ERCB/AGS Open File Report 2010-12

Bedrock Topography and Sediment Thickness Mapping in the Edmonton–Calgary Corridor, Central Alberta: An Overview of Protocols and Methodologies

Energy Resources Conservation Board

Alberta Geological Survey

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Abstract

Groundwater conservation and exploration studies, geotechnical investigations, aggregate exploration programs and other land-use applications extensively use bedrock topography and sediment thickness data. Recently, Alberta Geological Survey (AGS) developed a series of protocols to generate regional bedrock topography and sediment thickness maps as part of a broader groundwater-mapping project for the Edmonton–Calgary Corridor (ECC).

Map generation was based on data obtained from water-well, geotechnical, oil-and-gas–well and borehole records and field-based geological observations. The methodology for data preparation and standardization involved a multi-stage process that adhered to the following steps. Water-well datasets were filtered for erroneous well records. These records included wells without an assigned location or located within permanent lakes, wells with questionable geological information, wells without depths assigned to the material layers, etc. Wells that failed this initial screening process were removed from the working database. Geological descriptors used to characterize material layers or rock types in wells were identified using a query-based approach in Microsoft® Access. Each of the 2662 unique geological descriptors identified were then manually assigned to one of twenty-five primary lithology codes. All materials in the working database were populated using the 25 primary lithology codes. Wells that contain bedrock that correspond to the primary lithology legend were extracted from the database and used in the interpolation process. Wells containing undefined or nongeological descriptions, such as “sea shells, unknown, see comments, hard ledges, etc.”, were inspected manually to determine material type. In many cases, these wells were excluded from the dataset due to insufficient or ambiguous geological data.

The ESRI ArcGIS ordinary kriging function was used to interpolate the elevation points from wells with bedrock and data obtained from existing bedrock maps, such as observed outcrop locations, to generate an initial bedrock topography map. This map was inspected to identify anomalous depressions or peaks in the bedrock topography. These anomalies are typically caused by wells with erroneous bedrock elevations. Further inspection of these anomalies determined the validity of the bedrock elevations and they were either adjusted or excluded from the interpolation process. The dataset was re-kriged, honouring the adjusted well data points. The interpolated bedrock surface was then constrained to a 60 m grid-spaced digital elevation model (National Aeronautics and Space Administration’s Shuttle Radar Topography Mission). Lastly, using the minus function in ArcGIS 3DAnalyst, a sediment thickness map was produced by subtracting the bedrock surface elevation from the corresponding elevation in the digital elevation model.

1 Introduction

Groundwater is an essential source of drinking water for approximately 600 000 Albertans (Alberta Environment, 2008). It is estimated that individual farms and households consume up to 50% of groundwater used in the province (Alberta Environment, 2008). In areas of rapid urban expansion, such as the Edmonton–Calgary Corridor (ECC), ongoing land-use planning will be important to ensure that adequate supplies of water exist for future use. As urban development moves beyond major urban centres, access to surface water supplies will decrease and the demand for groundwater will undoubtedly increase with growing population and industrialization. To help with land-use planning and the implementation of a groundwater protection policy, an understanding of the hydrogeological framework, including bedrock, preglacial and glacial geology, within the area is essential as these deposits form significant areas of recharge, and contain both local and regional aquitards and producing aquifers.

Alberta Geological Survey (AGS) in partnership with Alberta Environment (AENV) has initiated a multi-year project to characterize nonsaline aquifer complexes in Alberta. In response to increasing rates of urbanization and industrialization in the ECC and the foreseeable pressures that this will have on existing water supplies, the ECC was selected as the first study area (Figure 1) by AGS and AENV. When completed, this provincial mapping program will characterize and document the nonsaline groundwater resources for the entire province.

The purpose of identifying aquifer complexes and understanding the geological framework of the ECC is multi-fold. First, the recognition of unmapped aquifers may relieve current and/or future stresses on existing aquifer systems caused by urban sprawl. Second, a better understanding of the geological framework will allow for an improved geological model of the ECC, which in turn will better define aquifer/aquitard complexes. It is anticipated that this model will form the cornerstone for numerous applications, such as groundwater exploration programs, aquifer protection studies and identification of significant recharge areas. More importantly, this model will form the framework for numerical groundwater-flow models and future water-budget exercises. The results of these investigations will assist all levels of government in making informed decisions regarding groundwater allocation, protection policies and land-use planning initiatives.

This report outlines the protocols developed by AGS to generate GIS-based, regional-scale, three-dimensional bedrock topography and sediment thickness maps for the ECC (Figures 1–3). Recent advances in data storage and retrieval allow for the collection and use of extensive water-well, geotechnical, oil-and-gas–well and borehole records, as well as field-based geological observations compiled through mapping exercises. These advances have made meaningful data extraction from large datasets and the production of regional-scale digital maps both timely and possible.

Using ESRI ArcGIS and EarthFX VIEWLOG® analysis functions and interpolation techniques, such as kriging, extensive datasets of subsurface information were integrated and analyzed to generate bedrock topography and sediment thickness maps for the ECC.

This report focuses on the methodology used to complete bedrock topography and sediment thickness maps for the ECC. The methodology consists of four components:

1) data acquisition
2) data preparation and standardization
3) bedrock topography interpolation
4) sediment thickness calculation

The products presented in this report provide users with a framework for regional-scale geological and hydrogeological investigations. For local-scale investigations, more detailed assessments may be required.

