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Alberta Energy Regulator

State of Subsurface Knowledge to Support Aquifer Mapping Across the Alberta–Northwest Territories Border

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Abstract

This review summarizes the state of subsurface information and knowledge to support aquifer mapping across the Alberta–Northwest Territories (AB–NWT) border, which will address some of the elements identified in the Groundwater Learning Plan of the Bilateral Water Management Agreement between the Government of Northwest Territories and the Government of Alberta. The state of subsurface knowledge to support aquifer mapping across the AB–NWT border (approximately 60°N) is variable, but can be clearly divided into three geographic zones based on the density of available data. In the Kakisa–Cameron Hills area (120°W to 117°30′W), the bedrock deposits are not expected to contain aquifers. The greatest potential for aquifers will be within the sediments that have infilled bedrock valley systems; however, at the AB–NWT border a difference in the interpretation of sediment thickness exists between the two jurisdictions that will require further investigation. Using different data sources in Alberta compared to the Northwest Territories likely causes the different interpretations of sediment thickness. For the Kakisa–Cameron Hills area, the priority for future research is to re-evaluate the major buried valleys previously identified; refine the bedrock topographic surface; and investigate the feasibility of a ground-based geophysical survey (e.g., electrical and shallow seismic methods) to confirm the depth and shape of bedrock valleys. In the Hay River corridor (117°30′W to 116°W), there is about 5 to 10 m of sediment overlying bedrock that may contain localized aquifers, and potential for aquifers within the Upper Devonian bedrock formations. For the Hay River corridor, the priority for future research is to analyze the borehole data (geophysical, water well) and determine if hydrostratigraphic units can be mapped. A synoptic sampling project along the Hay River for naturally-occurring isotopic tracers could also be considered to gain insight to the hydrogeology in conjunction with research related to surface water quality and aquatic ecosystems. For the Wood Buffalo area (116°W to 112°30′W), there is very little subsurface information and only a conceptual model recently developed at the University of Alberta offers some insight to transboundary groundwater in the Upper Devonian bedrock formations.

1 Introduction

The Mackenzie River Basin Transboundary Waters Master Agreement and subsequent Bilateral Water Management Agreement (BWMA) between the Government of Northwest Territories and Government of Alberta establishes a commitment to manage water resources in a shared manner, such that use does not impact the ecological integrity of aquatic ecosystems in either jurisdiction. Under the BWMA risk-informed management approach, transboundary groundwater is classified as Class 1 because of limited knowledge (AB-NWT, 2015; Appendix F) and absence of specific details in a formal Groundwater Learning Plan (AB-NWT, 2015; Appendix H2). To advance knowledge, each jurisdiction is to work towards gathering hydrogeological information, characterizing transboundary groundwater, and delineating aquifers. These activities would inform key elements of a Groundwater Learning Plan.

The Department of Environment and Natural Resources (ENR) of the Government of Northwest Territories (GNWT), the Department of Environment and Parks (AEP) of the Government of Alberta, and the Alberta Geological Survey (AGS) of the Alberta Energy Regulator (AER) are seeking to better understand transboundary groundwater that spans the Alberta–Northwest Territories (AB–NWT) border. For this region, there is limited knowledge about groundwater quality and quantity (VanGulck, 2016) and details of the hydrogeological framework have not been integrated for delineating aquifers yet. The majority of groundwater use and knowledge in the region is constrained to the Hamlet of Zama, Alberta (Belair and Sibbald, 2016), which is located 100 km south of the AB–NWT border.

The focus of this report is to review the state of subsurface information and knowledge to support aquifer mapping across the AB–NWT border. The AGS led the compilation and synthesis of information through the AEP–AER/AGS Provincial Groundwater Inventory Program. The following objectives were met in this review:

- Describing existing groundwater-related information, including the information type, the data quality and usability, and the source and ownership of the information.
- Evaluating the ability of existing groundwater-related information to infer and delineate aquifers or groundwater areas across the AB–NWT border.
- Identifying the required needs to complete a preliminary aquifer delineation and characterization, including prioritization of efforts for future aquifer mapping and research.

1.1 Study Area

Under the BWMA, watershed boundaries are used as a surrogate for delineating transboundary groundwater at the sub-basin level (AB-NWT, 2015; Appendix F). The sub-basins provide an area-based framework for data collection and synthesis and identification of key information gaps. For this review, the following watershed boundaries from the National Hydrographic Network (NHN; Natural Resources Canada, 2019) were used to define the extent of the study area from west to east, as shown in Figure 1:

- Upper Petitot River (east part of NHN sub-basin 10DA000)
- Kakisa River (NHN sub-basin 07UC001)
- Lower Hay River (NHN sub-basin 07OB000)
- Buffalo River (NHN sub-basins 07PA000, 07PC000)
- Little Buffalo River (NHN sub-basin 07PB000)

These sub-basins encompass the majority of the AB–NWT border, spanning from approximately 120°W to 113°W. The remaining part of the AB–NWT border (113°W to 110°W), which includes the Slave River watershed and bedrock of the Canadian Shield either exposed or relatively close to surface, is expected to have very limited groundwater and has not been included in the review.

