Edmonton–Calgary Corridor Groundwater Atlas

Government of Alberta

ERCB Energy Resources Conservation Board

AGS Alberta Geological Survey

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1. Introduction

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Why We Map Groundwater

Water is one of Alberta's most important resources. Managing it requires high-quality scientific information. This atlas will help Albertans better understand the province's ***groundwater*** resources by describing the groundwater-mapping processes used to map these resources. It starts with descriptions of the study area, geology, and physical and chemical properties of groundwater, and then provides details of the results of the mapping work.

The *Water for Life*[1] strategy outlines the Government of Alberta's commitment to managing water resources. Groundwater-resource management aligns with each of the following *Water for Life* goals:

- safe, secure drinking water;
- healthy, aquatic ecosystems; and
- reliable, quality water supplies for a sustainable economy.

Groundwater mapping is identified in the 2009 *Water for Life* Action Plan[2] as a key action to improve knowledge about our groundwater resources.

This groundwater-mapping atlas focuses on the Edmonton–Calgary Corridor (ECC) and examines fresh groundwater based on its geological, hydrological and hydrochemical properties.

Why the Atlas Focuses on the ECC
The corridor between Edmonton and Calgary

- is a data-rich region of the province. As the most populated area of Alberta, it has more water wells than any other part of Alberta. The area also has many other sources of information on geology and ***hydrogeology***. As a result, the ECC is an excellent area to study groundwater.
- has a very high demand for water. The ECC is experiencing rapid urban and industrial growth, as well as ongoing agricultural development and possible climate shifts. All of these influences have the potential to affect the area's water resources. Therefore, thorough planning is essential to ensure Albertans have enough groundwater in the future.

Alberta Geological Survey (AGS), which is part of the Energy Resources Conservation Board, and Alberta Environment worked together to map groundwater in the ECC and plan to do ongoing mapping work for the rest of the province.

Understanding Alberta's Changing Water Landscape
Most water users in the ECC rely on water in lakes, rivers, sloughs and springs. But growing demand from urban, industrial and agricultural users is straining these surface-water sources. This means that the urban, industrial and agricultural users will be turning more and more to groundwater sources to meet their growing water needs. This will affect current users of groundwater resources who have traditionally been rural residents.

Groundwater mapping will tell us how much groundwater is available and will show the shapes and locations of ***aquifers*** (sources of groundwater) and ***aquitards*** (underground barriers to water movement). Information about aquifers and aquitards is critical when assessing how to meet new demands for groundwater.

Understanding aquifers and the geology around them can

- direct new water users to additional groundwater sources, giving them the water they need and limiting depletion of any stressed groundwater sources;

Red Deer River in the southeastern part of the Edmonton–Calgary Corridor. In the photo you can see a number of meander bends and a broad flood plain. The water is carrying sediment giving it a murky look.

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- provide a scientific basis for protecting groundwater sources and areas that replenish groundwater;
- help us create models for groundwater flow in Alberta;
- support sustainable groundwater use; and
- help all levels of government make informed decisions about protecting groundwater.

How the Atlas is Organized

To understand groundwater in an area as large as the ECC, we began by studying the area's geology (the history, structure and composition of the Earth), then the hydrogeology (groundwater and its physical properties and movements), and finally, we looked at the ***hydrochemistry*** (the chemical characteristics of groundwater).

To provide an overview of groundwater resources in the ECC, we organized the atlas into the following sections:

- ***bedrock*** geology;
- ***surficial*** geology;
- ***hydrology***;
- hydrogeology;
- hydrochemistry; and
- a summary.

Each section summarizes the work that AGS completed for the ECC groundwater-mapping project and provides a short summary of the methods used to create the various maps. Words highlighted with ***bold italics*** are defined in the glossary. The maps in the atlas are based on available geological data. They give general information about the geology in the ECC, as well as the hydrogeological and hydrochemical properties of the ECC's geological units. However, the atlas is not intended to be a technical document. Readers who would like more technical publications and maps about the ECC should visit the AGS website at http://www.ags.gov.ab.ca/publications.

Study Area

The ECC is about 49 500 km^2 in area and is roughly the size of Nova Scotia (55 284 km^2) (Figure 1.1). The ECC lies in portions of the North Saskatchewan, Battle, Red Deer and Bow river basins (Figure 1.2). The irregularly shaped boundary is the result of combining the shapes of 10 smaller drainage basins contained within the major river basins.

ECC Land Use and Vegetation

White Zone

The ECC is located mainly in Alberta's *white zone* (Figure 1.1). The Alberta Government's Ministry of Sustainable Resource Development uses the term white zone to describe land that is generally privately owned, settled, populated and used for agriculture. Public land in the white zone is managed by Sustainable Resource Development. These lands are generally used for agricultural purposes, such as grazing.

Green Zone

Small portions of the ECC's western edge are in the *green zone*, which is Alberta's forested land (Figure 1.1). Sustainable Resource Development manages public land in the green zone for timber production, watershed protection, wildlife, fisheries, recreation and other activities.

Alberta's Natural Regions and Subregions

Landforms, soil type, vegetation and elevation are the main factors influencing land use in Alberta. Sustainable Resource Development combined these factors to produce the Natural Regions and Subregions of Alberta map. The ECC lies within parts of five natural regions and 11 subregions (Figure 1.3).

