colorado Group/Smoky Group/Fort St. John Group Equivalent Interval (Branscombe, et al., 2018)

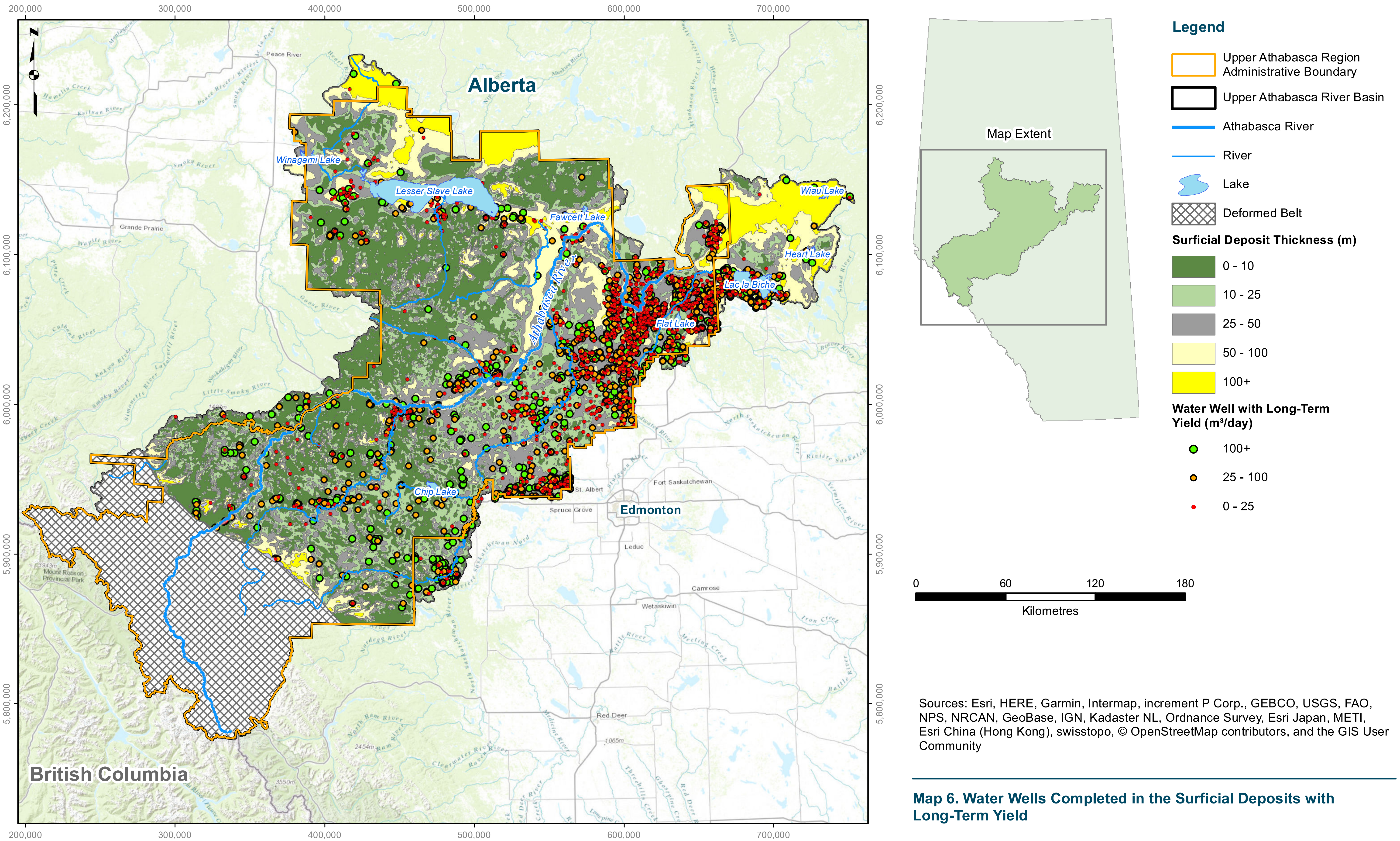
Map 4. Geological Map per Branscombe, et al. (2018)



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

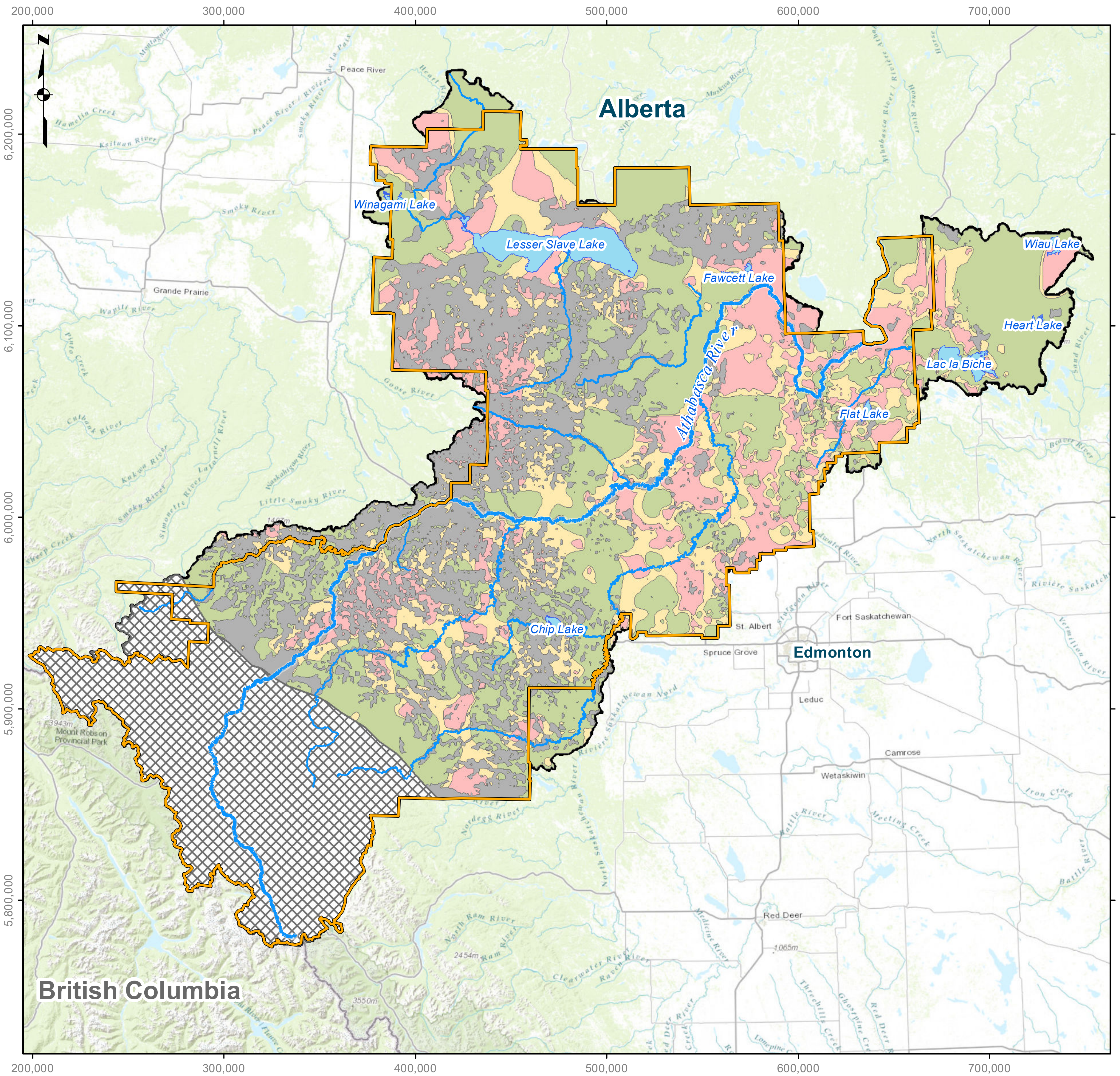
Branscombe, et al. (2018)

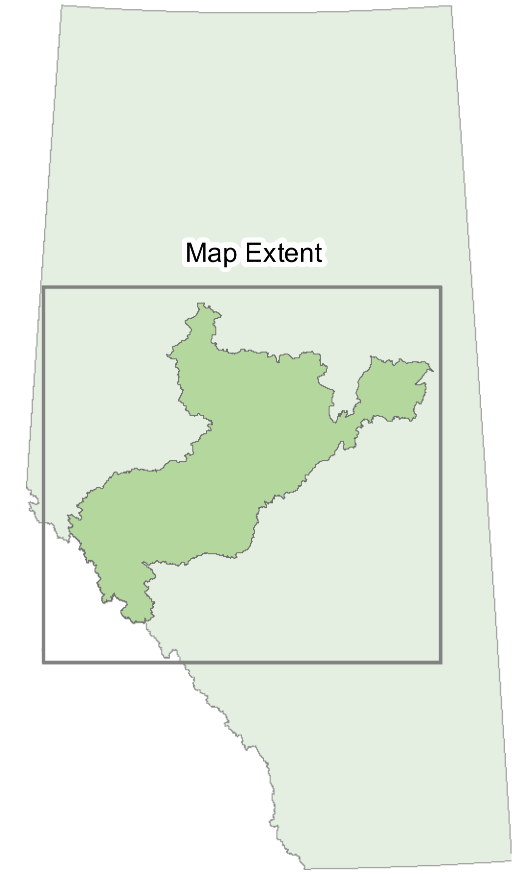
Map 5. Thickness of the Surficial Deposits



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 6. Water Wells Completed in the Surficial Deposits with Long-Term Yield





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Surficial Aquifer Not Present

Long-Term Water Well Yield (m^3/day)

- 0 - 25
- 25 - 100
- 100+

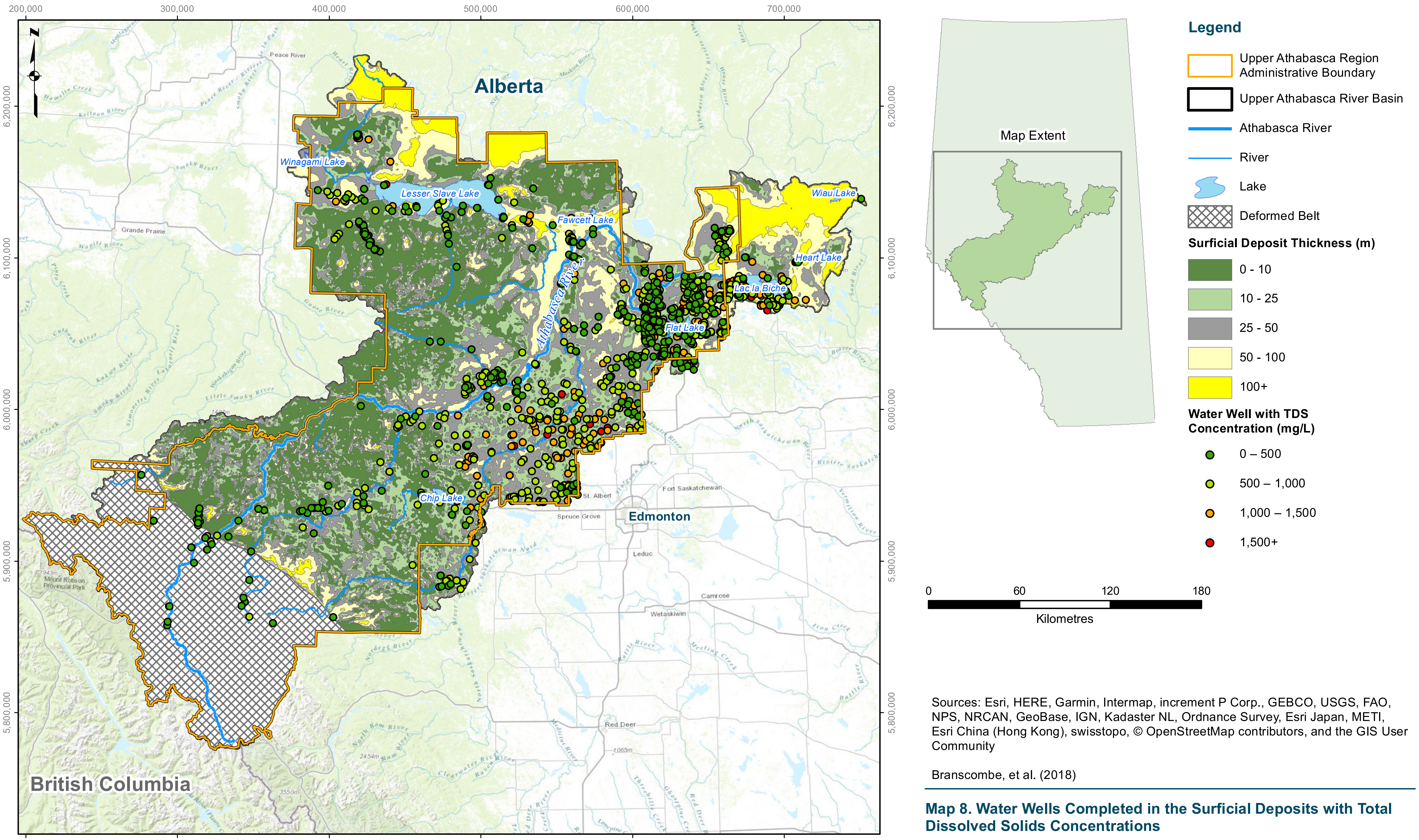
0 60 120 180
Kilometres

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the surficial deposits.

Branscombe, et al. (2018)

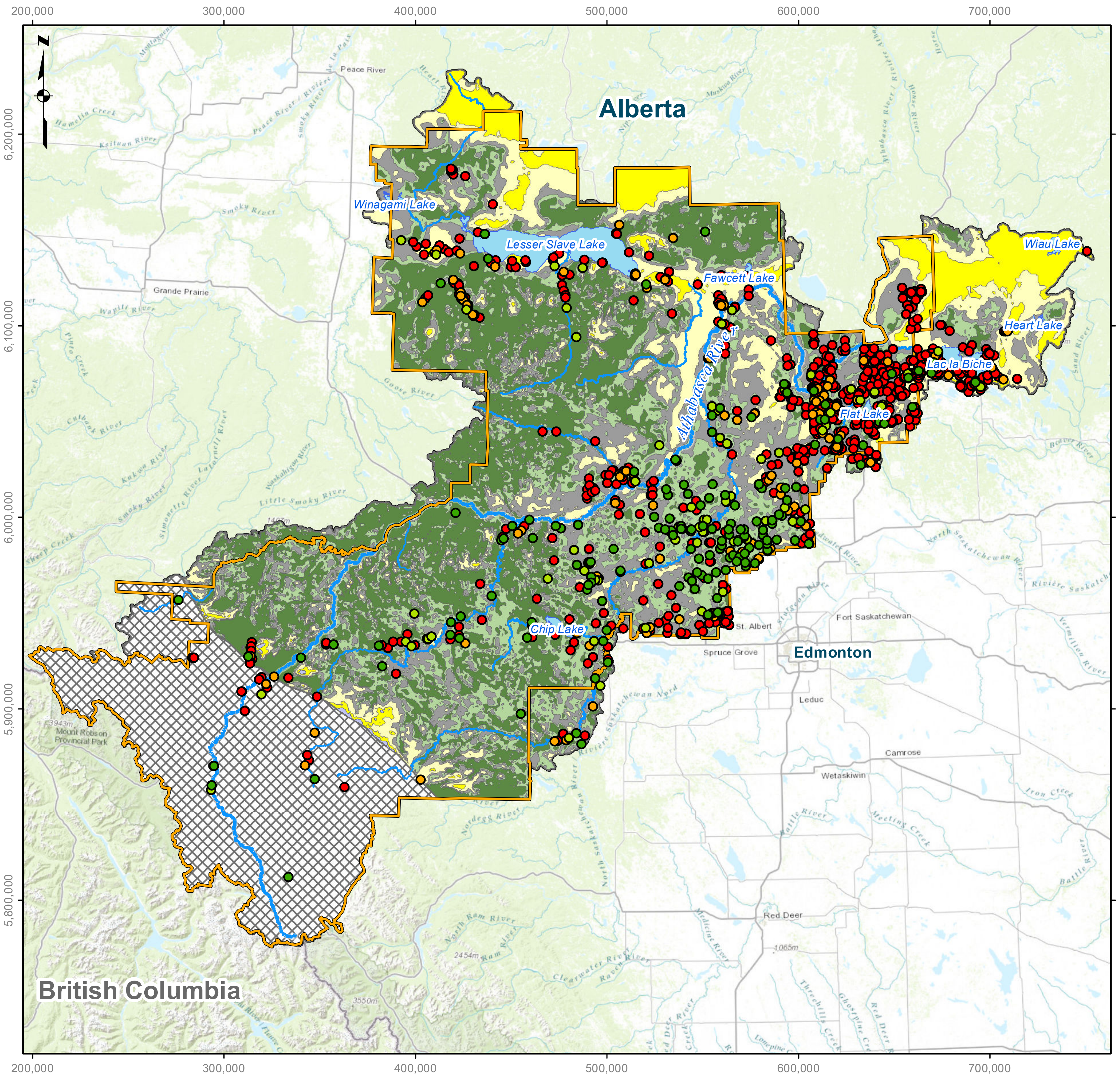
Map 7. Long-Term Water Well Yields Within the Surficial Deposits

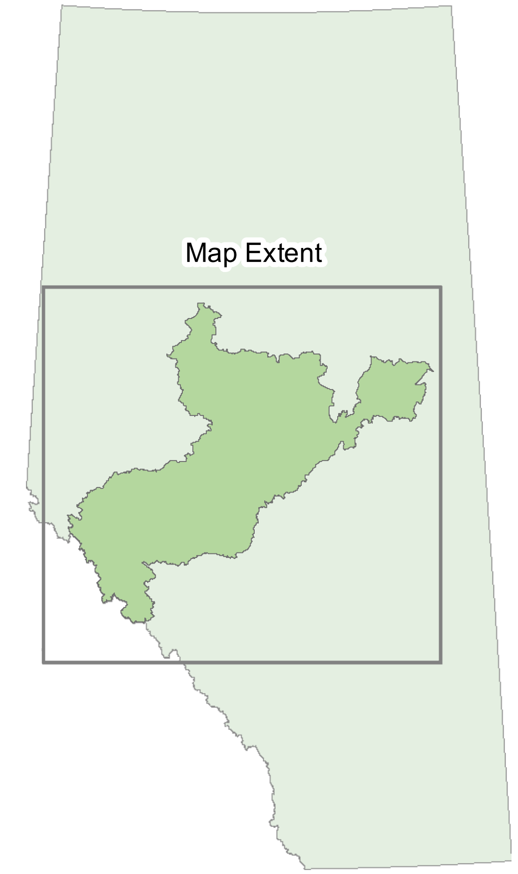


Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 8. Water Wells Completed in the Surficial Deposits with Total Dissolved Solids Concentrations





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt

Surficial Deposit Thickness (m)

- 0 - 10
- 10 - 25
- 25 - 50
- 50 - 100
- 100+

Water Well with Hardness Concentration (mg/L)

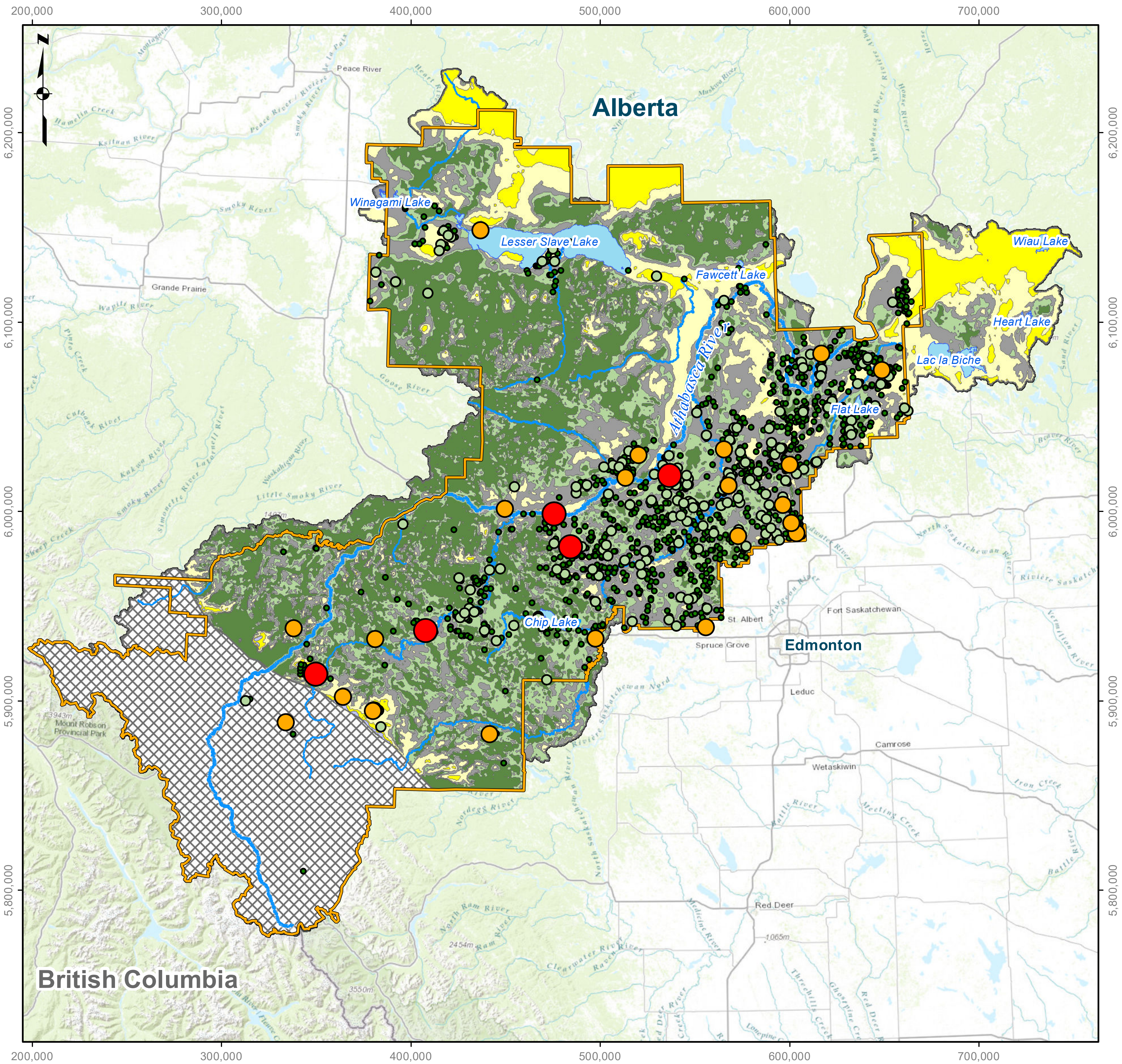
- 0 – 60 (Soft)
- 60 – 120 (Moderately Hard)
- 120 – 180 (Hard)
- 180+ (Very Hard)

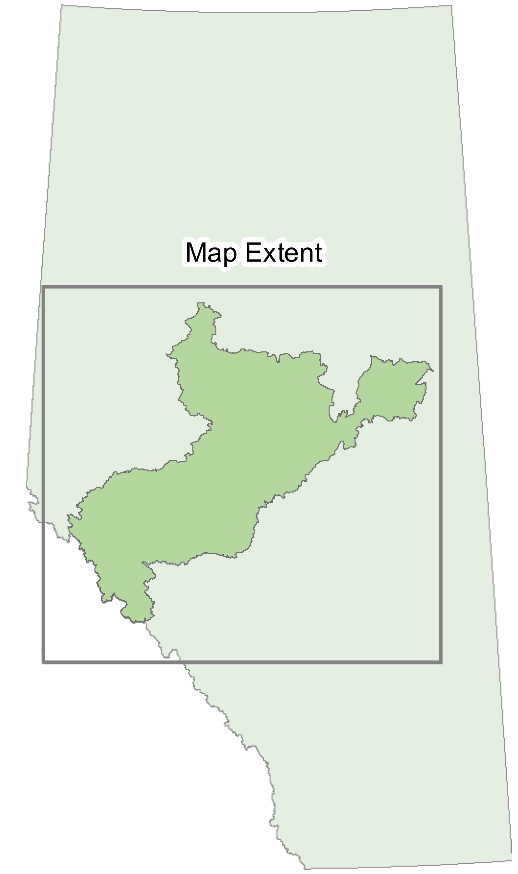
0 60 120 180
Kilometres

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 9. Water Wells Completed in the Surficial Deposits with Hardness Concentrations





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt

Surficial Deposit Thickness (m)

- 0 - 10
- 10 - 25
- 25 - 50
- 50 - 100
- 100+

Authorization (m^3/year)

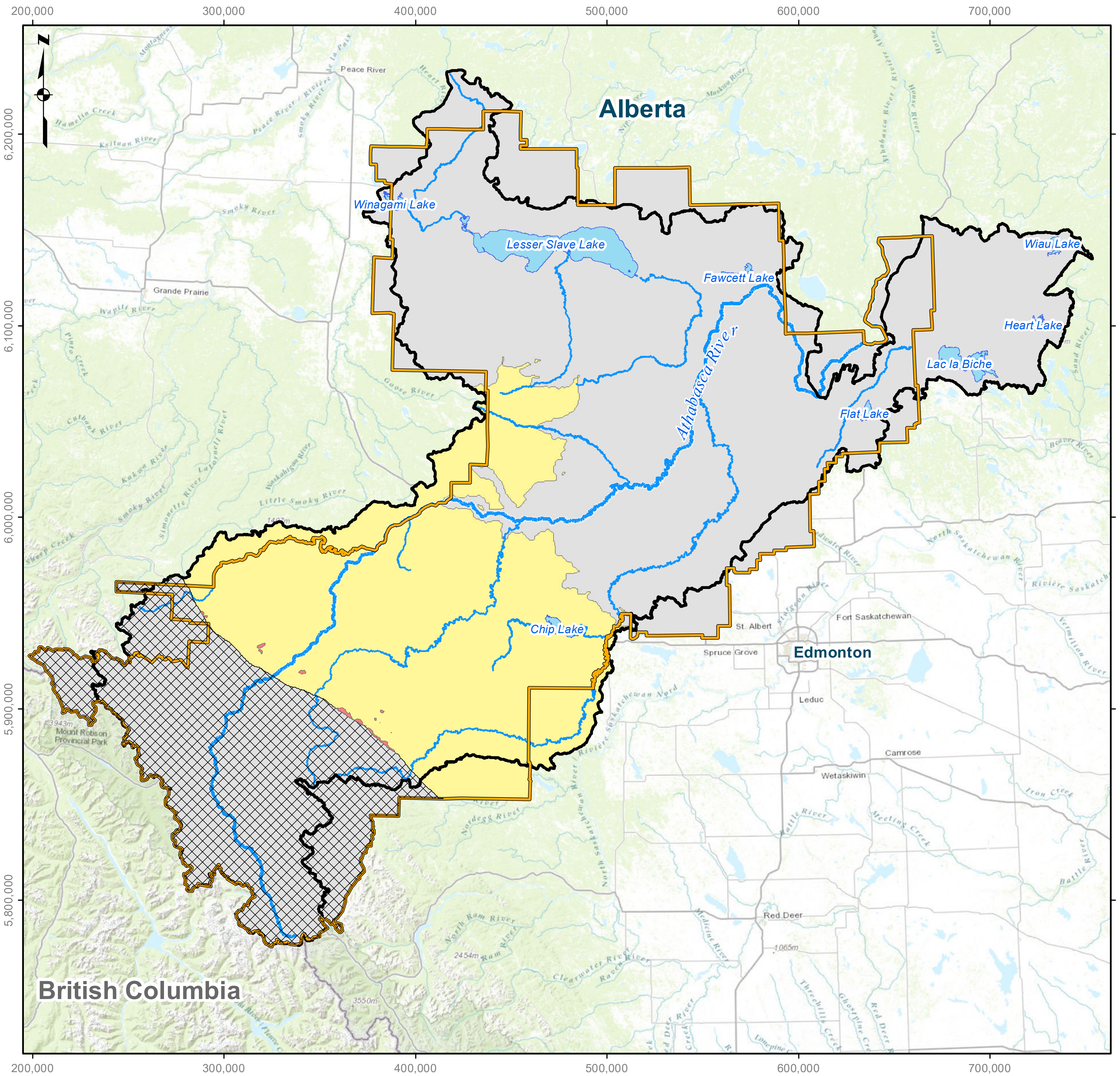
- 0 – 2,500
- 2,500 – 10,000
- 10,000 – 100,000
- 100,000 +