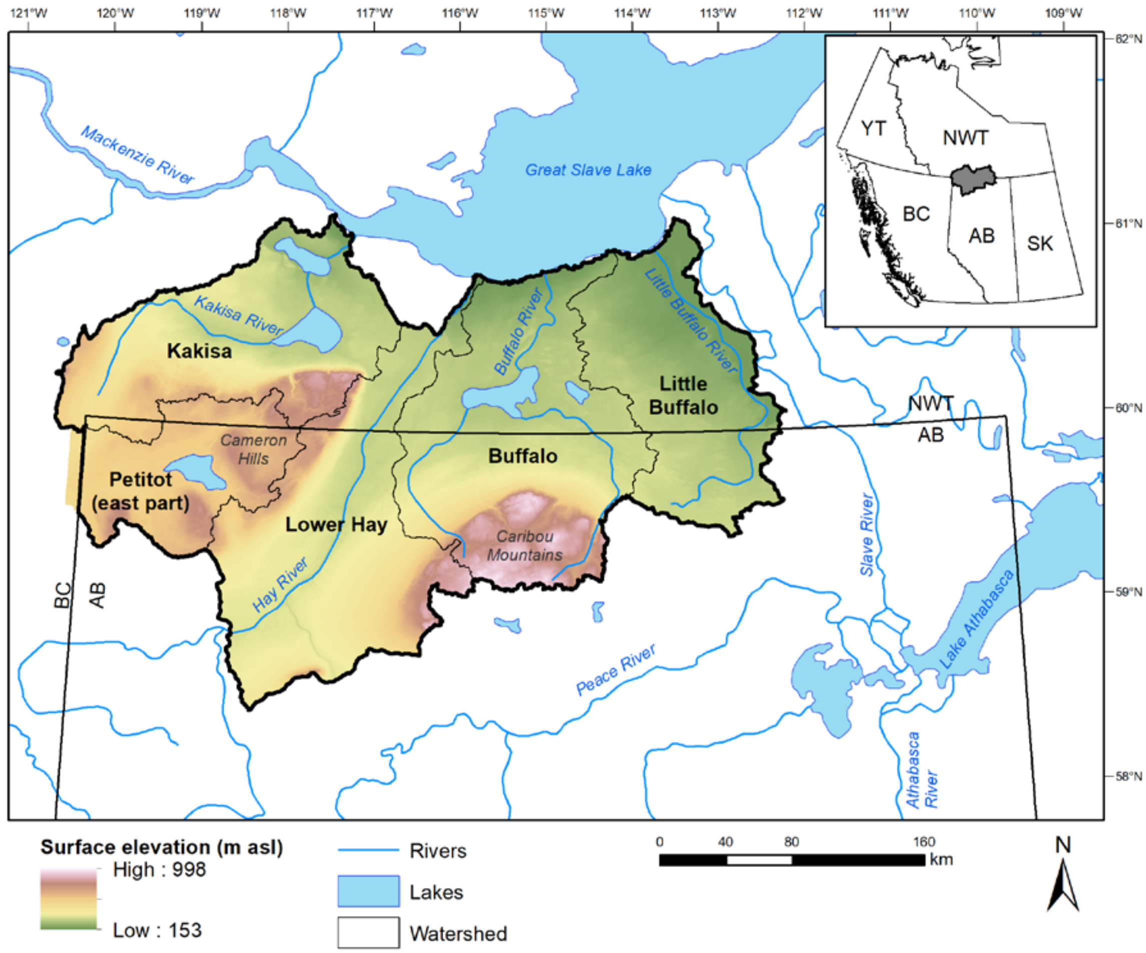

Figure 1. Location of the study area defined by watershed boundaries, shown with ground surface elevation. Inset map depicts the study area spanning Alberta and the Northwest Territories within western Canada.

2 Sources of Information

This review considered publicly accessible data sources available from the Geological Survey of Canada (GSC), the AGS, the Northwest Territories Geological Survey (NTGS), and information provided to the AGS by ENR. The sources of information are presented sequentially from broad coverage (e.g., regional maps) to specific point data (e.g., boreholes) that would support the development of a hydrogeological framework in subsequent work. Identification of additional information needed and prioritization of efforts for future aquifer mapping and research is discussed in Section 3.

2.1 Bedrock Units

The extent of bedrock geological formations has been compiled by the AGS (Prior et al., 2013) and the NTGS (Okulitch and Irwin, 2014). Each data source is available digitally and shown on Figure 2 based on geological period or epoch. The colours for bedrock units shown in Figure 2 follow the international chronostratigraphic chart of the International Commission on Stratigraphy (ICS) version 2018/08 (Cohen et al., 2013 updated), which is also consistent with the Alberta Table of Formations (AGS, 2019a). The extent of geological formations and members is only shown as lines in Figure 2 and additional information is available within the digital data. At the geological period or epoch scale there is general agreement across the AB–NWT border, with the exception of minor discrepancies in the Cretaceous units. At the formation and member scale there is agreement between most geological formations, with some difference in formation or member naming between AB and NWT. In addition to geological formation mapping, the AGS has developed a 3D Geological Framework Model that represents rock volumes at stratigraphic member, formation or group level for the Alberta part of the study area (AGS, 2019b). Compared to the bedrock formation extent mapping (Figure 2), the 3D model would be helpful in future aquifer delineation by representing the depth, thickness and geometry of bedrock formations.

The west part of the AB–NWT border (120°W to 117°W) includes Cretaceous siltstone and mudstone of the Shaftesbury Formation and mudstone of the Loon River Formation. These bedrock deposits are expected to have relatively low permeability and not contain significant aquifers (Borneuf and Pretula, 1980); however, localized aquifers may be present within isolated sandstone bodies. The elevated uplands of the Cameron Hills and Caribou Mountains are expected to influence regional hydrogeological conditions by providing topographic drivers for groundwater to move toward the Hay River in the Lower Hay sub-basin, and northward in the Buffalo sub-basin. Bachu (1997) identified the Scatter Aquifer to exist completely within the western part of the Loon River Formation, with a groundwater flow direction towards the north and northeast. The Scatter Aquifer is more prevalent in British Columbia east of the study area, and is considered to be a poor aquifer due to relatively low permeability (Petrel Roberts Consulting Ltd., 2014).

The central part of the AB–NWT border (117°W to 114°W) includes Upper Devonian limestone of the Twin Falls Formation and shale of the Hay River Formation. These formations would also underlie some of the Cretaceous bedrock to the west. Although the shallow parts of these formations are not expected to contain any significant aquifers (Ozoray, 1980), Bachu (1997) identified that an Upper Devonian Aquifer System exists where permeability is sufficient. Beneath the Upper Devonian Aquifer System, the Beaverhill Lake Aquifer exists (Bachu, 1997), which has saline groundwater that flows from southwest to northeast beneath the Caribou Mountains.

The east part of the AB–NWT border (eastward from 114°W) contains limestone and dolostone of the Muskeg River, Keg River, and Chinchaga formations. The Keg River Formation is considered a regional aquifer (Bachu, 1997) and parts of the Muskeg River and Chinchaga formations may contain localised aquifers where permeability is sufficient. These Devonian formations are expected to contain saline groundwater.

2.2 Surficial Units

Information on the surficial geology and surface geological materials is available from a variety of sources and at different spatial scales. The AGS and GSC have created the following generalized compilation maps that provide an overview of surficial geological deposits in the region (Figure 3):

- AGS Map 601, Surficial Geology of Alberta (Fenton et al., 2013)
- GSC Canadian Geoscience Map 195, Surficial Geology of Canada (GSC, 2014)

More detailed mapping of surficial geological deposits spanning the AB–NWT border can be obtained from the following data sources, for the locations shown on Figure 3:

- AGS Map 360 (Paulen et al., 2006a); Map 361 (Paulen et al., 2006b); Map 395 (Plouffe et al., 2006); Map 396 (Paulen et al., 2007); Map 419 (Paulen and Plouffe, 2008); Map 420 (Paulen and Plouffe, 2009); Map 540 (Pawley et al., 2010); Map 552 (Pawley, 2011); Map 541 (Mougeot and Fenton, 2010); and Map 145 (Bayrock, 1972)
- GSC Open File 6012 (Duk-Rodkin, 2010); Open File 1905A (Lemmen, 1998a); and Open File 1906A (Lemmen, 1998b)

Based on mapping of surficial geological deposits, the majority of sediments across the region are till (diamicton; wide grain-size distribution) represented as a variety of moraine types on AGS surficial maps. The various till units are not expected to contain significant aquifers; however, localized aquifers could be present where sufficient permeability exists. Coarse textured deposits, such as the glaciofluvial deposits associated with the Hay River and buried sediments (e.g., channels or lenses) not shown on the surficial geology maps, could also contain aquifers of limited extent.

2.3 Lithological Data

Several data sources are available to determine the lithology of sediments and the uppermost bedrock formations across the AB–NWT border. The lithological descriptions are critical to advance from a general understanding of regional geology to more specific hydrostratigraphic units and aquifers.