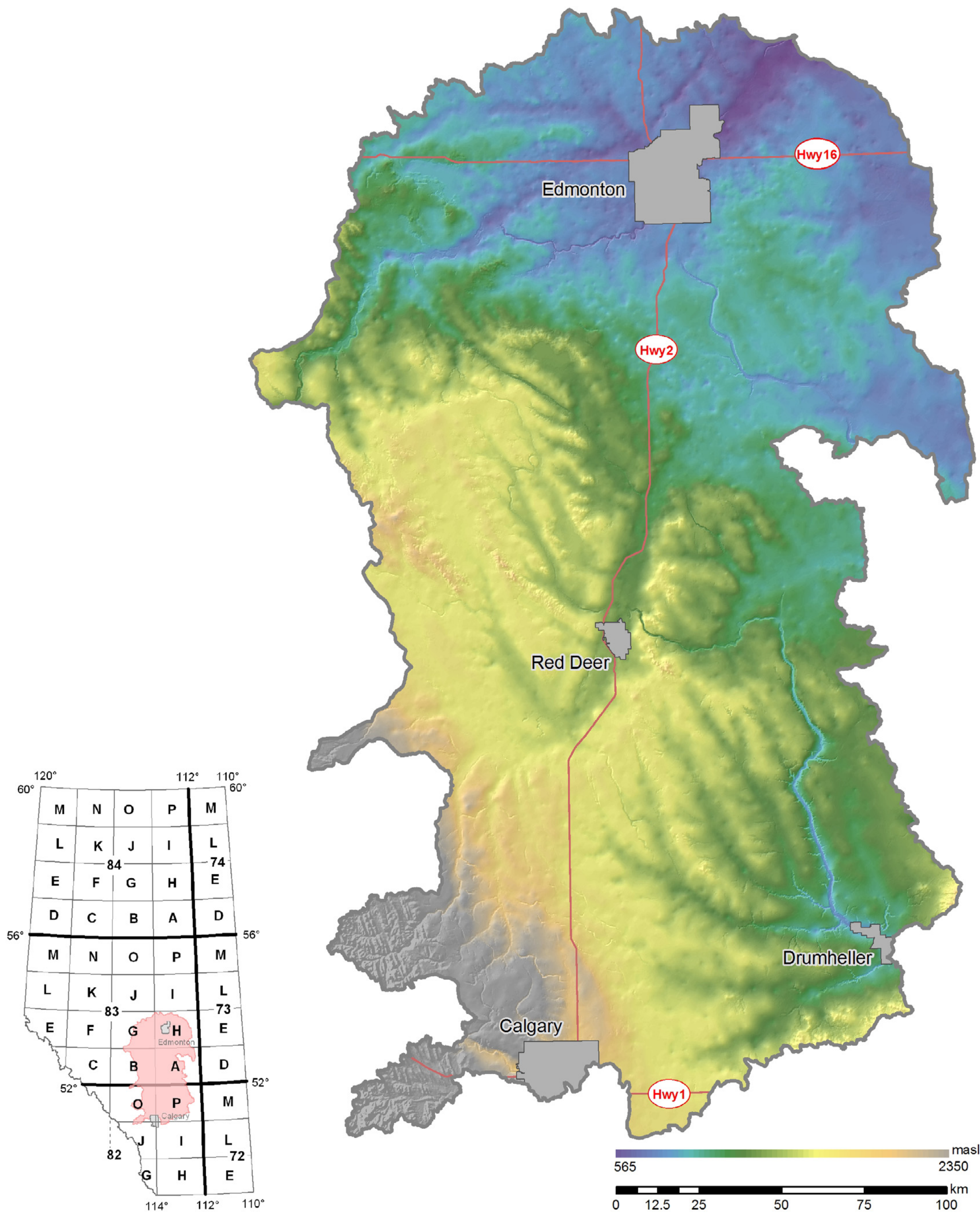

Figure 1. Bedrock topography map of the Edmonton–Calgary Corridor (ECC), Alberta. The map is accented by hillshaded relief and a vertical exaggeration of 20x. Inset map depicts location of the ECC.

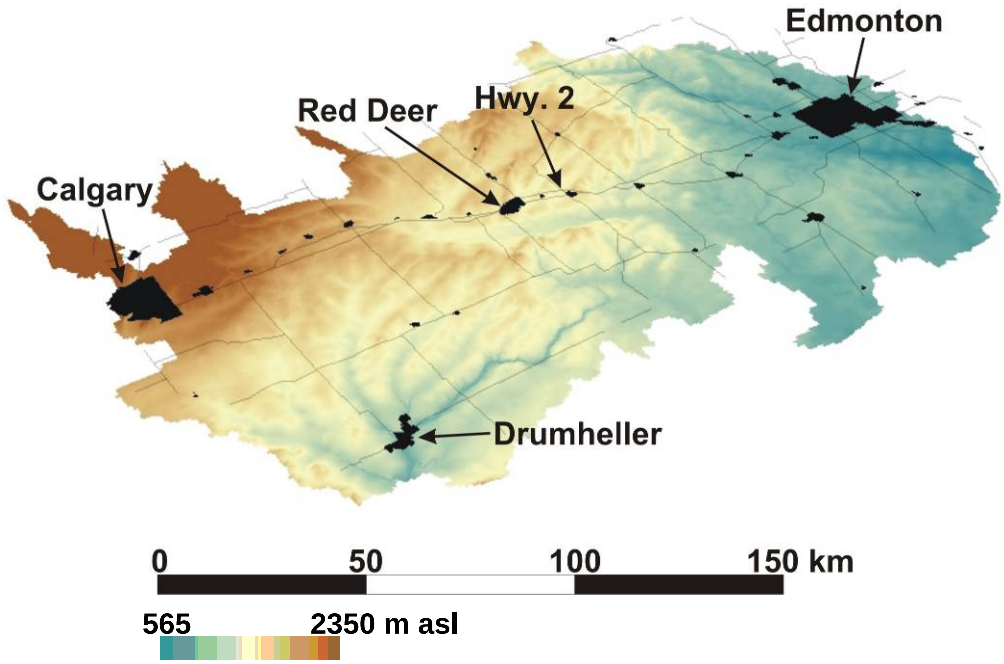

Figure 2. Bedrock topography map of the Edmonton–Calgary Corridor, Alberta, looking northwest. The map is accented by hillshaded relief and a vertical exaggeration of 20x. Urban centres and roads are offset vertically by 3 km. Elevation of bedrock in metres above sea level is defined by colour ramp.