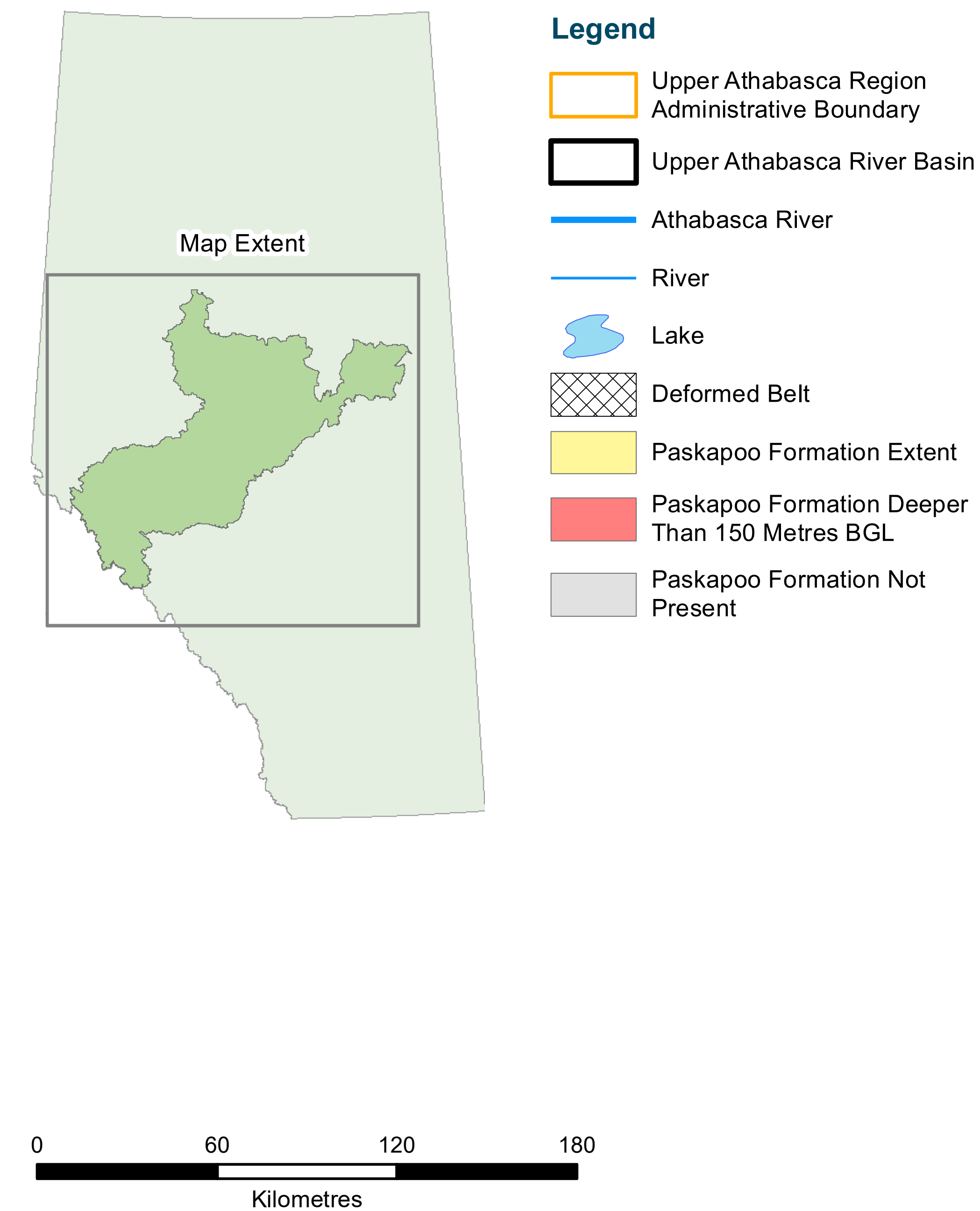
0 60 120 180

Kilometres

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 10. Groundwater Authorizations in the Surficial Deposits

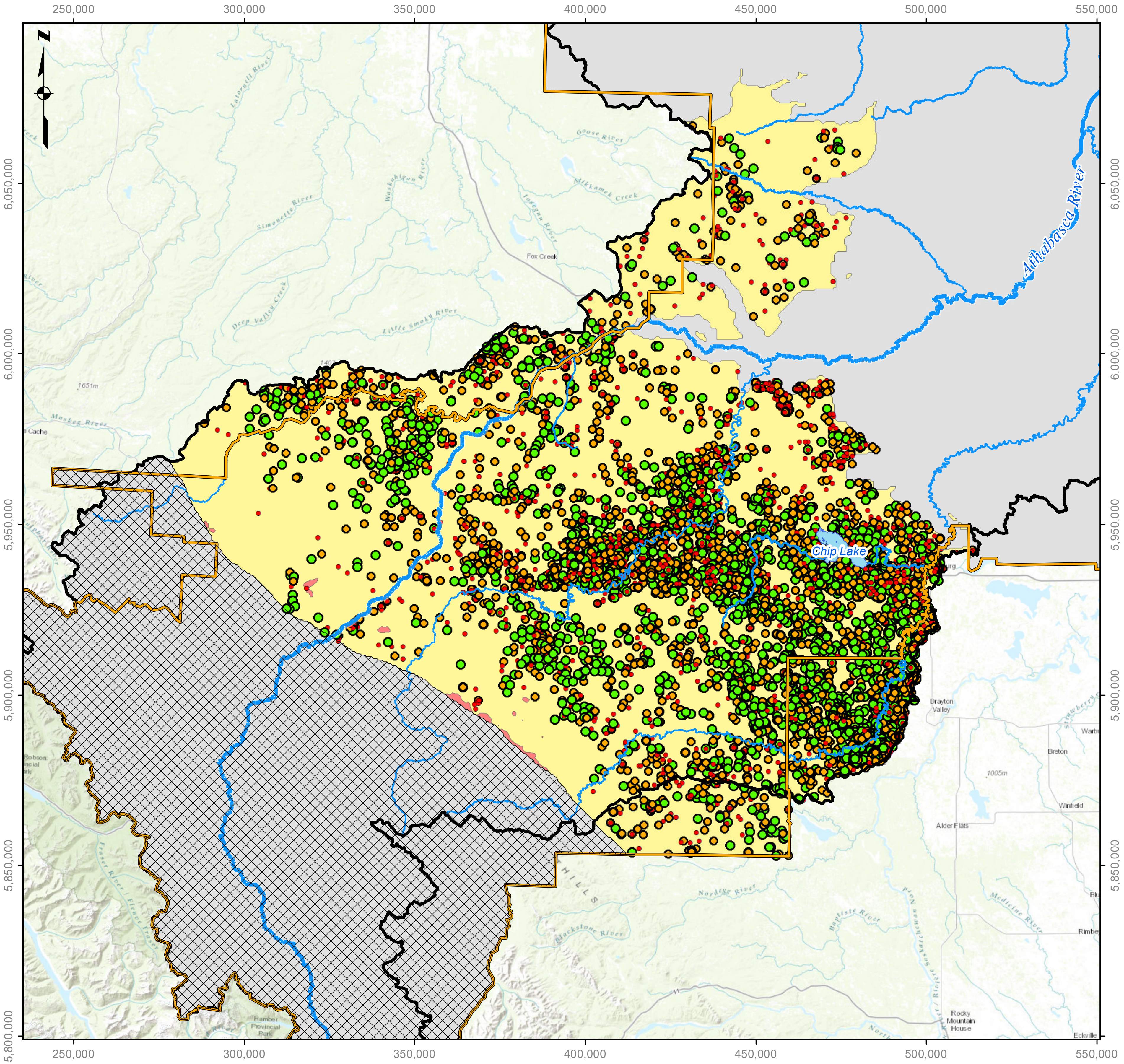




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 11. Extent of the Paskapoo Formation Within the UAR



Legend

- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Paskapoo Formation Extent
- Paskapoo Formation Deeper Than 150 Metres BGL
- Paskapoo Formation Not Present

Water Well with Long-Term Yield (m³/day)

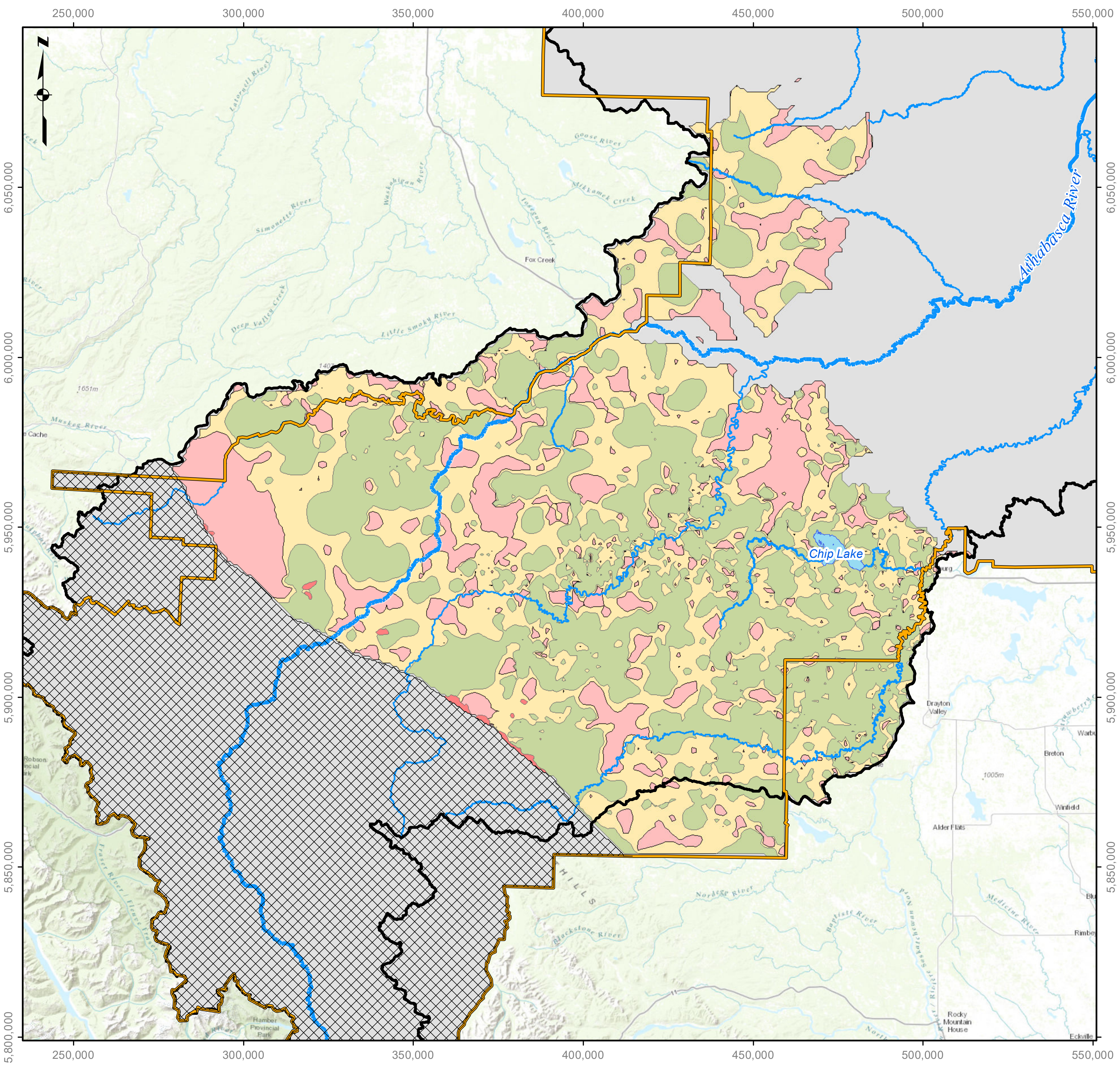
- 100+
- 25 - 100
- 0 - 25

0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 12. Water Wells Completed in the Paskapoo Formation with Long-Term Yield

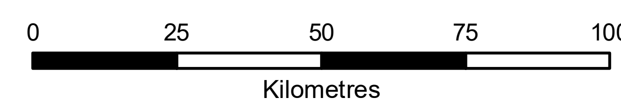


Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Paskapoo Formation Deeper than 150 Metres BGL
- Paskapoo Formation Not Present

Long-Term Water Well Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+

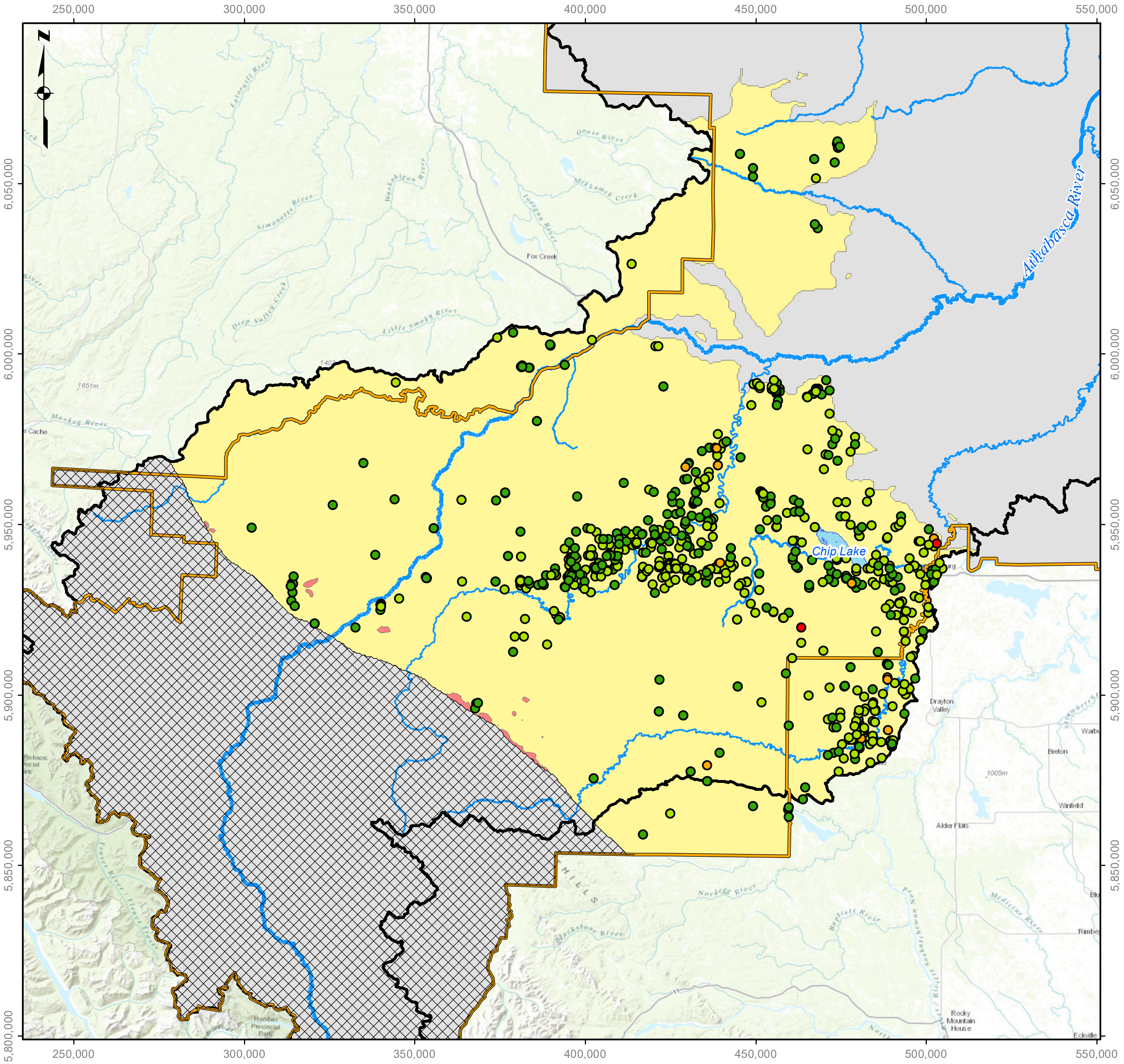


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Paskapoo Formation.

Branscombe, et al. (2018)

Map 13. Long-Term Water Well Yields Within the Paskapoo Formation



Legend

Upper Athabasca Region Administrative Boundary

Upper Athabasca River Basin

Athabasca River

River

Lake

Deformed Belt

Paskapoo Formation Extent

Paskapoo Formation Deeper than 150 Metres BGL

Paskapoo Formation Not Present

Water Well with TDS Concentration (mg/L)

0 – 500

500 – 1,000

1,000 – 1,500

1,500+

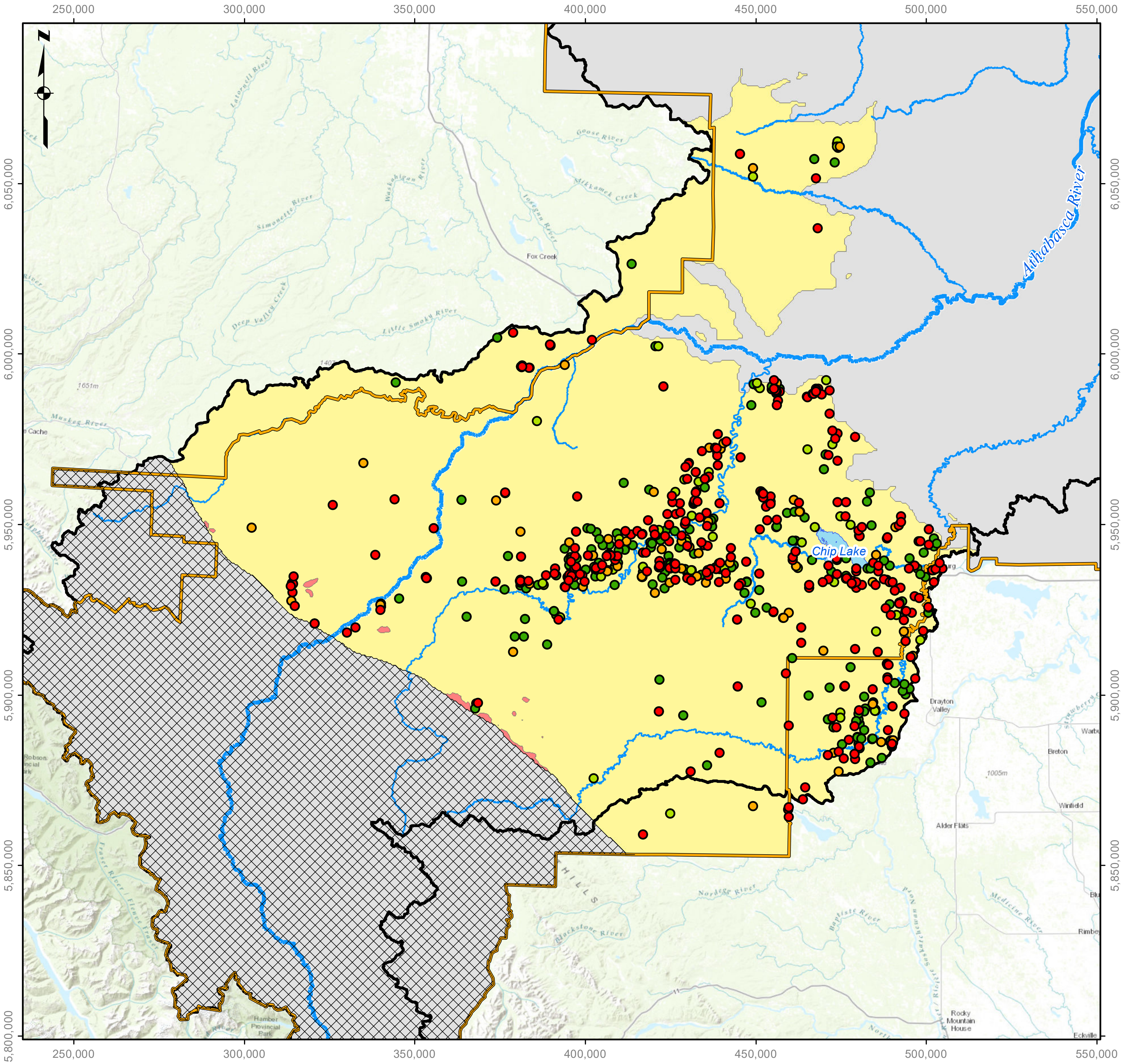
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 14. Water Wells Completed in the Paskapoo Formation with Total Dissolved Solids Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Paskapoo Formation Extent
- Paskapoo Formation Deeper Than 150 Metres BGL
- Paskapoo Formation Not Present

Water Well with Hardness Concentration (mg/L)

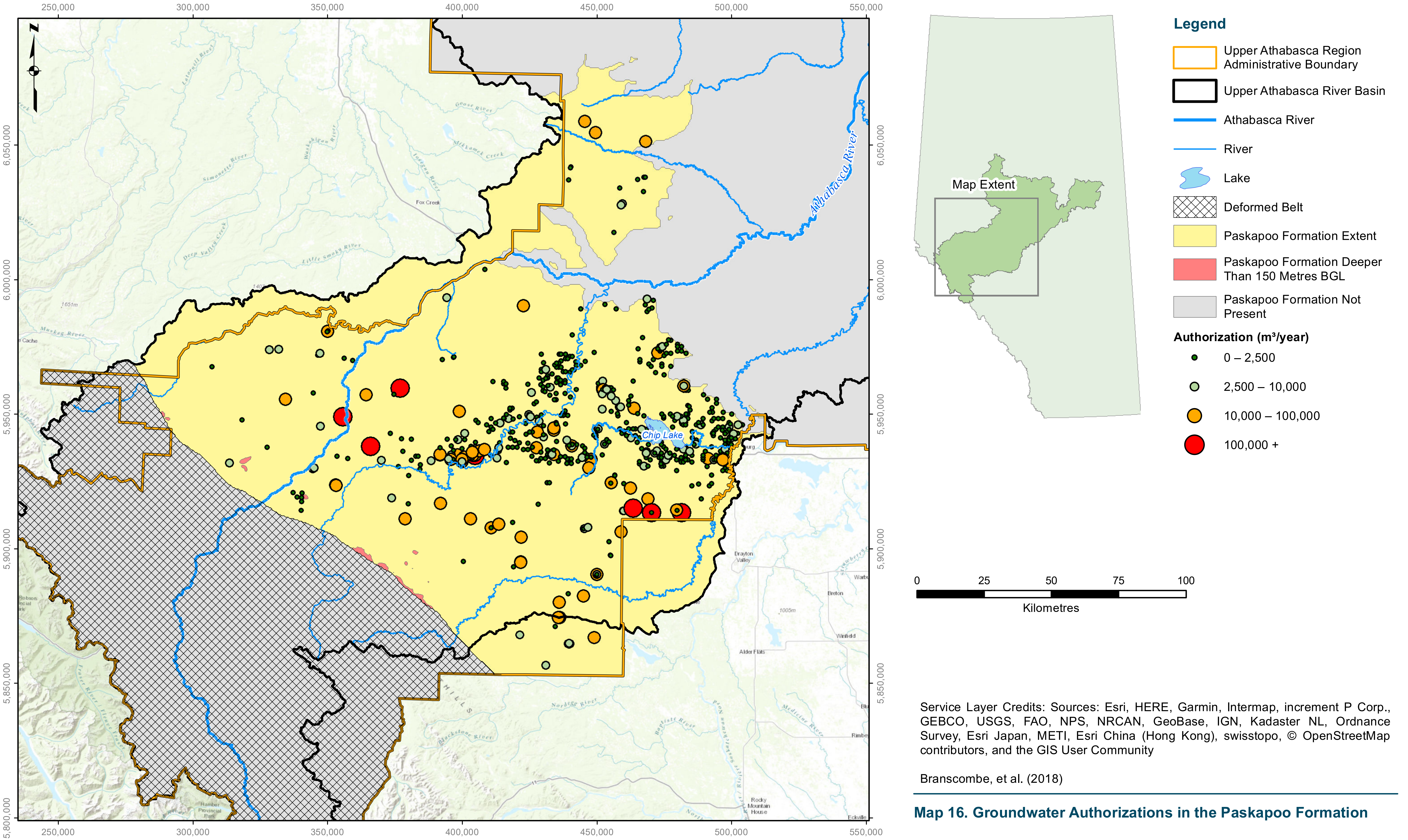
- 0 – 60 (Soft)
- 60 – 120 (Moderately Hard)
- 120 – 180 (Hard)
- 180+ (Very Hard)

0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

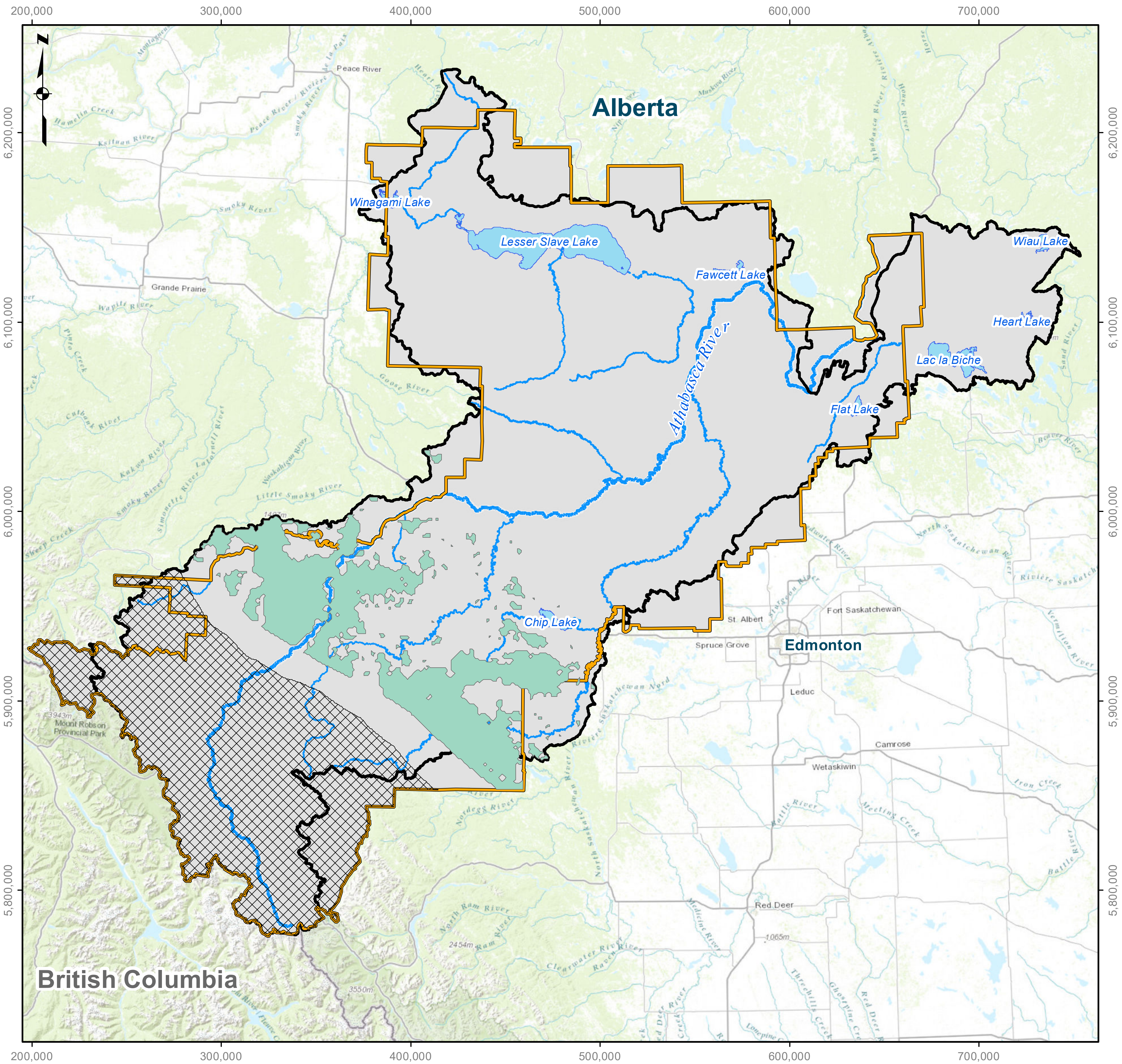
Map 15. Water Wells Completed in the Paskapoo Formation with Hardness Concentrations

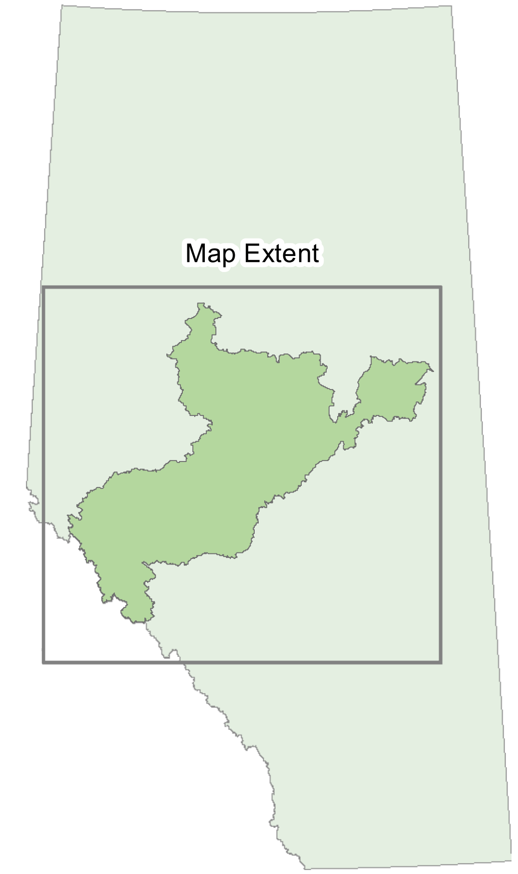


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 16. Groundwater Authorizations in the Paskapoo Formation





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Sunchild Aquifer Extent
- Sunchild Aquifer Not Present