Table 1 identifies boreholes that have descriptive information (e.g., geologist or drillers log); however, these data are nonstandardized and have varying quality. Boreholes with lithological information are concentrated in the western half of the study area (Figure 4) and not distributed uniformly. A brief review of the data sources indicates that basic lithology is described (e.g., clay, sand) that would be sufficient to support some additional geoscience mapping. Table 2 identifies boreholes that have one or more geophysical wireline well logs (e.g., resistivity, gamma-ray). For this review, the focus has been on boreholes with a geophysical log with information in the uppermost 150 m of the subsurface. For many oil and gas wells, the geophysical logs may only be present at greater depths. In the near subsurface (150 m), the geophysical logs are useful to interpret differences in geological formations. For example, gamma-ray logs are often used to describe sandstone–shale sequences because shale contains a high proportion of clay (producing a high gamma-ray value) whereas clean sandstone does not (producing a low gamma-ray value). Similar to the borehole logs with lithological descriptions, the boreholes with geophysical logs are concentrated in the western half of the study area (Figure 5). In a few cases, a single borehole will contain both lithological description and geophysical logs.

2.4 Sediment Thickness

Considering the importance of sediments above bedrock in forming potential aquifers, knowledge of the depth to bedrock (i.e., sediment thickness) is critical. Sediment thickness mapping is often completed to develop an understanding of the underlying bedrock topography – the 3D surface representing the erosional top of the bedrock units. For the study area, two different approaches have been used to quantify sediment thickness (Figure 6).

In AB, the most recent bedrock topography and sediment thickness models (AGS, 2020a; AGS 2020b) were generated using a machine learning approach that combined several sources of data of varying quality and coverage. The machine learning used geological predictors such as surficial geology and distance to bedrock thalwegs, and topographic predictors such as relative height in the landscape and slope. A total of 39 terrain and geological predictors were used to supplement point data and create a bedrock topography that appears to realistically represent the subsurface data and geological interpretations across various parts of Alberta. Sediment thickness varies from 0 to 348 m (Figure 6). Lowland areas north of the Caribou Mountains and most of the Hay River sub-basin has sediment thickness on the order of 5 to 10 m, with a few areas having sediment thickness of about 20 m. For the Cameron Hills area and most of the Petitot sub-basin within AB, the sediment thickness is greater than 60 m. In this most northwest part of AB, 230 to 348 m of sediment is associated with the location of three bedrock valleys (Pawlowicz et al., 2007; Andriashek, 2018).

In the NWT, the sediment thickness model used seismic shothole drillers' logs collected during auger drilling of shotholes that varied from about 10 to 40 m deep (Smith, 2011; Smith, 2015). The shothole information was used to create cumulative sediment thickness models (Smith and Lesk-Winfield, 2010), which varies from 0 to 18 m (Figure 6). At the AB–NWT border a difference in the interpretation of sediment thickness exists that will require further investigation. Using different data sources used in AB compared to the NWT likely causes the different interpretations of sediment thickness.

Table 1. Summary of boreholes with lithology information.

Borehole type	Number of boreholes	Depth range (m)	Comments	Source
Geotechnical (Mackenzie Valley)	31	1 – 21	Digital data of geotechnical boreholes to support Mackenzie Valley highway and pipeline investigations. Relational database containing basic lithology (e.g. ~3 units).	GSC OF 4924 (Smith et al., 2005)
Geotechnical	26	4 – 18	Clustered boreholes to support highway, slope stability, and transmission towers. Specific borehole logs available from NWT.	ENR personal communication (summary table)
Shothole	13 421 702 with appreciable sand/gravel thickness	3 – 31	Digital data of seismic shotholes with drillers logs (OF 6833) and summary of potential granular aggregate (OF 6849). ArcGIS and data tables.	GSC OF 6833 (Smith, 2011) GSC OF 6849 (Smith et al., 2011)
Groundwater observation well	4	5 – 49	Alberta Groundwater Observation Well Network (GOWN). 1 well at Meander River active with water level time series, 1 well at Meander River sampled for chemistry in 1994 and 2012, 2 wells at Indian Cabins sampled for chemistry in 1994 and 2012 then reclaimed.	AEP
Water wells	118	1 – 478	Alberta Water Well Information Database (AWWID) records with lithology entered for one of more depths.	AEP, 2019

Table 2. Summary of boreholes with geophysical logs.

Data	Number of boreholes	Comments	Source
NWT oil and gas wells (public)	18	Raster images of various geophysical logs completed for exploration	ENR personal communication
AGS LAS database	547	Log ASCII Standard (LAS) files for geophysical wireline well logs. Geophysical log present within 150 m from the ground surface.	AGS unpublished data
Accumap digital logs	620	Various geophysical logs present within 150 m from the ground surface.	Accumap^{TM} (IHS Markit, 2019)

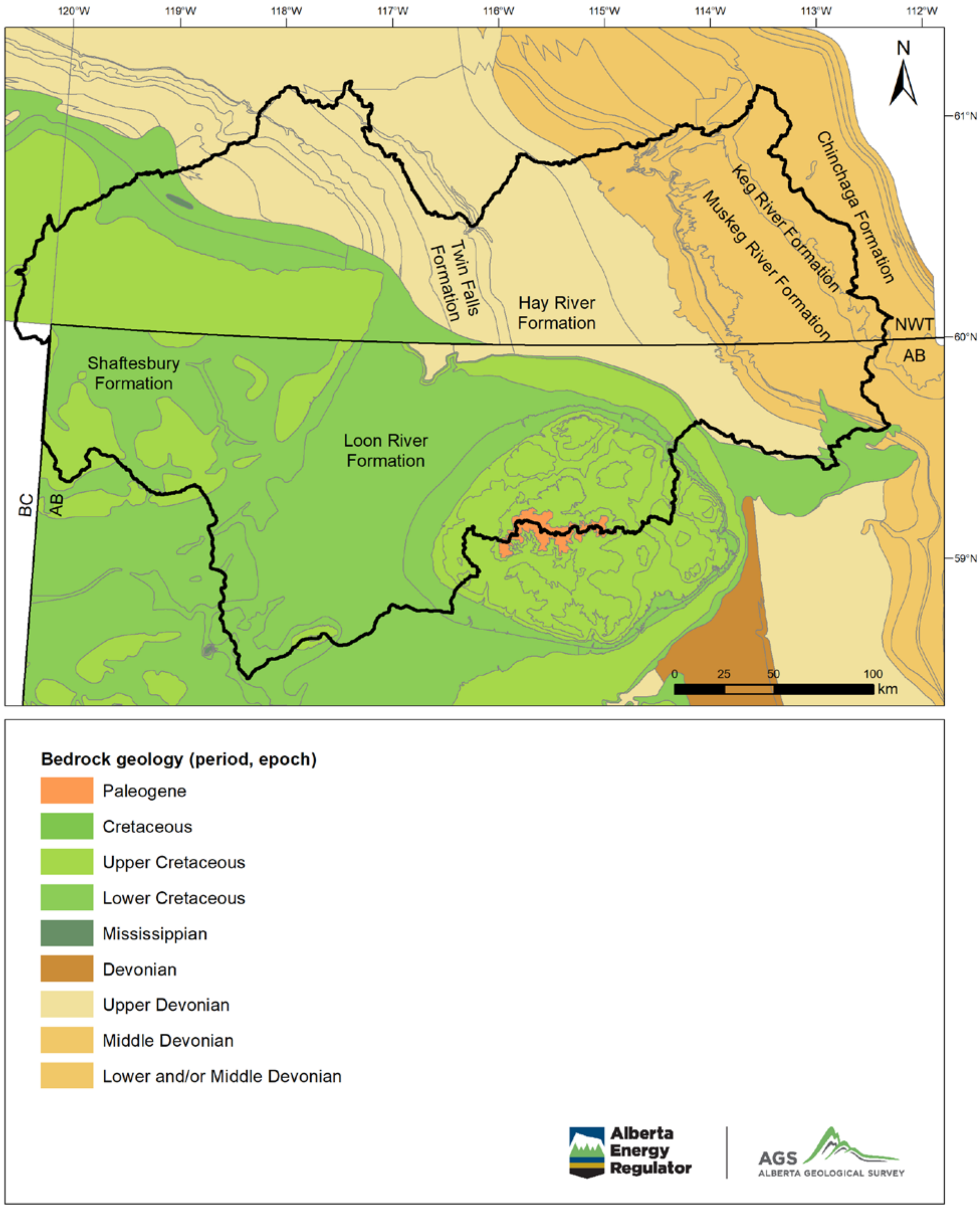

Figure 2. Simplified bedrock geology of the region as compiled by Prior et al. (2013) for Alberta and Okulitch and Irwin (2014) for the Northwest Territories. Geological formation boundaries are indicated with a thin grey line and only those formations discussed in the text are labelled. Colours follow the international chronostratigraphic chart (Cohen et al., 2013 updated).