1.1 Bedrock Geology and Topography of the Edmonton–Calgary Corridor

Cretaceous and lower Tertiary (Paleocene) sedimentary rocks of the ECC collectively form a portion of the Western Canadian Sedimentary Basin (Hamilton et al., 1999). From youngest to oldest, these rocks include Paleocene rocks of the Paskapoo Formation, which are predominantly composed of nonmarine calcareous, cherty sandstones, siltstones and mudstones. Conglomerates, coal and tuff beds also occur in the Paskapoo Formation but are uncommon. These rocks unconformably overlie Paleocene and Cretaceous rocks of the Scollard Formation, which are defined by sequences of nonmarine feldspathic sandstones, bentonitic mudstones and coalbeds. These rocks overlie Cretaceous rocks of the Battle and Whitemud formations, which are defined by bentonitic mudstones interbedded with siliceous tuffs (Battle Formation) and nonmarine bentonitic sandstones and mudstones (Whitemud Formation). Below these rocks are nonmarine feldspathic, clay-rich sandstones, bentonitic mudstones, carbonaceous shales, and scattered beds of ironstone and coal of the Horseshoe Canyon Formation. These rocks overlie a sequence of marine shales and sandstones of the Bearpaw Formation, which in turn overlie nonmarine rocks of the Belly River Group, which are composed of feldspathic sandstones and clayey siltstones.

The present-day topography of these rock formations is variable, largely due to the effects of chemical and physical erosion, tectonic events, isostatic rebound and the erosive effects of the Laurentide Ice Sheet during the Quaternary period. In many areas of the ECC, preglacial, ice-marginal and subglacial fluvial systems sculpted the bedrock topography. In other areas, such as Buffalo Lake, glacial tectonism has resulted in a quarried or ‘pitted’ bedrock surface where blocks of bedrock have been displaced several metres (or kilometres) and subsequently buried by variable thicknesses of till, clay, silt, sand and gravel deposits. These processes significantly modified the bedrock topography from its original state, thereby posing obvious challenges to topographic modelling exercises.

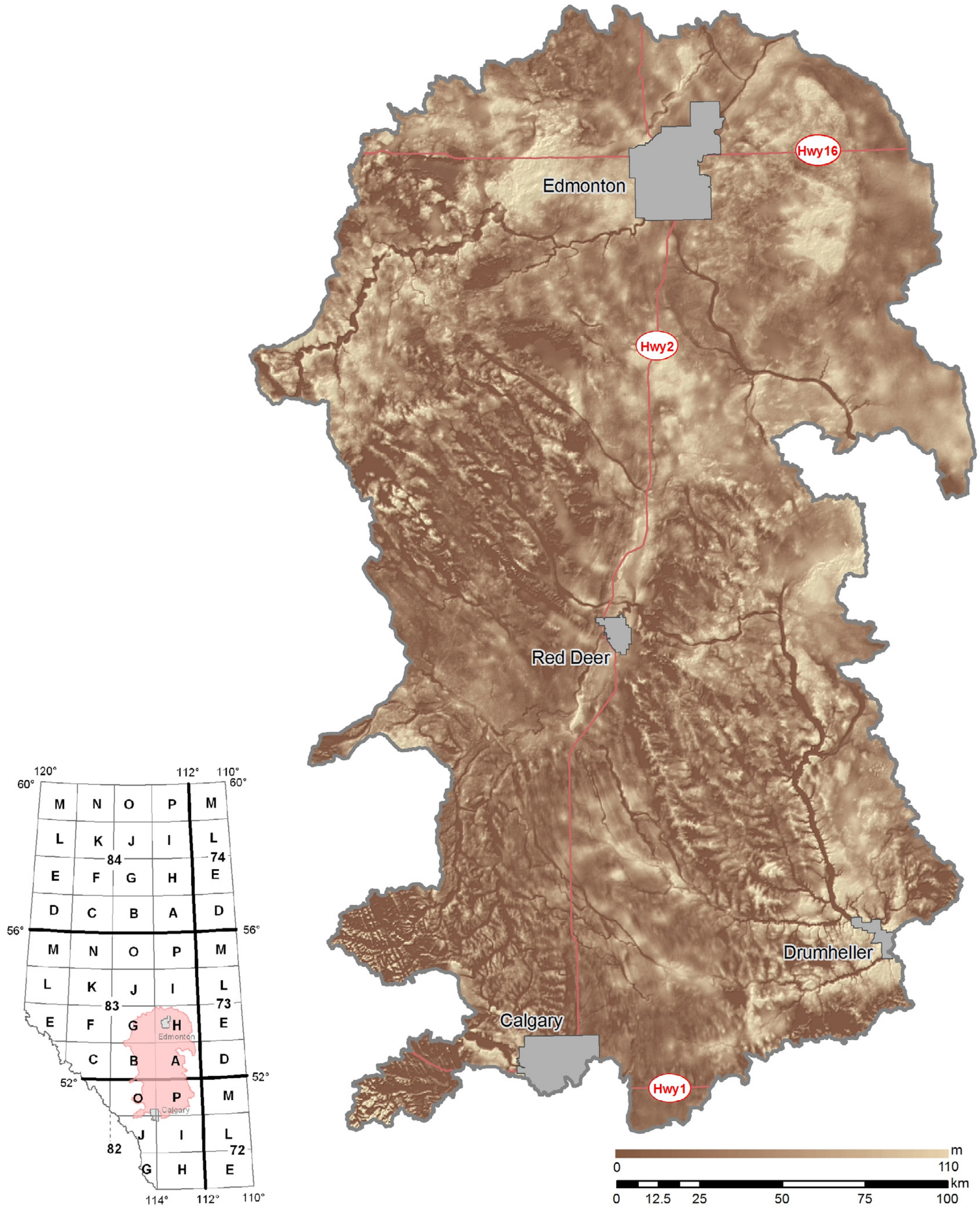

Figure 3. Quaternary and Neogene sediment thickness map of the Edmonton–Calgary Corridor (ECC), Alberta. Sediment thickness in metres above sea level is defined by colour ramp. Vertical exaggeration is 20x. Inset map shows location of the ECC.

1.2 Previous Studies

Investigations pertaining to bedrock topography, sediment thickness and Quaternary geological mapping in the ECC have been completed at a variety of scales by Carlson (1967, 1969, 1971a, b), Bayrock and Reimchen (1980), Andriashek (1987a, b), Shetsen (1987, 1990) and Pawlowicz and Fenton (1995).