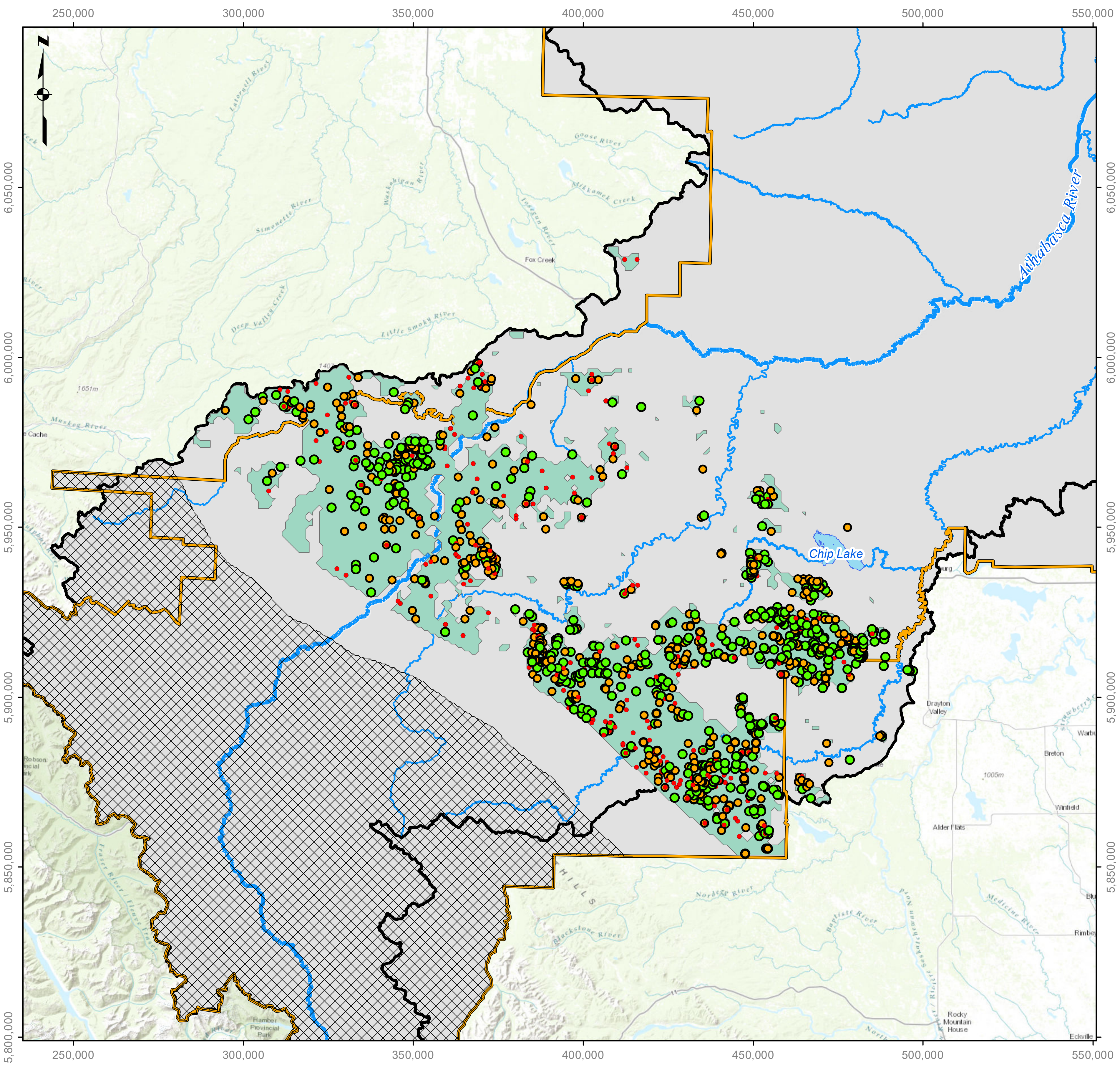
0 60 120 180

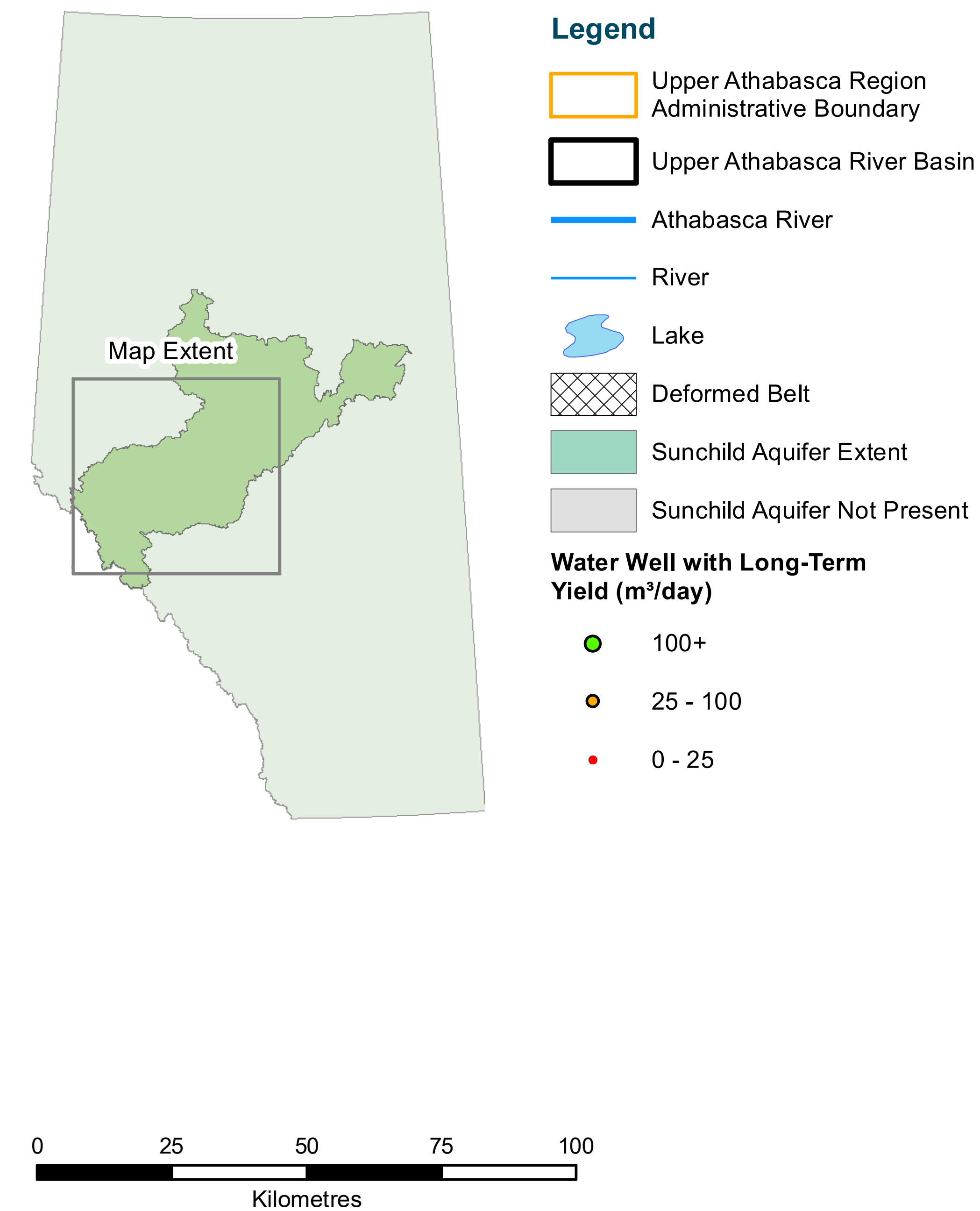
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 17. Extent of the Sunchild Aquifer Within the UAR

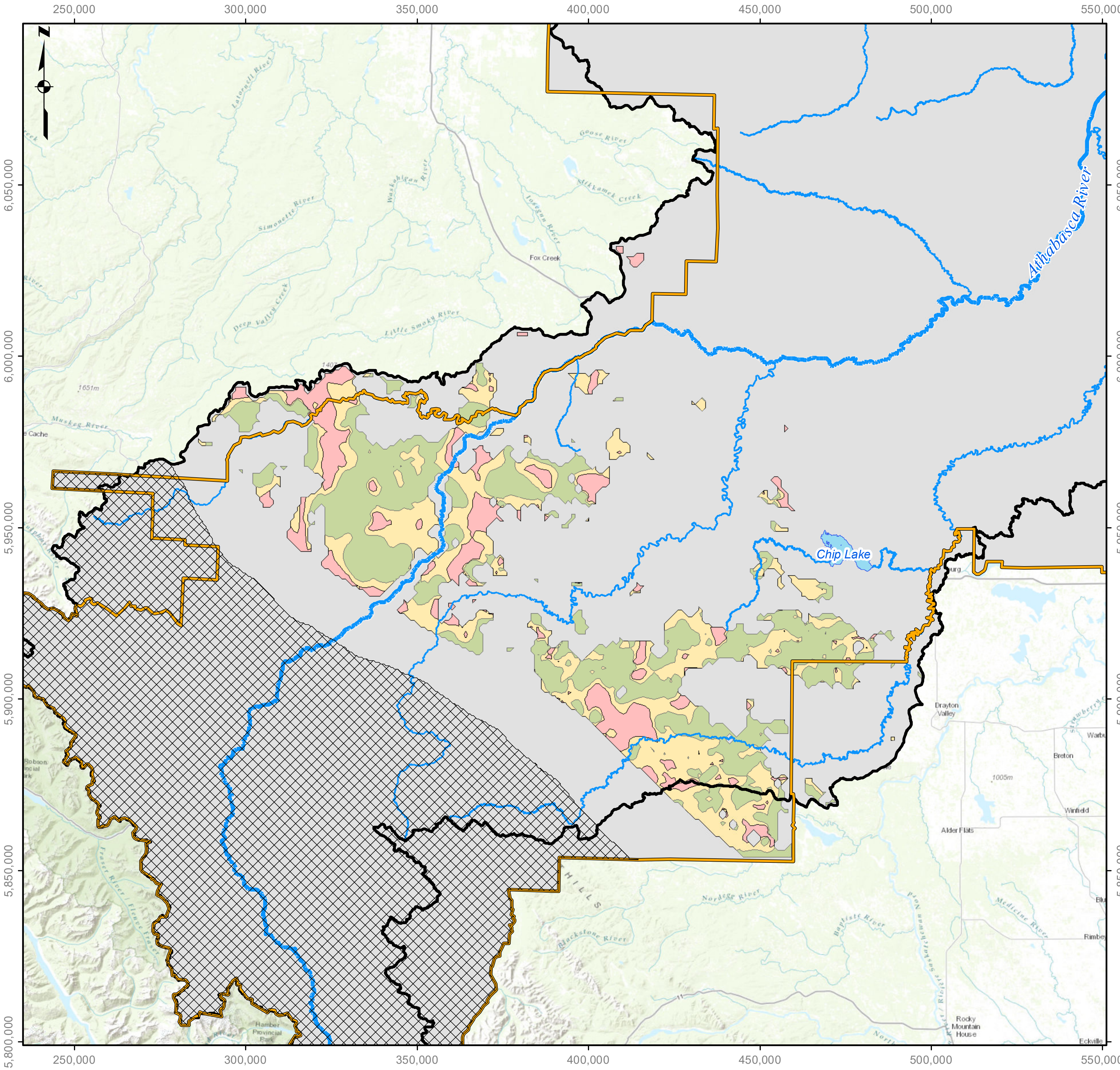




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 18. Water Wells Completed in the Sunchild Aquifer with Long-Term Yield



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Sunchild Aquifer Not Present

Long-Term Water Well Yield (m³/day)

- 0 – 25
- 25 – 100
- 100+

0 25 50 75 100

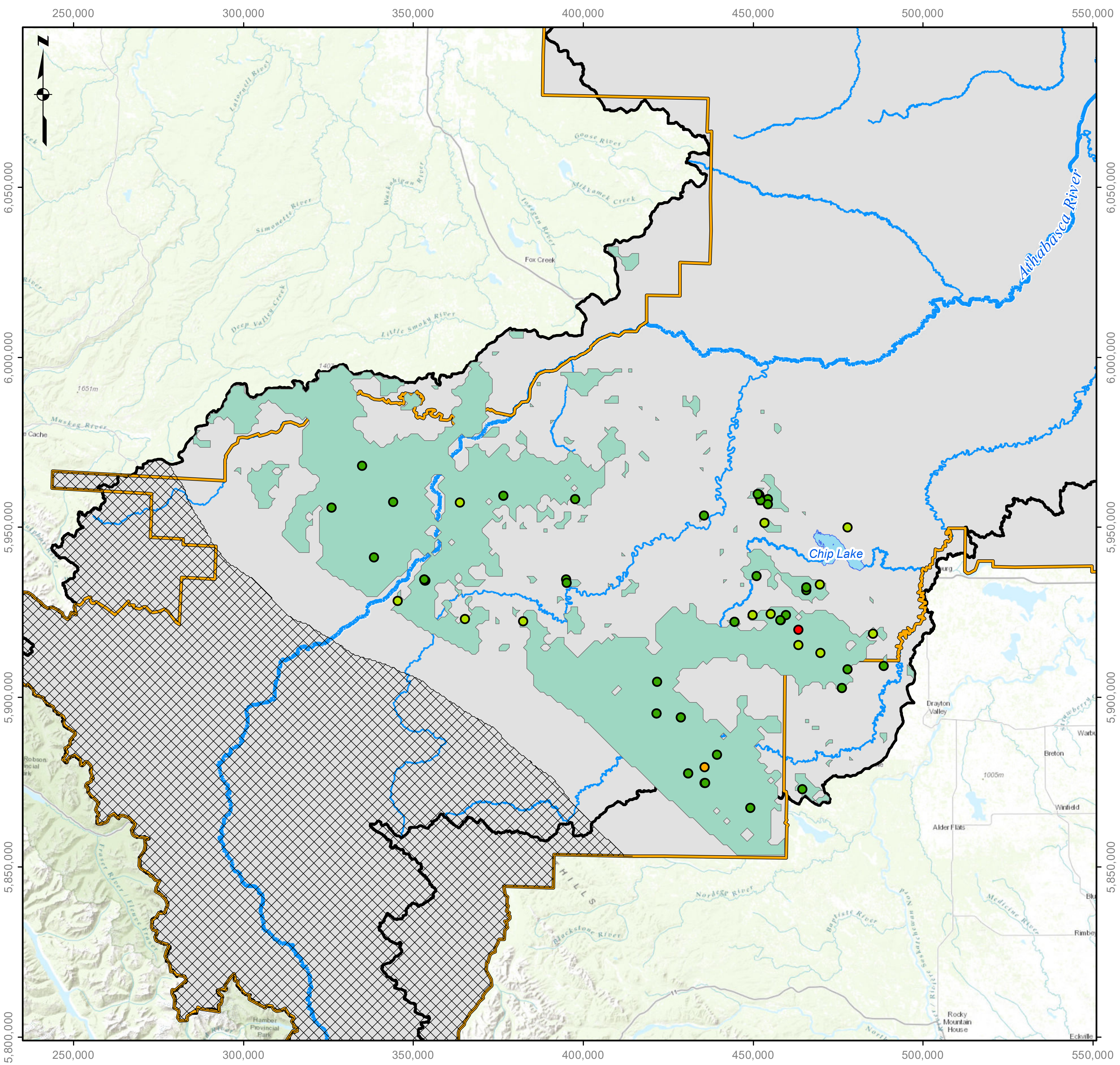
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Sunchild Aquifer.

Lyster and Andriashek (2011)

Map 19. Long-Term Water Well Yields Within the Sunchild Aquifer



Legend

Upper Athabasca Region Administrative Boundary

Upper Athabasca River Basin

Athabasca River

River

Lake

Deformed Belt

Sunchild Aquifer Extent

Sunchild Aquifer Not Present

Water Well with TDS Concentration (mg/L)

0 – 500

500 – 1,000

1,000 – 1,500

1,500+

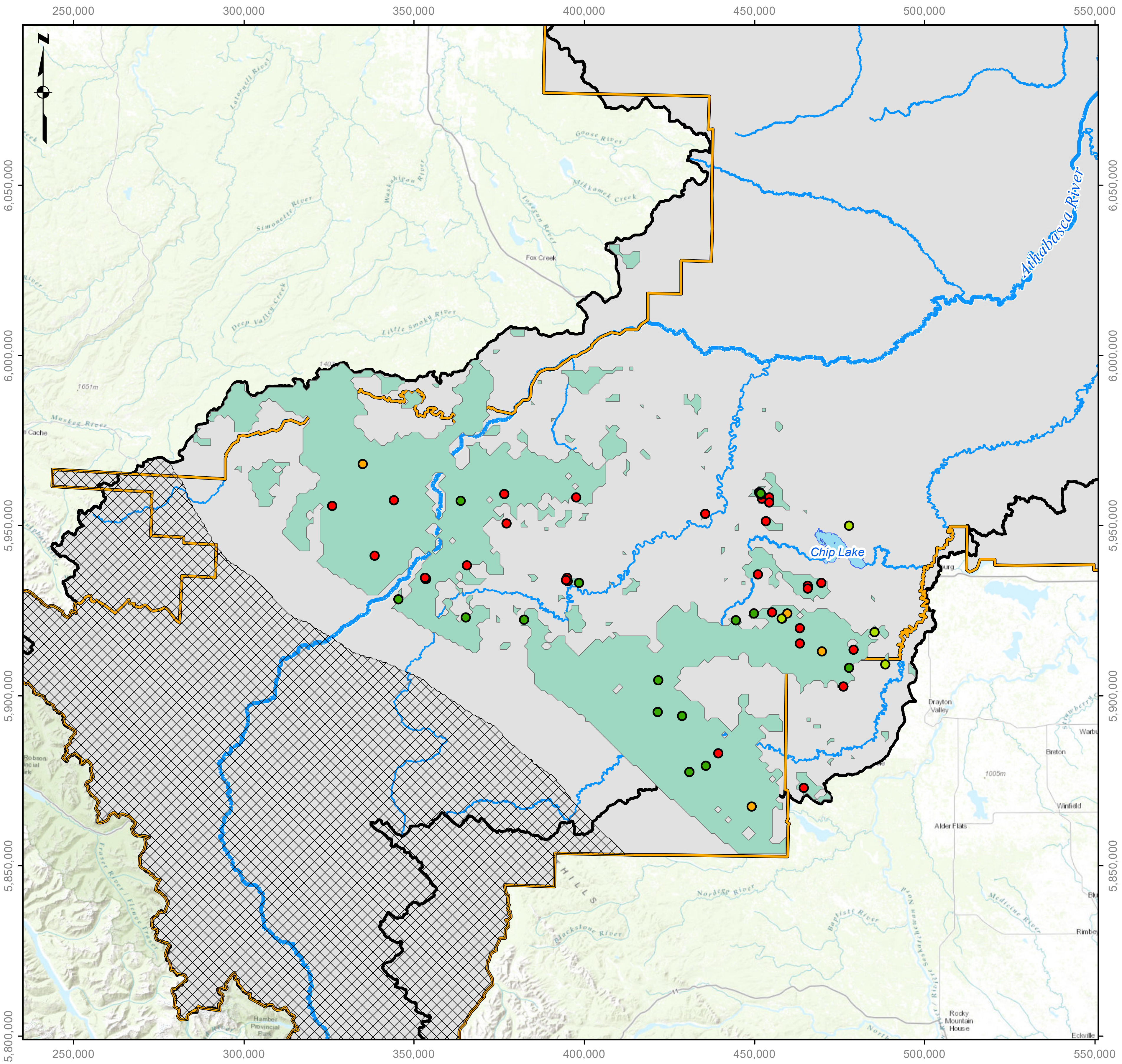
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 20. Water Wells Completed in the Sunchild Aquifer with Total Dissolved Solids Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Sunchild Aquifer Extent
- Sunchild Aquifer Not Present

Water Well with Hardness Concentration (mg/L)

- 0 – 60 (Soft)
- 60 – 120 (Moderately Hard)
- 120 – 180 (Hard)
- 180+ (Very Hard)

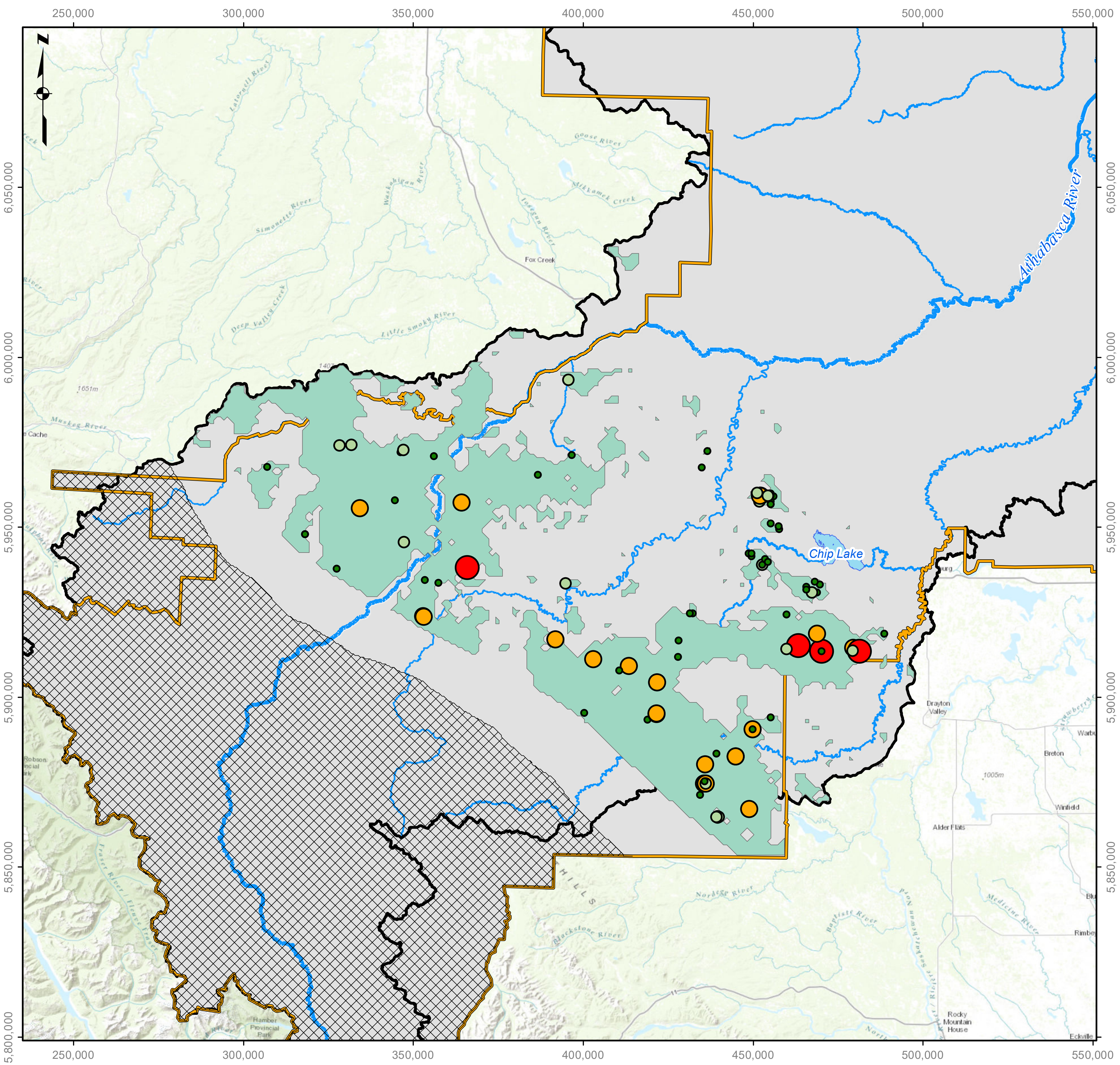
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 21. Water Wells Completed in the Sunchild Aquifer with Hardness Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Sunchild Aquifer Extent
- Sunchild Aquifer Not Present

Authorization (m³/year)

- 0 – 2,500
- 2,500 – 10,000
- 10,000 – 100,000
- 100,000 +

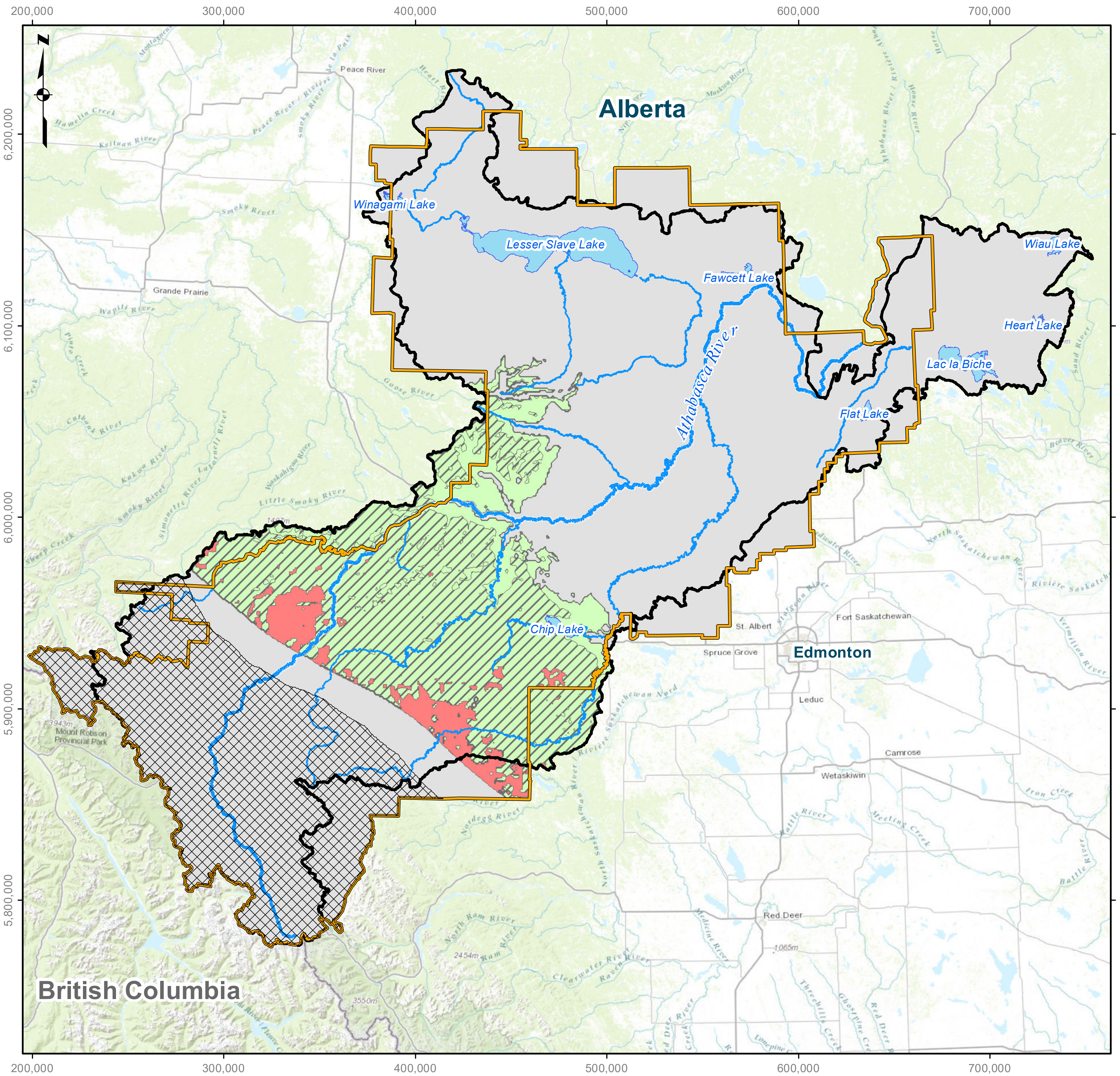
0 25 50 75 100

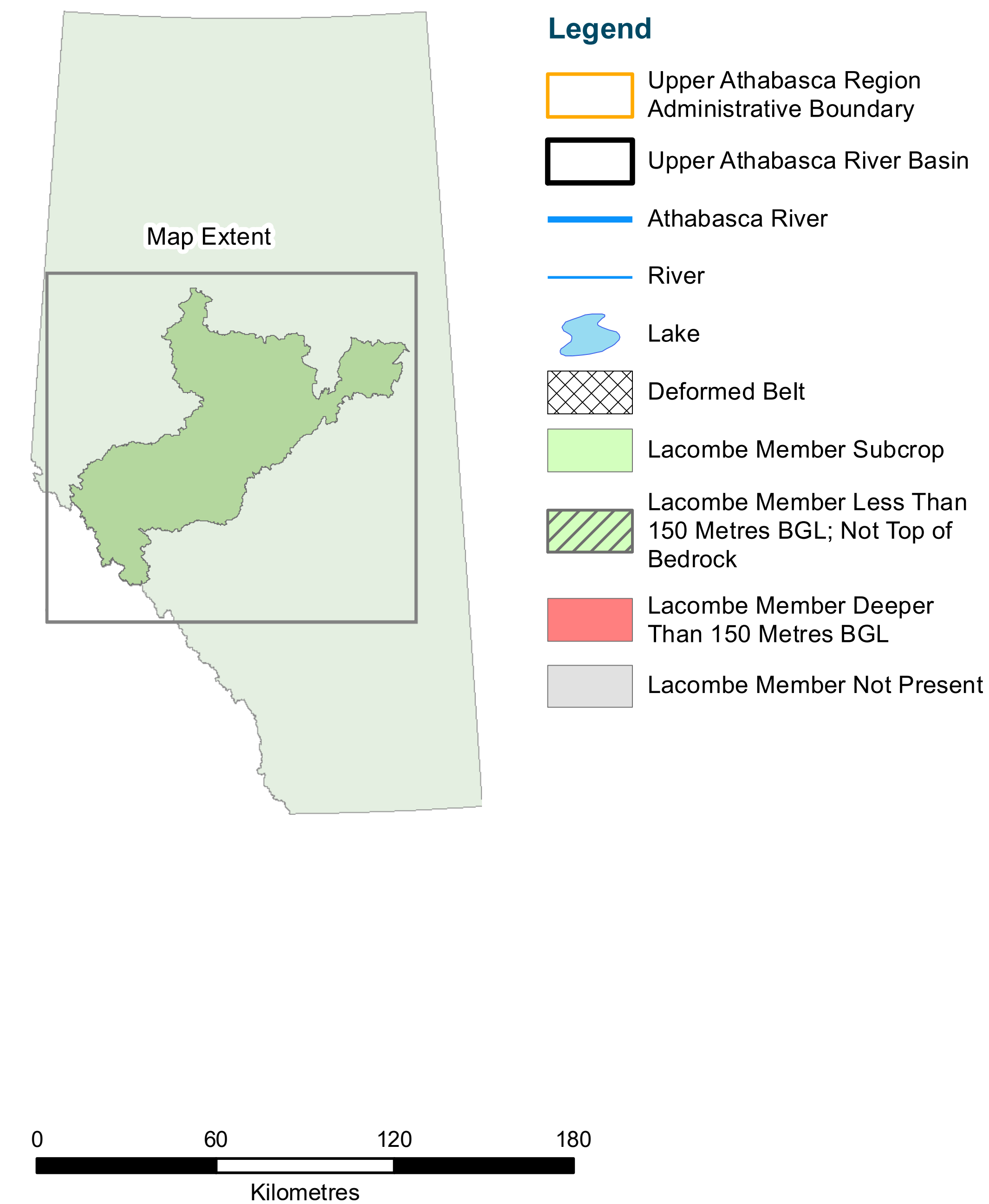
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 22. Groundwater Authorizations in the Sunchild Aquifer