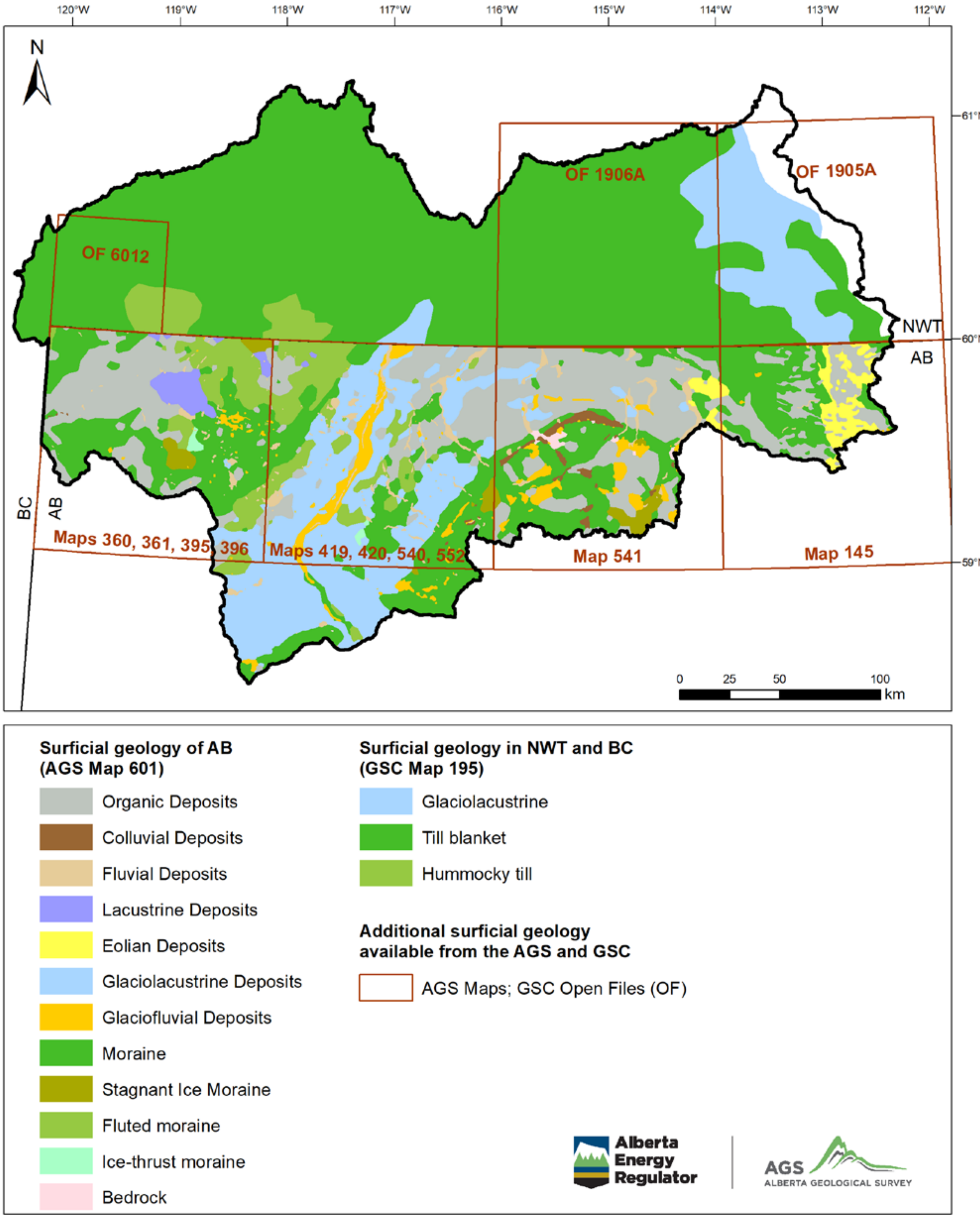

Figure 3. Surficial geology of the region as compiled by Fenton et al. (2013) and the Geological Survey of Canada (GSC, 2014). More detailed mapping is available from the Alberta Geological Survey (AGS) Maps and GSC Open Files shown (references cited in Section 2.2).