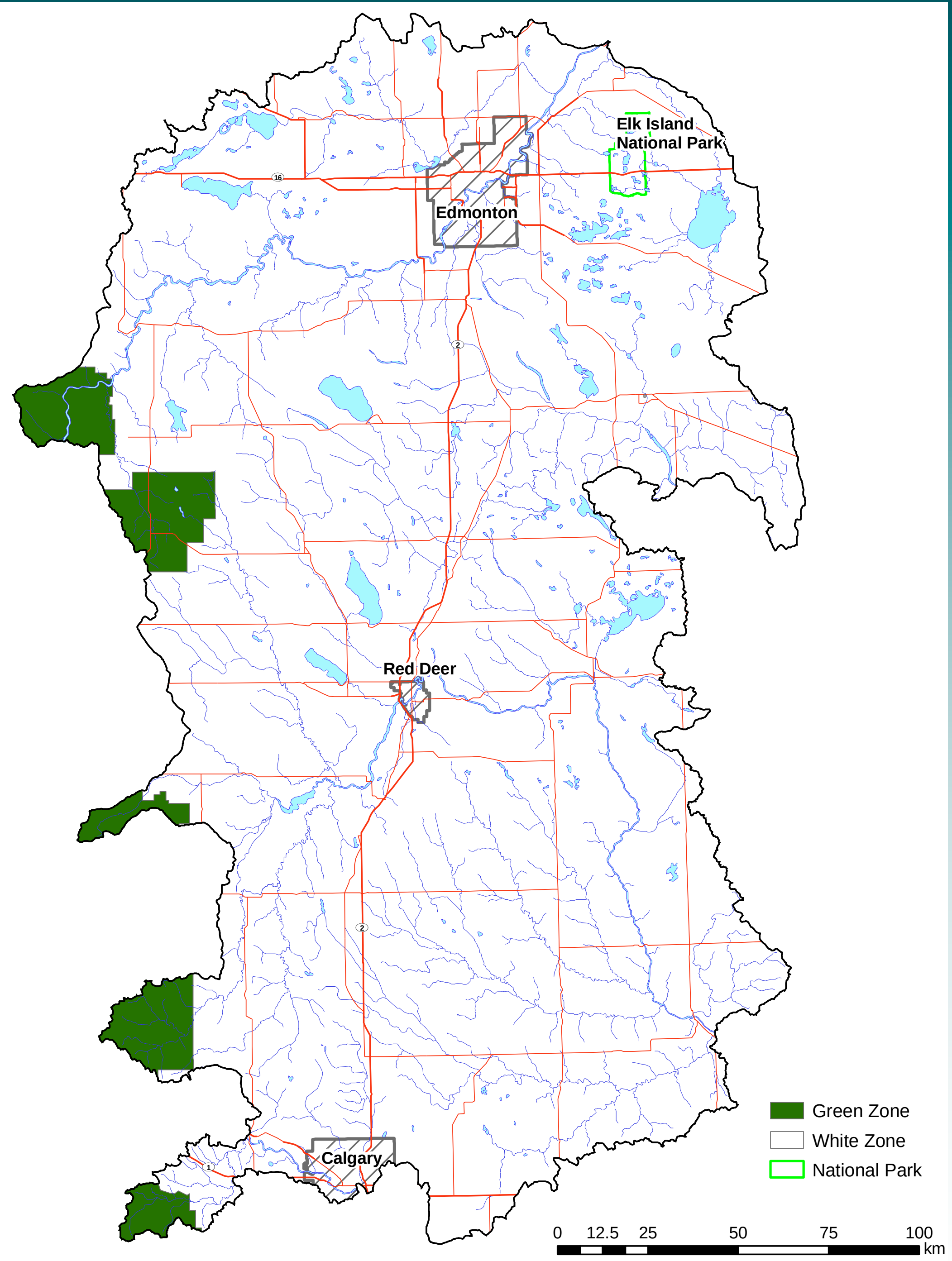
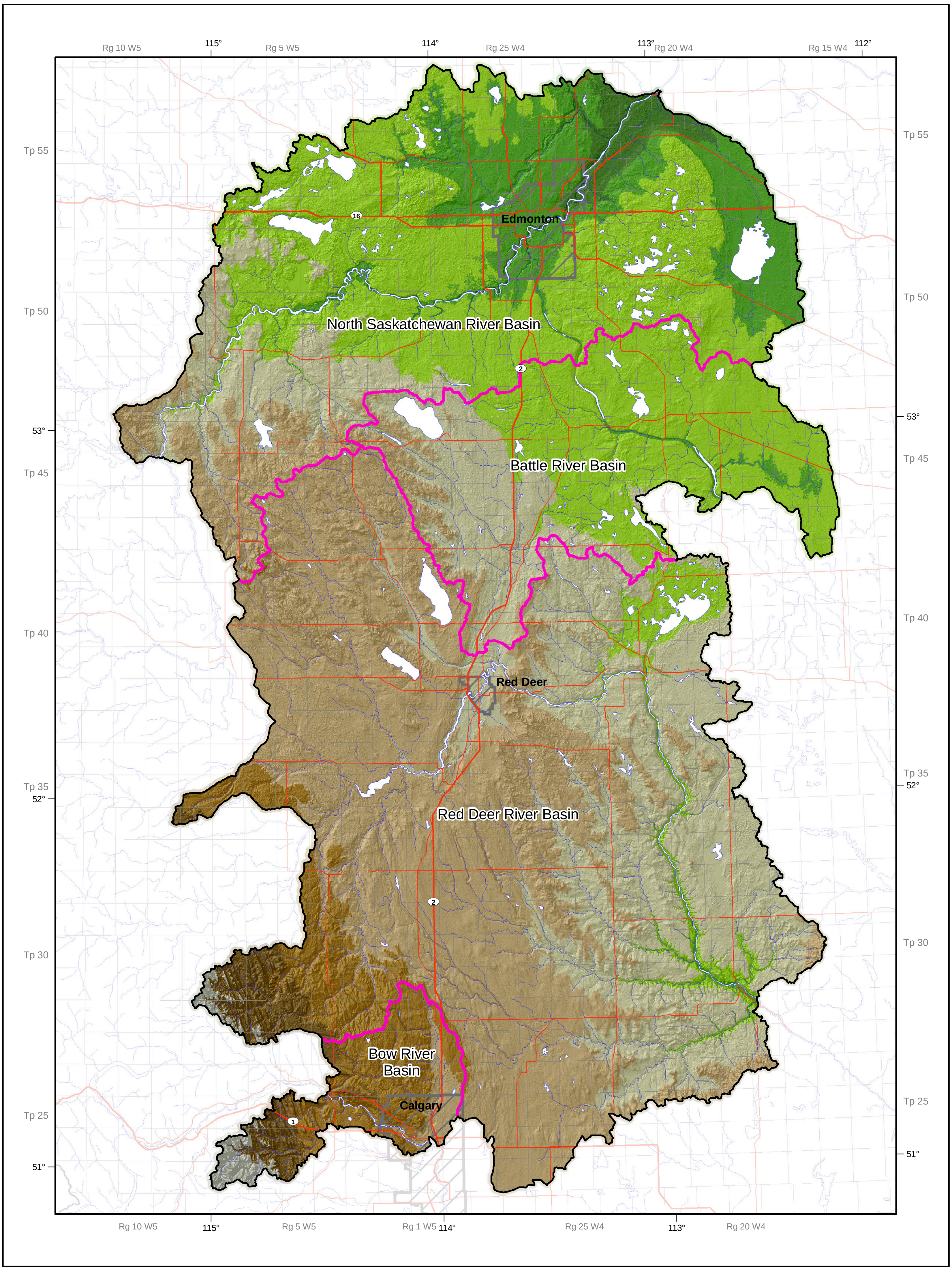


Figure 1.1. Study area with green and white zones.

1. Introduction



Edmonton-Calgary Corridor Study Area with Topography and Major Drainage Basins (Figure 1.2)

Ground Elevation (m asl)

- 582 - 650
- 651 - 700
- 701 - 800
- 801 - 900
- 901 - 1100
- 1101 - 1300
- 1301 - 1500
- 1501 - 2450

Major Basin Boundaries

0 12.5 25 50 75 100 km

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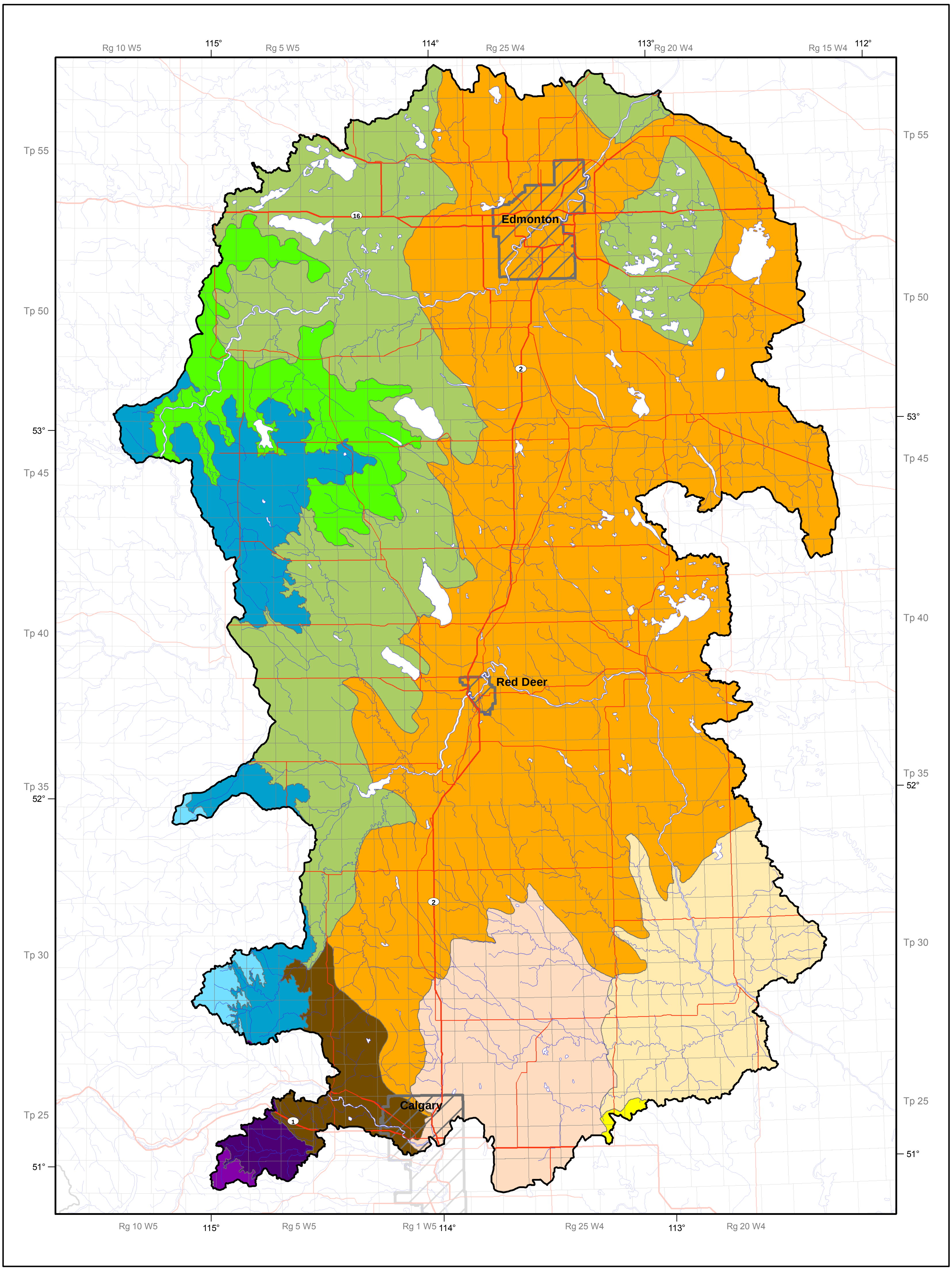
1. Introduction



Natural Regions of Alberta (Figure 1.3)

Natural Regions and Subregions

Rocky Mountain
- Subalpine
- Montane

Foothills
- Lower Foothills
- Upper Foothills

Boreal Forest
- Central Mixedwood
- Dry Mixedwood

Parkland
- Foothills Parkland
- Central Parkland

Grassland
- Foothills Fescue
- Northern Fescue
- Mixed Grass

0 12.5 25 50 75 100 km

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The natural regions and subregions (the subregions are in parentheses) are