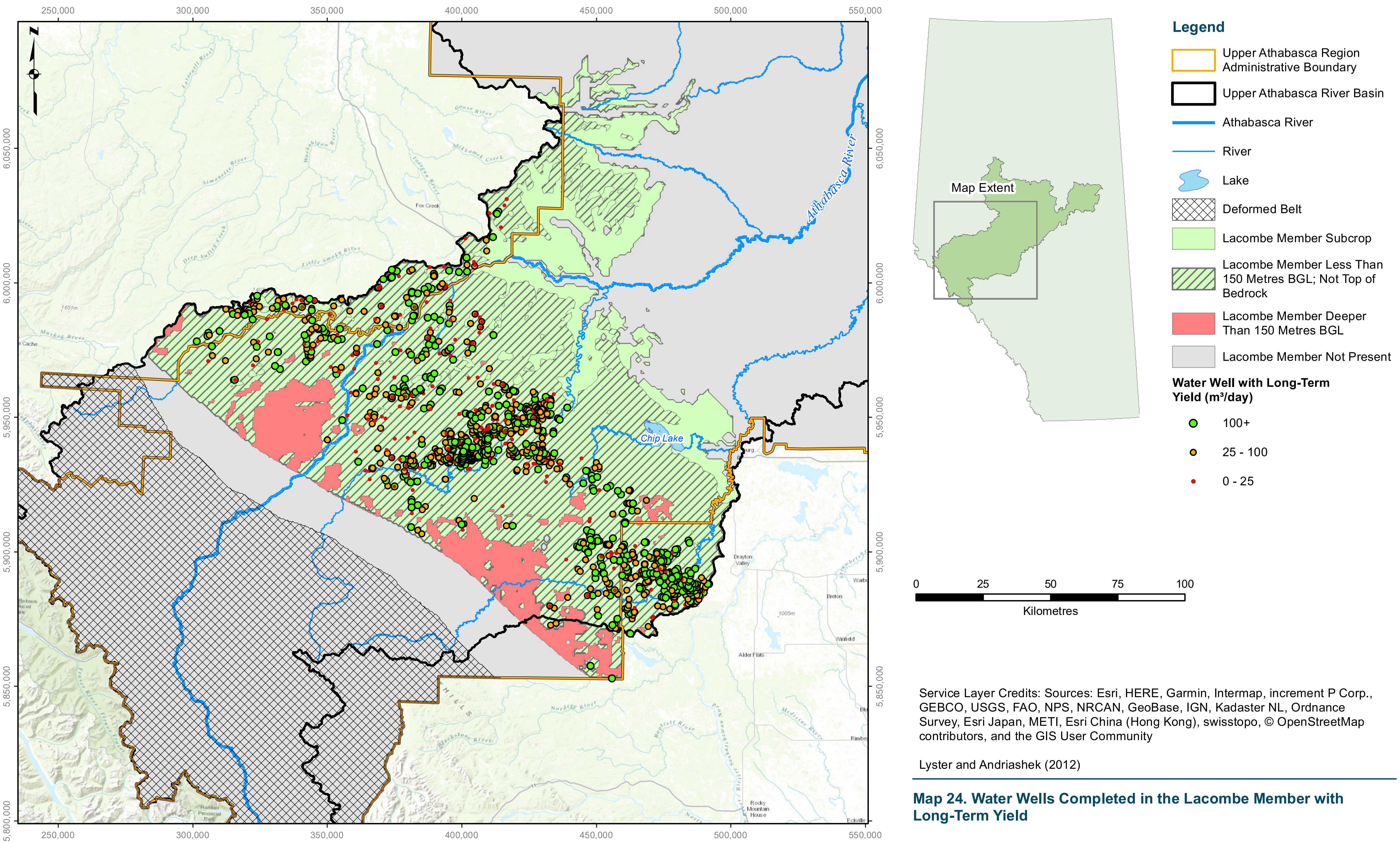




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

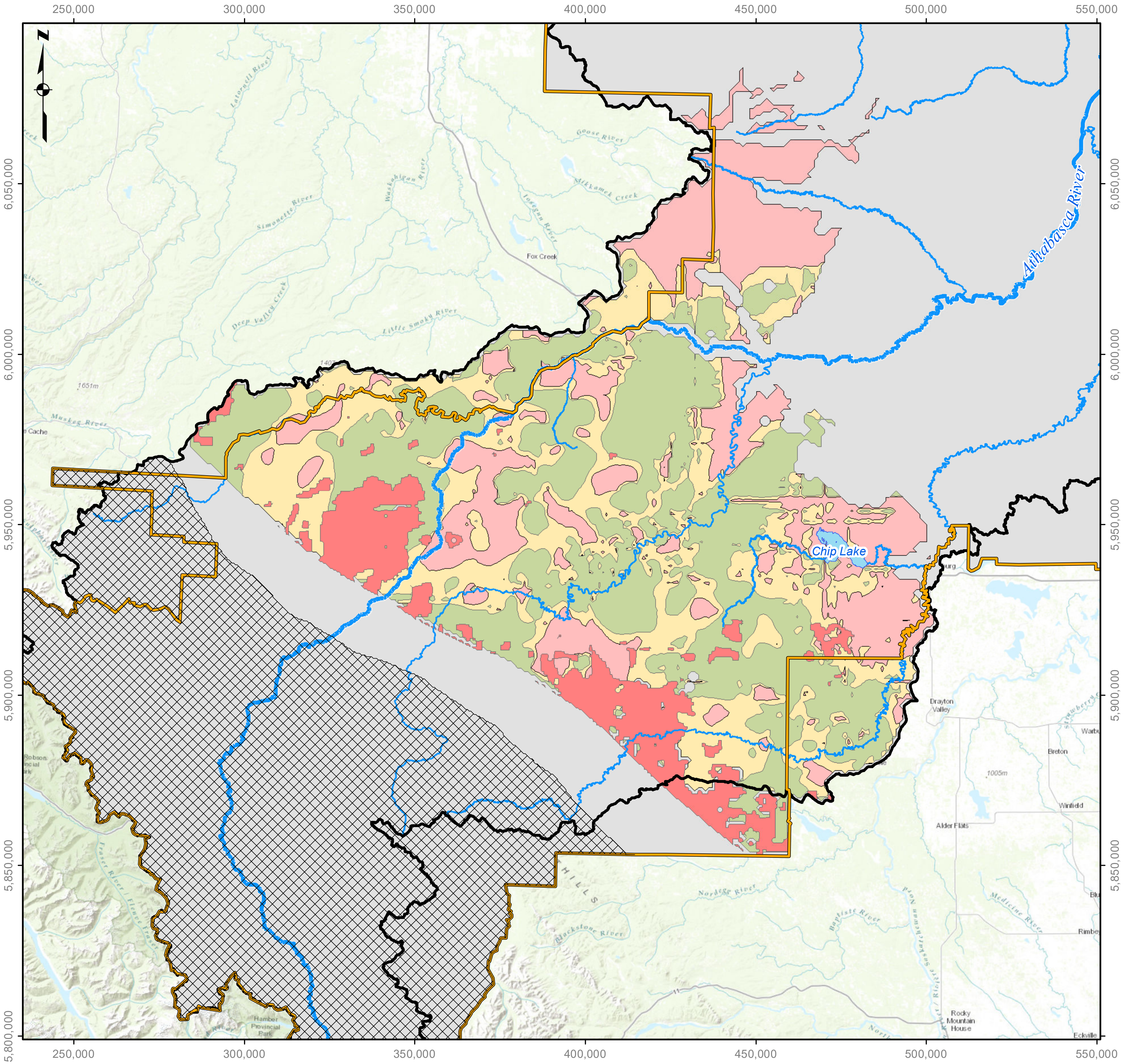
Map 23. Extent of the Lacombe Member Within the UAR



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 24. Water Wells Completed in the Lacombe Member with Long-Term Yield



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Lacombe Member Deeper Than 150 Metres BGL
- Lacombe Member Not Present

Long-Term Water Well Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+

0 25 50 75 100

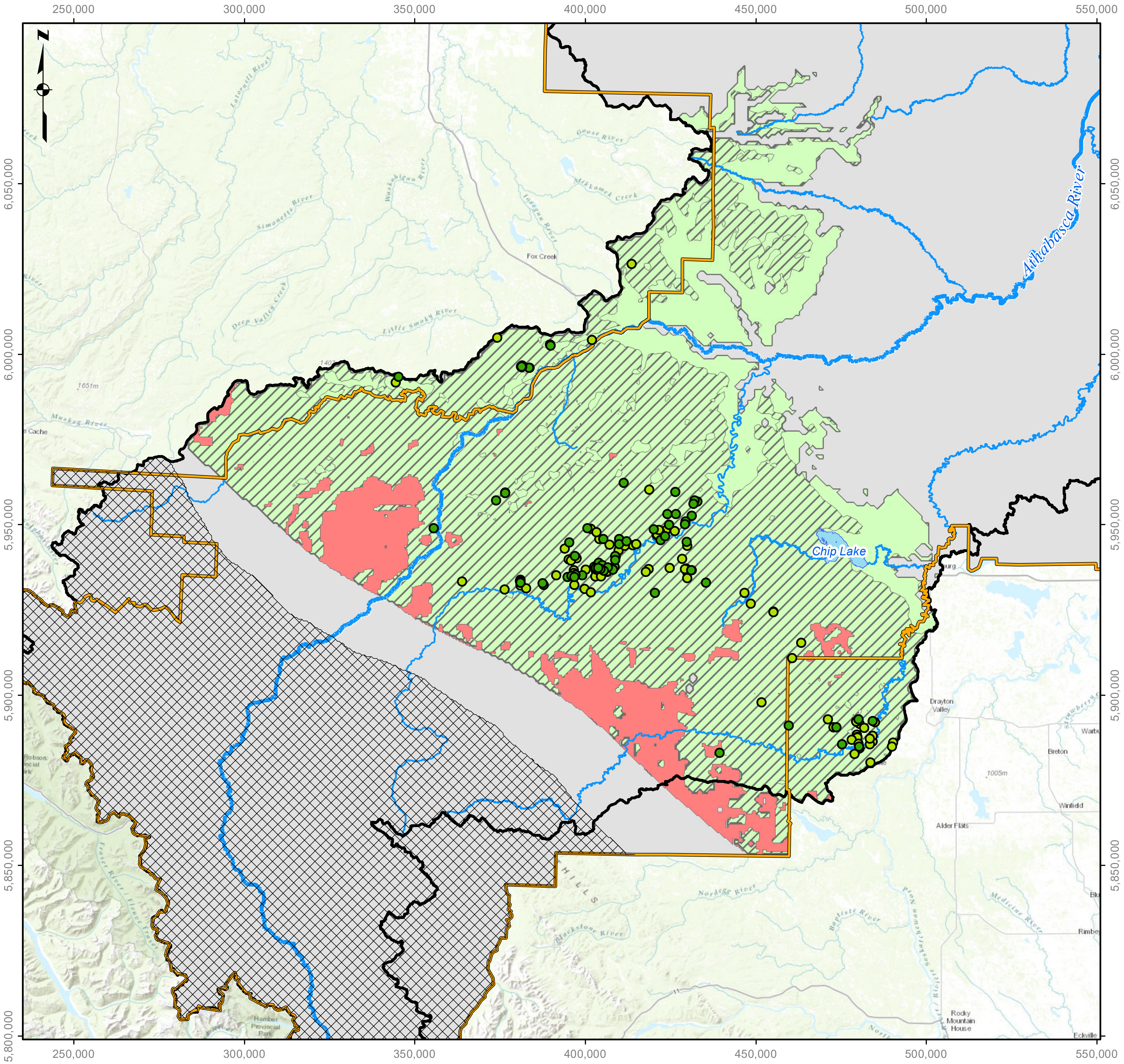
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Lacombe Member.

Lyster and Andriashek (2012)

Map 25. Long-Term Water Well Yields Within the Lacombe Member



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Lacombe Member Subcrop
- Lacombe Member Less Than 150 Metres BGL; Not Top of Bedrock
- Lacombe Member Deeper Than 150 Metres BGL
- Lacombe Member Not Present

Water Well with TDS Concentration (mg/L)

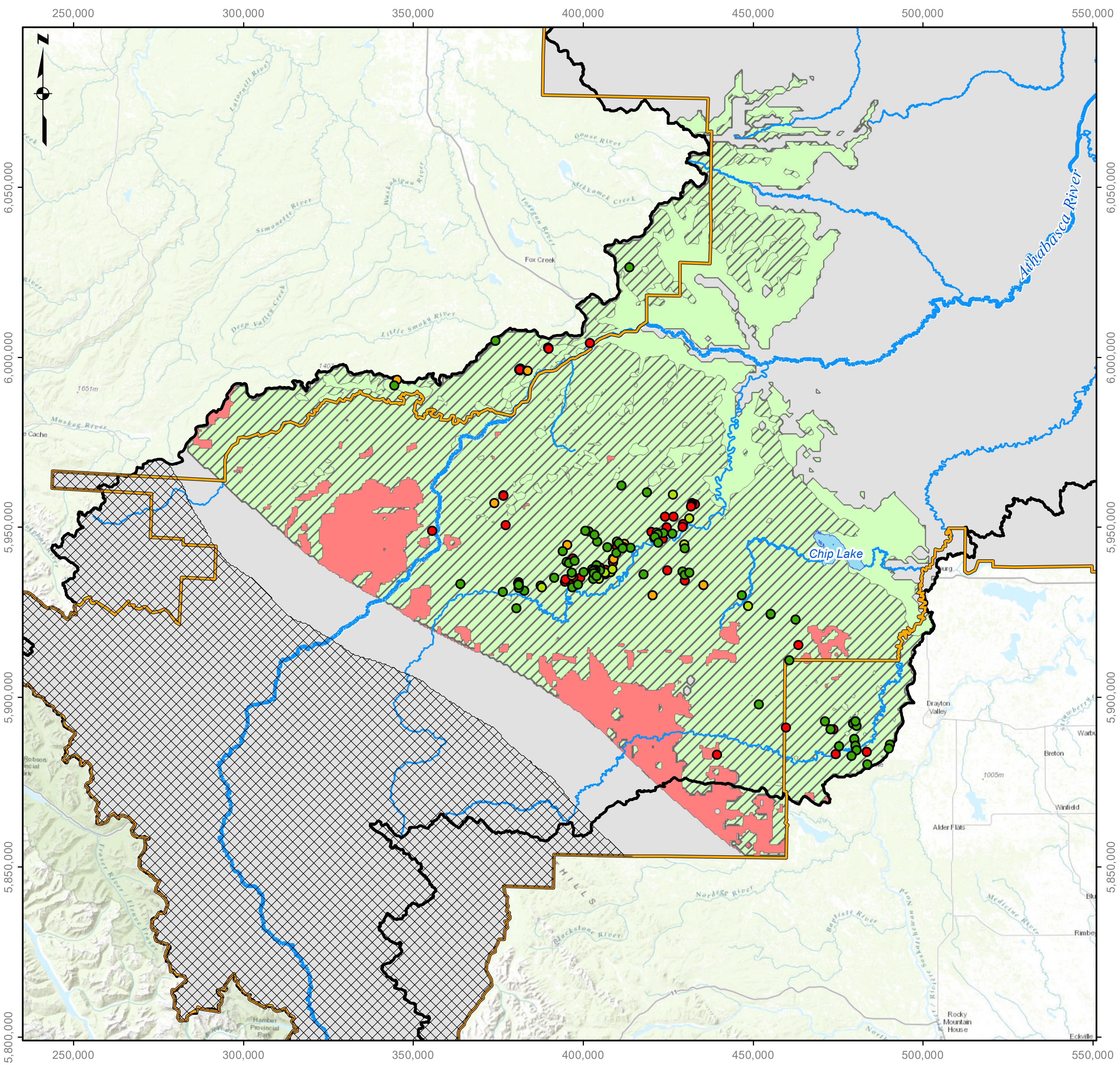
- 0 – 500
- 500 – 1,000
- 1,000 – 1,500
- 1,500+

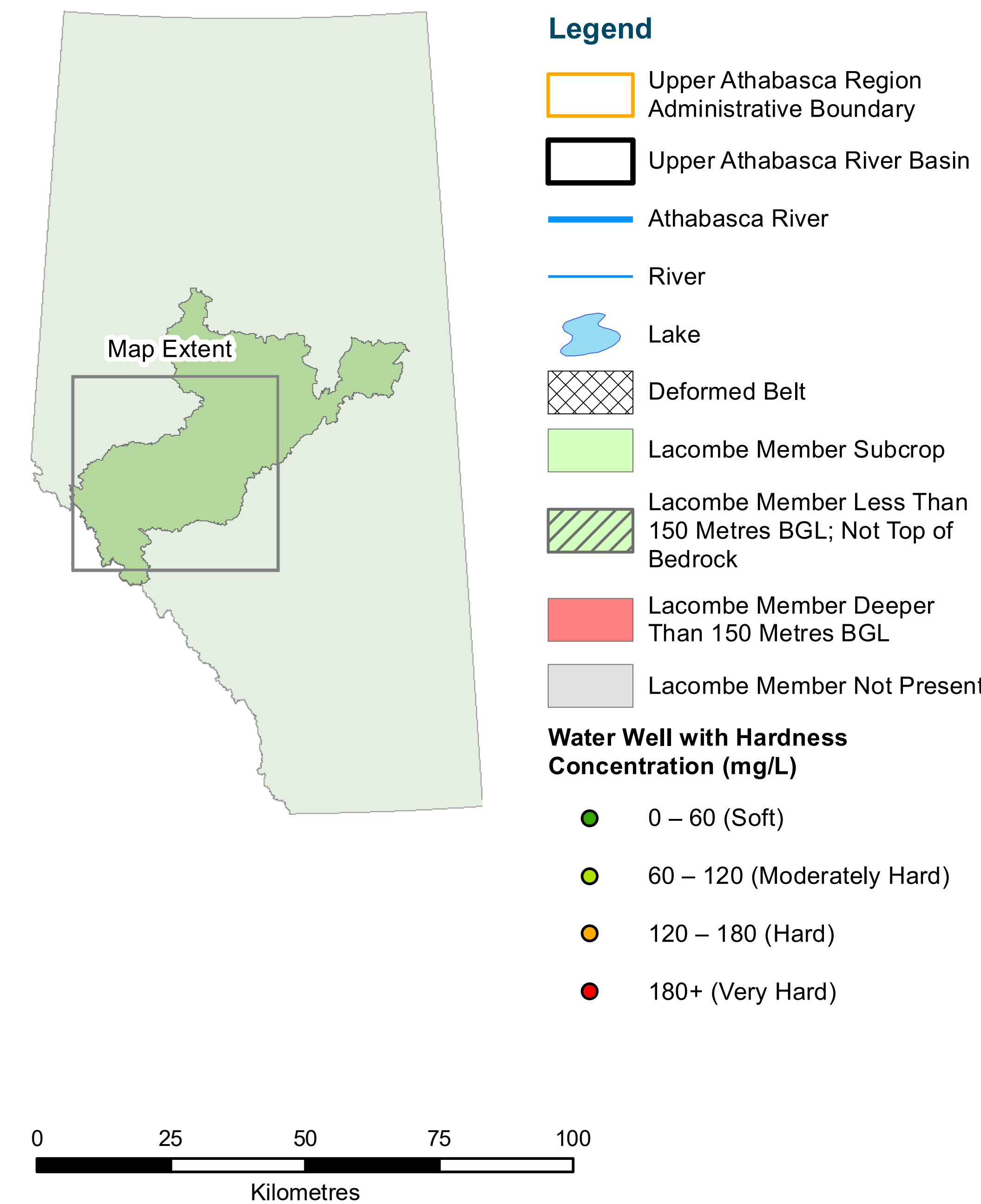
0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 26. Water Wells Completed in the Lacombe Member with Total Dissolved Solids Concentrations

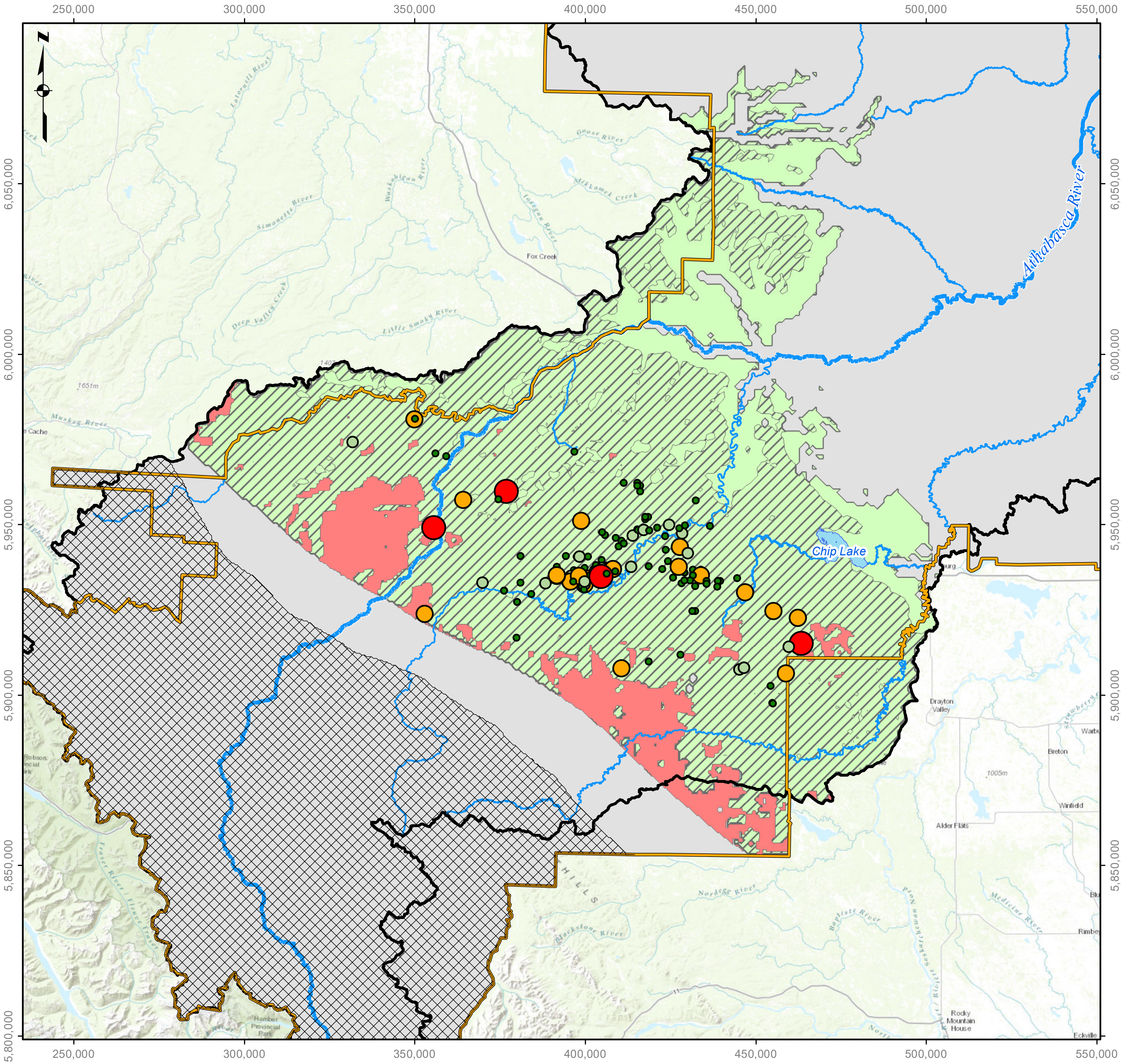




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 27. Water Wells Completed in the Lacombe Member with Hardness Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Lacombe Member Subcrop
- Lacombe Member Less Than 150 Metres BGL; Not Top of Bedrock
- Lacombe Member Deeper Than 150 Metres BGL
- Lacombe Member Not Present

Authorization (m^3/year)

- 0 – 2,500
- 2,500 – 10,000
- 10,000 – 100,000
- 100,000 +

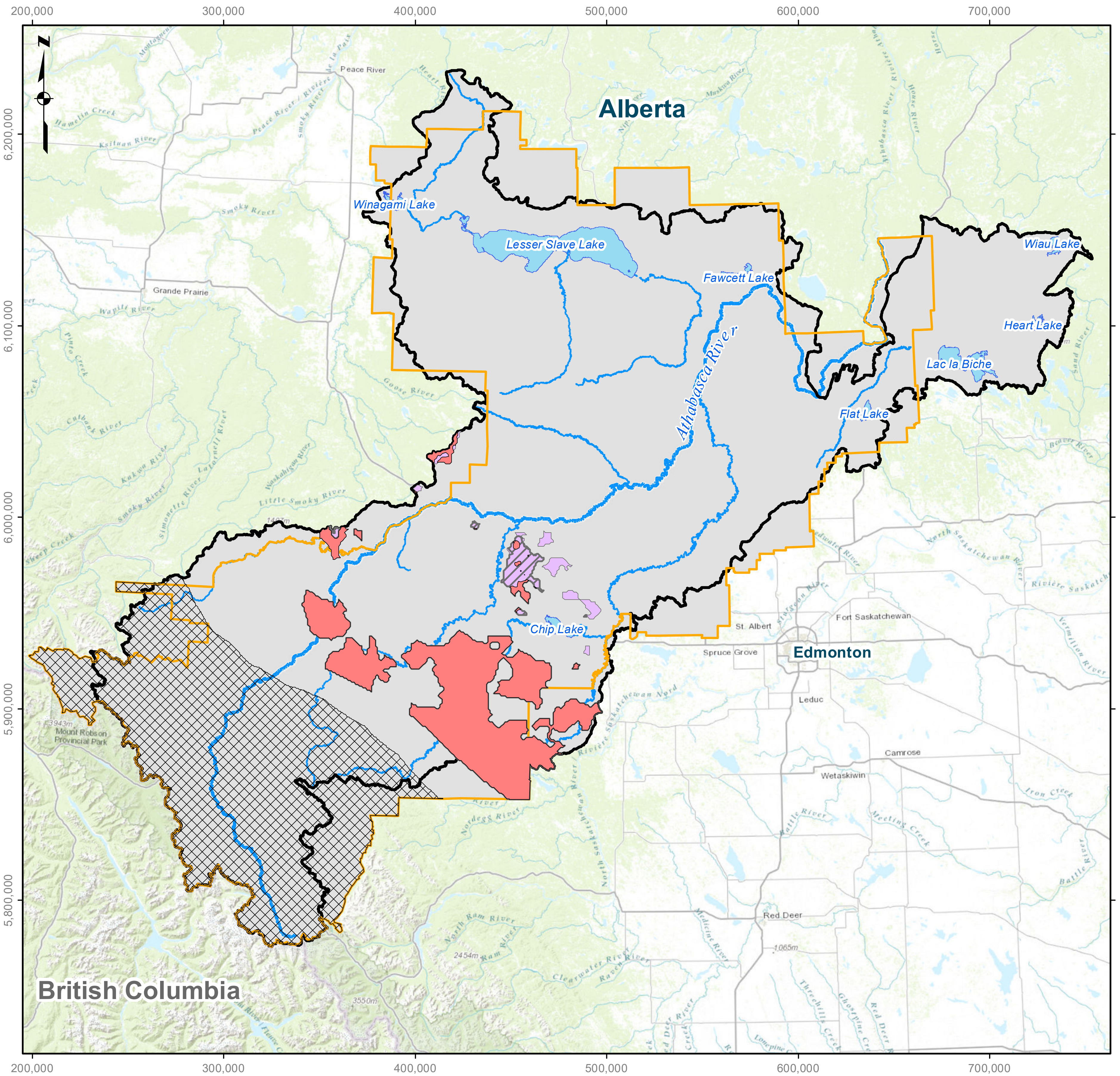
0 25 50 75 100

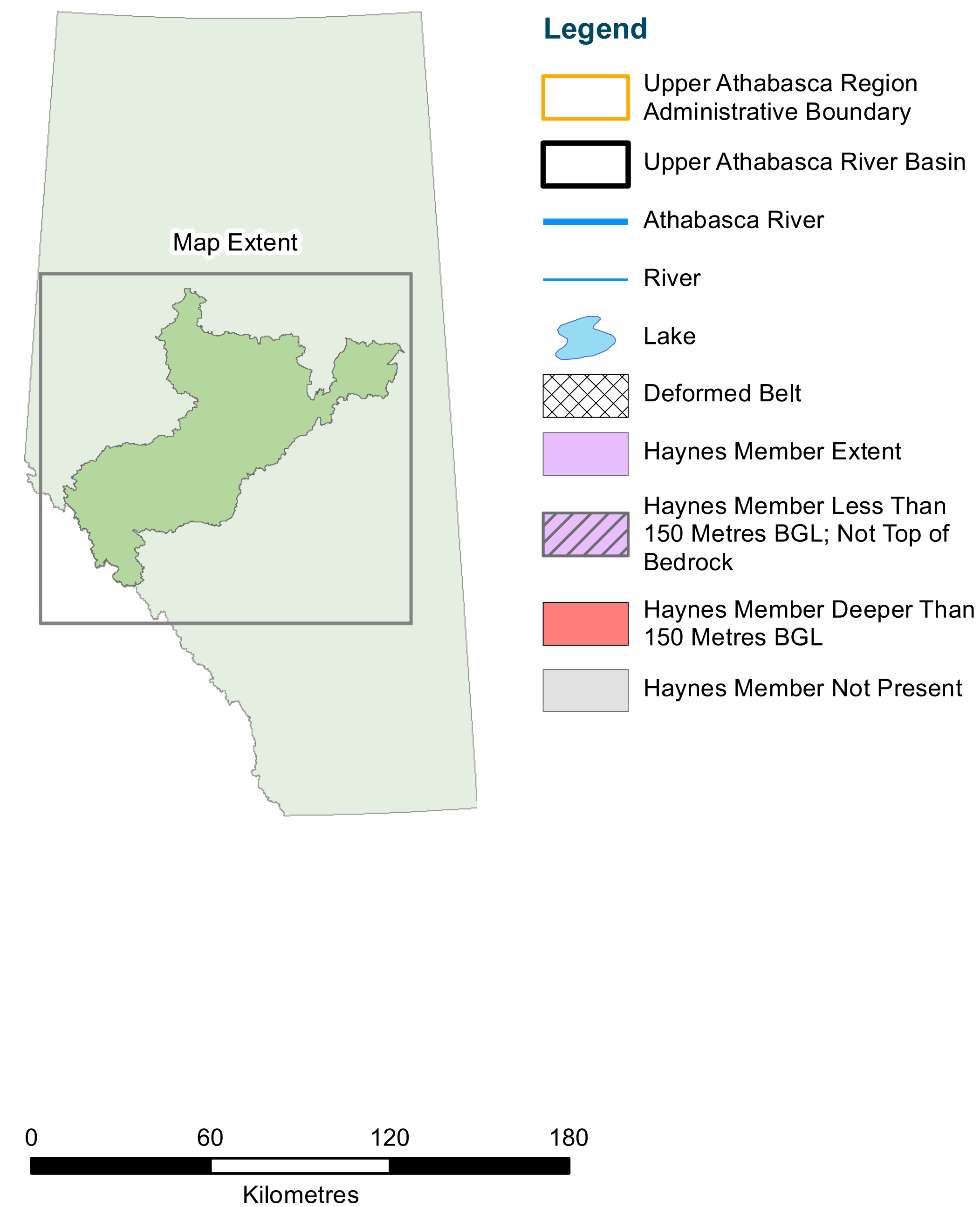
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 28. Groundwater Authorizations in the Lacombe Member