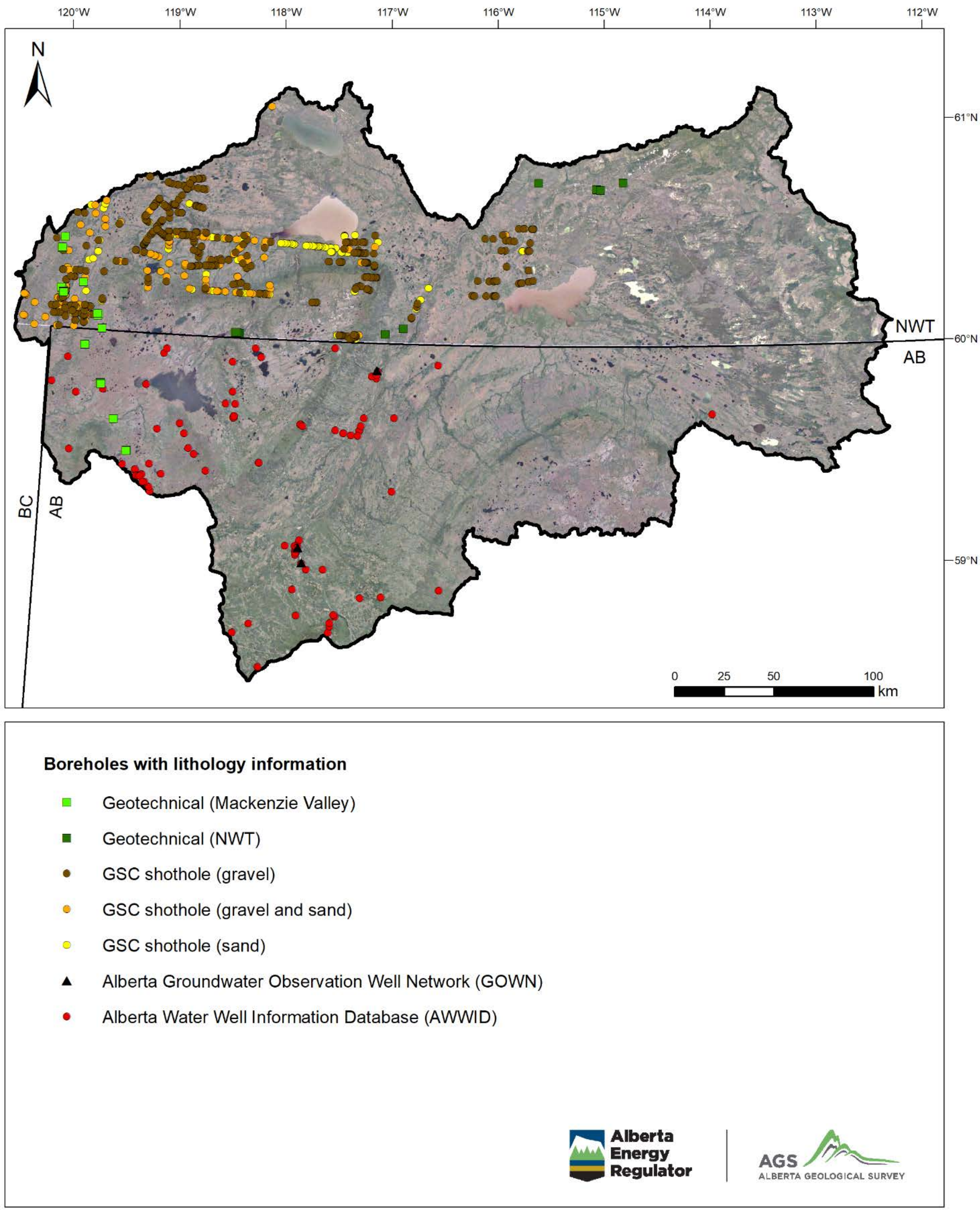

Figure 4. Location of boreholes with descriptive lithological information overlain on Google Earth image.

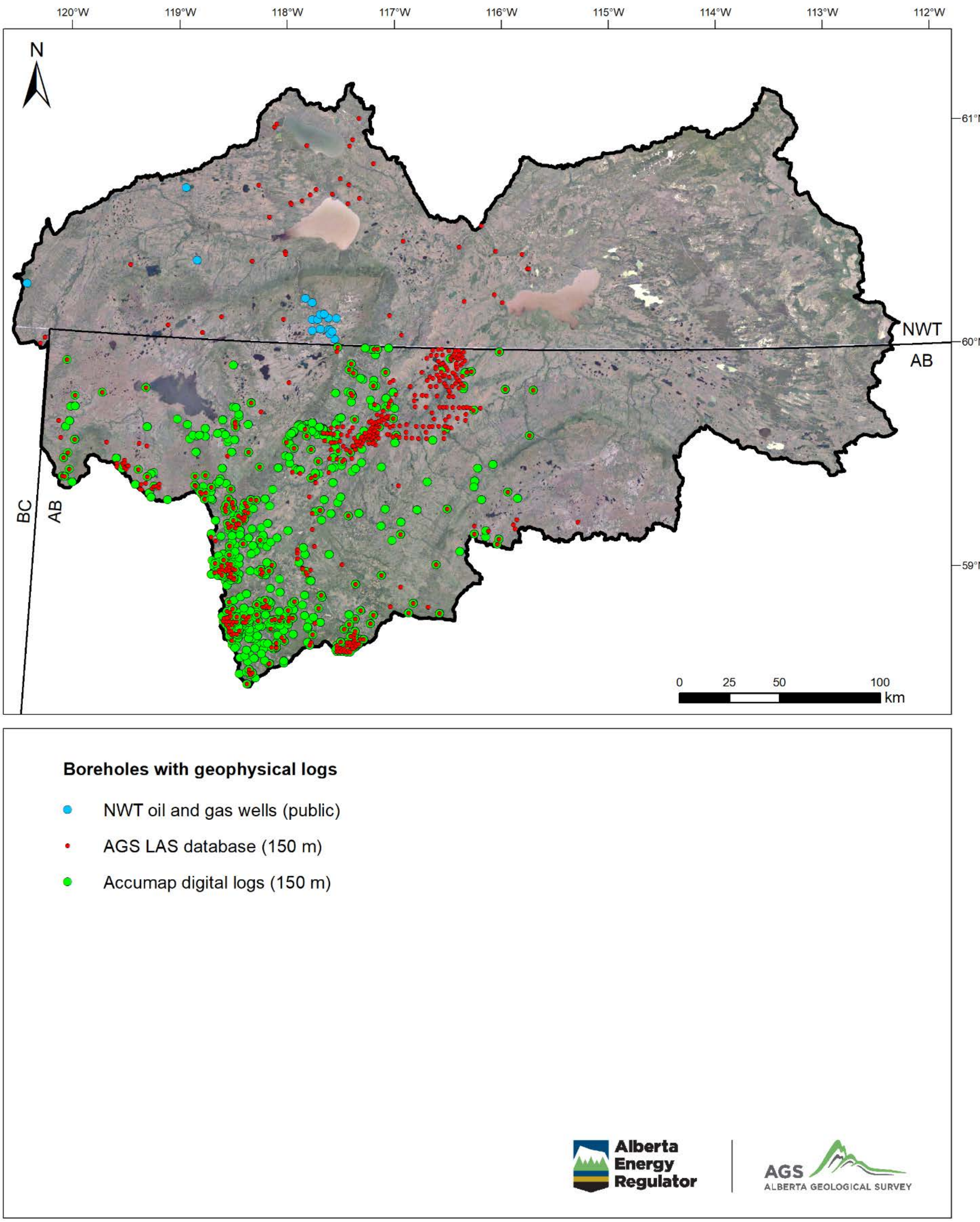

Figure 5. Location of boreholes with geophysical logs overlain on Google Earth image.