Geological data from these investigations, and subsequent interpretations, provided the necessary geological framework for regional-scale studies. Since the completion of these investigations, increases in industrial activity (i.e., oil-and-gas and aggregate exploration programs) and the need for groundwater have provided additional geological data that were unavailable to past investigators. In addition, advances in computing efficiencies, digital data storage and 3-D modelling software have allowed current investigators to visualize the geological data in 3-D space. These advances have enabled faster map preparation and improvements in assessing quality assurance thereby increasing confidence in geological interpretations.

2 Study Area Location and Data Acquisition

The ECC occupies a land mass of approximately 49 500 km^2 and lies within portions of NTS map sheets 82I, J, O, P, 83A, B, G and H. Ten subwatershed boundaries form the irregularly shaped boundary of the ECC study area (Figure 1).

To ensure that all available data were used, a 5 km buffer was created around the boundary of the ECC. A variety of sources provided data on bedrock topography and sediment thickness for the ECC and the buffer zone. These included water-well records from AENV's digital water-well database, oil-and-gas–well records maintained by ERCB, geological maps produced by AGS, a Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with 60 m grid spacing (National Aeronautics and Space Administration, 2000) and geological data obtained from field observations (Carlson 1967, 1969, 1971a, b; Bayrock and Reimchen, 1980; Andriashek, 1987a, b; Shetsen, 1987, 1990; Pawlowicz and Fenton, 1995). Sources of data used are outlined in Table 1 and discussed in detail below. The number of well records and bedrock polygons per township in the ECC are illustrated in Figure 4.

2.1 Water Wells

Water-well records from AENV's digital water-well database (Alberta Environment, 2007) formed the largest portion of data used to generate the bedrock topography and sediment thickness maps. A total of 234 902 water-well records was examined and integrated into the working database. Of these records, approximately 138 284 contain lithological information that describe each material stratum or layer using

Table 1. Data sources and classes used to complete bedrock topography and sediment thickness maps for the Edmonton–Calgary Corridor, Alberta. Abbreviations: AENV, Alberta Environment; AGS, Alberta Geological Society; ERCB, Energy Resources Conservation Board; NASA, National Aeronautics and Space Administration; n/a, not applicable.

Data Source	Data Class	Number of Well Records	Number of Bedrock Polygons
AENV digital water-well database	Water-well records	234 902	n/a
AGS geotechnical database	Geotechnical borehole records	1202	n/a
ERCB oil-and-gas–well database	Oil-and-gas–well records	5161	n/a
AGS borehole database	Geological borehole records	363	n/a
AGS Quaternary maps	Bedrock polygons	n/a	62
NASA, Shuttle Radar Topography Mission	Digital elevation model, 60 m grid spacing	n/a	n/a

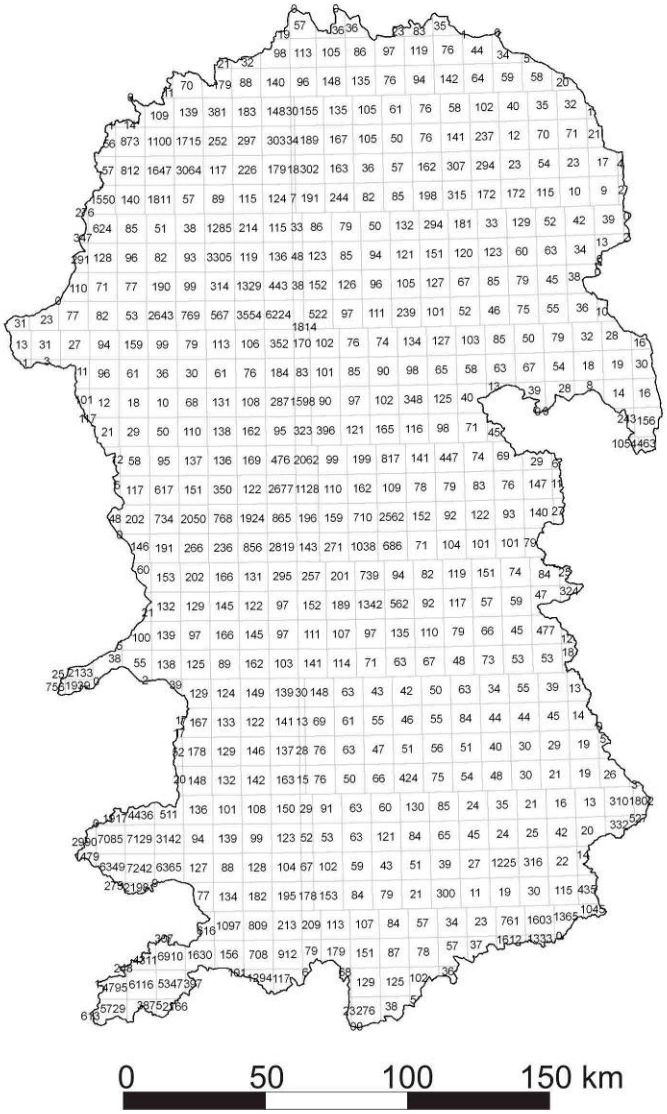

Figure 4. Data density map of the Edmonton–Calgary Corridor, Alberta. Numbers within township boundaries define cumulative number of water-well, oil-and-gas–well, geotechnical, geological borehole records and bedrock polygons within each township.

a combination of primary and secondary geological descriptors. As water-well drillers are typically not familiar with these geological descriptors, the quality is inconsistent (inaccurate material descriptions or misused geological terminology). Also, the records frequently contain georeferencing errors. Quality assurance-quality control (QA-QC) of the water-well dataset is, therefore, critical. This data filtering, discussed in detail below, allows the exclusion of erroneous water-well records.

2.2 Oil-and-Gas Wells

Oil-and-gas–well records for the ECC, which the Energy Resources Conservation Board (ERCB) maintains, contain information on bedrock units and their relative depths. In addition to geological data, downhole geophysical data (i.e., resistivity, gamma, etc.) supplement many of these records. The geological quality of these records is high compared to water-well records contained in the AENV water-well database. In several areas where subsurface data were scarce, these records were used as high-quality reference points during the bedrock topography map generation. A total of 5161 oil-and-gas–well records was integrated into the database.