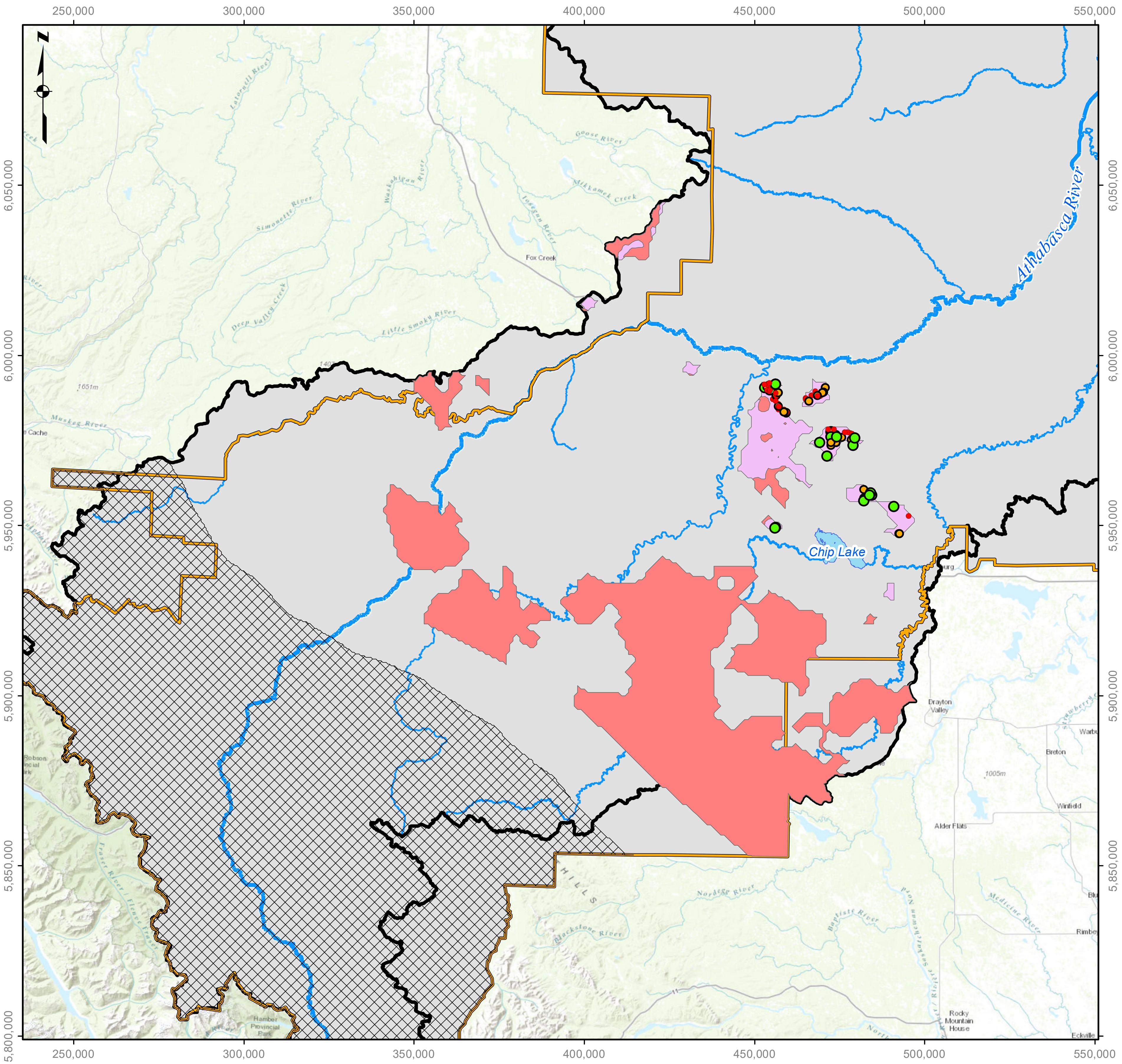




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 29. Extent of the Haynes Member Within the UAR



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Haynes Member Extent
- Haynes Member Deeper Than 150 Metres BGL
- Haynes Member Not Present

Water Well with Long-Term Yield (m^3/day)

- 100+
- 25 - 100
- 0 - 25

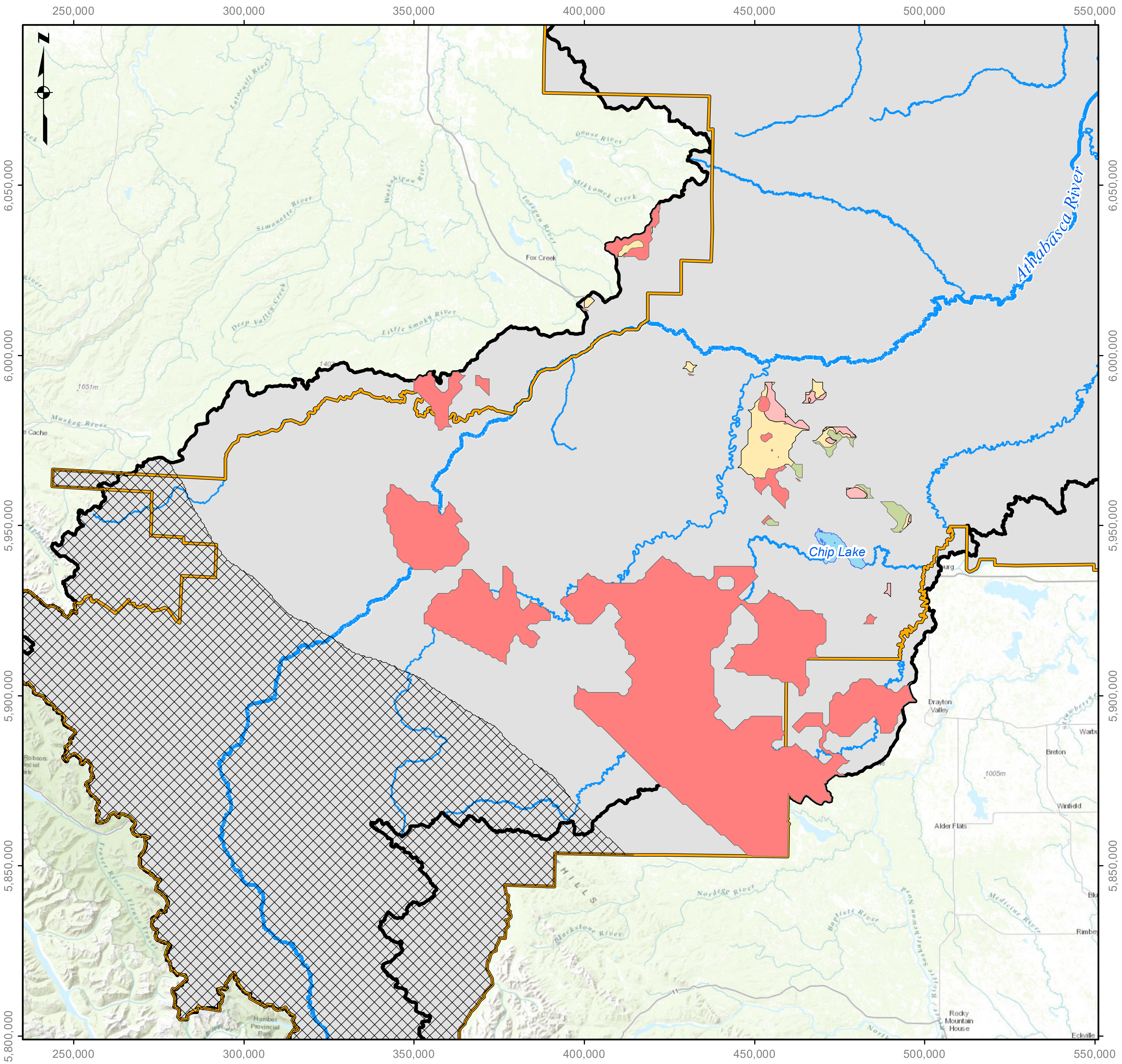
0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 30. Water Wells Completed in the Haynes Member with Long-Term Yield

HCL



Legend

- Upper Athabasca Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Haynes Member Deeper Than 150 Metres BGL
- Haynes Member Not Present

Long-Term Water Well Yield (m³/day)

- 0 – 25
- 25 – 100
- 100+

0 25 50 75 100

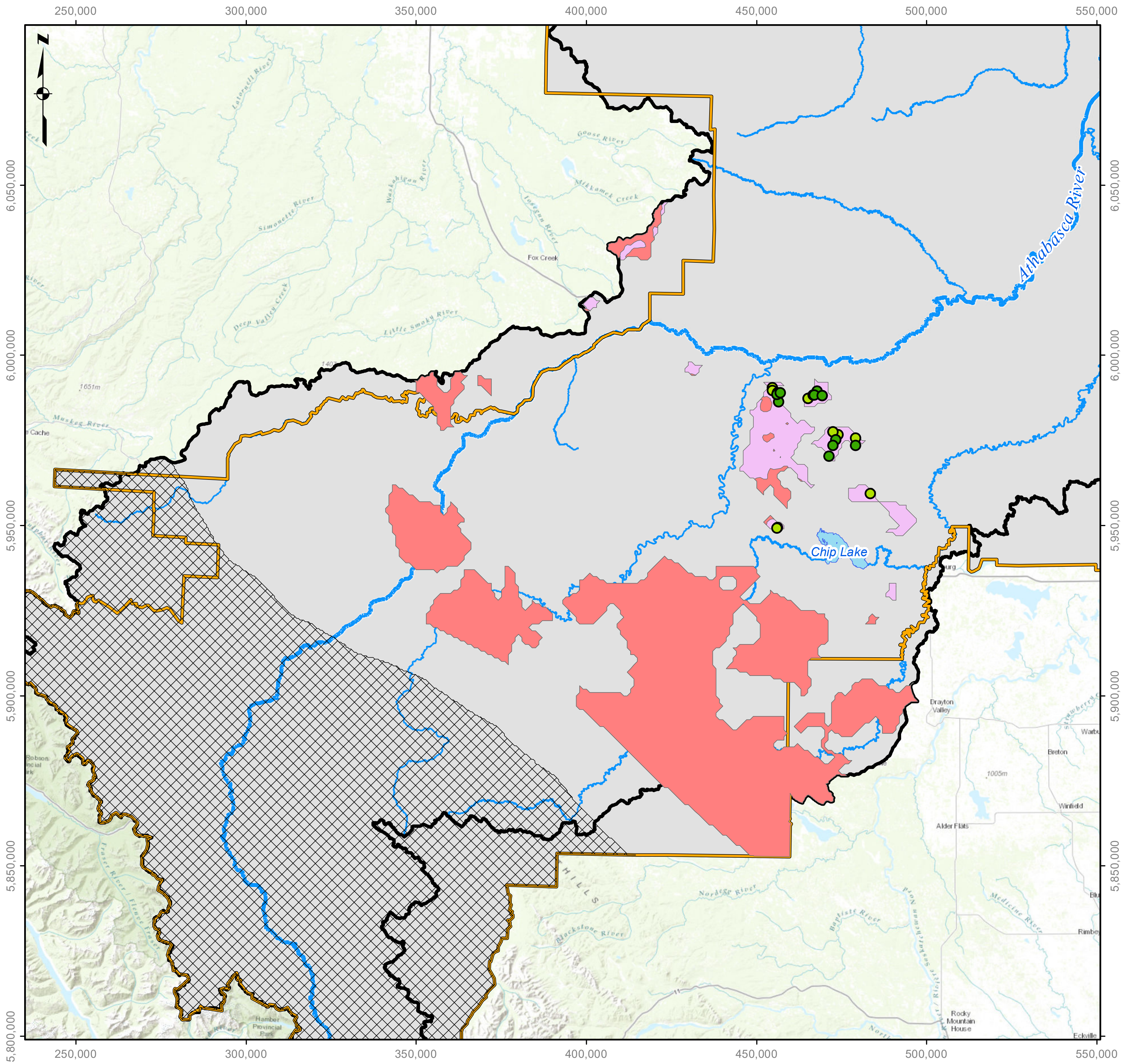
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Haynes Member.

Lyster and Andriashek (2012)

Map 31. Long-Term Water Well Yields Within the Haynes Member



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Haynes Member Extent
- Haynes Member Deeper Than 150 Metres BGL
- Haynes Member Not Present

Water Well with TDS Concentration (mg/L)

- 0 – 500
- 500 – 1,000
- 1,000 – 1,500
- 1,500+

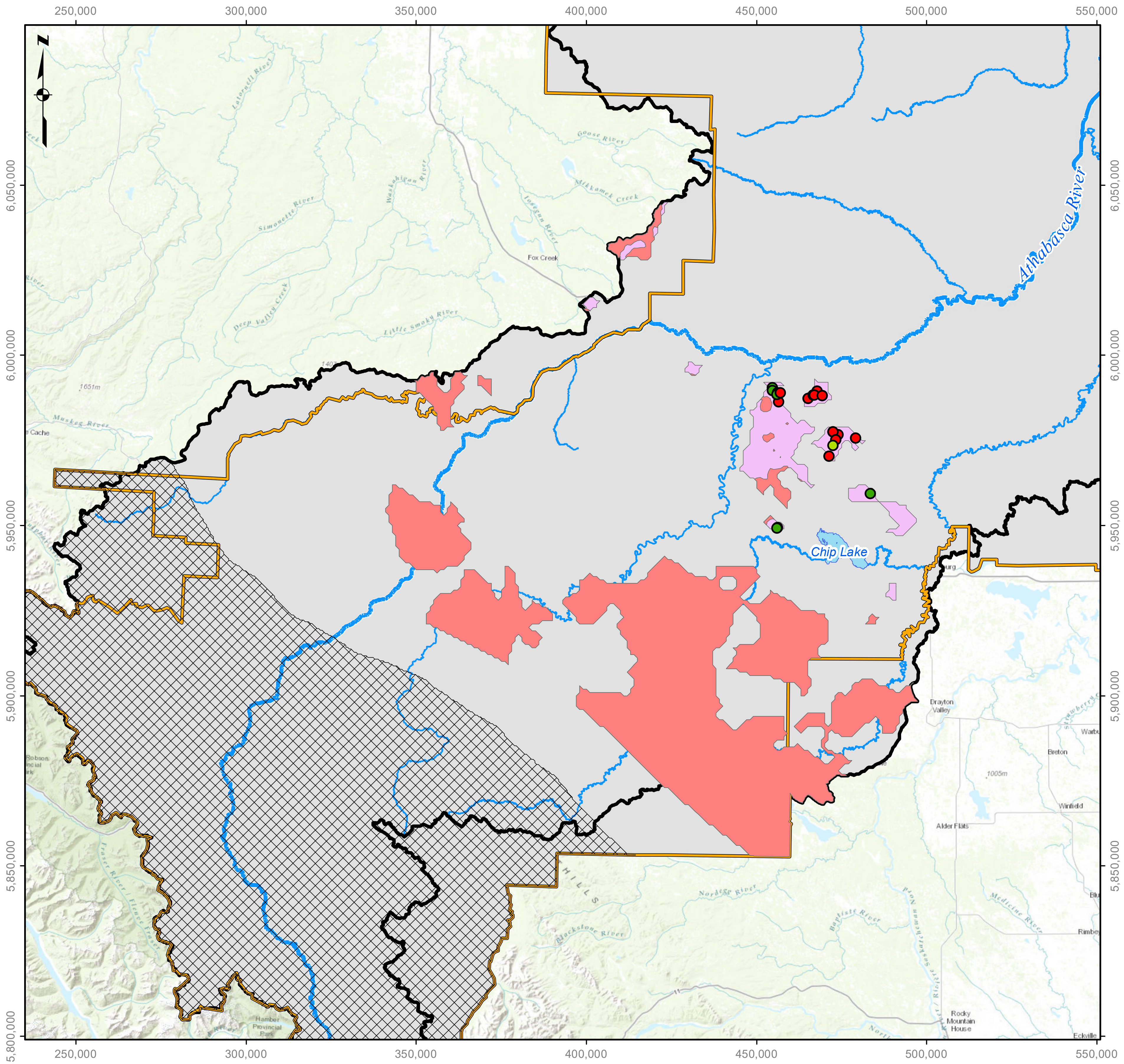
0 25 50 75 100

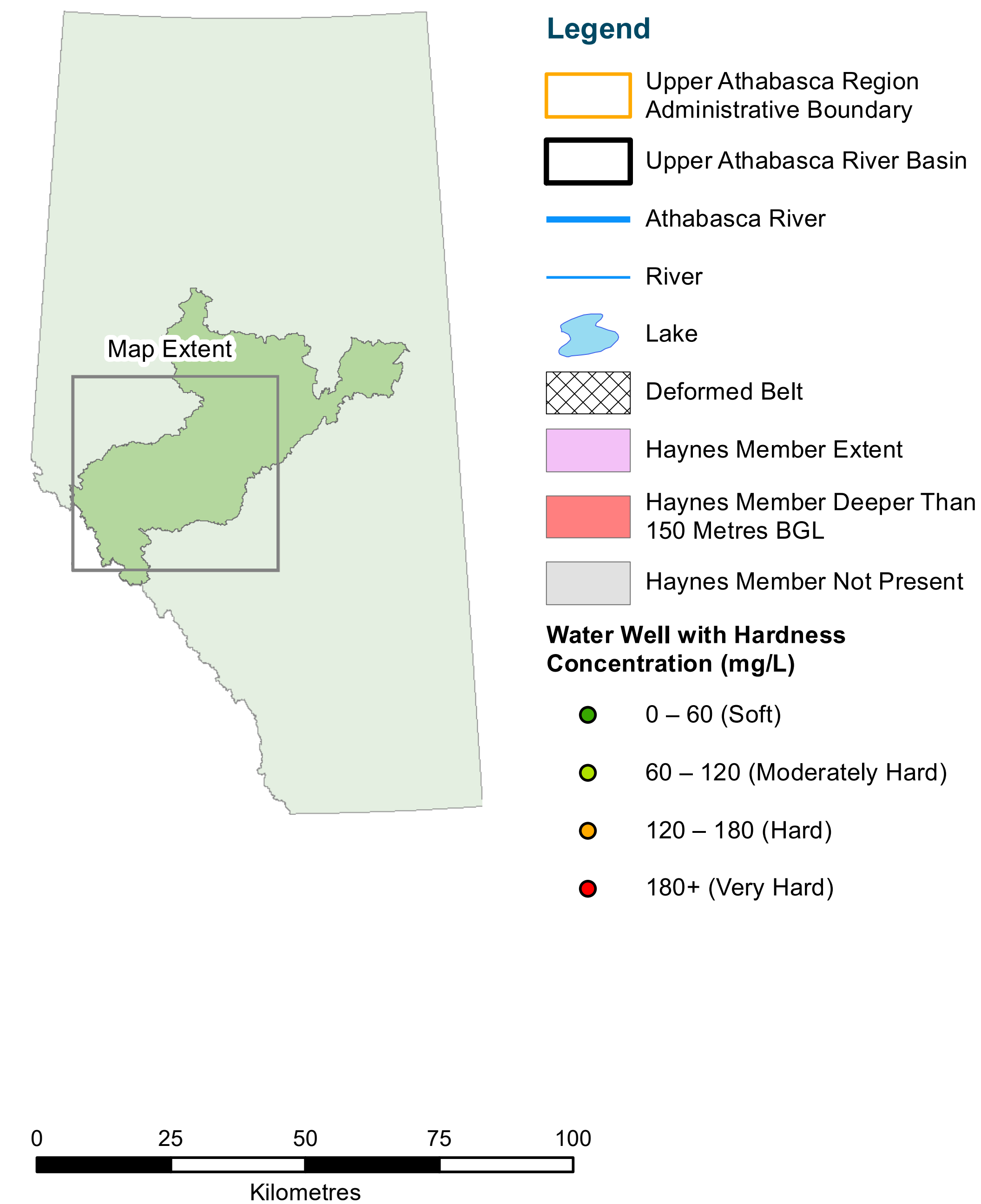
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 32. Water Wells Completed in the Haynes Member with Total Dissolved Solids Concentrations

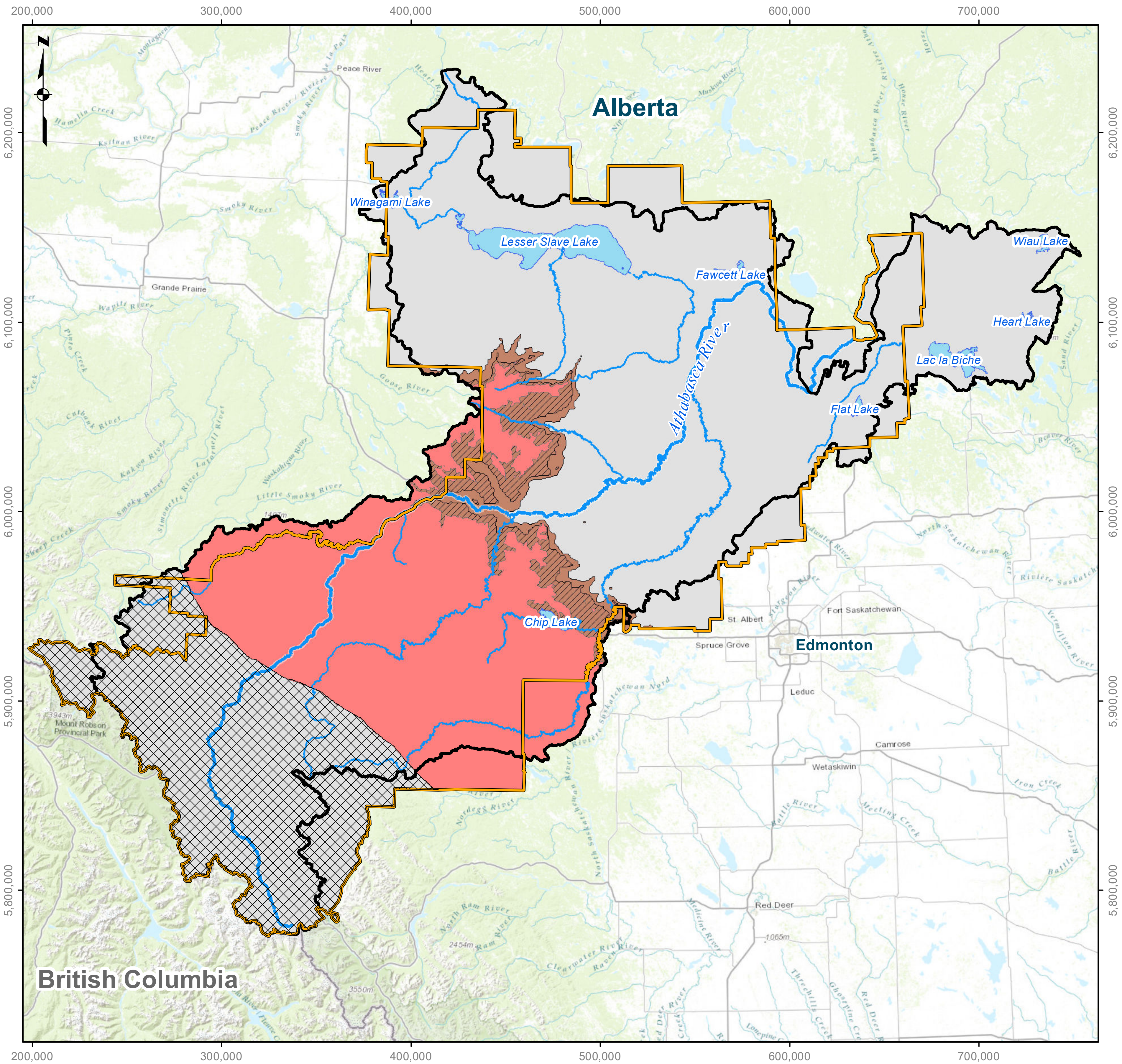


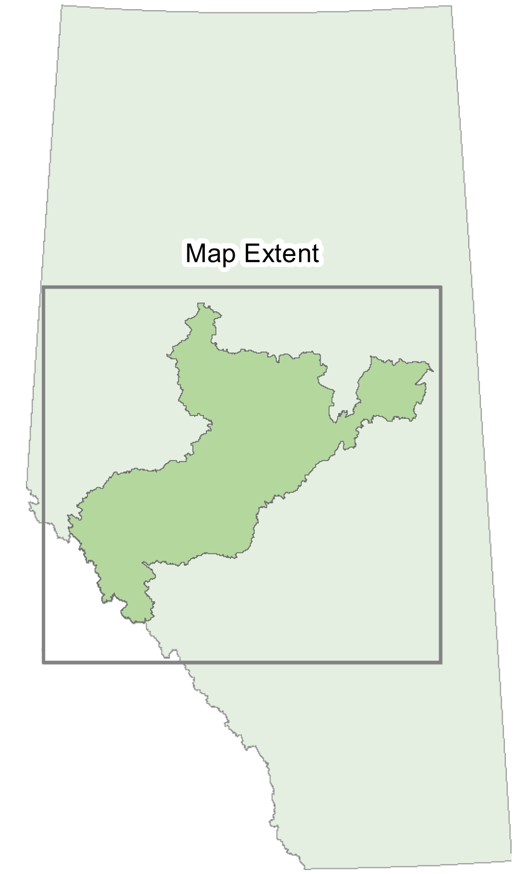


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Lyster and Andriashek (2012)

Map 33. Water Wells Completed in the Haynes Member with Hardness Concentrations





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Scollard Formation Subcrop
- Scollard Formation Less Than 150 Metres BGL; Not Top of Bedrock
- Scollard Formation Deeper Than 150 Metres BGL
- Scollard Formation Not Present

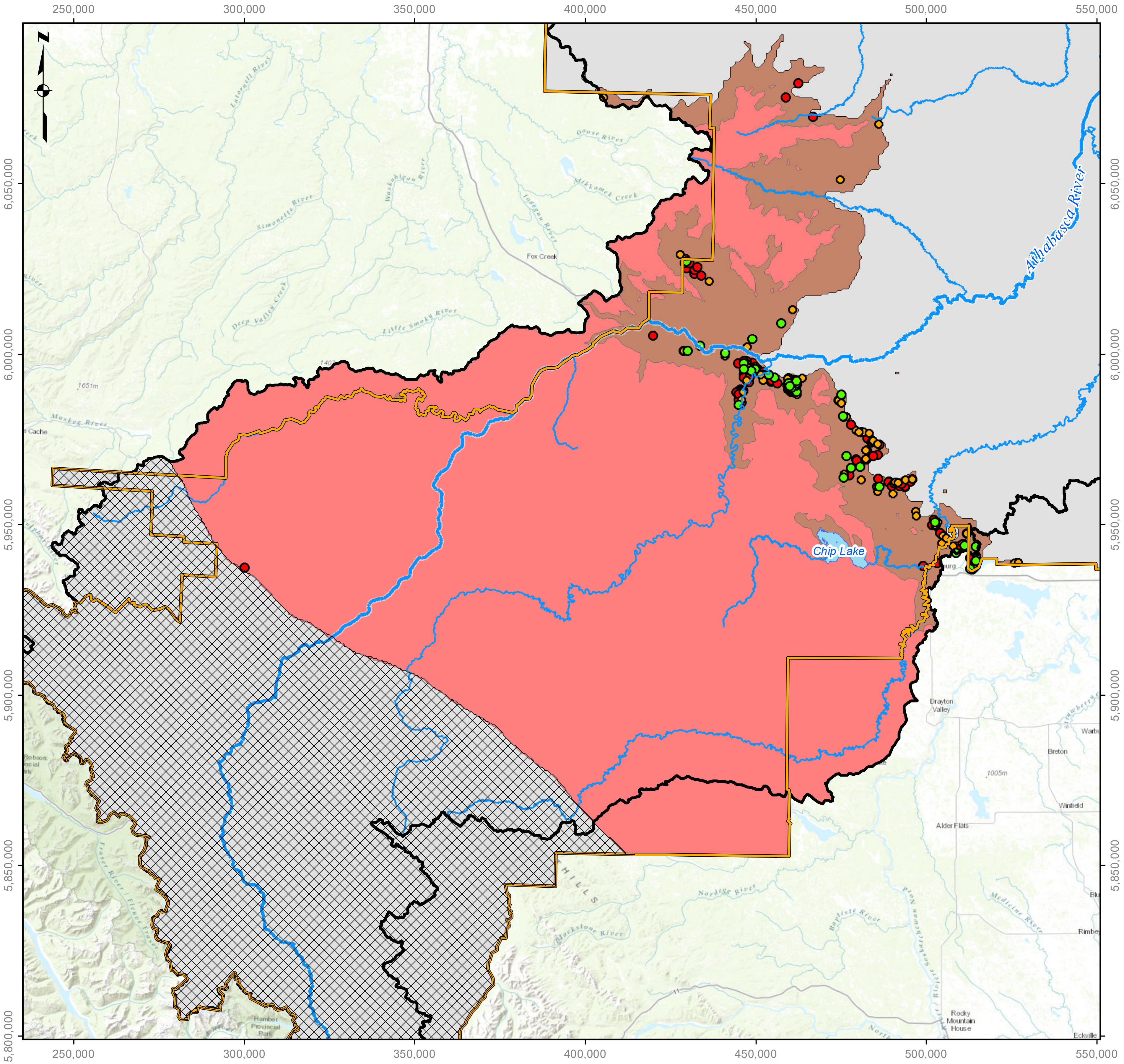
0 60 120 180

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 34. Extent of the Scollard Formation Within the UAR



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Scollard Formation Subcrop
- Scollard Formation Deeper Than 150 Metres BGL
- Scollard Formation Not Present