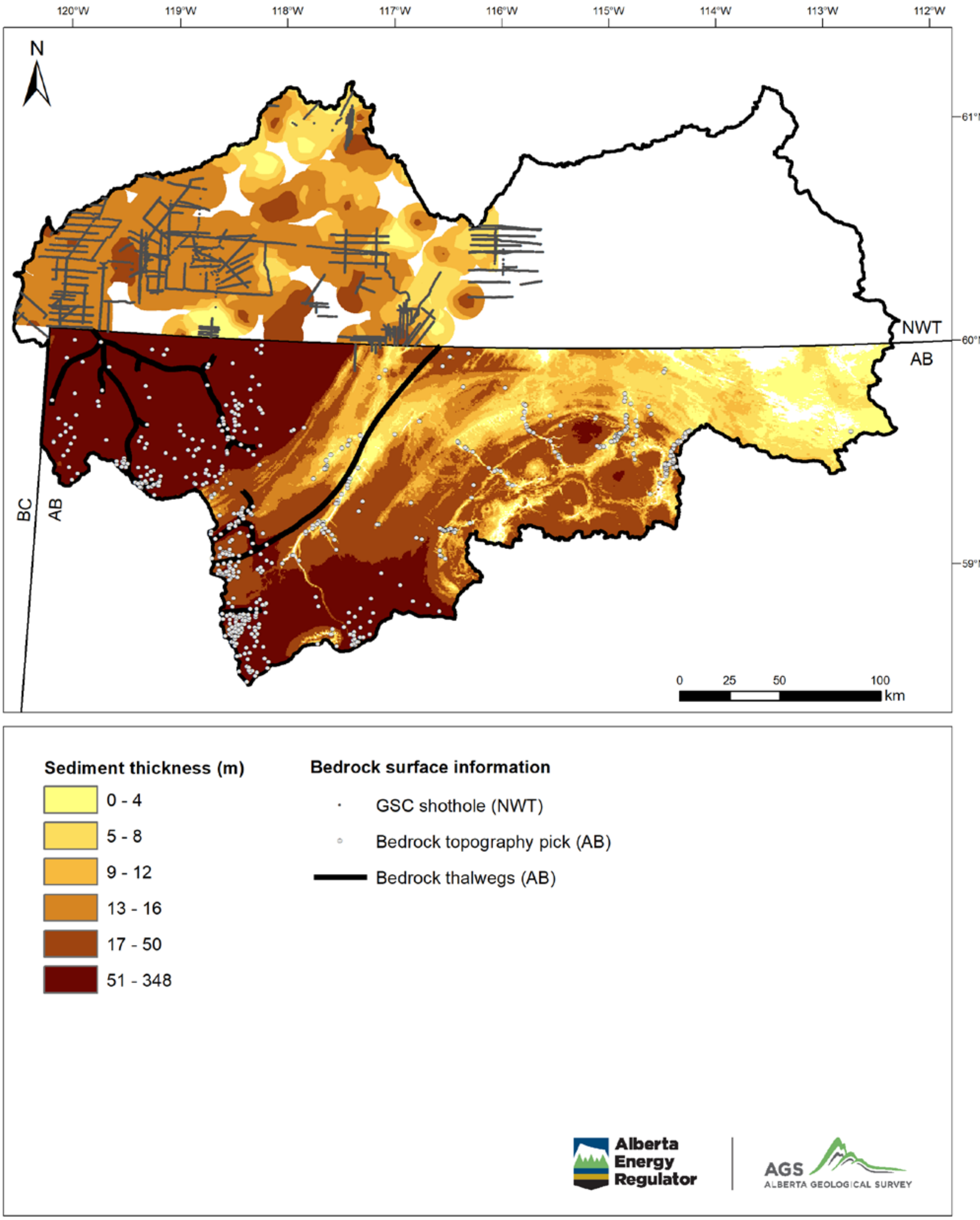

Figure 6. Modelled sediment thickness by the Alberta Geological Survey (2020b) for Alberta and by Smith and Lesk-Winfield (2010) for the Northwest Territories.

3 Requirements for Aquifer Mapping

The state of subsurface knowledge to support aquifer mapping across the AB–NWT border is variable, but can be clearly divided into three geographic zones based on the density of available data, as shown in Figure 7. For this discussion, each zone is shown to extend by 30′ north and 30′ south of the AB–NWT border (60° N), which is approximately a distance of 55 km. The efforts required for future aquifer mapping differs between each of these zones, and is discussed in the following sub-sections.

3.1 Kakisa–Cameron Hills Area

For the Kakisa–Cameron Hills area (120°W to 117°30′W; Figures 7 and 8), the bedrock deposits are expected to have relatively low permeability and not contain aquifers (Borneuf and Pretula, 1980), so the greatest potential for aquifers will be within the sediments that overlie the bedrock, including those that have infilled bedrock valley systems. In this area a discrepancy in the interpretation of sediment thickness exists between AB and NWT. Within AB, Pawlowicz et al. (2007) identified major buried valleys that were interpreted to have a northwest trend in gradient, suggesting a paleovalley system that likely flowed to the Mackenzie River valley. Based on information from the few oil and gas wells in this area, these major valleys are considered to be infilled with 230 to 348 m of sediment. The presence of these major valleys has been retained in the recent modelling of bedrock topography and sediment thickness (AGS, 2020a; AGS 2020b); however, it is important to note the sparseness of borehole data in this area (Figure 8) to verify the presence of the major buried valleys. Within the NWT, much less sediment thickness has been modelled from the seismic shothole database (Smith and Lesk-Winfield, 2010). The GSC are currently revising the sediment thickness model for this region (Smith et al., 2019) by incorporating diamond drill hole and petroleum well log records, interpolated points from surficial mapping, and most recent seismic shothole database (Smith, 2011). It should be noted that the quality of lithological descriptions is often quite poor for shotholes, so it is possible that a greater sediment thickness exists than has been predicted.

For future aquifer mapping, the priority for the Kakisa–Cameron Hills area (Figures 7 and 8) is to resolve the discrepancy in sediment thickness and re-evaluate the buried valleys identified by Pawlowicz et al. (2007). A cursory review of some oil and gas wells in this area indicates that surface casing was often installed to hundreds of meters depth; however, it is not readily apparent what geological material has been isolated by the surface casing (i.e., the composition of uppermost bedrock and/or sediments overlying the bedrock). Similarly, a cursory review of the shothole logs found many inaccurate and/or ambiguous lithological descriptions that would be challenging to use for precisely determining the depth to bedrock. A project focused on re-evaluating the sediment thickness and topography of the bedrock surface is recommended, which would include re-interpreting the original data. The project would benefit from considering the morphology of other valleys that have been mapped in Cretaceous bedrock to constrain the width and depth.

Following a re-evaluation of the sediment thickness, acquisition of new information may be required to confirm the presence and depth of any aquifer system that might exist within the bedrock valley system. It is unlikely that sufficient information exists to determine if the bedrock valleys are filled with fine- or coarse-grained sediments. Given the remoteness of the Kakisa–Cameron Hills area, especially the location of the major buried valleys (Figure 8), reconnaissance ground-based geophysical surveying might be a feasible approach. A combined electrical and shallow seismic survey that is oriented along transects that cross the buried valleys would help understand the shape of the bedrock valley, presence and thickness of permafrost, and potentially any variation in sediment. Given the likelihood of permafrost in this area, an airborne geophysical survey would need to consider the similarity in response of ground ice and aquifer-forming gravel deposits (e.g., Minsley et al., 2012).

3.2 Hay River Corridor

For the Hay River corridor (117°30′W to 116°W; Figures 7 and 9), there is about 5 to 10 m of sediment overlying bedrock, which may contain localized aquifers where glaciofluvial material is present. Within the bedrock formations, the Lower Cretaceous shales have erosional edge in the vicinity of the AB–NWT border (Figure 2), and do not likely contain aquifers. At slightly greater depths in the bedrock the Upper Devonian units are expected to have low permeability for an aquifer system (Bachu, 1997), but could be investigated further for aquifer potential. Within AB, there are about 150 geophysical logs (AGS LAS database; Figure 9) in the 10 to 50 m depth range that would be useful for aquifer mapping. Within the NWT, there is much less subsurface information.

For future aquifer mapping, the priority for the Hay River corridor (Figures 7 and 9) is to analyze the borehole data (geophysical, water well) and determine if hydrostratigraphic units can be mapped in the surficial sediments and upper bedrock (to an approximate depth of 50 m). A project aimed at hydrostratigraphic unit delineation could follow a less detailed approach than has been completed in recent years for other regions in Alberta by the AGS (e.g., Atkinson and Hartman, 2017).

Given the accessibility of the Hay River, it would also be informative to complete a reconnaissance river sampling program aimed at measuring the occurrence of naturally-occurring isotopic tracers. The AGS has done this recently to more rapidly understand the hydrogeology of data-poor areas in the Upper Peace Region (e.g., Smerdon, 2019; Smerdon et al., 2019). When combined with a general understanding of the regional geological framework, identifying young water cycling through the shallow groundwater system and older baseflow sources potentially coming from a deeper groundwater flow system provides a basis for a conceptual hydrogeological model.