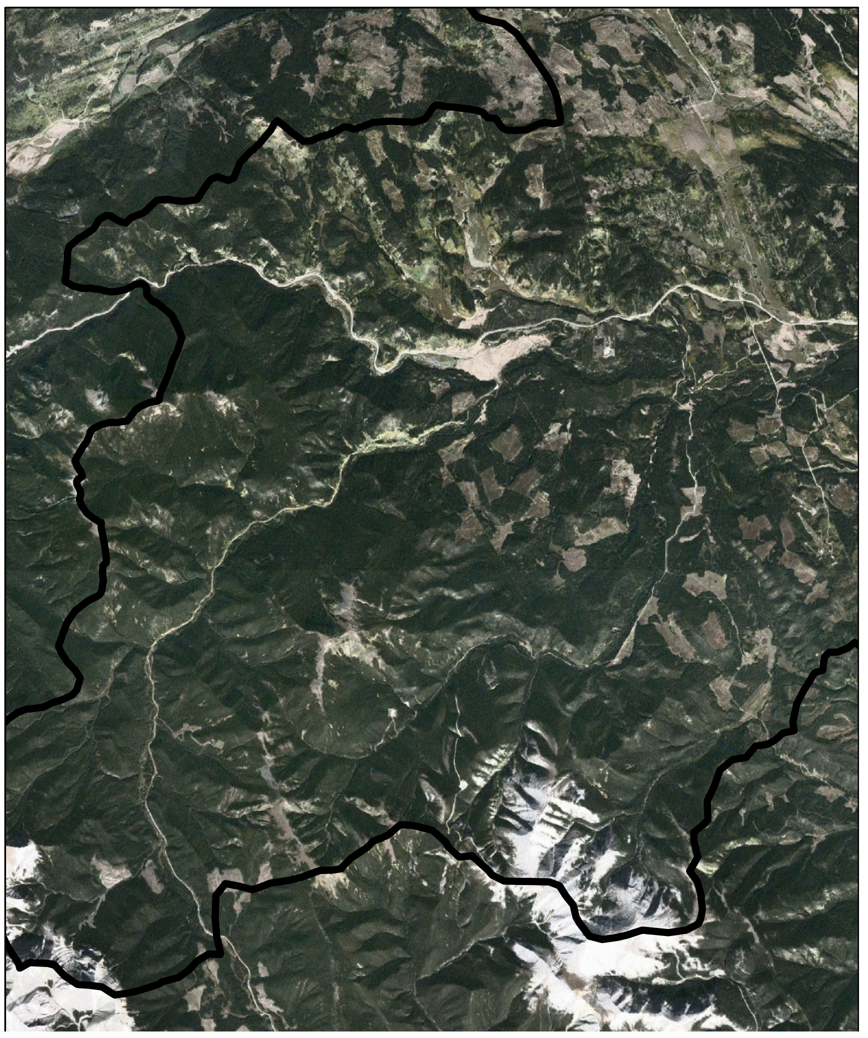
- Rocky Mountain Natural Region (Subalpine and Montane);
- Foothills Natural Region (Lower Foothills and Upper Foothills);
- Boreal Forest Natural Region (Central Mixedwood and Dry Mixedwood);
- Parkland Natural Region (Foothills Parkland and Central Parkland); and
- Grassland Natural Region (Foothills Fescue, Northern Fescue and Mixedgrass).

Most of the ECC is within the Parkland and Boreal Forest natural regions. A small part along the ECC's western edge is within the Foothills and Rocky Mountain natural regions. The south-central and southeastern sections of the study area lie in the Grassland Natural Region.

Vegetation
Geographic latitude and elevation affect the types of vegetation that grow in the ECC. The native vegetation in the southern portion of the ECC consists mostly of grasses and shrubs. The main species include porcupine grass, buckbrush, northern wheatgrass, western wheatgrass, rose shrubs and mountain rough fescue.

The central and northeastern portion of the ECC is extensively cultivated. Where native vegetation exists, it consists generally of aspen trees mixed with grasslands (plains rough fescue).

Land-surface elevation in the study area increases to the west, strongly affecting the type of vegetation that grows along the ECC's western edge. Aspen stands with shrubby understories (growth beneath the forest canopy), white spruce and jack pine dominate at lower elevations.



Satellite image of an example of the terrain in the green zone in the ECC west of Calgary (black line indicates ECC boundary.) (Photo courtesy of the Alberta Department of Transportation, acquisition 2008, resolution 2.5 m panchromatic, originator Iunctus Geomatics.)

Pastureland in the white zone of the ECC. Much of the landscape in the ECC is flat-lying, and the types of sediment near the surface are good for growing crops and forage.

Alyssa Barker, Alberta Environment, Joanna Chan, (Alberta Geological Survey summer student) and Tony Lemay, Alberta Geological Survey, logging core for the ECC borehole-drilling program. Rocks of the Horseshoe Canyon Formation are being described. The Horseshoe Canyon Formation contains many different rock types, including sandstone, siltstone, mudstone and coal. This core in particular contained abundant finer grained sandstone.

Red Deer River cutting through the Paskapoo Formation to form a steep-sided valley. Ski Hill Road, Red Deer, Alberta.

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Foothills physiographic region in the ECC. We can see some large, steep-sided hills that are characteristic of a foothills region. Photo taken in the southwestern part of the ECC.

Evergreens (white spruce, black spruce, jack pine and tamarack) become more abundant to the west and begin to dominate as the age of forest stands increases.

In the Foothills and Montane areas, the vegetation at lower elevations generally consists of mixedwood forests (aspen, lodgepole pine and white spruce). At higher elevations, mixed conifer-dominated forests (lodgepole pine, black and white spruces, and Douglas fir) grow.

Land Use
Agriculture and oil and gas activities dominate land use in the ECC. Coal mining occurs in the northern and western parts. The western part of the ECC also has forestry and recreational land uses.

Physiography

The ECC straddles the boundary between the Cordilleran and Interior Plains major physiographic divisions of Canada[3]. The ***physiography*** of Alberta has been further broken down from divisions to regions,[4] with the ECC lying within five main physiographic regions (Figure 1.4):

- Eastern Alberta Plains
- Western Alberta Plains
- Southern Alberta Uplands
- Rocky Mountain Foothills
- Rocky Mountains

These regions are subdivided into physiographic sections based on elevation and ***morphological*** characteristics.[4] The following sections describe each main physiographic region and the physiographic sections that lie in each region.

Drill site near Wetaskiwin, Alberta. A water-well rig completed all of the drilling for the ECC drilling program. Alberta Environment and AGS staff described all of the core on site and boxed the core for additional examination and analysis.

Tony Lemay and Gordon Jean, Alberta Geological Survey, and Hira Moktan, Alberta Environment, examining a bedrock outcrop.

Example of a Plains physiographic region in the ECC. Plains regions have a gently rolling landscape like what we see in this photo. Because of their flat-lying landscape and the types of sediments near the surface, the Plains physiographic regions are commonly used for agricultural purposes, like growing crops or forage.

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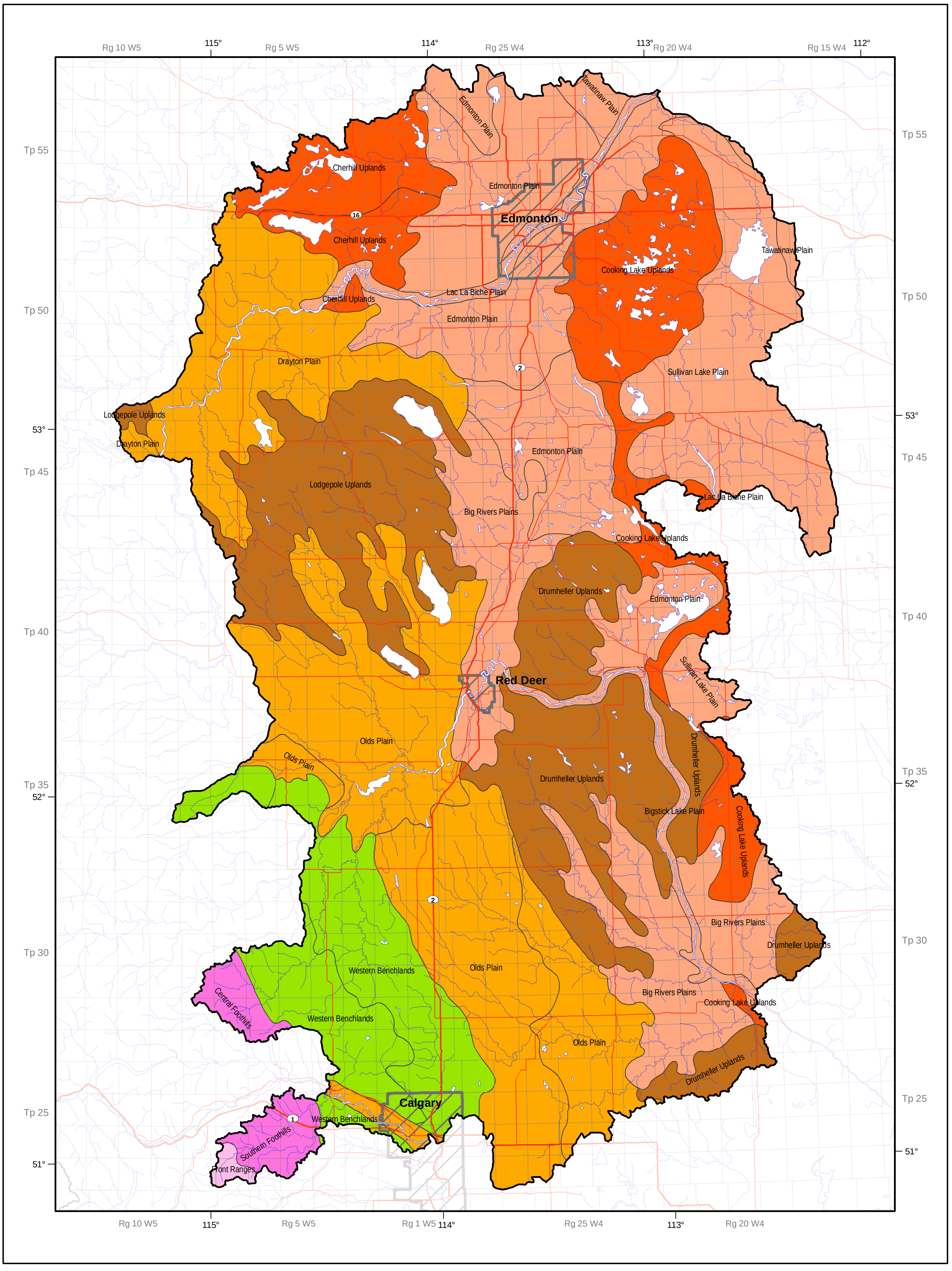