Water Well with Long-Term Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+

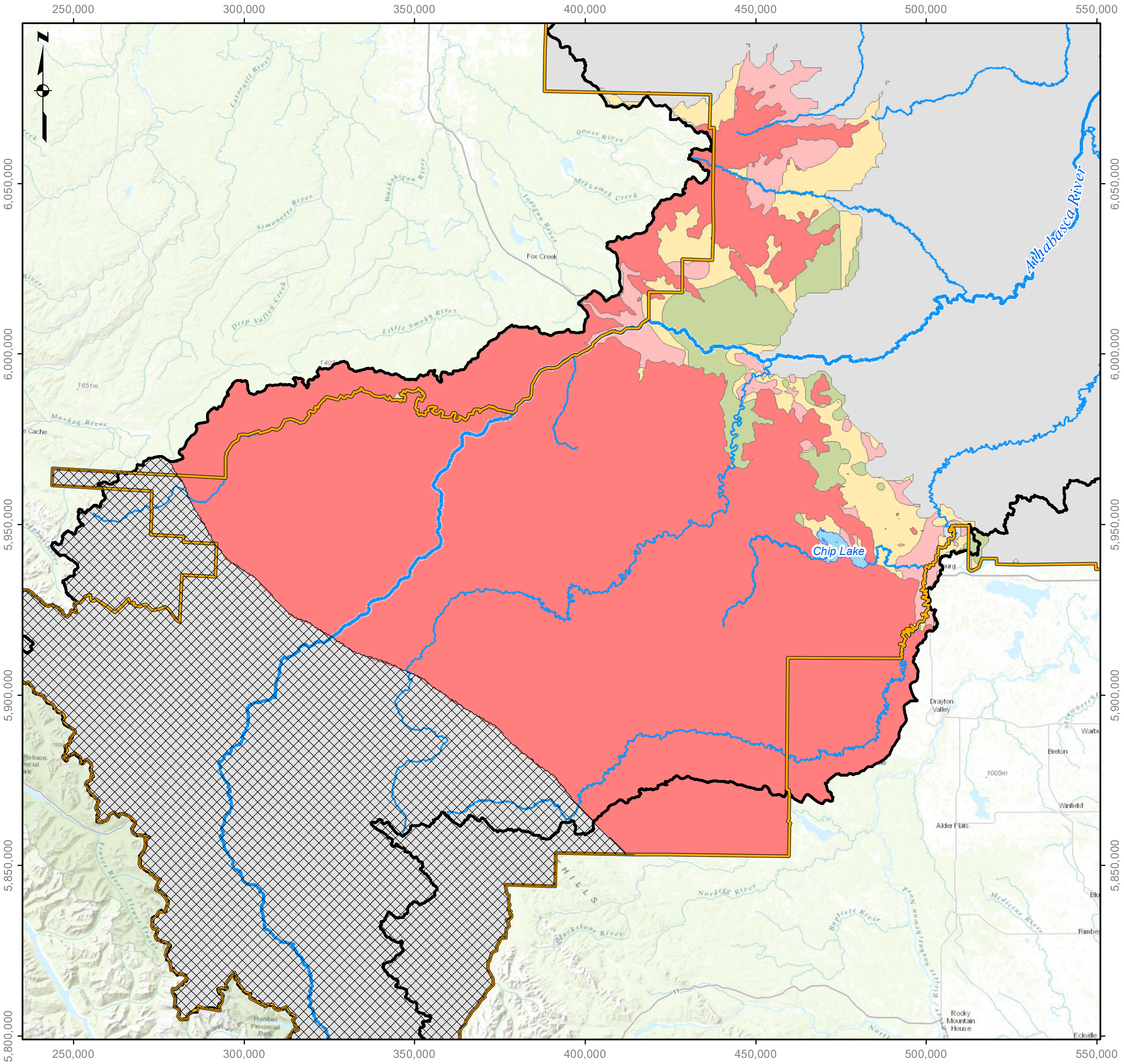
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 35. Water Wells Completed in the Scollard Formation with Long-Term Yield



Legend

- Upper Athabasca Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Scollard Formation Deeper Than 150 Metres BGL
- Scollard Formation Not Present

Long-Term Water Well Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+

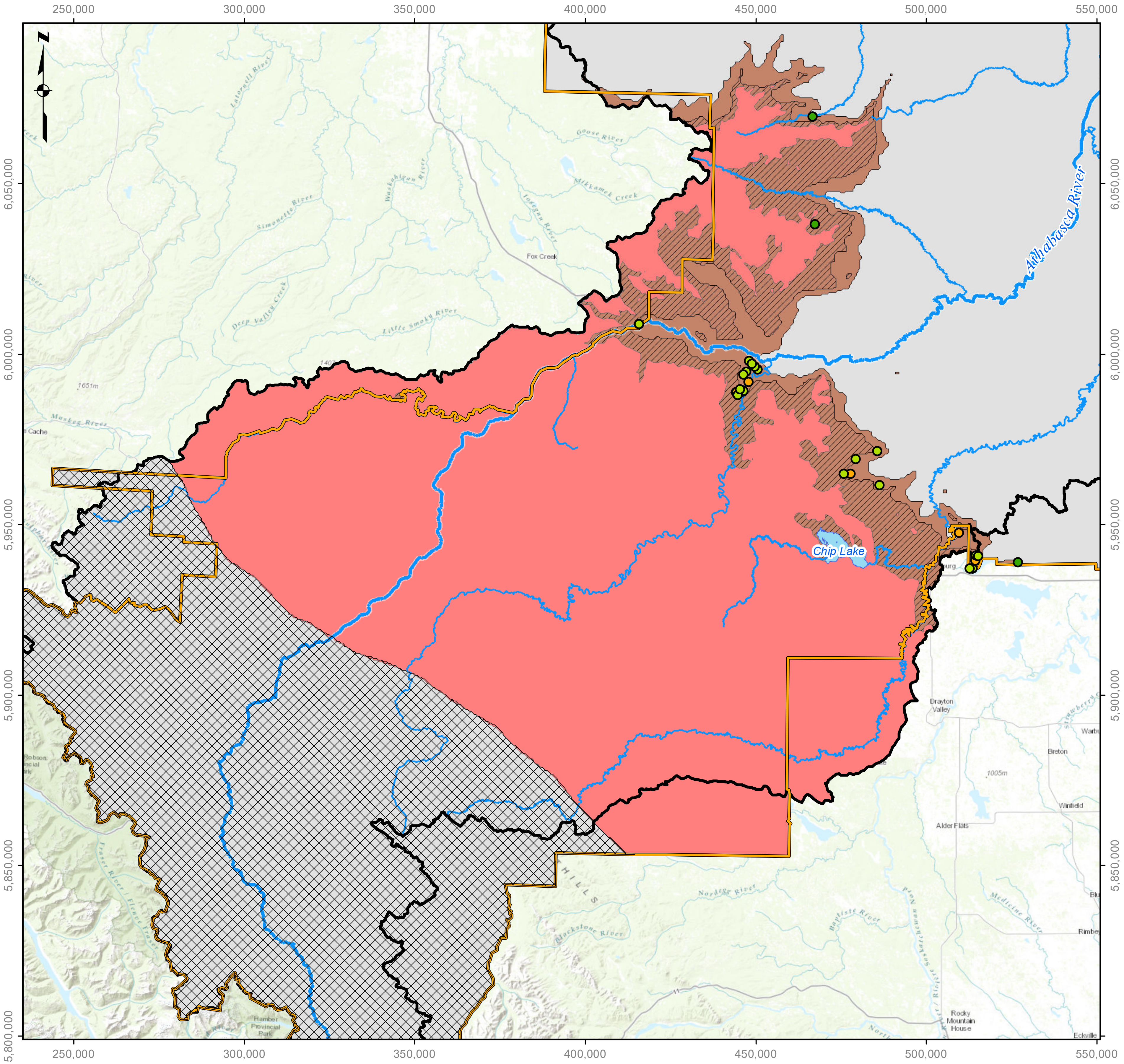
0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Scollard Formation.

Branscombe, et al. (2018)

Map 36. Long-Term Water Well Yields Within the Scollard Formation



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Scollard Formation Subcrop
- Scollard Formation Less Than 150 Metres BGL; Not Top of Bedrock
- Scollard Formation Deeper Than 150 Metres BGL
- Scollard Formation Not Present

Water Well with TDS Concentration (mg/L)

- 0 – 500
- 500 – 1,000
- 1,000 – 1,500
- 1,500+

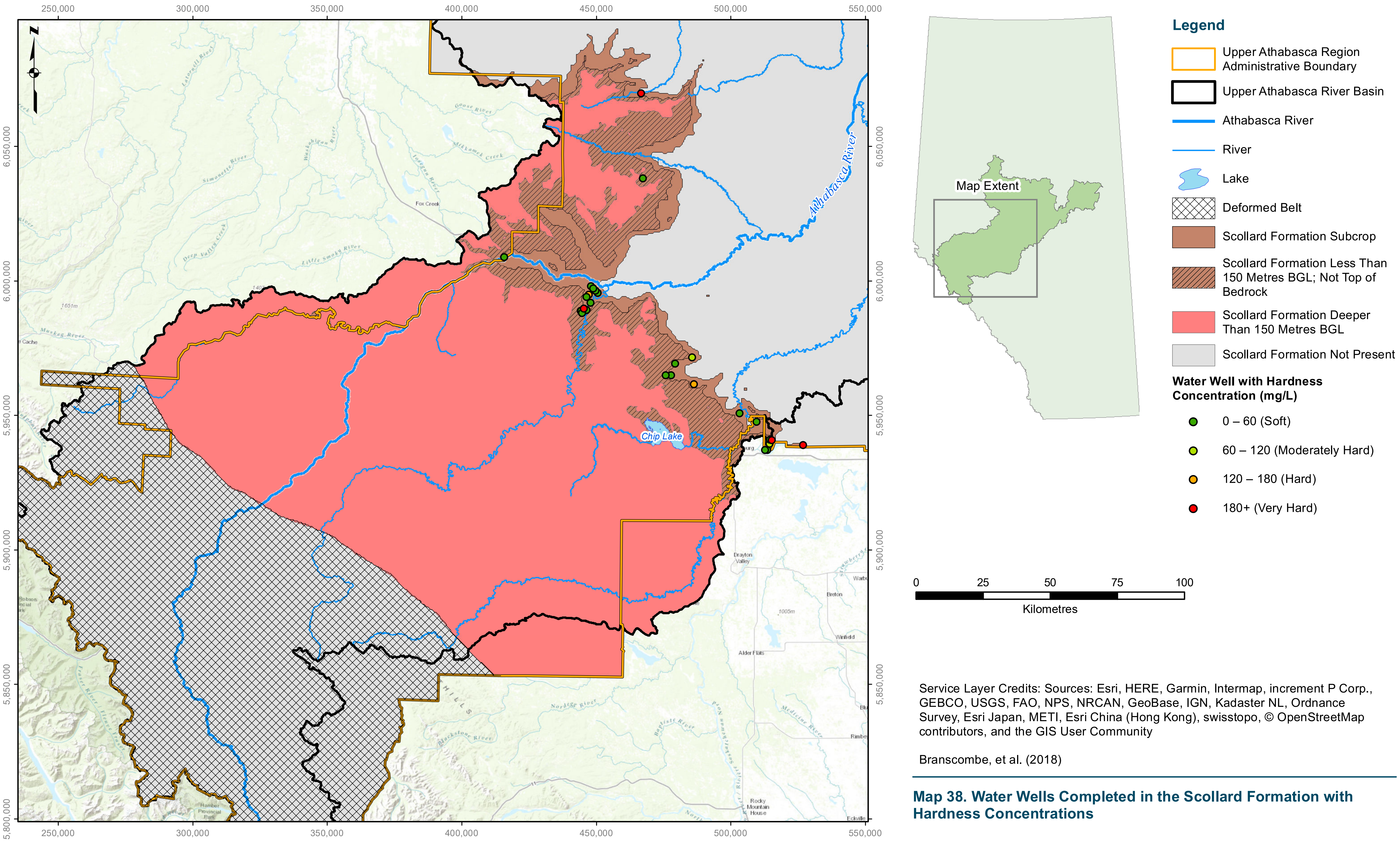
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

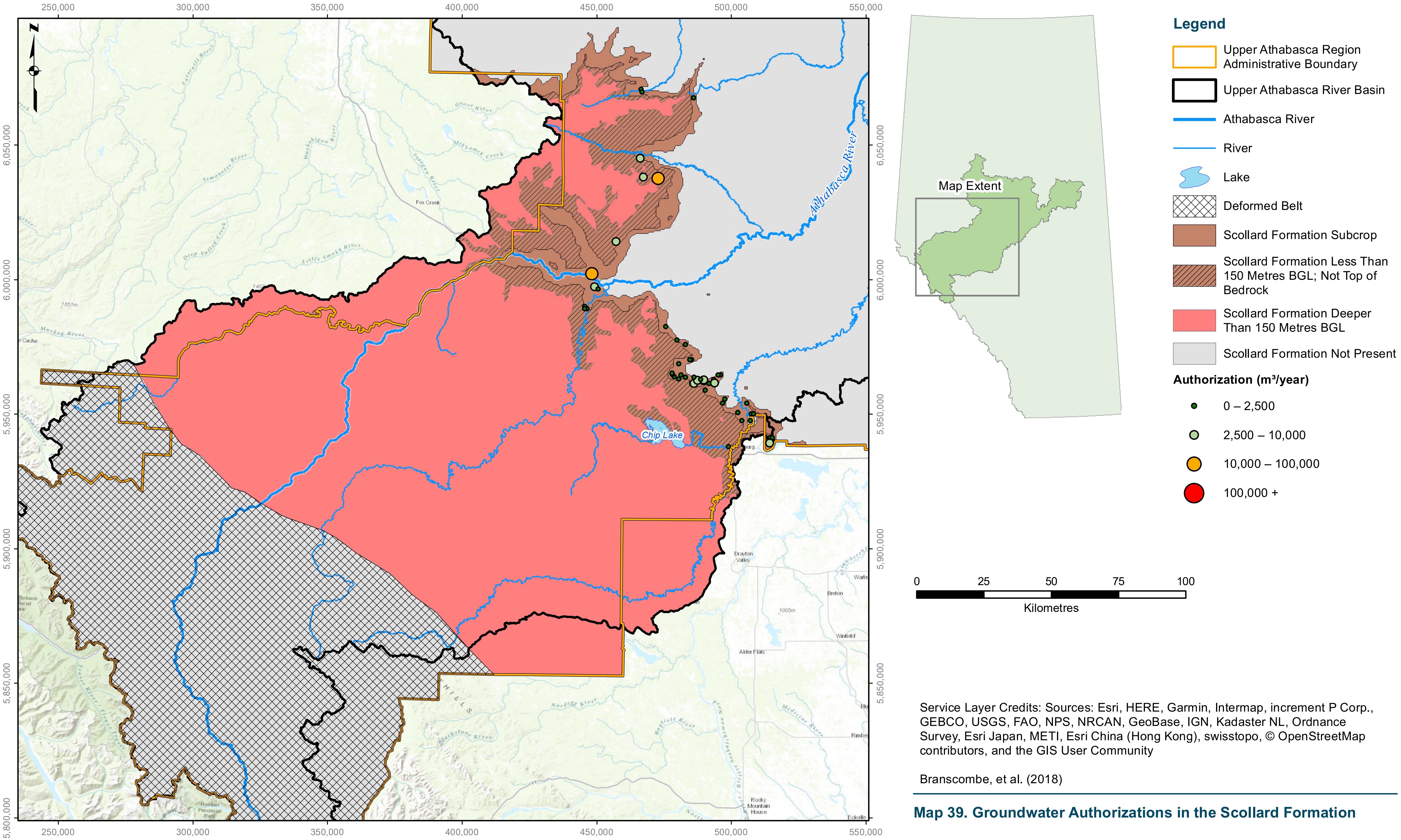
Map 37. Water Wells Completed in the Scollard Formation with Total Dissolved Solids Concentrations



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

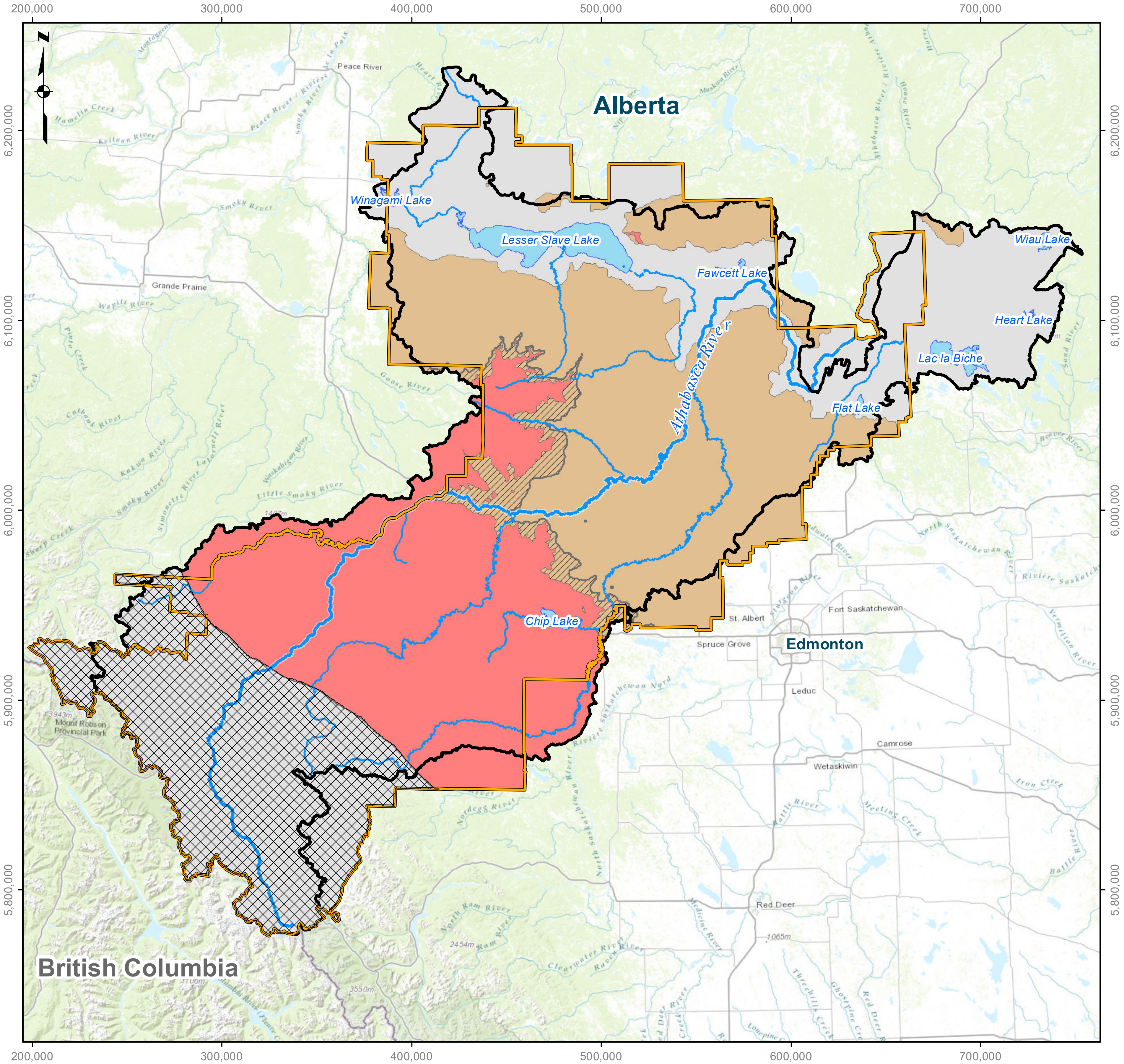
Map 38. Water Wells Completed in the Scollard Formation with Hardness Concentrations

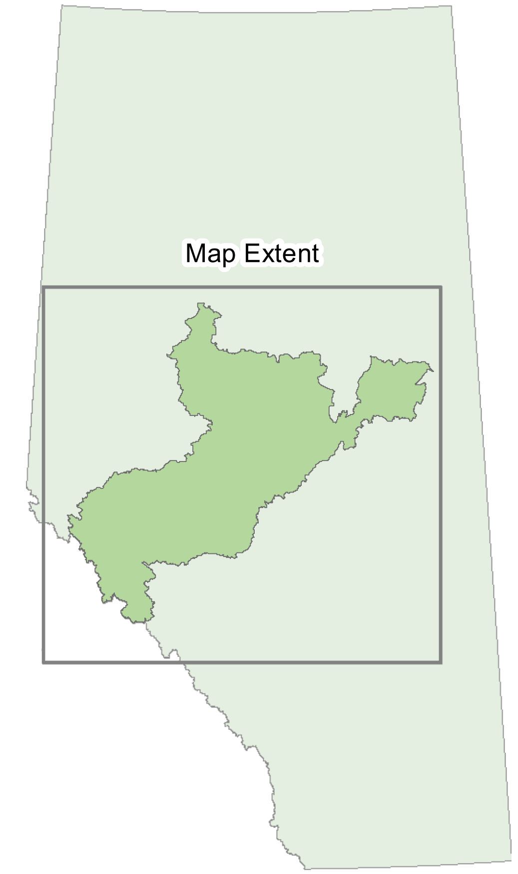


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 39. Groundwater Authorizations in the Scollard Formation





Legend

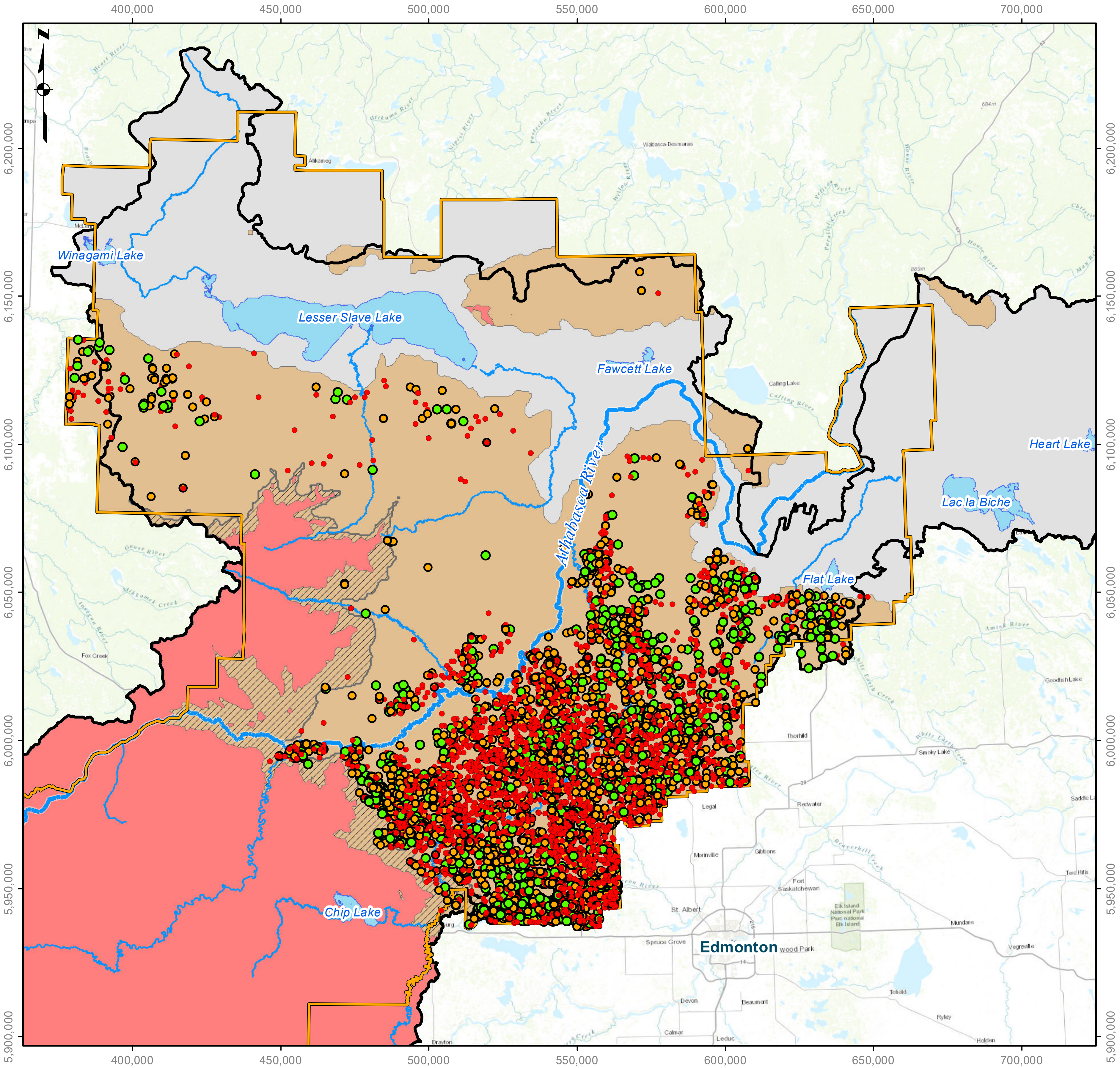
- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Deformed Belt
- Wapiti Interval Subcrop
- Wapiti Interval Less Than 150 Metres BGL; Not Top of Bedrock
- Wapiti Interval Deeper Than 150 Metres BGL
- Wapiti Interval Not Present

0 60 120 180
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 40. Extent of the Wapiti Interval Within the UAR

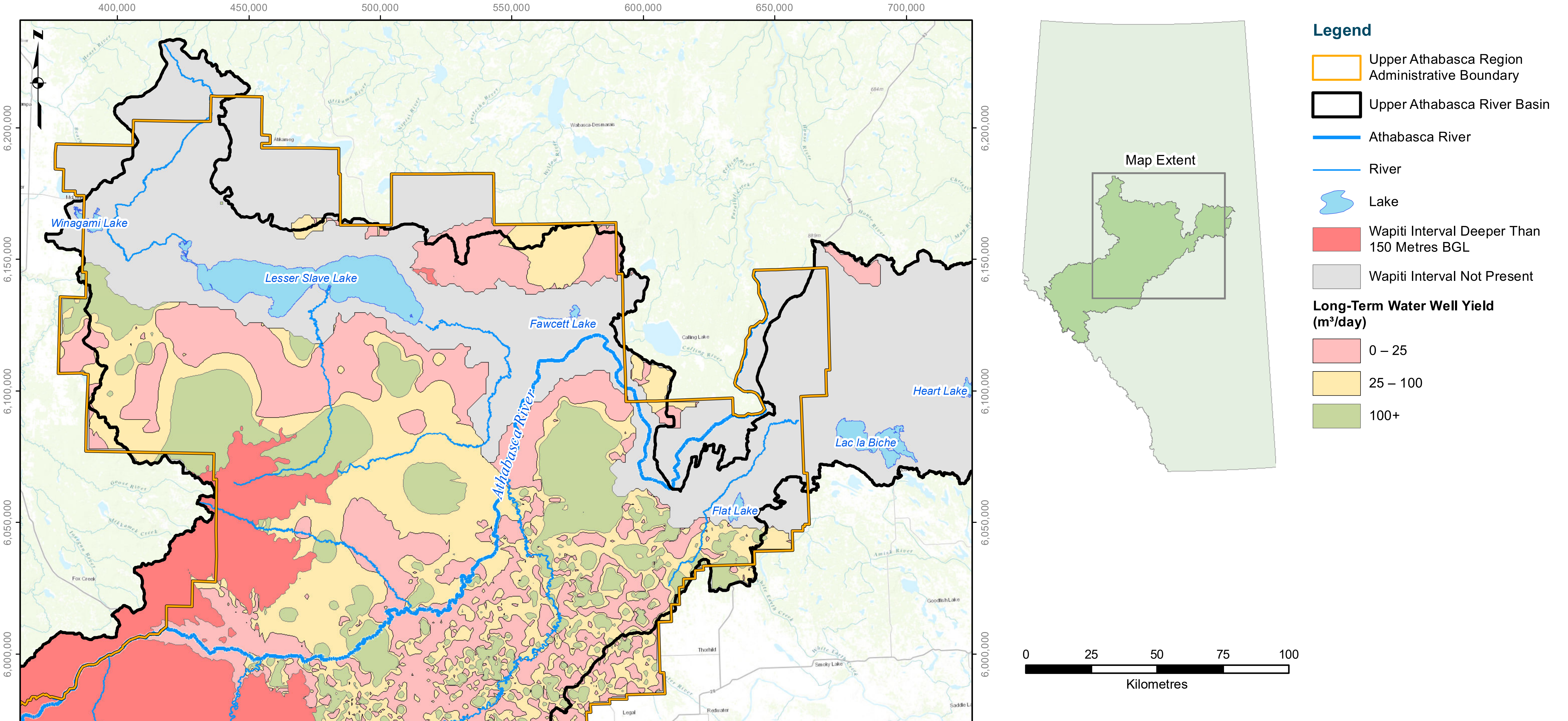


Legend

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 41. Water Wells Completed in the Wapiti Interval with Long-Term Yield

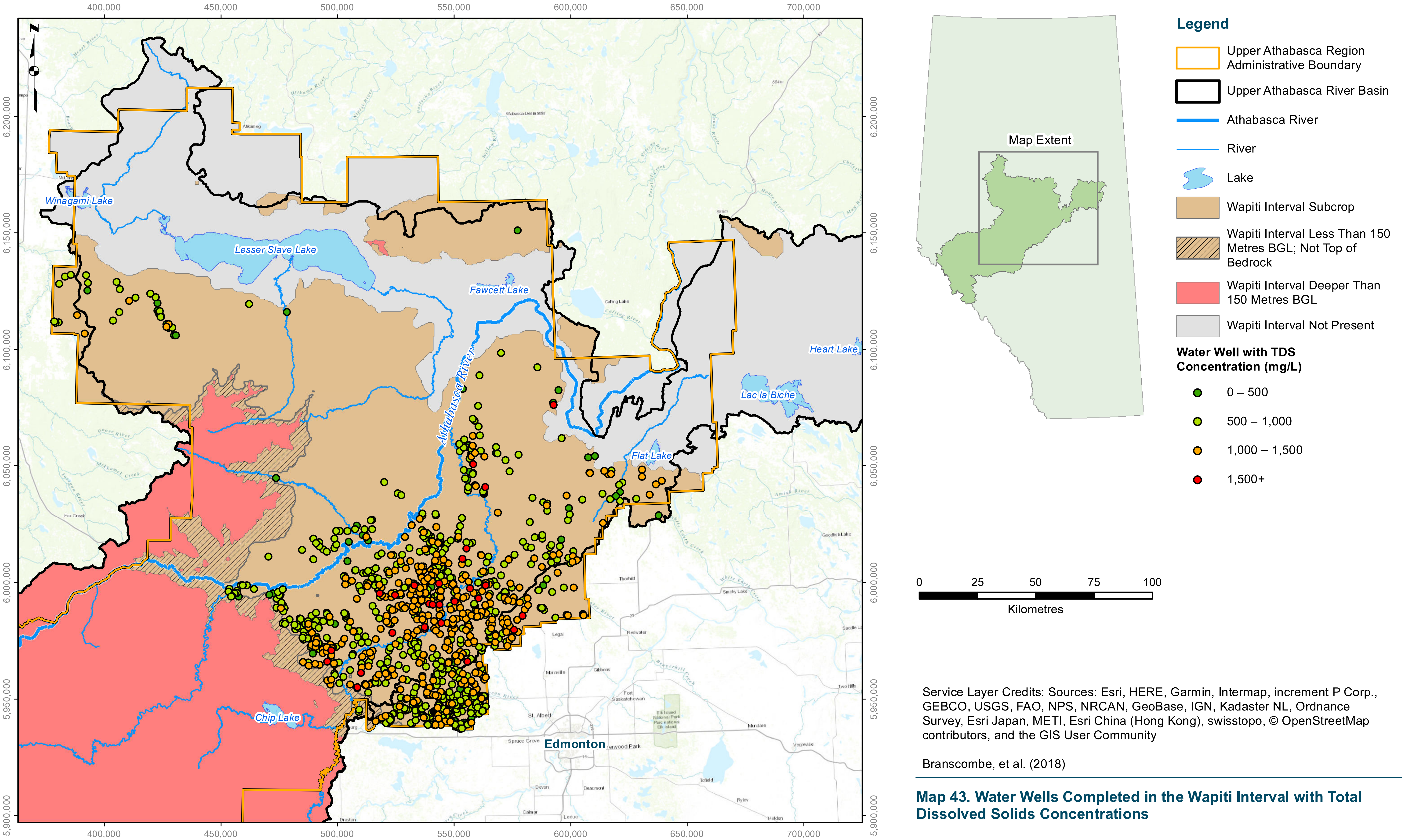


Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Wapiti Interval.