2.3 Geological Maps

The location of bedrock outcrops and bedrock covered by a veneer of discontinuous sediment (approximately 1 m in thickness) as recorded during past AGS mapping investigations, provided additional high-quality data to the working database. During QA-QC protocols, these data were used to calibrate the bedrock topography and sediment thickness maps. The locations and elevations of bedrock outcrops within the ECC were obtained from existing Quaternary and bedrock topography maps completed by Carlson (1967, 1969, 1971a, b), Bayrock and Reimchen (1980), Andriashek (1987a) and Shetsen (1987, 1990).

2.4 Digital Elevation Model (DEM)

The definition of a DEM is a grid of points that provide digital data on the ground surface relief. In the ECC, a 60 m grid-spaced DEM was used to assign surface and water-well strata elevations, to constrain 3-D geological surfaces, such as bedrock topography, and to calculate sediment thickness. Data used to compile the DEM for the bedrock topography and sediment thickness mapping were obtained from the SRTM (National Aeronautics and Space Administration, 2000).

2.5 Additional Datasets

Additional high-quality geological data, such as records of continuously cored boreholes and geophysical picks completed by AGS, stored within the AGS borehole and geotechnical databases, were also incorporated into the database. These data points were considered as high-quality calibration points during map generation and subsequent QA-QC measures.

3 Data Preparation and Filtering

When dealing with large datasets compiled from a variety of sources, how to extract and prepare meaningful data for map generation is critical. Successfully filtering out erroneous data prior to map interpolation enhances map quality, increases the level of confidence in geological interpretations and reduces the amount of time required for QA-QC protocols.

Common problems associated with well records, in particular water-well records, are ambiguous geospatial information (e.g., unknown UTM zones and datums, unreliable locations such as wells located inside lakes), material layers without depth values, and ground surface elevations inconsistent with DEM values. Prior to initial map generation, wells with these inconsistencies are flagged and either adjusted within or removed from the working database (Table 2).

3.1 Data Filtering: Duplicate Wells

In the AENV database, the geographic position of water wells is based on the Dominion Land Survey (DLS) system. The AGS approach to plotting these wells is to assign well locations to the centre of the smallest described land parcel. The smallest of which is termed a legal subdivision, which is approximately 400 by 400 m. Typically, the smallest described land parcel in the AENV database is at the quarter section level, which is approximately 800 by 800 m. Therefore, several wells located within a single parcel of land may have identical location co-ordinates.

For each of the locations with multiple well data, an average depth to bedrock was calculated for each location. Wells with bedrock depths that differed by more than 3 m from the calculated average were

Table 2. Data quantity before and after using AGS filtering processes; used to complete bedrock topography and sediment thickness maps for the Edmonton–Calgary Corridor, Alberta. Abbreviations: AENV, Alberta Environment; AGS, Alberta Geological Society; ERCB, Energy Resources Conservation Board.

Data Source	Data Class	Number of Data Points (pre-filtering)	Number of Data Points or Polygons (post-filtering)	Percentage of Data Used in Map Generation
AENV digital water-well database	Water-well records	234 902	138 284	58%
ERCB oil-and-gas–well database	Oil-and-gas–well records	5161	5161	100%
AGS geotechnical database	Geotechnical records	1202	1202	100%
AGS borehole database	Geological well records	363	363	100%
AGS Quaternary maps	Bedrock polygons	62	62	100%

removed from the database. The interpolation process used the remaining average values to reflect a best-estimate depth to bedrock within a specific land parcel.

3.2 Data Filtering: Depth Values

In some water-well records, material layers do not have depth values. Without depth constraints, the layers 'float' without a fixed position in the succession of strata, causing an incorrect allocation of the bedrock surface. Wells containing floating layers were removed from the database.

3.3 Data Filtering: Wells Located within Lakes

Wells located inside permanent lakes are regarded as erroneous and were removed from the database. Digital lake coverage for the ECC was used to filter out these wells.

3.4 Material Determination: Construction of a Primary Lithology Legend

The manual selection of specific materials (i.e., clay, silty clay, shale, siltstone, etc.) in a well record, often referred to as picking, is a labour-intensive exercise that is time consuming and in many cases impractical due to the large number of water wells and resource constraints. In recognition of this problem, a primary lithology legend to both filter ambiguous materials in the database and to reduce the variations of terms used by the water-well industry to describe the same geological material. Russell et al. (1998), Slattery (2003) and Gao et al. (2006) used similar systematic approaches to condense large datasets.

The AENV database contains up to two fields of geological descriptors for each material recorded by well drillers and geologists. These descriptors, entitled Material 1 and Material 2, describe the texture and physical characteristics of individual layers or rock types. Generally, material descriptions, such as rock or sediment type, populate the Material 1 field, whereas additional physical attributes (such as colour, density, etc.) populate the Material 2 field (Table 3).

Table 3. An example of geological data from the Alberta Environment digital water-well database (Alberta Environment, 2007).

Well ID	Depth to Top of Material Layer (m) [1]	Depth to Bottom of Material Layer (m) [1]	Material 1	Material 2
190888	121	124	Clay and silt	Loamy
190888	124	138	Gravel	Mixed
190888	138	144	Sandstone	Soft

[1]below ground surface

In the working database, more than 22 000 different combinations of descriptors describe the various strata or rock types in the ECC. Manual inspection of every combination is not feasible due to time constraints. Therefore, an automated approach to identify unique combinations of descriptors was constructed for the ECC database. This method simplified and streamlined descriptors used to describe the same materials. This approach identified 2662 unique combinations of descriptors that describe materials found in the ECC. To further condense the descriptors and provide users with a standardized set of geological descriptions, the unique combinations of descriptors were manually translated into one of twenty-five primary lithologies devised by AGS (Table 4; modified from Russell et al., 1988). Each of the primary lithologies was assigned a code. A query in Microsoft Access® translated all descriptors in the working database to one of the twenty-five primary lithology codes.

Coding unique combinations of material descriptions relies on the assumption that the descriptions used by well drillers refer to the same materials and correspond to geological descriptions used by geologists (Table 5). In some cases, these descriptions are clear and sufficient to determine whether the material is of sediment (e.g., sand or gravel) or bedrock (e.g., sandstone or shale). Comparison of well records with local bedrock geology maps was completed to decipher questionable geological descriptions used by drillers. For example, water-well drillers frequently use claystone to describe rocks of the Horseshoe Canyon Formation.