Physiographic Regions and Sections (Figure 1.4)

Eastern Alberta Plains
- Big Rivers Plains
- Bigstick Lake Plain
- Sullivan Lake Plain
- Edmonton Plain
- Lac La Biche Plain
- Tawatinaw Plain
- Cherhill Uplands
- Cooking Lake Uplands

Western Alberta Plains
- Drayton Plain
- Olds Plain
- Drumheller Uplands
- Lodgepole Uplands

Southern Alberta Uplands
- Western Benchlands

Rocky Mountain Foothills
- Central Foothills
- Southern Foothills

Rocky Mountains
- Front Ranges

0 12.5 25 50 75 100 km

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Eastern Alberta Plains

The central and northeastern areas of the ECC are part of the Eastern Alberta Plains. These plains cover a large area with a gently rolling landscape dissected by steeply banked river valleys. Physiographic sections in this region include

- Big Rivers Plains
- Sullivan Lake Plain
- Edmonton Plain
- Lac La Biche Plain
- Cherhill Uplands
- Cooking Lake Uplands

Western Alberta Plains

The western portion of the ECC lies in the Western Alberta Plains. Rolling hills and steeply banked river valleys dominate these plains. Physiographic sections of this region include

- Drayton Plain
- Olds Plain
- Drumheller Uplands
- Lodgepole Uplands

Southern Alberta Uplands

The Southern Alberta Uplands region is represented in the ECC by the Western Benchlands section. This section occurs along the western edge of the ECC.

Rocky Mountain Foothills

Only the southwestern part of the ECC is in the Rocky Mountain Foothills region, and that part overlaps with the Central and Southern foothills sections. The Foothills are composed of large, steep-sided ridges and hills.

Rocky Mountains

Only the southwestern tip of the ECC is in the Rocky Mountains region, west of Calgary. The region has ridged to steeply inclined ***topography*** in the Front Ranges section. The elevation varies from 1200 to 3300 metres above sea level (m asl).

Mapping Activities in the ECC

There has been a substantial amount of mapping work done in the Edmonton–Calgary Corridor over the course of this project. We have pulled together information on the climate, geology and water systems of the study area. We have used new approaches to complete this mapping work, and have improved our understanding in all of these areas. The following subsections provide an introduction to our mapping work. Each of these topics is reviewed in detail in subsequent sections of the atlas.

Geological Mapping

Geological mapping looks for the boundaries between formations, which are the differences in the properties of ***sediment*** at and below the land surface, with the goal of understanding the processes that occurred to deposit the types of sediment observed within a study area. The primary geological mapping unit is the ***formation***. Formations are bodies of sediment identified by their physical properties (like a rock type or the type of grains or minerals that make up a rock) and age. Understanding the geology of an area lets us make better models of how the various types of sediment occur in relation to one another in three dimensions.

Buildup of coarser grained materials (like sand, gravel and sandstone) may form potential aquifers, whereas buildup of finer grained sediment (like clay, silt and shale) may form aquitards. Through geological mapping and modelling, we can better understand the extent and characteristics

View of Wabamun Lake, Alberta, which is in the northeastern portion of the ECC. The photo was taken from Fallis point looking south, near Wabamun, Alberta.

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Borehole-drill bits for coring. The silver bit on the left has a diamond-impregnated cutting surface for bedrock coring. The gold bit on the right is for coring unconsolidated sediments above bedrock.

of aquifers and aquitards. We then use this information to design approaches for groundwater studies, such as groundwater-exploration programs, aquifer-protection studies and groundwater-***flow modelling*** exercises.

We used existing data and new field-based observations to map the geology of the ECC. The existing data came from the following sources:

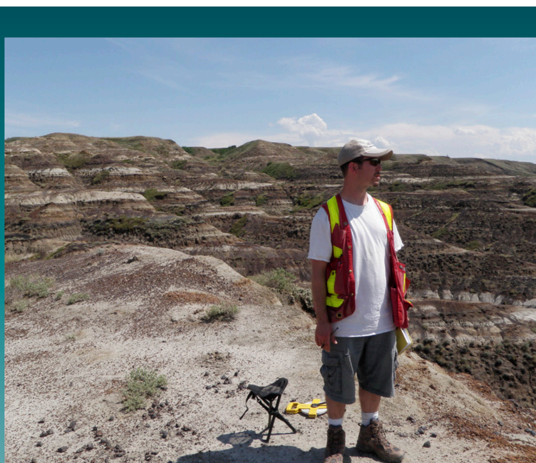
- Alberta Environment's Alberta Water Well Information Database;
- Alberta Research Council (now Alberta Innovates – Technology Futures); and
- Energy Resources Conservation Board and Alberta Geological Survey.

Geological mapping that AGS has done in the area of the ECC to date includes mapping the

- tops of the various bedrock formations;
- depth of the bedrock surface;
- thickness of sediment between the bedrock surface and the land surface; and
- distribution of the types of sediments that occur at the surface.

These types of mapping activities can mainly be done by geologists at their computers with existing information, combined with fieldwork to check the results of the mapping.

It is important to note that the sediment very close to the ground surface may not be the same as the sediment at deeper depths between the ground surface and the top of the bedrock surface. The geological processes responsible for forming the ground-surface sediments generally only affect the very near-surface sediments, leaving the sediments below unchanged from how they were deposited.



Joseph Riddell, Alberta Geological Survey, in the Drumheller area studying the distribution of mud and sandstone in the Horseshoe Canyon Formation.

Outcrop along the Red Deer River, near Red Deer, Alberta.

Landon Woods (Alberta Geological Survey summer student) and Hira Moktan, Alberta Environment, sampling groundwater.

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The geological field-mapping program examined surface materials in outcrops (rocks and sediment exposed at the surface) and gravel pits. These field activities provided information on the geological history of the ECC, as well as on how landforms were created, and how materials were deposited. The other data collection activities included a borehole-drilling program and airborne-***resistivity*** surveys. The geological field mapping and other data collection activities that the AGS did for this project helped confirm that the products of the computer-mapping exercises are as accurate as possible.

Borehole Drilling

To supplement what we know about the geology from existing sources of information, AGS conducted a borehole-drilling program in 2008. The goal of this program was to get more information about the subsurface geology in the central portion of the ECC. We drilled and recovered core from 12 boreholes (Figure 1.5). To obtain core, specialized drilling equipment is used. The drill bit is open in the middle, which allows the drill pipe to capture the sediments or rocks into a core barrel. The core barrel is then pulled to the surface, and geologists can examine the core to understand the nature of the sediments. During this project, the work we did included

- making detailed, on-site records of sediment and rock properties (logging);
- supervising contractors as they collected ***downhole geophysics*** data (a record of the physical rock properties of the rocks encountered in the borehole);
- transporting the core samples we obtained to the AGS Mineral Core Research Facility in Edmonton to further document rock properties and store the core; and
- comparing the downhole geophysics data to the detailed logging records.

The data we collected from this drilling program gave us high-quality, reliable information that we used to improve the geological model of the ECC. Further information on the drilling program is available in Open File Report 2009-17.[5]

Airborne Geophysical Surveying

Choosing the Right Technology

Alberta Geological Survey and Alberta Environment hired a survey company to conduct several airborne-resistivity surveys over the ECC area. These surveys measured the electrical properties of the sediments and water within the pores of the sediments. The interpretation of the survey results can help to map sediment types and the characteristics of the water within the rocks. Many countries use these techniques to map groundwater resources, including Australia and Denmark.