Branscombe, et al. (2018)

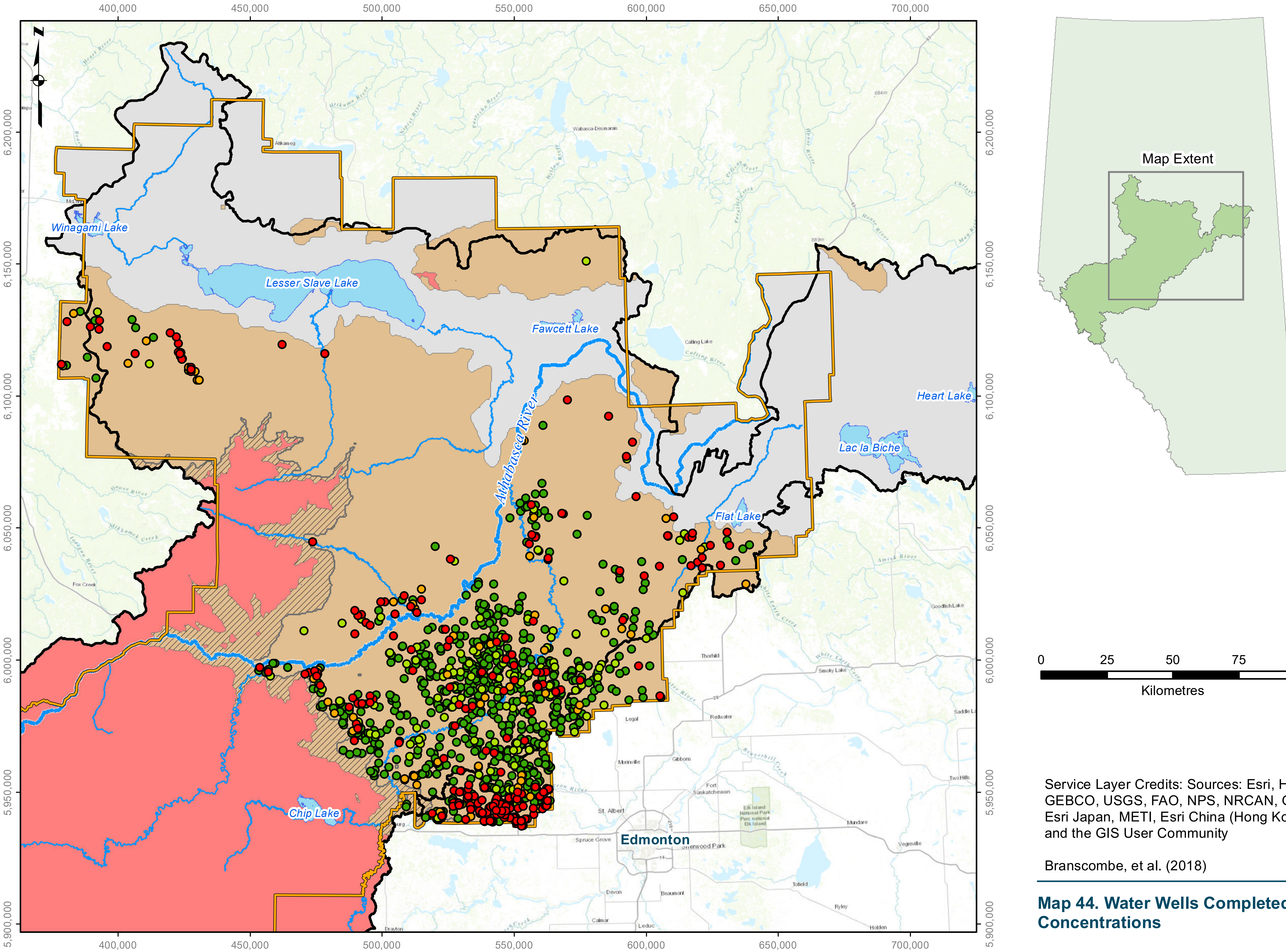
Map 42. Long-Term Water Well Yields Within the Wapiti Interval



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 43. Water Wells Completed in the Wapiti Interval with Total Dissolved Solids Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Wapiti Interval Subcrop
- Wapiti Interval Less Than 150 Metres BGL; Not Top of Bedrock
- Wapiti Interval Deeper Than 150 Metres BGL
- Wapiti Interval Not Present

Water Well with Hardness Concentration (mg/L)

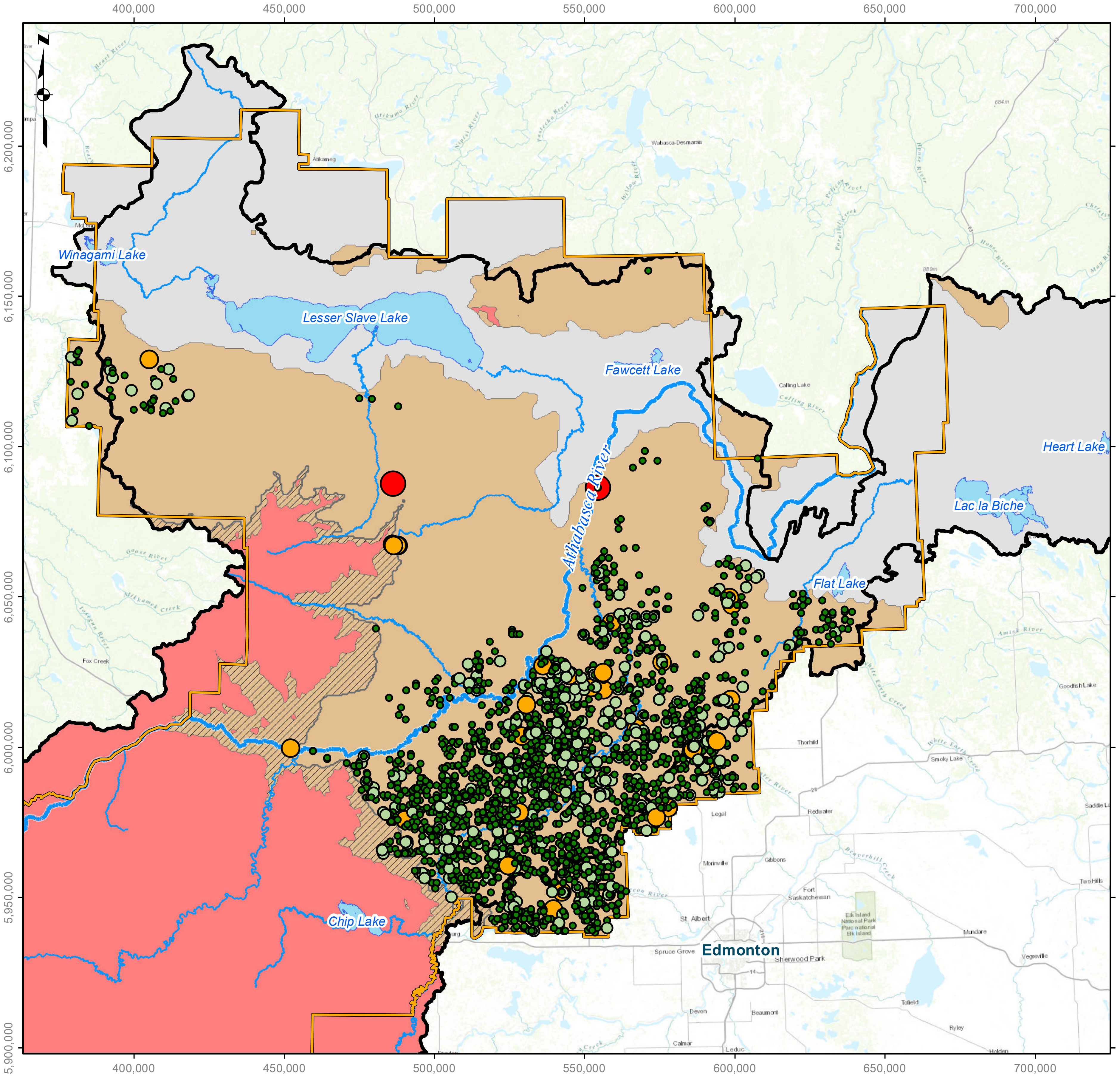
- 0 – 60 (Soft)
- 60 – 120 (Moderately Hard)
- 120 – 180 (Hard)
- 180+ (Very Hard)

0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 44. Water Wells Completed in the Wapiti Interval with Hardness Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Wapiti Interval Subcrop
- Wapiti Interval Less Than 150 Metres BGL; Not Top of Bedrock
- Wapiti Interval Deeper Than 150 Metres BGL
- Wapiti Interval Not Present

Authorization (m^3/year)

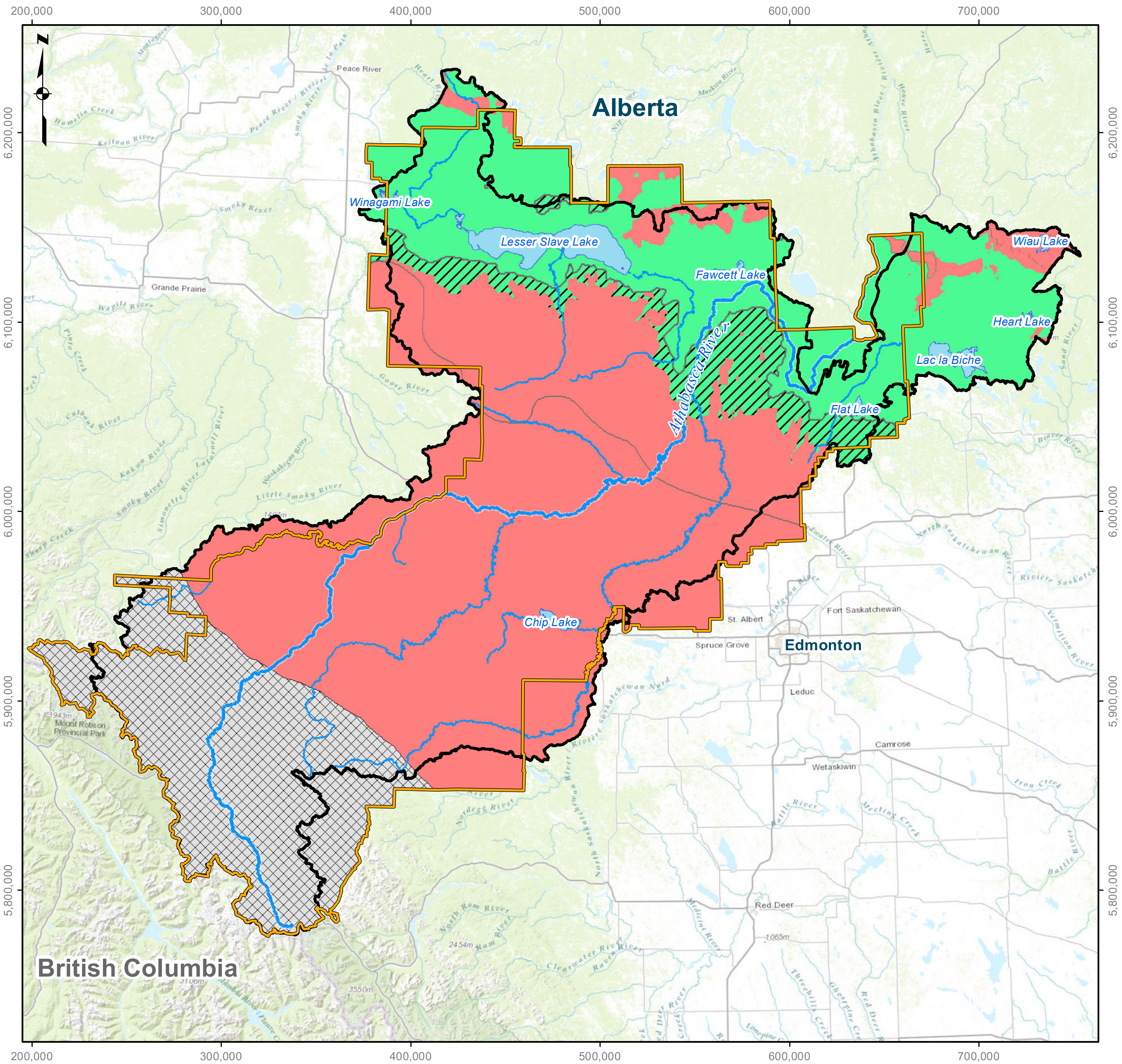
- 0 – 2,500
- 2,500 – 10,000
- 10,000 – 100,000
- 100,000 +

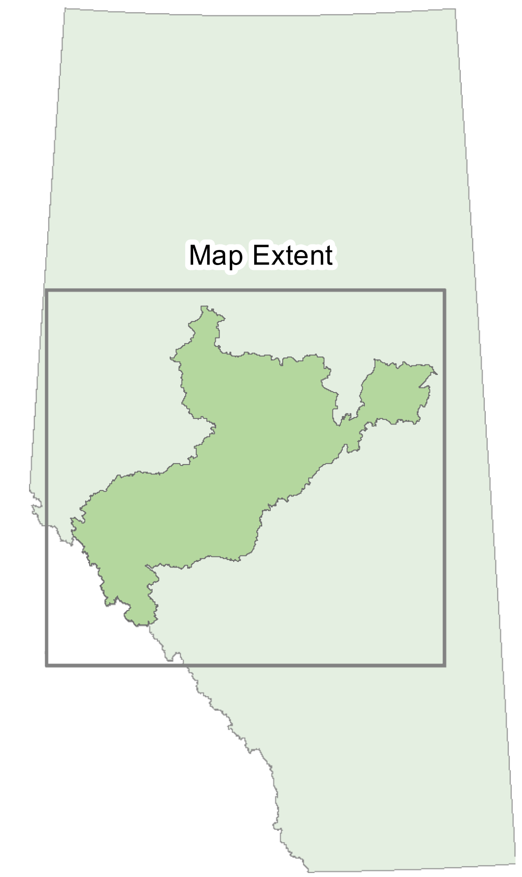
0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 45. Groundwater Authorizations in the Wapiti Interval

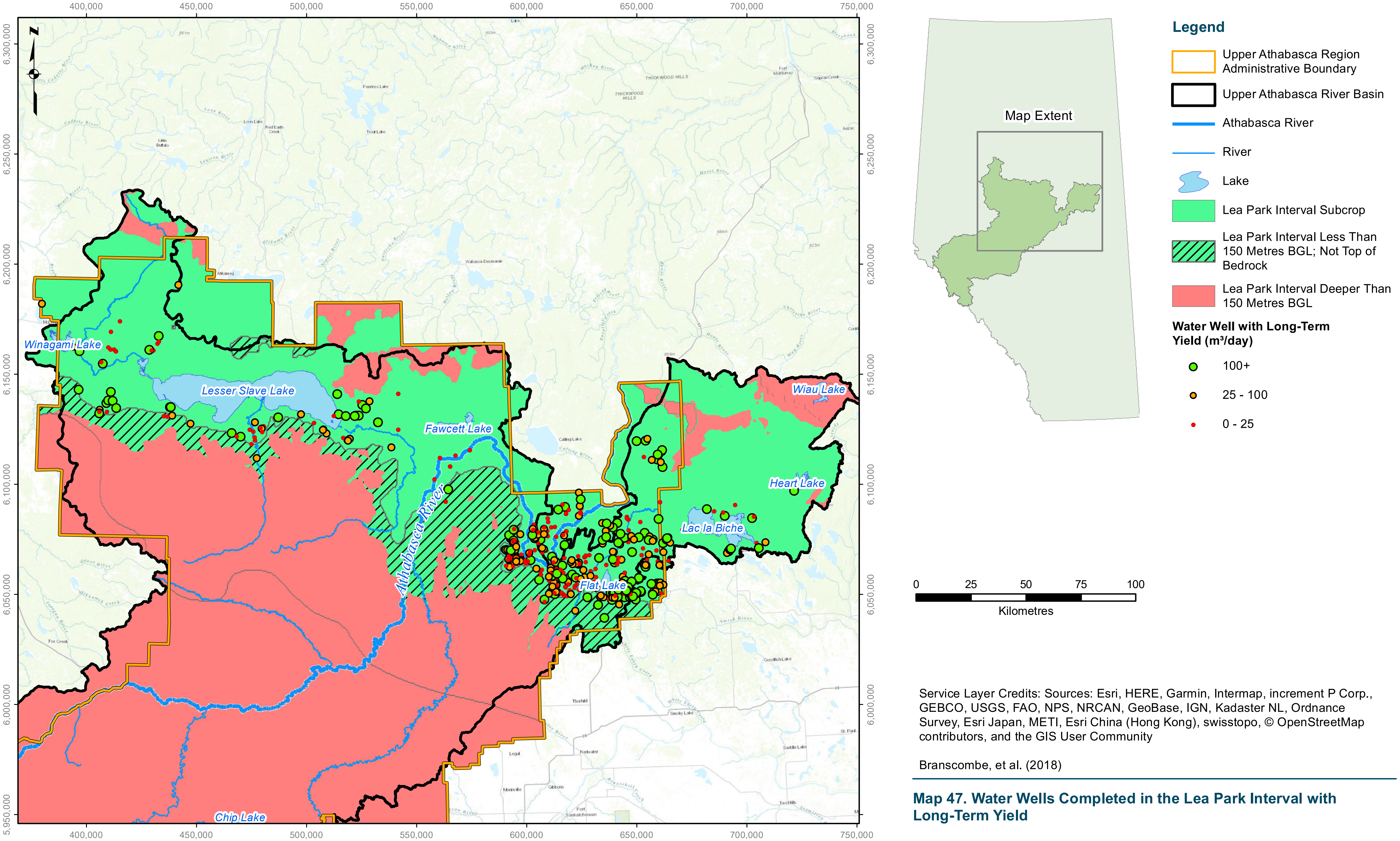




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe et al. (2018)

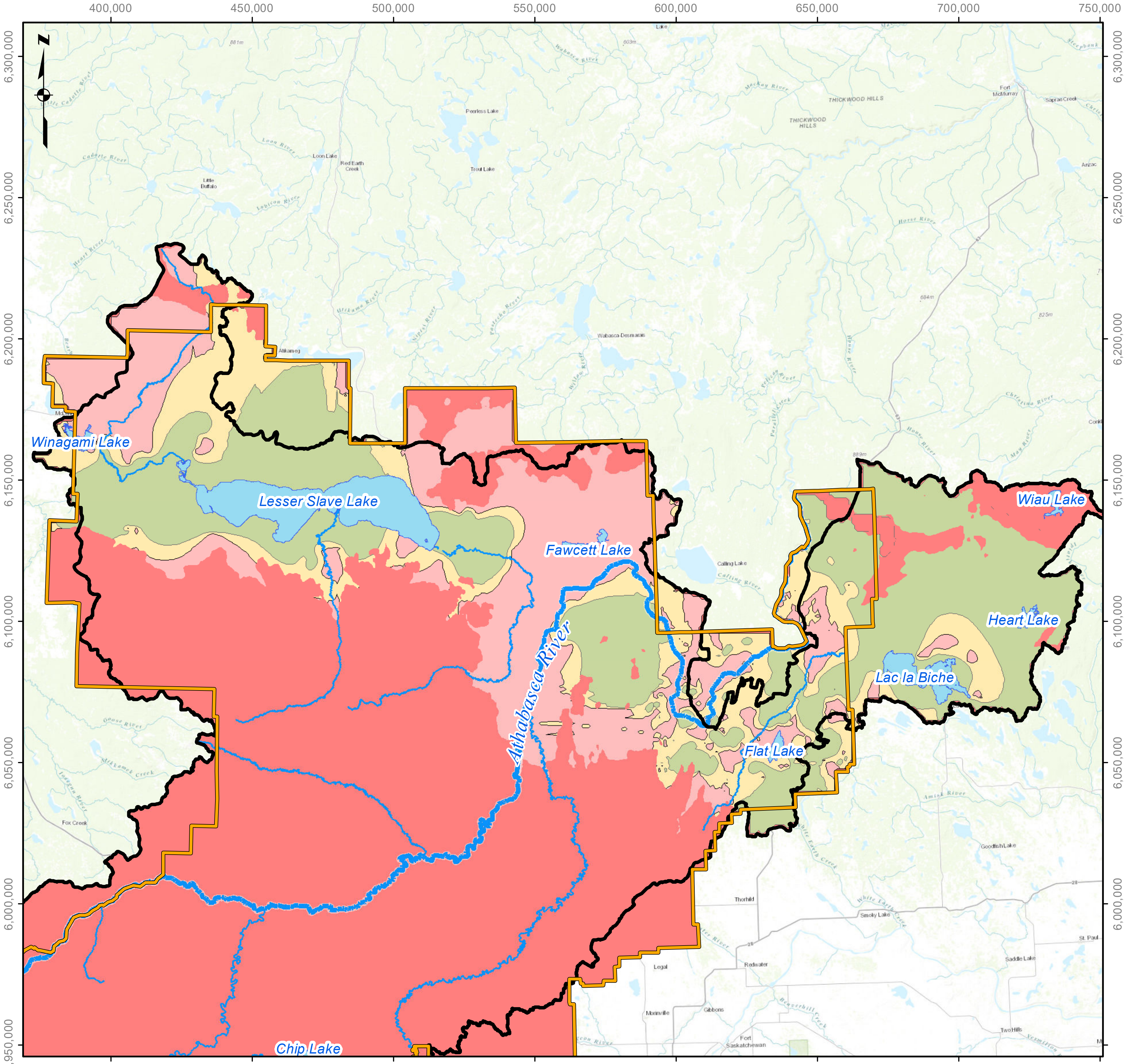
Map 46. Extent of the Lea Park Interval Within the UAR



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 47. Water Wells Completed in the Lea Park Interval with Long-Term Yield



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Lea Park Interval Deeper Than 150 Metres BGL

Long-Term Water Well Yield (m^3/day)

- 0 – 25
- 25 – 100
- 100+

0 25 50 75 100

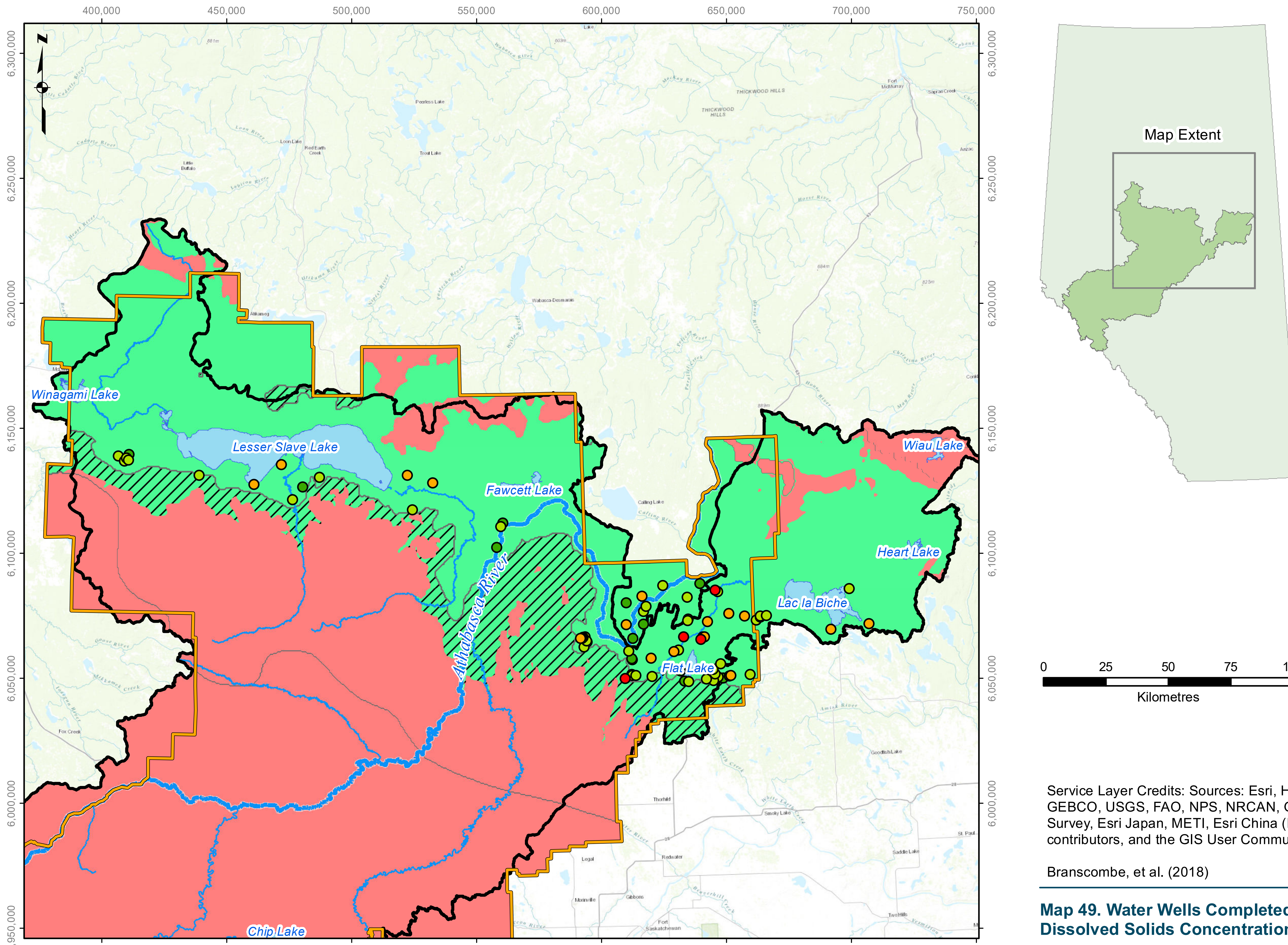
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Long-term yield data are contoured from water wells completed in the Lea Park Interval.