Table 4. Alberta Geological Survey's primary lithology codes (modified from Russell et al., 1998).

Code	Primary Lithology
13	No obvious material
12	Covered: missing; previously bored
11	Fill (including topsoil, waste)
10	Organic
9	Clay, silty clay
8	Silt, sandy silt, clayey silt
7	Sand, silty sand
6	Gravel, gravelly sand
5	Clay-clayey silt diamicton
5.1	Clay-clayey silt diamicton, stony
4	Silt-sandy silt diamicton
4.1	Silt-sandy silt diamicton, stony
3	Silty sand-sand diamicton
3.1	Silty sand-sand diamicton, stony
2	Diamicton, texture unknown
1	Bedrock
1.1	Sandstone
1.2	Siltstone
1.3	Claystone
1.4	Mudstone
1.5	Limestone
1.6	Shale
1.7	Dolomite
1.8	Potential bedrock
1.9	Coal

Table 5. An example of coding the layers of geological material in a water well, based on Alberta Geological Survey's primary lithology legend.

Well ID	Depth to Top of Material Layer (m) [1]	Depth to Bottom of Material Layer (m) [1]	Material 1	Material 2	Primary Lithology	Code
190888	121	124	Clay and silt	Loamy	Clay-clayey silt diamicton	5
190888	124	138	Gravel	Mixed	Gravel, gravelly sand	6
190888	138	144	Sandstone	Soft	Sandstone	1.5

[1] below ground surface

3.5 Bedrock Determination: Computing Algorithm

Once all descriptors in the database were populated with the primary lithology numeric codes, a series of Microsoft Access® queries were used to identify wells containing bedrock. The queries identified the numeric codes that coincide with bedrock in the primary lithology legend (codes 1 through 1.9; refer to Table 4). Wells with bedrock numeric codes were then flagged in the database.

3.6 Displaced Bedrock

In the ECC, evidence of glaciotectonism is found in ice-thrust moraines, ice-thrust ridges/blocks and source depressions. In some areas, blocks of bedrock have been displaced vertically and horizontally several metres to kilometres and subsequently buried by variable thicknesses of glacial sediments. In many cases, well drillers and geologists misinterpret displaced blocks of bedrock as in situ bedrock.

The following method was used to identify displaced bedrock in well records. Wells with any numeric codes (2 through 13; Table 4) occurring stratigraphically below those layers assigned bedrock numeric codes (1 through 1.9; Table 4) were flagged as potential locations of displaced bedrock. Table 6 presents an example of displaced bedrock in a water-well record.

As a cautionary note, whereas this method provides an elevation estimate of the top of the bedrock in well records that contain solitary intervals of displaced bedrock, it does not identify the true elevation of the bedrock surface in well records with multiple intervals of displaced bedrock. For example, for well records that contain multiple zones of displaced bedrock (separated by lithologies other than bedrock), the elevation of the bedrock surface is inadvertently assigned to the elevation of the second bedrock interval.

Table 6. An example of filtering water-well records for in situ and displaced bedrock.

Well ID	Depth Interval (m) [1]	Material 1	Material 2	Primary Lithology	Code	Interpretation
190881	121–124	Clay and silt	Loamy	Clay-clayey silt diamicton	5	Diamicton (till?)
190881	124–138	Gravel	Mixed	Gravel, gravelly sand	6	Glaciofluvial(?)
190881	138–144	Limestone	Soft	Limestone	1.5	Displaced bedrock
190881	144–152	Limestone	Soft	Limestone	1.5	Displaced bedrock
190881	152–166	Clay and silt	Loamy	Clay-clayey silt diamicton	5	Diamicton (till?)
190881	166–178	Clay and silt	Loamy	Clay-clayey silt diamicton	5	Diamicton (till?)
190881	178–197	Sandstone	Soft	Sandstone	1.5	In situ bedrock
190881	197–212	Sandstone	Soft	Sandstone	1.5	In situ bedrock
190881	212–267	Sandstone	Soft	Sandstone	1.5	In situ bedrock

[1] below ground surface

Therefore, this method is only an initial means of locating areas of displaced bedrock in the ECC. Until an improved filtering method is developed, it is advised that site specific investigations (i.e., additional borehole drilling) are used to determine depth to bedrock in areas of displaced bedrock within the ECC.

3.7 Bedrock Outcrops

The locations of bedrock outcrops and bedrock covered by a thin (approximately 1 m thick) layer of discontinuous sediment within the ECC were obtained from digitized Quaternary and bedrock topography maps completed by Carlson (1967, 1969, 1971a, b), Bayrock and Reimchen (1980), Andriashek (1987a) and Shetsen (1987, 1990).

Locations of bedrock outcrops were converted from georeferenced polygons (polygons with assigned northing and easting co-ordinates with unknown elevation values) to point data coverage (points with assigned northing, easting and elevation values) using ArcGIS software.

To complete this conversion, grids with internal dimensions of 100 by 100 m were constructed for each bedrock polygon (Figure 5). At grid intersections, an elevation point was assigned using a DEM with a 60 m grid spacing. A similar approach was used to integrate bedrock polygons covered by thin (approximately 1 m) layers of sediment. Prior to the integration process, an assigned thickness of 1 m was subtracted from DEM values to reflect bedrock elevations in these areas.