In Alberta, the oil and gas industry has done resistivity (or ***electromagnetic***) surveying from aircraft to make maps showing oil-sands deposits in the Athabasca Oil Sands Area and shallow-gas deposits in northern Alberta buried valleys. Aggregate companies use similar techniques to find sand and gravel deposits. The ECC survey was used to explore how these tools could help map Alberta's groundwater resources.

Various Tools for Surveying

Three different tools were used in different portions of the study area. The reason for this is that depending on the specifications of the tools, different depths can be explored, or higher resolution survey results can be achieved.

Two of the tools used different types of ***time-domain technology***. The difference between the two is the type of pulse emitted. The tools both emit an electromagnetic pulse at a set frequency, but the character of the pulses are different making each better suited for different types of settings. In both cases, the pulse travels downward into the ground, and

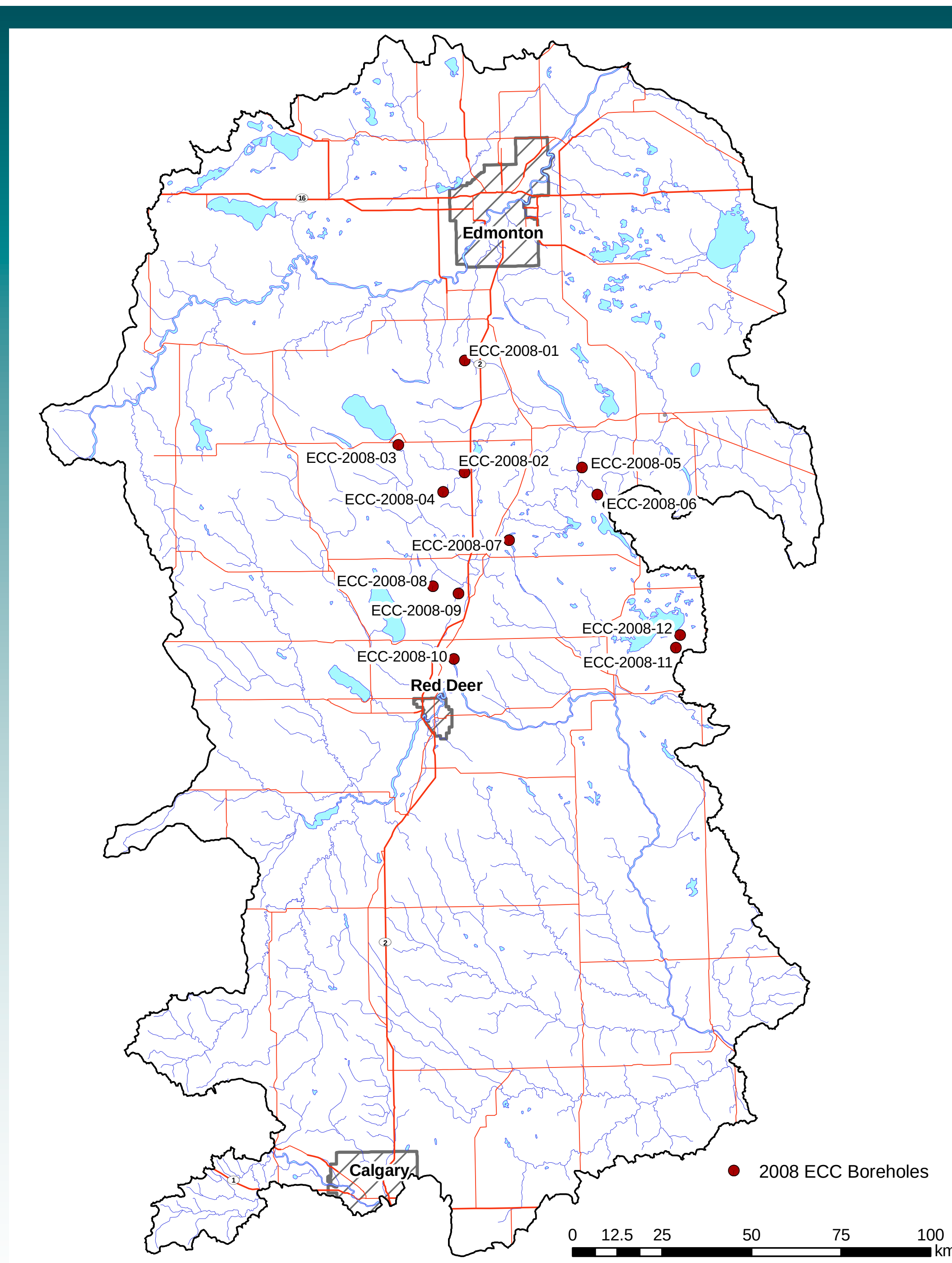


Figure 1.5. Edmonton–Calgary Corridor borehole locations indicated by the red dots.

the return signal from the ground is measured by a tool towed behind the aircraft. The tool records how long it took the signals to return. The signals measured first determine the properties of the upper sediments and water, whereas the signals measured later determine the properties of the deeper sediments and water.

The third type of tool used in the study area used ***frequency-domain technology***. The differences in the frequency of the return pulse are measured, and from that information, the characteristics of the sediments and water at different depths is figured out.

In 2011, AGS will publish a series of reports outlining the results of the airborne-***geophysical*** surveys.

Water-System Mapping

In our study of the ECC, we worked on understanding all aspects of the way water moves through the ECC. Using Government of Canada and Government of Alberta climate stations, we looked at the climate and how much water enters the water system. We also examined how much of this water flows into rivers, streams, lakes and wetlands, and how much evaporates or transpires. We examined how water infiltrates the ground, how it moves through the subsurface and where it exits the subsurface to discharge at the land surface as springs, or in rivers, streams, lakes and wetlands. We also examined how the chemistry of groundwater changes across the ECC.

Data Sources

During the description of the water system within the ECC, AGS made maps showing details of various aspects of the water budget. To do this, AGS assembled datasets on the climate, surface water and groundwater. These datasets came from several sources:

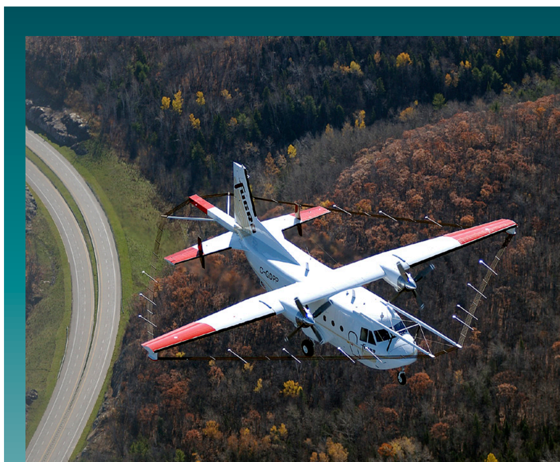
- Environment Canada's climate stations;
- Alberta Environment's stream-gauging stations;
- Environment Canada's stream-gauging stations;
- Alberta Environment's Alberta Water Well Information Database;
- Alberta Research Council (now Alberta Innovates – Technology Futures); and
- Energy Resources Conservation Board and Alberta Geological Survey

Deciding Which Data to Use

The process of choosing which data to use or exclude is a very important aspect in the mapping process. In the case of a climate station, we look at the length of time the station has been collecting data and where that station is located. When we are mapping aspects of groundwater flow, we look at well details, such as how deep it is and how it was constructed. Mapping water chemistry includes additional scrutiny of well records. A chemical dataset, or analysis, gives information about the chemical composition of the groundwater at a particular time, place and depth.

To ensure that the analyses were suitable for mapping, we selected analyses based on sample age, well-completion details, completeness (full set of chemical parameters) and an estimate of the quality of the analysis. We then matched each chemical analysis within the ECC to the unit that the water sample came from, based on the well location and on the depth of the well's completion.

In addition to using existing data, AGS conducted a field program to collect water samples. During the summer of 2009, AGS collected 39 water samples, which we analyzed to understand the groundwater chemistry of wells in the Paskapoo Formation, ***unconsolidated*** sediments above bedrock and springs in the ECC area. The focus of this activity was to build upon the information about the ***inorganic chemistry*** and processes affecting water chemistry within the sampling region.



An airplane outfitted with the GEOTEM system to perform airborne geophysical surveys for a portion of central Alberta. Photo courtesy Fugro Data Solutions (Canada) Inc.

Core samples from the borehole drilling program. The light grey rocks (left) are from the Scollard Formation and consist of mudstone, siltstone and fine-grained sandstone. The dark grey rocks (right) are from the Battle Formation and consist of mudstone. The dark colour and rock type are typical of the Battle Formation.

Josh Bishop and Elizabeth Kravontka (Alberta Geological Survey summer students) examining core at a drill site. They are examining the size of the grains in the samples. Important aspects to consider when examining core include the type of sediment encountered, its colour and the thickness of the material.

1. Introduction

Information Developed Based on the Data
Using the climate, stream flow, groundwater and chemical analyses data, AGS created maps that describe the various aspects of the water system in the ECC. We created maps showing trends in climate information, stream flow, groundwater flow and the regional quality of the groundwater in the ECC.