Branscombe, et al. (2018)

Map 48. Long-Term Water Well Yields Within the Lea Park Interval



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Lea Park Interval Subcrop
- Lea Park Interval Less Than 150 Metres BGL; Not Top of Bedrock
- Lea Park Interval Deeper Than 150 Metres BGL

Water Well with TDS Concentration (mg/L)

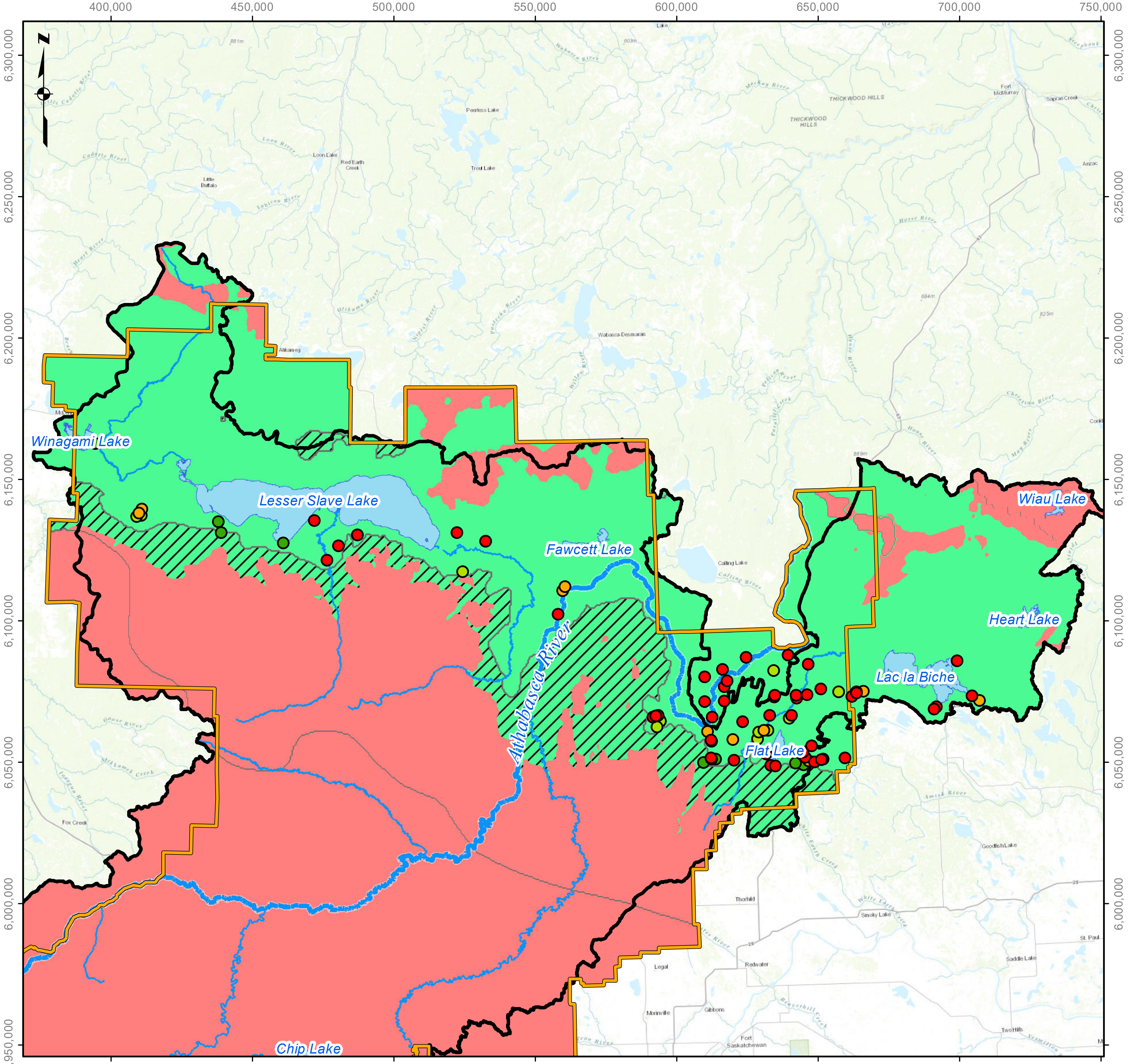
- 0 – 500
- 500 – 1,000
- 1,000 – 1,500
- 1,500+

0 25 50 75 100
Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

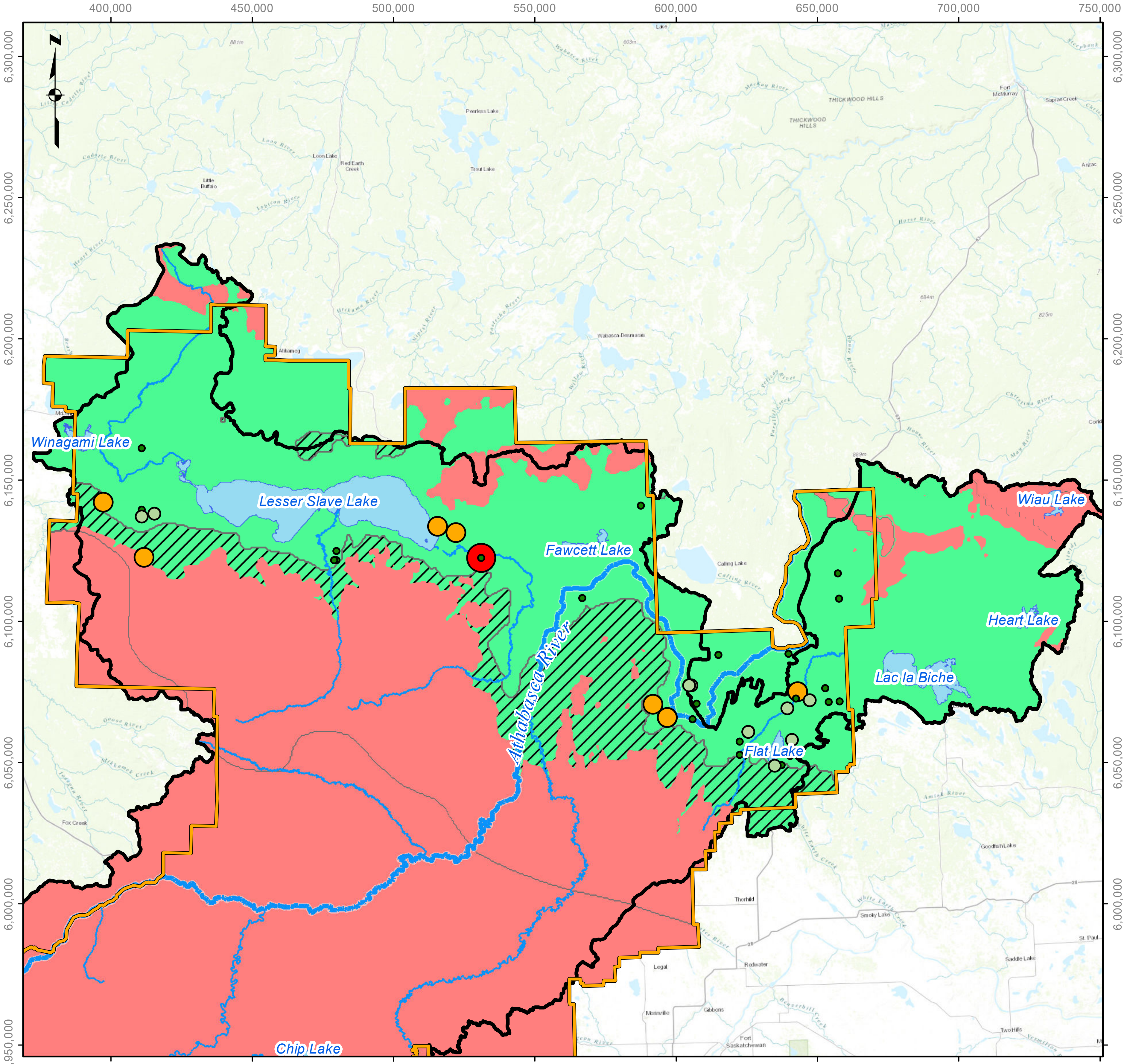
Map 49. Water Wells Completed in the Lea Park Interval with Total Dissolved Solids Concentrations



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Branscombe, et al. (2018)

Map 50. Water Wells Completed in the Lea Park Interval with Hardness Concentrations



Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake
- Lea Park Interval Subcrop
- Lea Park Interval Less Than 150 Metres BGL; Not Top of Bedrock
- Lea Park Interval Deeper Than 150 Metres BGL

Authorization (m^3/year)

- 0 – 2,500
- 2,500 – 10,000
- 10,000 – 100,000
- 100,000 +

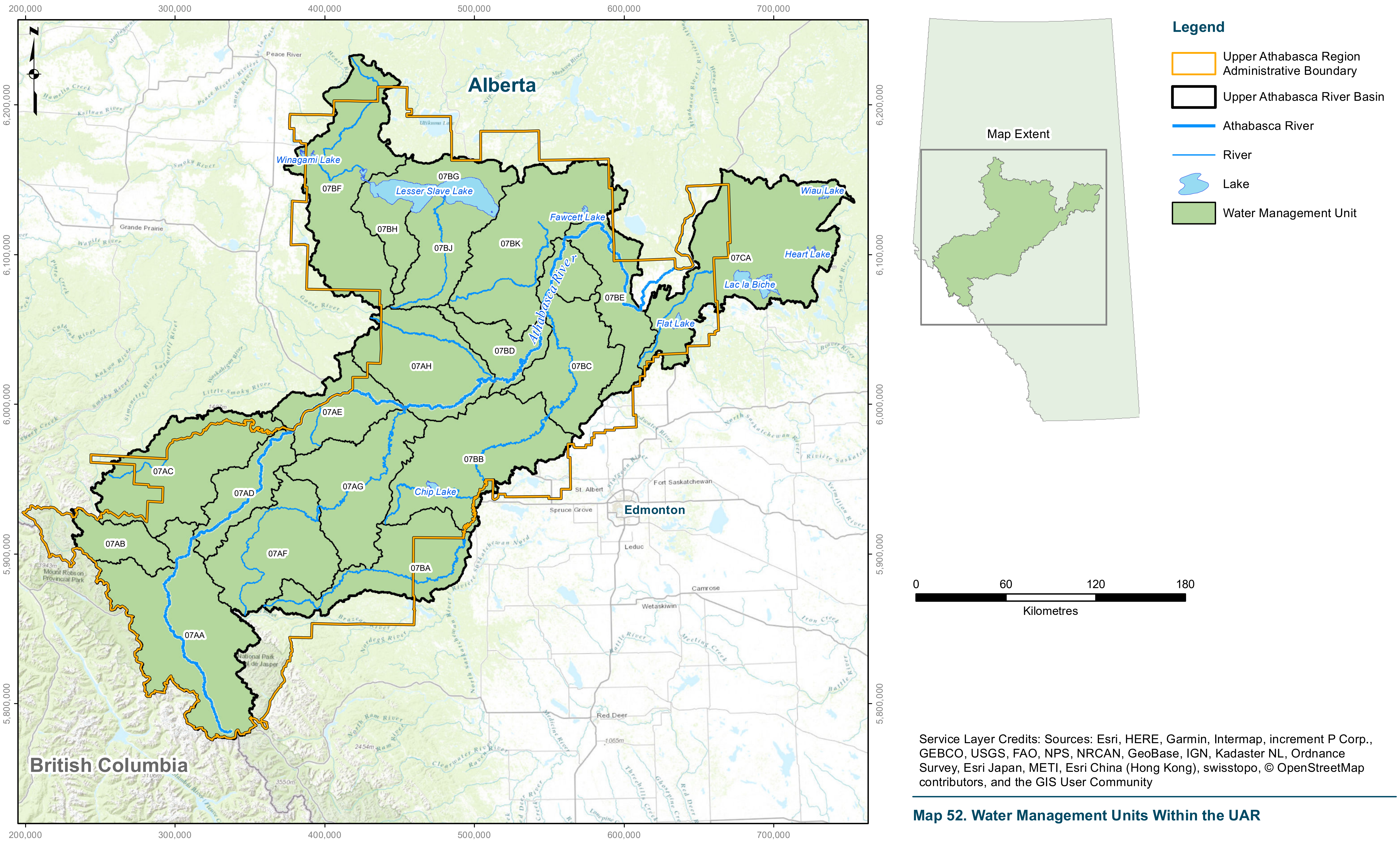
0 25 50 75 100

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

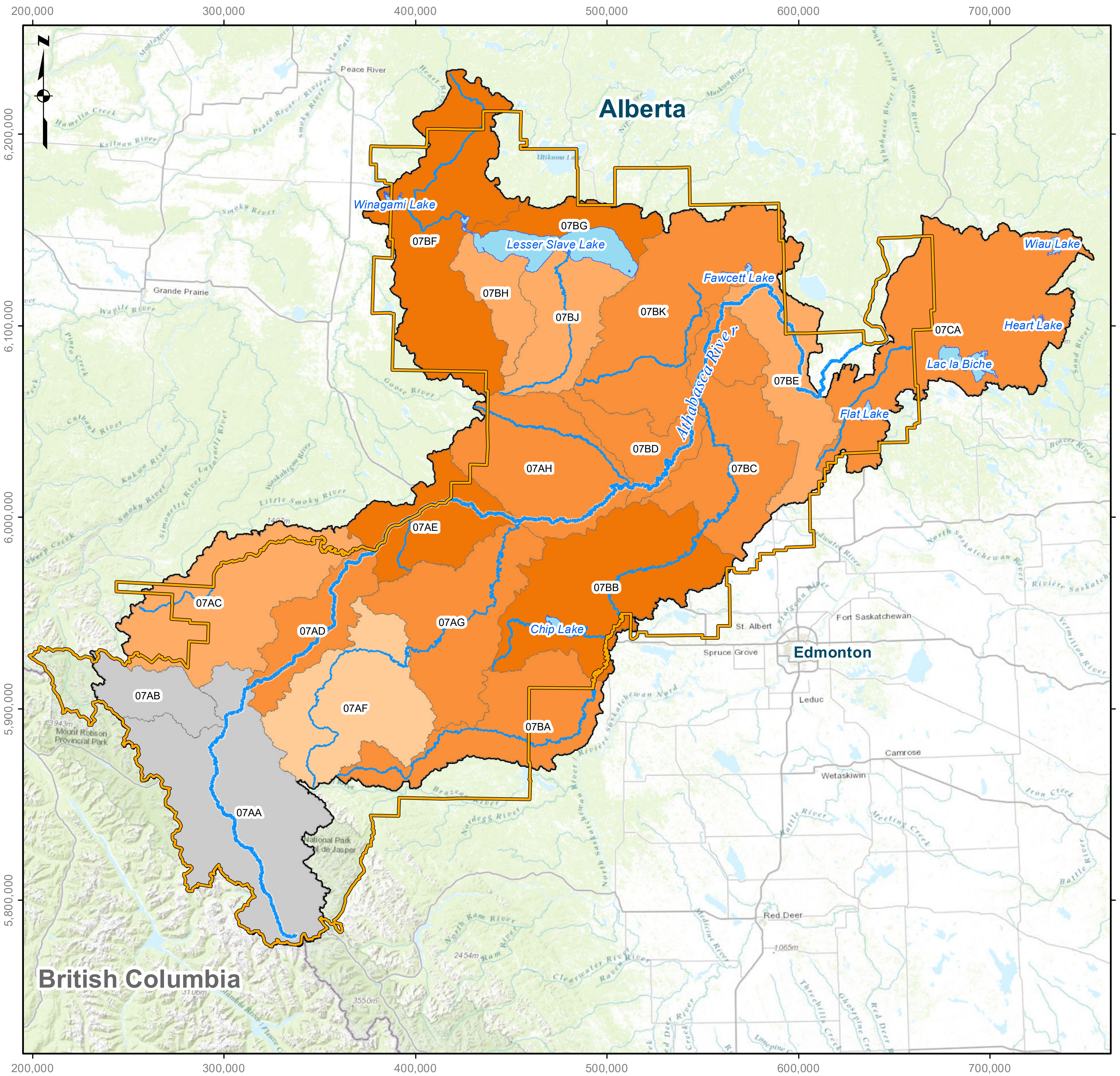
Branscombe, et al. (2018)

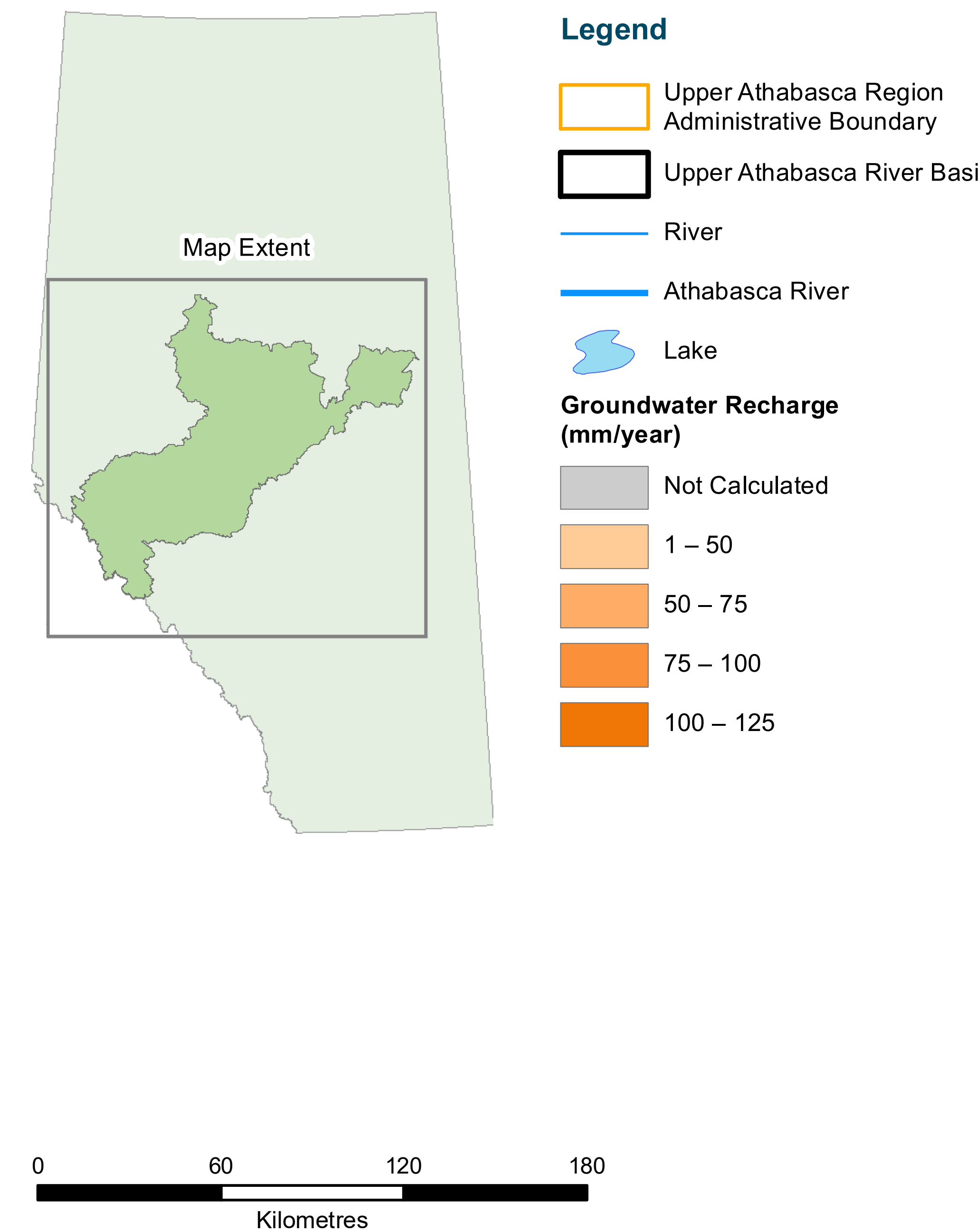
Map 51. Groundwater Authorizations in the Lea Park Interval



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

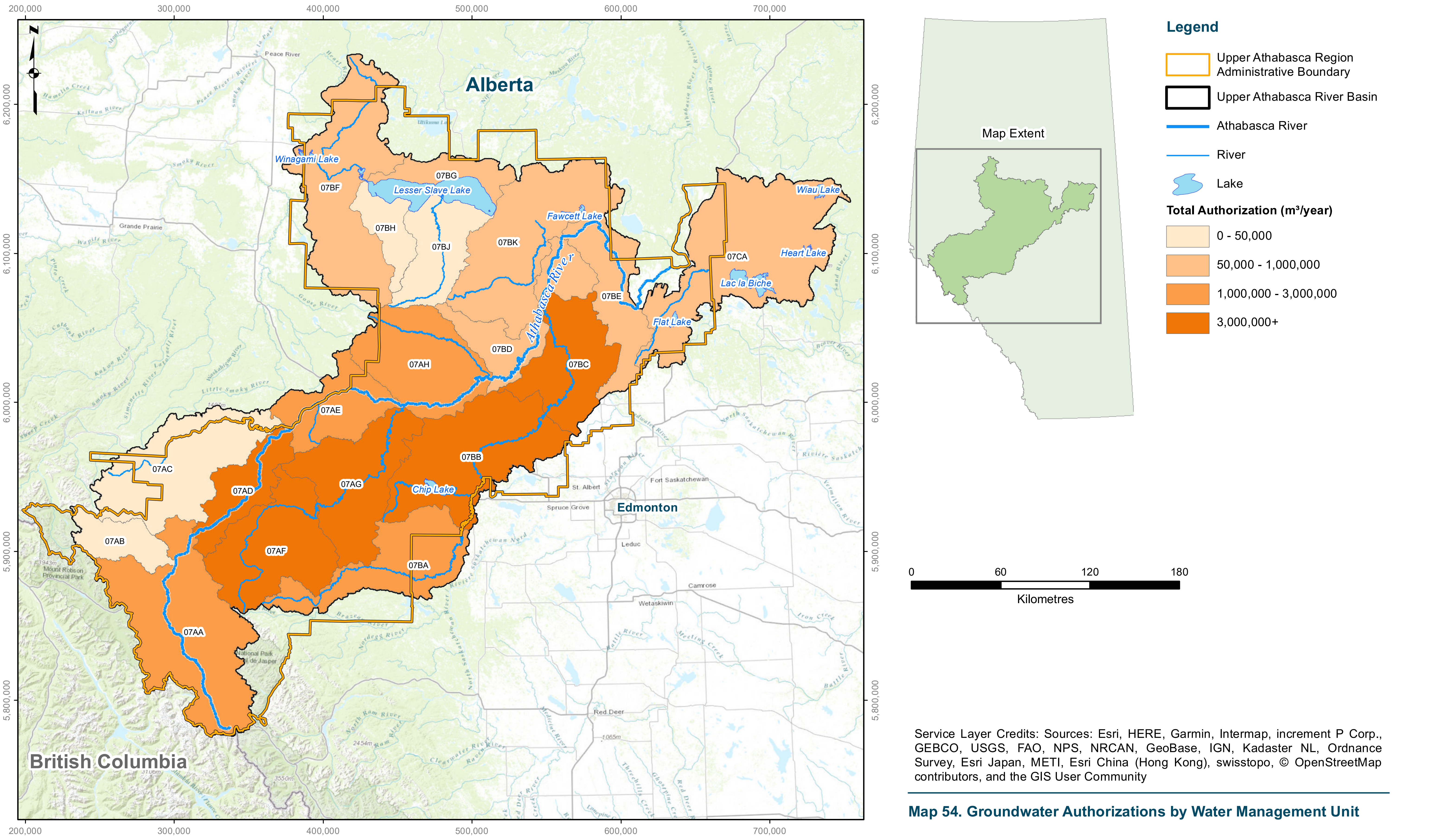
Map 52. Water Management Units Within the UAR





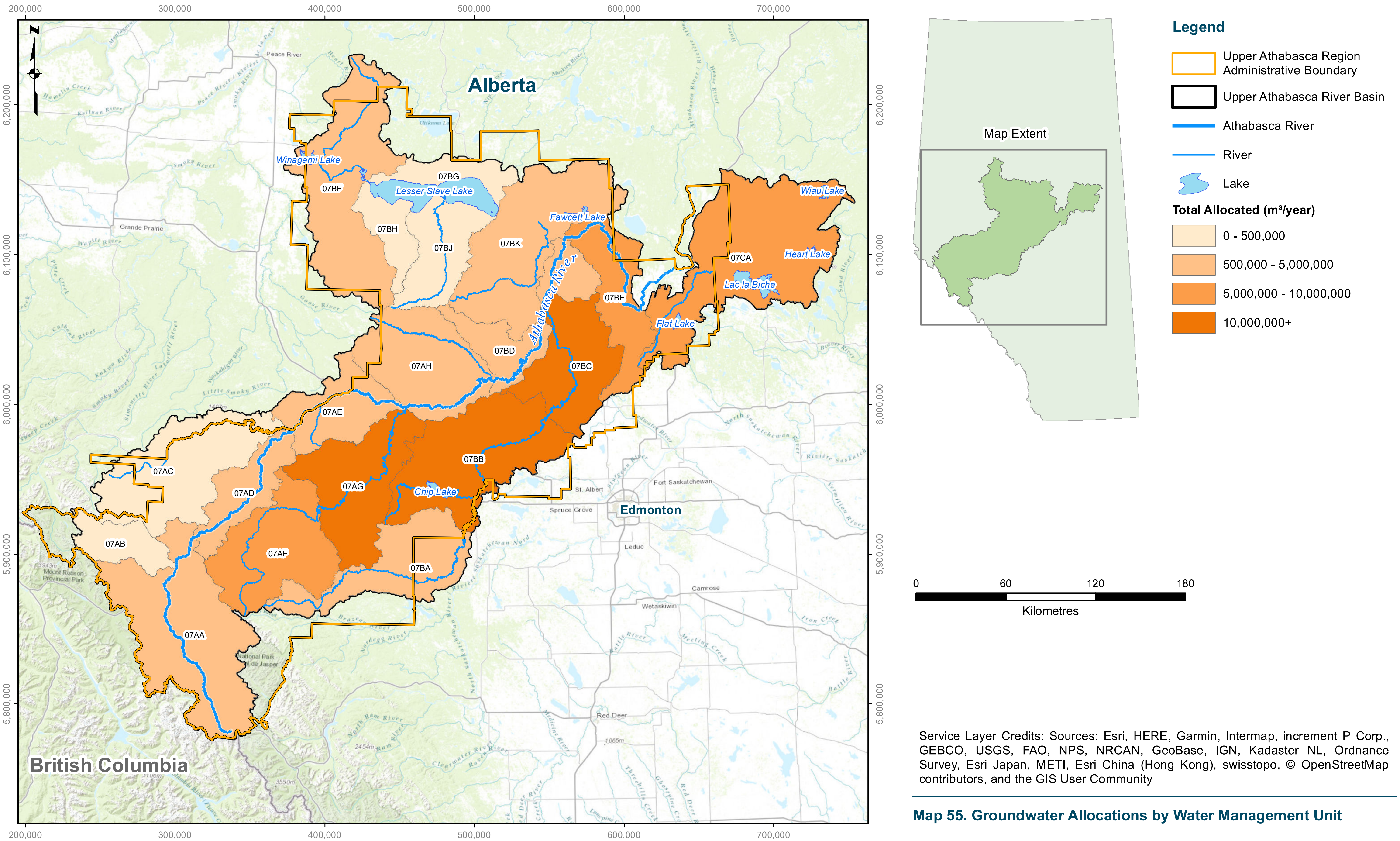
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 53. Groundwater Recharge by Water Management Unit



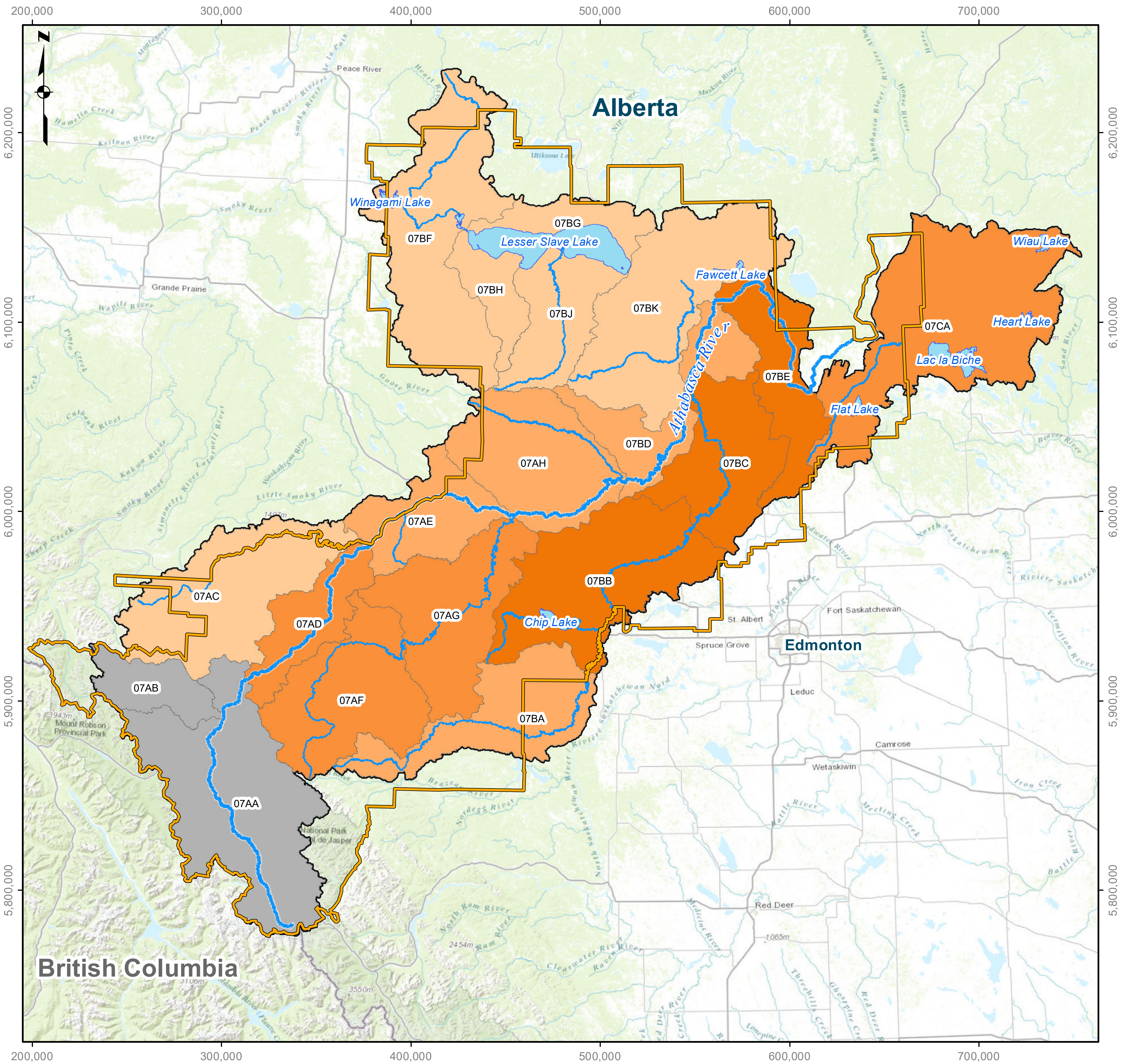
Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

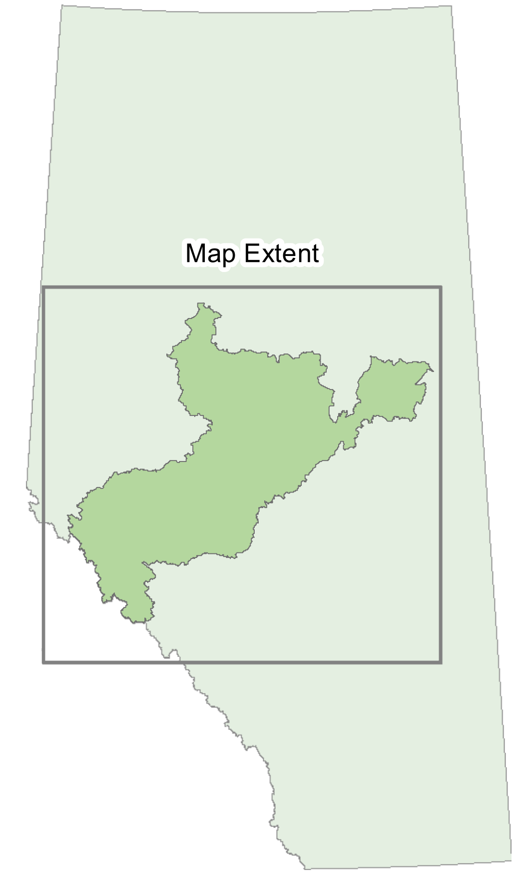
Map 54. Groundwater Authorizations by Water Management Unit



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 55. Groundwater Allocations by Water Management Unit





Legend

- Upper Athabasca Region Administrative Boundary
- Upper Athabasca River Basin
- Athabasca River
- River
- Lake

Total Allocated as a Percentage of Groundwater Recharge

- Not Calculated
- 0% – 0.25%
- 0.25% – 1%
- 1% – 2.5%
- 2.5%+

0 60 120 180

Kilometres

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Map 56. Groundwater Allocations as a Percentage of Groundwater Recharge