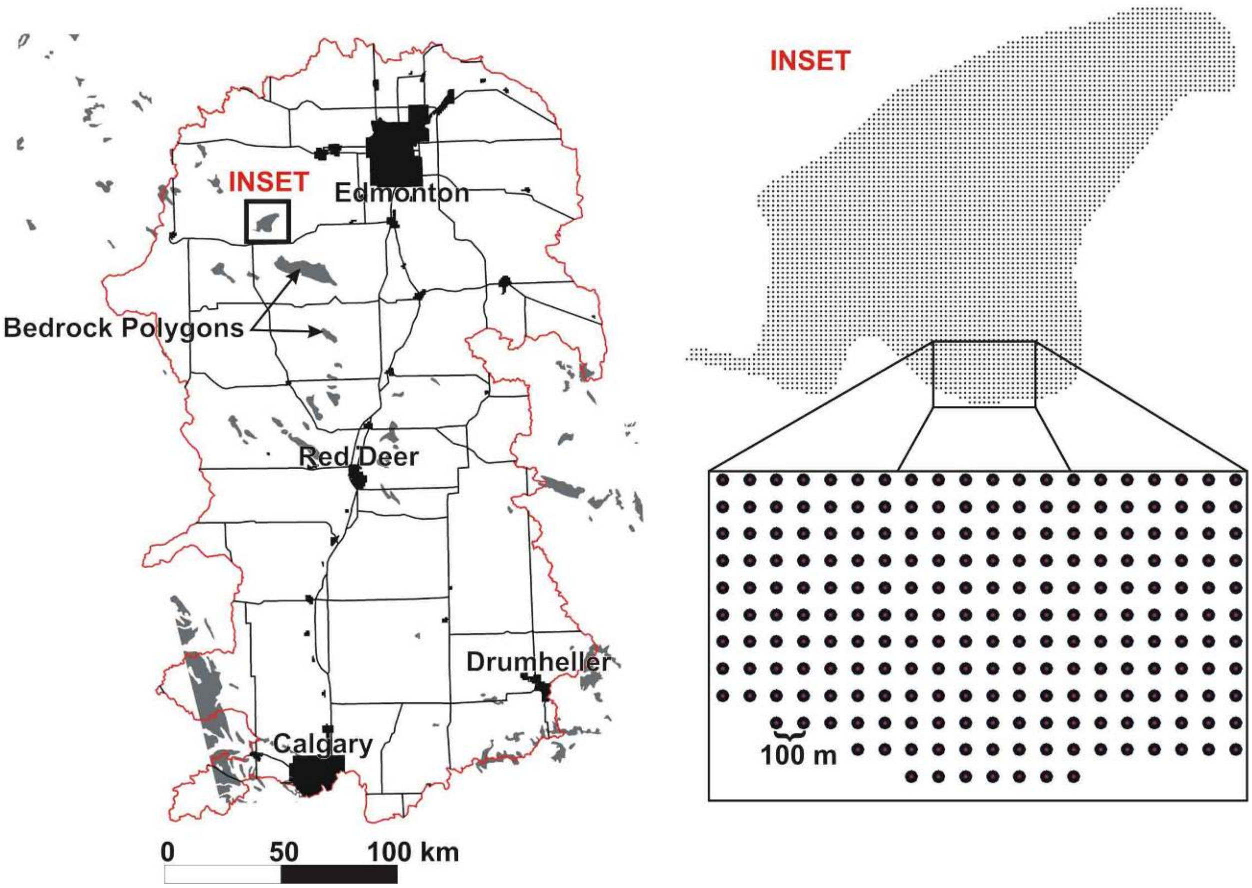

Figure 5. Integration of bedrock polygons to the working database, Edmonton–Calgary Corridor, Alberta. Inset depicts translation of polygons to point data. Points are constructed at 100 m intervals. Elevation data for the points were obtained from the Shuttle Radar Topography Mission, digital elevation model with 60 m grid spacing (National Aeronautics and Space Administration, 2000).

3.8 Deep Wells in Thin-Sediment Areas

Wells with deep bedrock depths that are located in thin-sediment areas (less than 1 m of overlying sediment) indicate a potential contradiction between the drilling record and geological observations. Since the Quaternary geology of the ECC was mapped at a regional scale (1:500 000), it is possible that wells reaching bedrock at greater depths (e.g., 20 m below ground surface) exist in a thin-sediment area. Such wells, if valid, can be used to define bedrock depressions. These records were manually checked and for those that appeared valid, the bedrock topography was adjusted accordingly.

3.9 Data Standardization

All data points in the database were standardized from UTM co-ordinates to 10 Degree Transverse Mercator (10TM) co-ordinates, and bedrock elevations were displayed as metres above sea level (m asl). Bedrock elevations were assigned or calculated based on the following three protocols:

1) for drilling records, bedrock surface elevations were calculated as the DEM elevation minus the depth to bedrock
2) for bedrock outcrops, bedrock surface elevations were assigned the corresponding DEM values
3) for artificial points, such as areas of thin-sediment cover (approximately 1 m sediment), identified from AGS bedrock maps, bedrock surface elevations were calculated as the DEM elevation minus 1 m

4 Bedrock Surface Interpolation

The ECC can be divided into two regions based on sediment thickness and Quaternary geological mapping (Shetsen 1987, 1990). These include areas of thick sediment cover, where sediment thickness exceeds 1 m, and thin-sediment cover, where sediment thickness rarely exceeds 1 m. In areas dominated by thick-sediment cover, the underlying bedrock topography is masked; whereas in areas of thin sediment cover, the relationship between ground surface and bedrock topography is much closer. For this reason, different approaches of interpolation were developed. These approaches are outlined below.

4.1 Kriging in Areas of Thick-Sediment Cover

Following data standardization, it is possible to interpolate the bedrock topography from all known bedrock elevation points. Based on geostatistical analysis using ArcGIS Geostatistical Analyst, bedrock elevation in the ECC shows a clear trend, increasing to the southwest toward the Rocky Mountains. A global first-order polynomial accounted for this trend. Higher order polynomials provided no further improvement to the model and added unnecessary complexity. The residual values (measurements minus the trend) were modelled using ordinary kriging, which accounted for local variations in the trend value. The final model included the global trend to the estimated residuals.

The best semivariogram fit to the spatial structure of the residuals has a nugget effect of 196 m^2 and an isotropic exponential structure with a range of 128 km and a contribution of 7073 m^2. The cross-validation mean squared error of the final model is 10.6 m with most of the large errors occurring in the Foothills of the southwest or associated with buried channel or valley features, where local-scale fluctuations in bedrock elevation occur.

Determining the bedrock topography involved a three-step process (Figure 6):

1) Kriging – Generation of an initial bedrock topography map from all bedrock elevation points in the working database.
2) Assess the quality and fit of the modelled surface to the data – The QA-QC process involved careful inspection of the kriged bedrock topography in plan and perspective views. Particular attention was

paid to wells that create excessive peaks or depressions in the surface. Problematic data points were either corrected or removed from the database.