The groundwater maps focus on the geological units in which the majority of well owners completed their wells. Therefore, the assessment provides an overview of the shallower portion of the ECC. Alberta Geological Survey will release the results of this work in a series of reports in 2011.

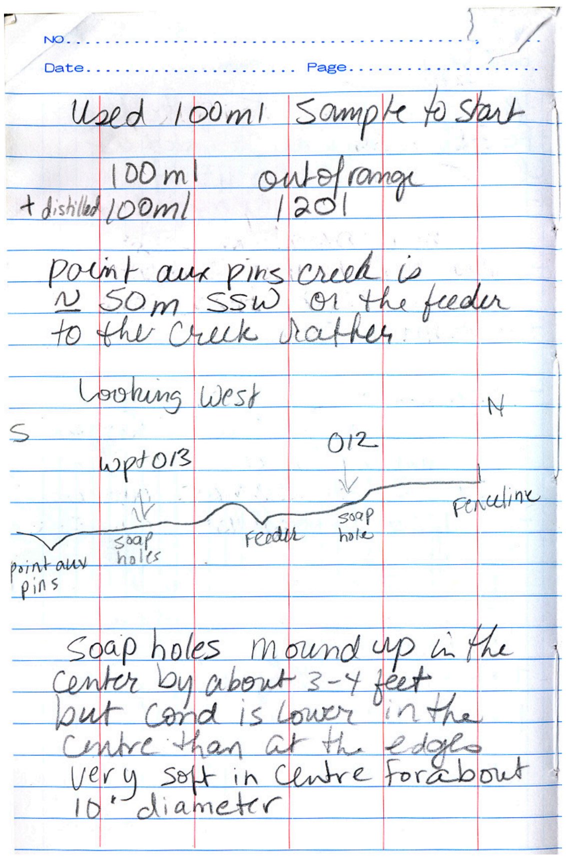
Mapping Where We Don't Have Data

Our environment is very complex. We continue to improve our understanding of it through investigations like measuring ***precipitation*** and temperature, drilling wells and flying geophysical surveys, but there are often times when we have to base our interpretations on estimates of these values rather than on direct observations.

For example, when we map the amount of precipitation that falls over an area, we rely on climate stations. These stations exist throughout Alberta and provide detailed information for the area near each station. Based on this information, we can create maps showing precipitation near the stations, as well as between the stations using statistical mapping techniques. These estimates are always better if we have a direct measurement, such as from a climate station. Whereas we have greater uncertainty for those locations between data control points.

Consider the three examples below (Figure 1.6). In case a), mapping a regularly spaced, dense network of data points will create a map with a low degree of uncertainty. In case b), the data points are still regularly spaced, but the distances between data points are greater, yielding greater uncertainty in the estimates for which there are no data points. In case c), we have areas with clustered data (shown in green), areas with more sparsely distributed data points (shown in yellow) and areas with no data points (shown in red). Case c) is common in geological mapping work. There is a low degree of uncertainty if more data points exist, with an increasing amount of uncertainty for areas with fewer data points and high uncertainty for areas without data points.

Given that several of the figures and maps of the ECC rely on data points with a distribution most like case c), it is important to consider the data distribution and the associated degree of certainty when drawing conclusions from any map.



Data collection begins with field notes.

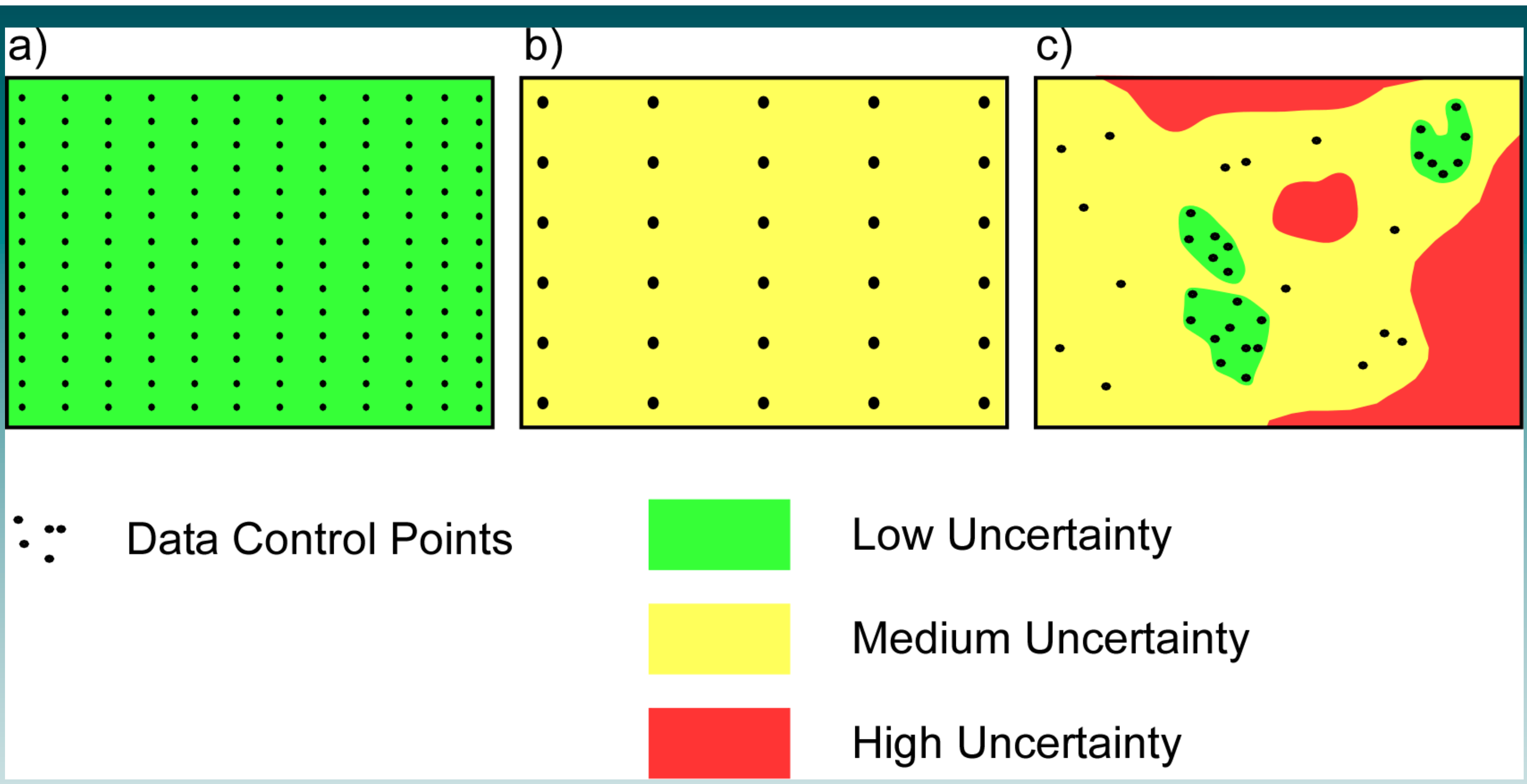


Figure 1.6. Data density and the relationship with uncertainty.

2. Bedrock Geology

2. Bedrock Geology

Why We Map Bedrock Geology

To understand groundwater resources and characteristics of an area, we must first understand the area. That is because groundwater movement and chemistry below the ground, within the bedrock environment, are determined by the physical and chemical characteristics, arrangement and boundaries of bedrock formations.

Regional Bedrock Geology

Historical Context

The term bedrock refers to rocks, usually solid, that generally lie beneath soil or other unconsolidated materials. Central Alberta's bedrock formed about 80 to 50 million years ago. This period was heavily influenced by mountain building (the ***Laramide Orogeny***), which occurred along the western edge of Alberta. During this time, rivers eroded and carried sediments from the mountains and deposited them to the east in a basin that thins toward the east. The sediments' own weight and the pressures exerted by the mountain-building forces caused the sediments to consolidate (compact and solidify), so that, over time, the sediments became the bedrock that lies under the ECC. The sediments that we've included in our study are mostly classified as ***clastic sedimentary rocks***, which means that they are composed of broken fragments of pre-existing rocks or minerals that were eroded and carried, likely by rivers, from their places of origin.

Geologists define bedrock units by the type of sediments they are composed of and by the time period during which they were deposited. The key bedrock units in our ECC study came from four time periods during which coarse-grained sediments were deposited (represented by rocks from the Belly River Group, Horseshoe Canyon, lower Scollard and Paskapoo formations) and four time periods during which finer grained sediments were deposited (represented by the Lea Park, Bearpaw, Battle and the upper Scollard formations).

Joseph Riddell, Alberta Geological Survey, measuring the thickness of the layers of rock in an exposure of the Horseshoe Canyon Formation near Drumheller, Alberta.

The different types of rocks that make up the Horseshoe Canyon Formation give it a layered look. Photo taken near Drumheller, Alberta.