3.3 Wood Buffalo National Park

For the Wood Buffalo area (116°W to 112°30′W; Figure 7), there is little to no subsurface information. The AGS has legacy surface water chemistry data from Alberta Research Council (ARC) mapping conducted in the 1970s (AGS, 2009) that could help understand groundwater conditions. Most of these unpublished data appear to be collected from springs and wetlands in the eastern part of Wood Buffalo National Park near the Slave River (Stewart, 2009; Stewart, 2014).

The recent Ph.D. work by Déri-Takács (2019) incorporated the legacy ARC chemistry data (AGS, 2009) with additional surface water sampling and groundwater modelling. Déri-Takács (2019) demonstrated that the Caribou Mountains create a local- to intermediate-scale groundwater flow system within the Upper Devonian formations that suppresses interaction with deeper saline groundwater, and focuses deeper saline groundwater to discharge closer to the Slave River east of the study area. This research provides a conceptualization of hydrogeological conditions for the central to east part of the AB–NWT border. Future work could include isotopic and geochemical sampling (similar to the recommendation for the Hay River) to help understand regional groundwater conditions.

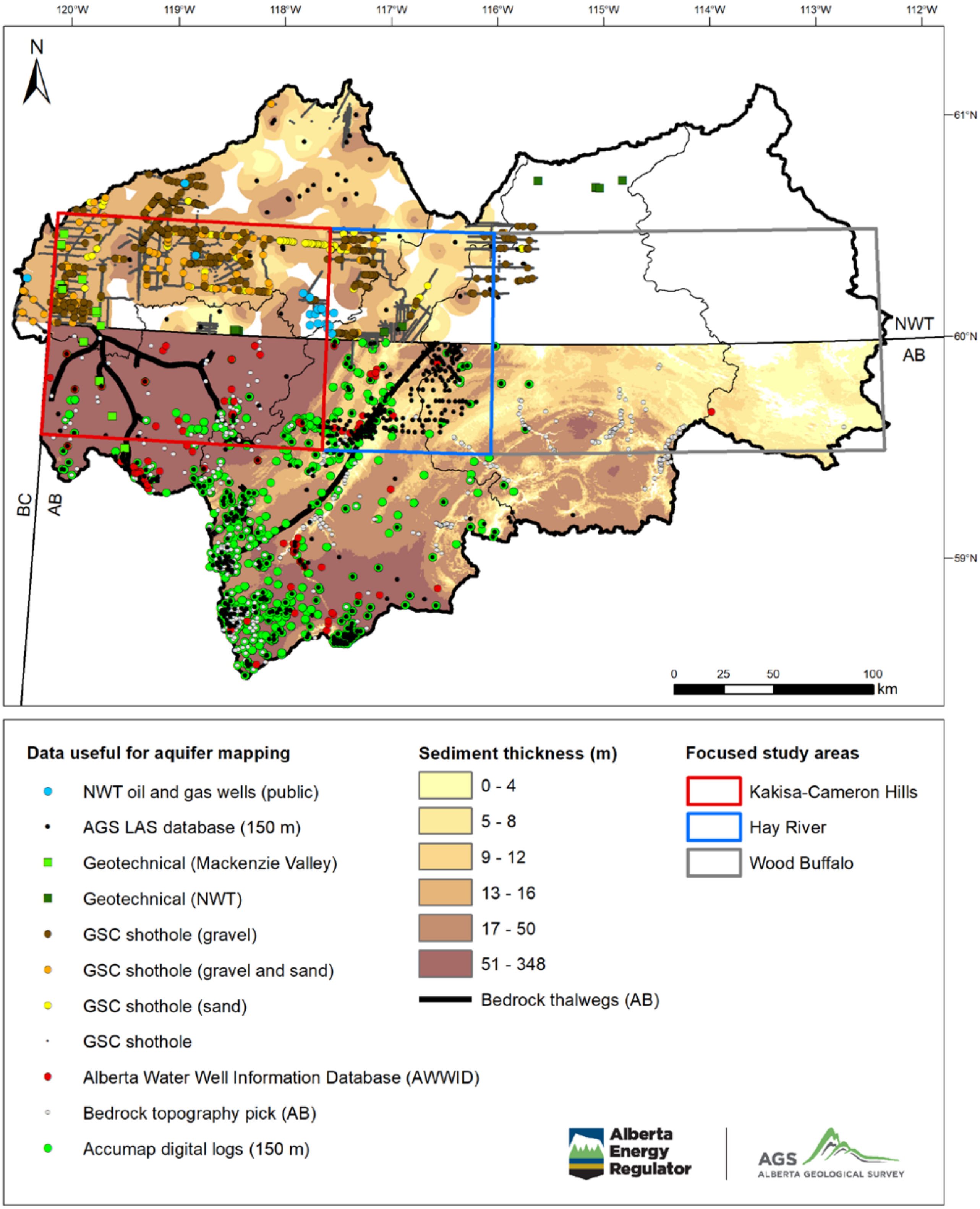

Figure 7. Summary of subsurface information available for aquifer mapping. Focused areas for further assessment and acquisition of new information is depicted based on the amount and type of existing information.