3) Re-kriging – The refined dataset of bedrock elevation points was re-kriged to generate a final bedrock topography map.

At the QA-QC stage, useful information sets that may assist in screening out problematic wells include

1) data from wells within a 100 m radius of the problematic well,
2) bedrock and Quaternary geology maps, and
3) a hillshaded ground surface relief map derived from the DEM.

4.2 Kriging in Areas of Thin-Sediment Cover

In areas of thin-sediment cover, where sediment thickness is less than 1 m, the ground surface reflects the bedrock surface. Using ArcGIS 3DAnalyst, bedrock topography was generated by subtracting the sediment depth from the DEM, a process referred to as thickness kriging. Using this kriging approach, it is possible to incorporate information from geological observations, such as the location of partially exposed bedrock outcrops. For simplicity, the depth value used for subtraction from the DEM is 1 m or zero depending on whether the bedrock is partially or fully exposed at ground surface.

4.3 Constraining Bedrock Topography to Ground Surface

To ensure that the bedrock topography surface did not exceed ground surface elevation, the elevation of the bedrock topography surface was constrained to a 60 m grid-spaced SRTM DEM. In areas such as river valleys, where the elevation of the bedrock topography surface exceeded ground surface, the 100 by 100 m bedrock surface grid cell was assigned a value of 0.5 m below the DEM. This series of calculations was completed using the grid calculator function in EarthFX VIEWLOG®.

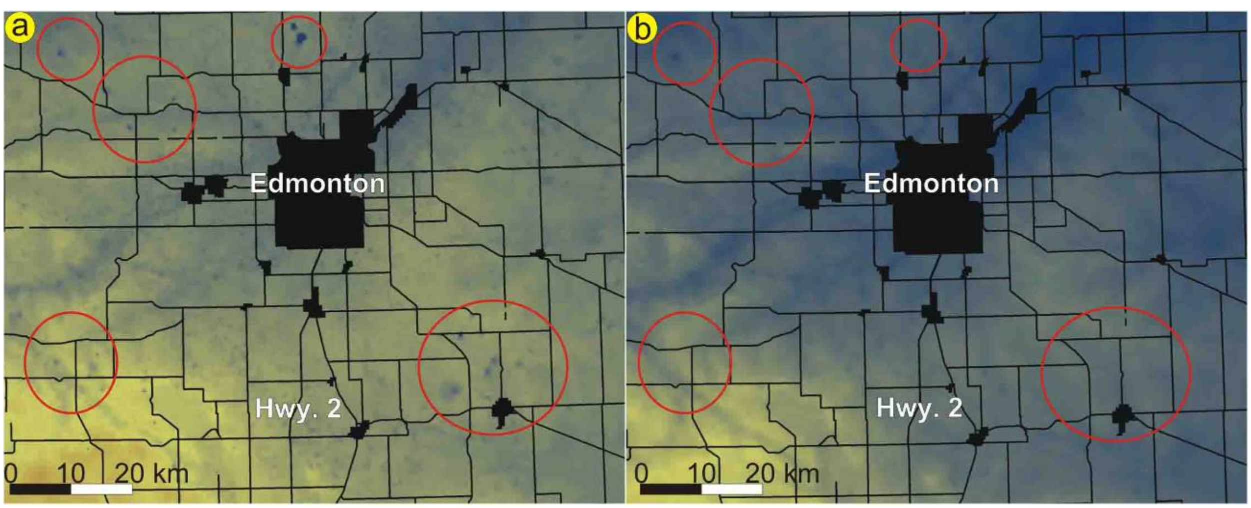

Figure 6. a) Initial generation of the bedrock topography surface at a vertical exaggeration of 25x, Edmonton, Alberta. Red circles depict areas of erroneous data. b) Erroneous data points are screened from the working database using appropriate quality assurance-quality control measures. Refined dataset of bedrock elevation points is re-kriged to generate a final bedrock topography map.

5 Sediment Thickness Calculation

The sediment thickness calculation is a subtraction of the constrained bedrock surface elevation from the corresponding elevation in the SRTM DEM using the minus function in ArcGIS 3DAnalyst. Negative sediment thickness values may occur in areas where there are complex slopes in the DEM or bedrock topography surface. This may occur when a linear surface is interpolated between data points across a steep escarpment or surface depression, such as a river valley. It is difficult, if not impossible, to collect enough data points in these areas to eliminate negative values. However, an understanding of landform architecture, morphology and the Quaternary geology of the study area and field-testing areas of question are helpful in rectifying these problems.

Negative thickness values commonly occur in regions where discontinuous veneers of sediment exist. As such, these negative values are changed to a sediment thickness of 1 m and are reclassified as areas of thin-sediment cover. Sediment thickness in these areas will require verification through field-based testing. The methods used to complete the sediment thickness map are summarized below:

1) Calculate the initial sediment thickness by subtracting the constrained bedrock surface from the DEM using the minus function in ArcGIS 3DAnalyst.
2) Reconcile negative thickness values by reclassifying into areas of thin sediment cover, if applicable.
3) Complete QA-QC through the inspection of high-quality wells located within areas of thin-sediment cover. Where possible areas of thin-sediment cover are field tested.
4) Re-krig the dataset to refine the sediment thickness map, after filtering the dataset for erroneous data points.

6 Conclusions

Development of the outlined methodology enabled the generation of bedrock topography and sediment thickness maps for the ECC (Figures 1–3). The pseudo-automated methodology described in this report allows one to integrate and analyze large geo-datasets compiled from a variety of sources in a time-efficient manner. In addition, this methodology provides future investigators with a user-friendly means of integrating newly acquired data.

Because data come from multiple sources in the ECC, numerous quality assessment and quality control measures have been developed to ensure that the scientific integrity of map products are upheld. It is paramount that subsurface data, in particular water-well records, are properly filtered to ensure that erroneous data are identified and eliminated prior to map generation. This enhances map quality, increases confidence in geological interpretations and efficiencies in data retrieval and manipulation.

The methodologies described throughout this report facilitate the generation of regional-scale bedrock topography maps. Maps presented in this report form the basis for future regional-scale groundwater studies (in particular, the identification of potential groundwater exploration targets, such as buried channel complexes), aggregate resource assessments, geotechnical work and other land-use applications.

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