2. Bedrock Geology

Composition of Bedrock Units

The bedrock units in the ECC are sedimentary rocks that are Cretaceous to Paleogene in age. The Cretaceous Period began 145.5 million years ago and ended 65.5 million years ago when the Paleogene Period began. The Paleogene Period ended 23 million years ago. The end of a period is typically marked by a significant geological event, such as the meteorite impact believed to have led to the extinction of the dinosaurs. This particular event happened 65.5 million years ago and marked the end of the Cretaceous and the beginning of the Paleogene.

Table 2.1 describes the various geological units mapped and discussed in our ECC work, with the youngest layer at the top.

Each of these bedrock units is in the ECC to some extent. Removing the overlying, unconsolidated sediment would reveal where each unit occurs at the bedrock surface (***subcrop*** location), as shown in Figure 2.1. Looking at the map, it becomes obvious that two of the formations are not shown. The Battle Formation occurs below the Scollard Formation and above the Horseshoe Canyon Formation. It is relatively thin compared to the other rock units; so at our map's scale, it would only show as a line the same thickness as the line between the Scollard Formation and the Horseshoe Canyon Formation. The Lea Park Formation lies below the Belly River Group; so it is not exposed at the subcrop surface in the ECC.

Table 2.1. Bedrock units in the ECC and their characteristics.

Layer Name	Period	**Defining** Rocks and Traits
Paskapoo Formation	Paleogene	• non-marine, ***calcareous***, ***cherty*** sandstone, siltstone and mudstones • generally a coarse-grained formation
Scollard Formation	Cretaceous to Paleogene	• non-marine ***feldspathic*** sandstone • mudstone containing the clay mineral ***bentonite*** • coalbeds
Battle Formation	Cretaceous	• bentonitic mudstone ***interbedded*** with consolidated silica-rich, volcanic ash (***siliceous tuff***)
Horseshoe Canyon Formation	Cretaceous	• non-marine, feldspathic, clay-rich sandstone • bentonitic mudstone • ***carbonaceous*** shale • scattered beds of ironstone, coal and limestone
Bearpaw Formation	Cretaceous	• marine shale and sandstone
Belly River Group	Cretaceous	• non-marine feldspathic sandstone • clay-rich siltstone and mudstone
Lea Park Formation	Cretaceous	• marine shale

Ben Hathway, Alberta Geological Survey, measuring a section in the Horseshoe Canyon Formation along the Red Deer River.

Steven Lyster, Alberta Geological Survey, at a Paskapoo Formation outcrop at Fallis point near Wabamun, Alberta. This occurrence of the Paskapoo Formation marks the easternmost occurrence of the formation in the northern portion of the ECC.

Alberta Geological Survey field party examines an outcrop of the Horseshoe Canyon Formation. In the photo we can see a thick layer of bentonite near the centre of the photo (yellow-grey material in the exposure face).

2. Bedrock Geology

Bedrock Topography Mapping

Why We Mapped Bedrock Topography

We mapped the top of the bedrock surface for the ECC because it forms an important boundary for both the geological and groundwater models. In the geological model, the bedrock surface is the boundary between consolidated sediments (which form the bedrock) and unconsolidated sediments (which lie on top of the bedrock). In the groundwater model, this surface can define the boundary between different groundwater-flow patterns. Several factors have significantly altered the bedrock topography from its original state:

- chemical and physical erosion (including erosion during the advance and melting of glaciers during the most recent ***glaciation***);
- structural changes from ***tectonic*** movement; and
- adjustment of the Earth's crust after the appearance or disappearance of glacier ice sheets and the erosion of sediments (***isostatic rebound***).

Physical erosion is caused mostly by river systems moving across the landscape, but glaciers also significantly eroded the bedrock surface. Physical erosion is generally the most obvious change to the landscape, especially in river valleys.

How Bedrock Topography Was Mapped

We mapped the bedrock topography using data from water wells, test holes and field-based geological observations. We collected these data as a series of points with information about location and elevation of the bedrock top.

To produce the bedrock topographic surface, we modelled the elevations (Figure 2.2) using a mathematical process called ***geostatistics***, which applies statistical analysis to the geological data to map it. Alberta Geological Survey recently published details of this work in Open File Report 2010-12.[6]

What Bedrock Topography Shows Us

The modelled bedrock surface shows us a variable underground topography that generally reflects the present-day surface topography. The morphological elements (distinctive landforms, rock structure and history) of the bedrock topography are grouped into four elements:

1. highlands;
2. uplands;
3. lowlands; and
4. channel complexes.

The distinguishing features for each element are the shape and elevation of the landforms in the area.

The highlands and uplands most closely mirror the present-day land surface and exist in the western part of the ECC.

The lowlands generally have a gently rolling bedrock surface, but the present-day ground surface is more uneven because of the buildup of sediment on top of the bedrock surface.

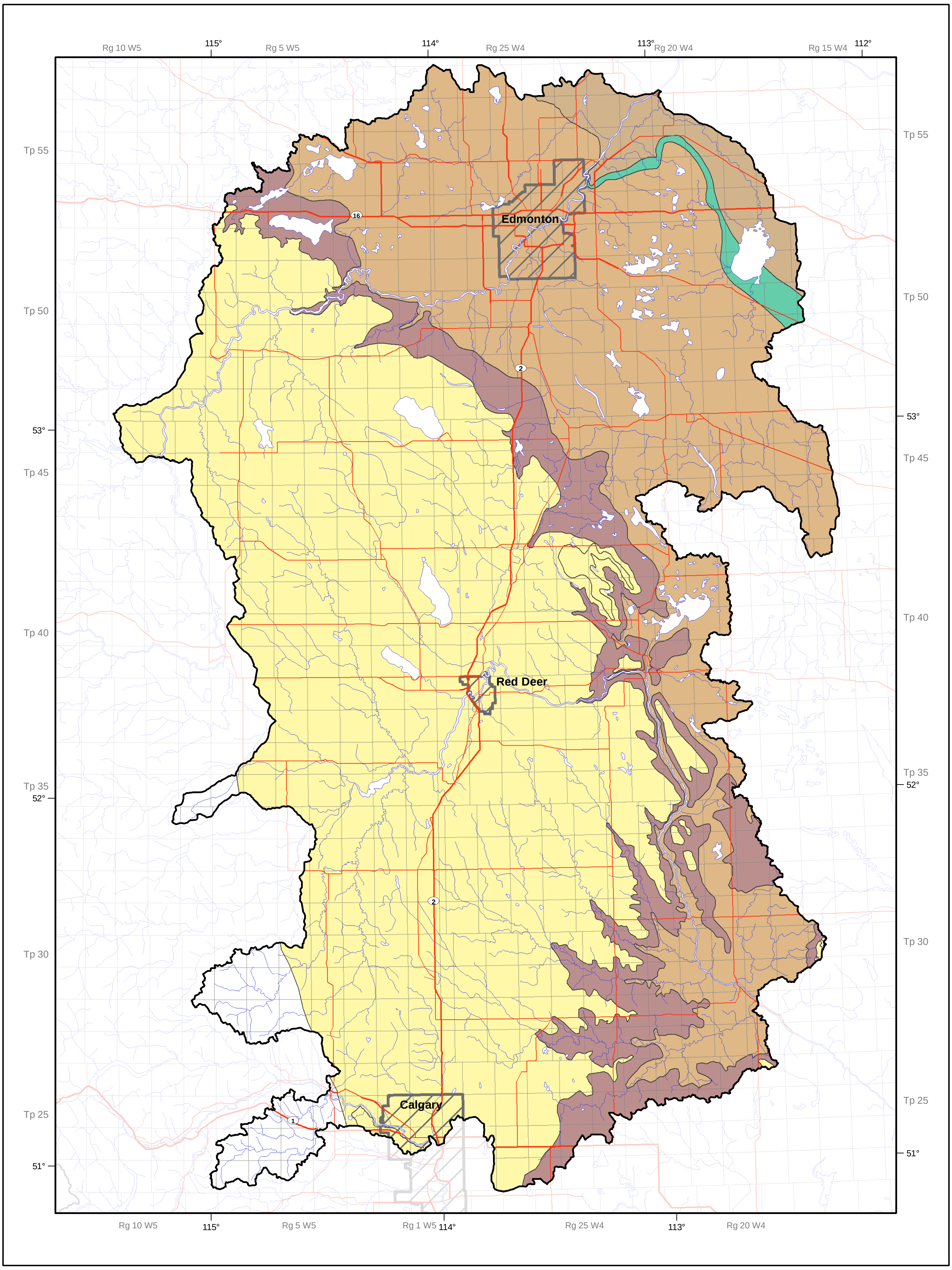
The bedrock topography shows three channel complexes or ***paleochannel*** complexes. This means that they are remnants of ancient river channels cut into the bedrock, later buried by younger sediments. In some areas, present-day rivers have eroded into the paleochannels, but other channels remain buried. The three paleochannel complexes are in the north of the ECC (Beverly-Onoway complex), the central part (Red Deer River complex) and the southeast corner (Drumheller complex).

Measuring the thickness of the types of rock material in a core sample. Once a core sample is brought to the surface, the types of sediment or rock material are described, including the thicknesses, their colour and any other important observations that may identify the formation, and the environment in which the materials were deposited.