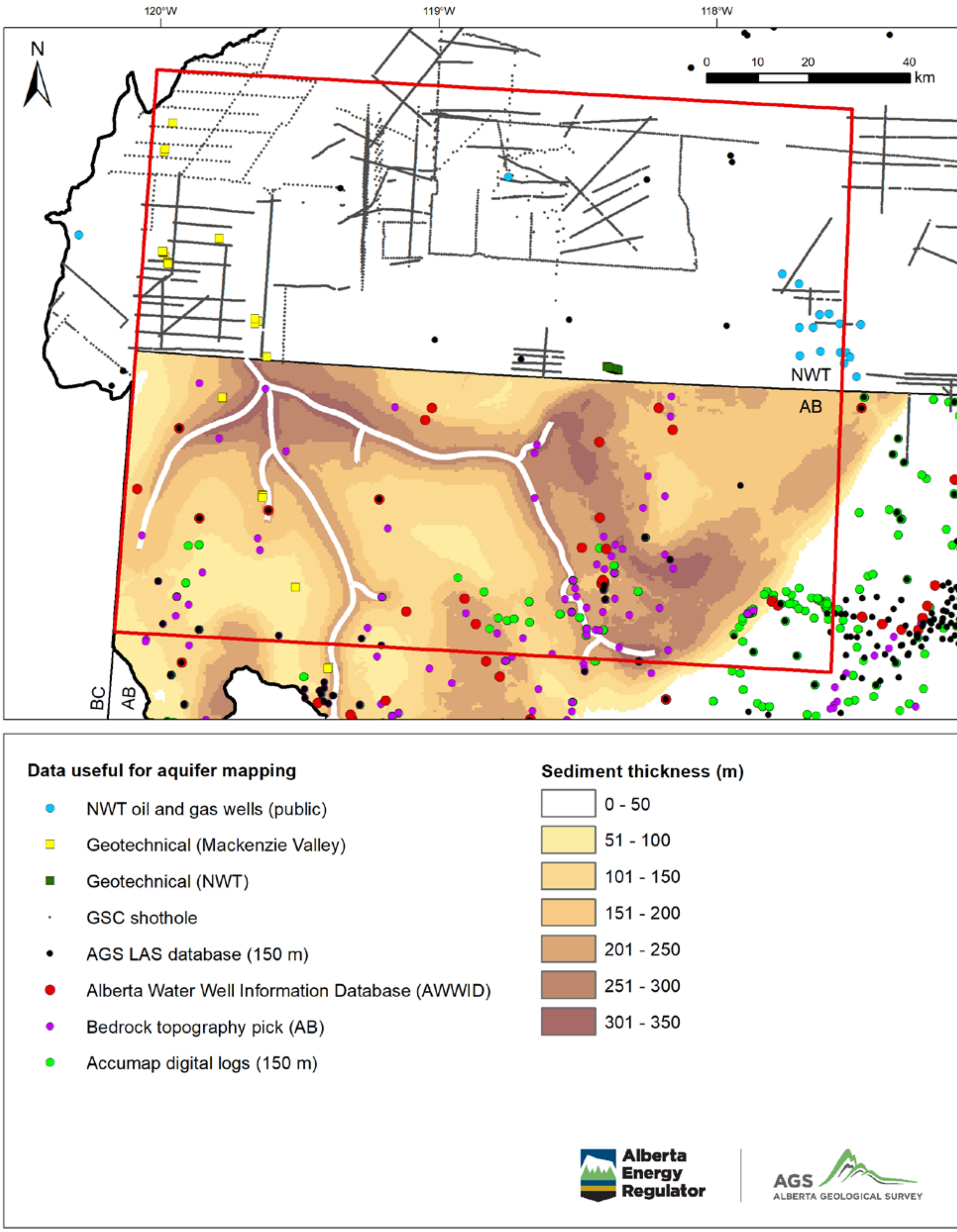

Figure 8. Detailed view of subsurface information in the Kakisa–Cameron Hills area. Compared to Figure 6, a greater sediment thickness interval is shown to highlight the potential major buried valleys in Alberta.

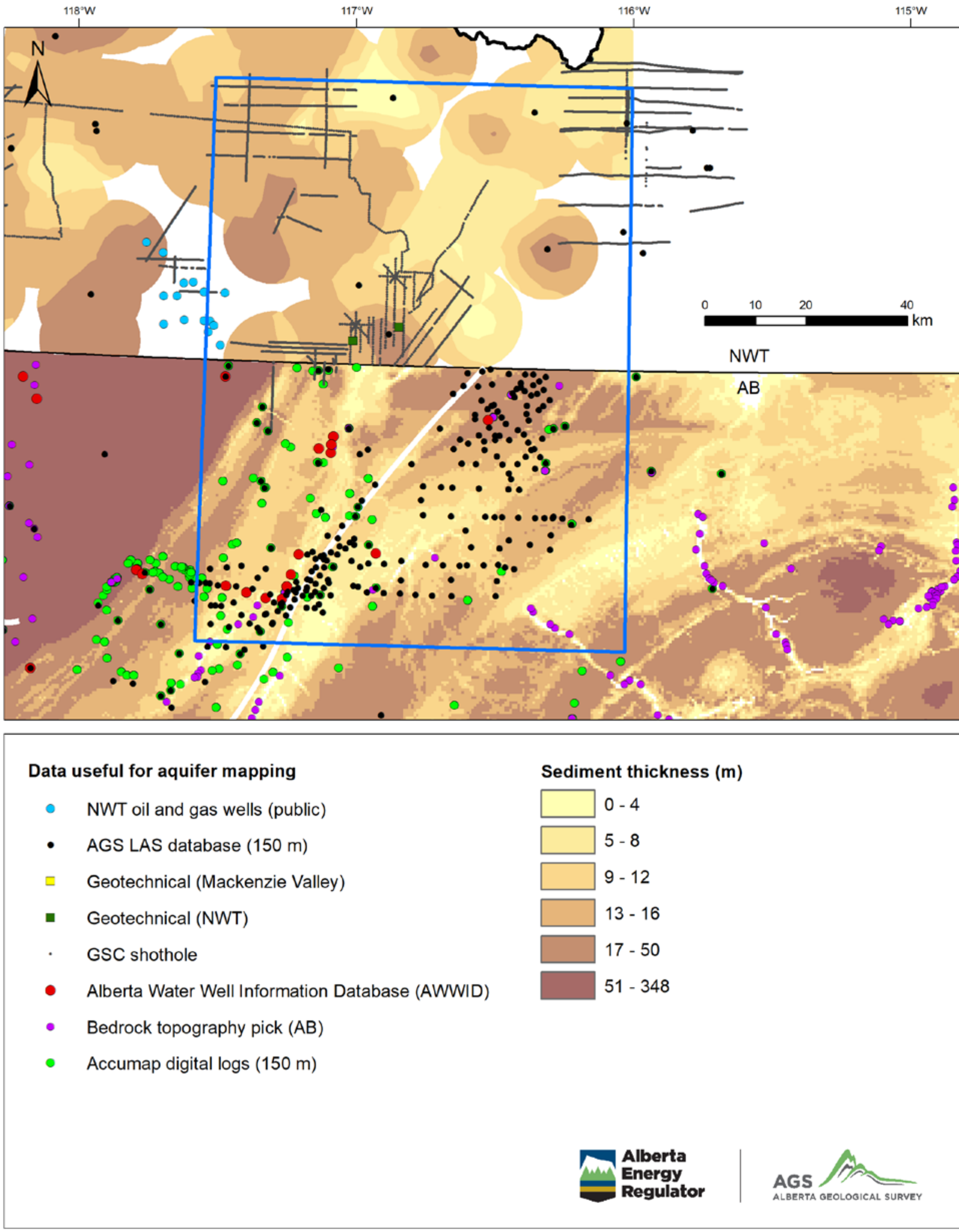

Figure 9. Detailed view of subsurface information in the Hay River corridor.

4 Recommendations

This review found that there are three distinct areas where future projects can be focused to better understand transboundary groundwater and address some elements identified in the Groundwater Learning Plan (AB-NWT, 2015; Appendix H2). With the exception of the Wood Buffalo area, which has no subsurface information, the following recommendations are made for the areas shown on Figure 7:

Kakisa–Cameron Hills Area (120°W to 117°30'W)

- Re-evaluate the major buried valleys identified by Pawlowicz et al. (2007) and the shallow sediment thickness identified by Smith and Lesk-Winfield (2010). This task would involve discussing sediment thickness mapping with the GSC and re-interpreting some of the original borehole data based on the quality of data to define depth to bedrock with certainty.
- Using the re-interpreted borehole data, develop a bedrock topographic surface for the Kakisa–Cameron Hills area.
- Investigate the feasibility of a ground-based geophysical survey (electrical and shallow seismic) to confirm the depth and shape of bedrock valleys.

Hay River Corridor (117°30'W to 116°W)

- Analyze the borehole data (geophysical, water well) and determine if hydrostratigraphic units can be mapped in the Hay River corridor.
- Sample the Hay River during a low flow period for naturally-occurring isotopic tracers to gain insight to the hydrogeology of the Hay River corridor. Sampling efforts could be integrated with additional research related to surface water quality and aquatic ecosystems.

In addition to the above recommendations, the scoping of future geoscience needs should also be integrated with state of permafrost knowledge and surface water, which are interrelated with transboundary groundwater.

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