Till overlying sandstone of the Paskapoo Formation. The till is grey-brown and the sandstone is olive-brown with some rusty brown. The pick handle is used for scale.

Coal within the Scollard Formation near Ardley, Alberta. Coal accumulations vary in thickness and can be several metres thick.

2. Bedrock Geology



Bedrock Geology (Figure 2.1)

Geological Formations

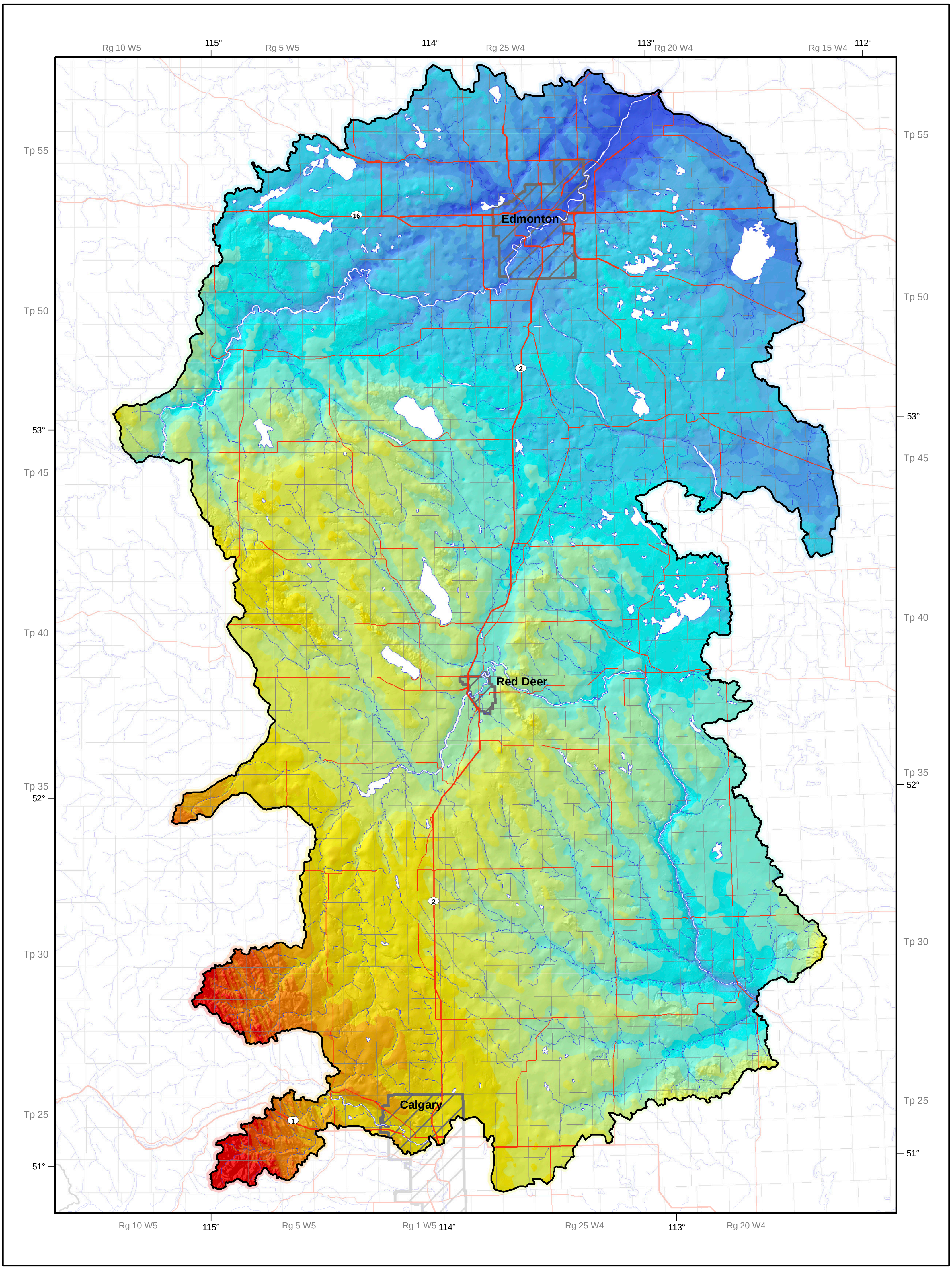
- Bedrock in deformed zone
- Paskapoo Formation
- Scollard Formation
- Horseshoe Canyon Formation
- Belly River Formation
- Bearpaw Formation

0 12.5 25 50 75 100 km

ERCB Energy Resources Conservation Board | AGS Alberta Geological Survey | Government of Alberta

Base Data Provided by Spatial Data Warehouse Ltd.

2. Bedrock Geology



Bedrock Topography (Figure 2.2)

Elevation (metres above sea level)

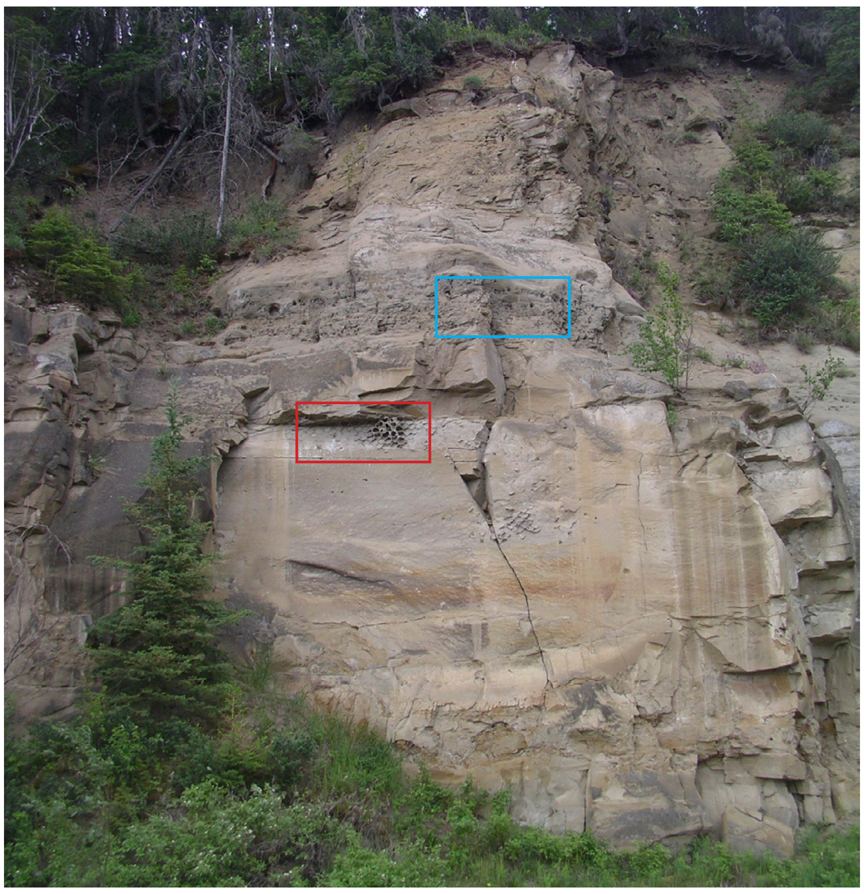
- 568 - 625
- 625 - 650
- 650 - 675
- 675 - 700
- 700 - 750
- 750 - 800
- 800 - 850
- 850 - 900
- 900 - 950
- 950 - 1000
- 1000 - 1100
- 1100 - 1200
- 1200 - 1300
- 1300 - 1400
- 1400 - 1500
- 1500 - 2348

0 12.5 25 50 75 100 km

ERCB Energy Resources Conservation Board | AGS Alberta Geological Survey | Government of Alberta

Base Data Provided by Spatial Data Warehouse Ltd.

2. Bedrock Geology



Outcrop of the Paskapoo Formation. The nesting sites point out important differences between the sandstone types at this exposure of the Paskapoo Formation. In the upper part of the exposure, you can see that the nesting sites are in the rock itself (blue rectangle), whereas the nesting sites in the lower part of the exposure (red rectangle) are built on the rock face. The rock in the upper part is also much more eroded than the rock in the lower part. These two pieces of information indicate that the rock in the upper part is softer than the lower part, likely related to the degree of cementation in the rock. Uncemented sandstone saturated with water forms desirable aquifers. Understanding the subsurface distribution of these rocks is, therefore, important in a groundwater study.

Three-Dimensional Bedrock Model

Alberta Geological Survey geologists built a three-dimensional model of the bedrock geology to show the arrangement of the bedrock units in relation to one another. This arrangement helps us understand groundwater movement. We built the bedrock model for the ECC using the top surfaces of the Paskapoo, Scollard, Battle, Horseshoe Canyon, Bearpaw and Lea Park formations, and the Belly River Group.

We modelled the bedrock surfaces for each bedrock unit using subsurface data from water wells, geotechnical borehole logs, and oil and gas logs. Alberta Geological Survey geologists examined these data sources to determine the tops of the bedrock units and then geostatistically modelled them to produce the surfaces for each unit. Figure 2.3 represents the three-dimensional bedrock model.

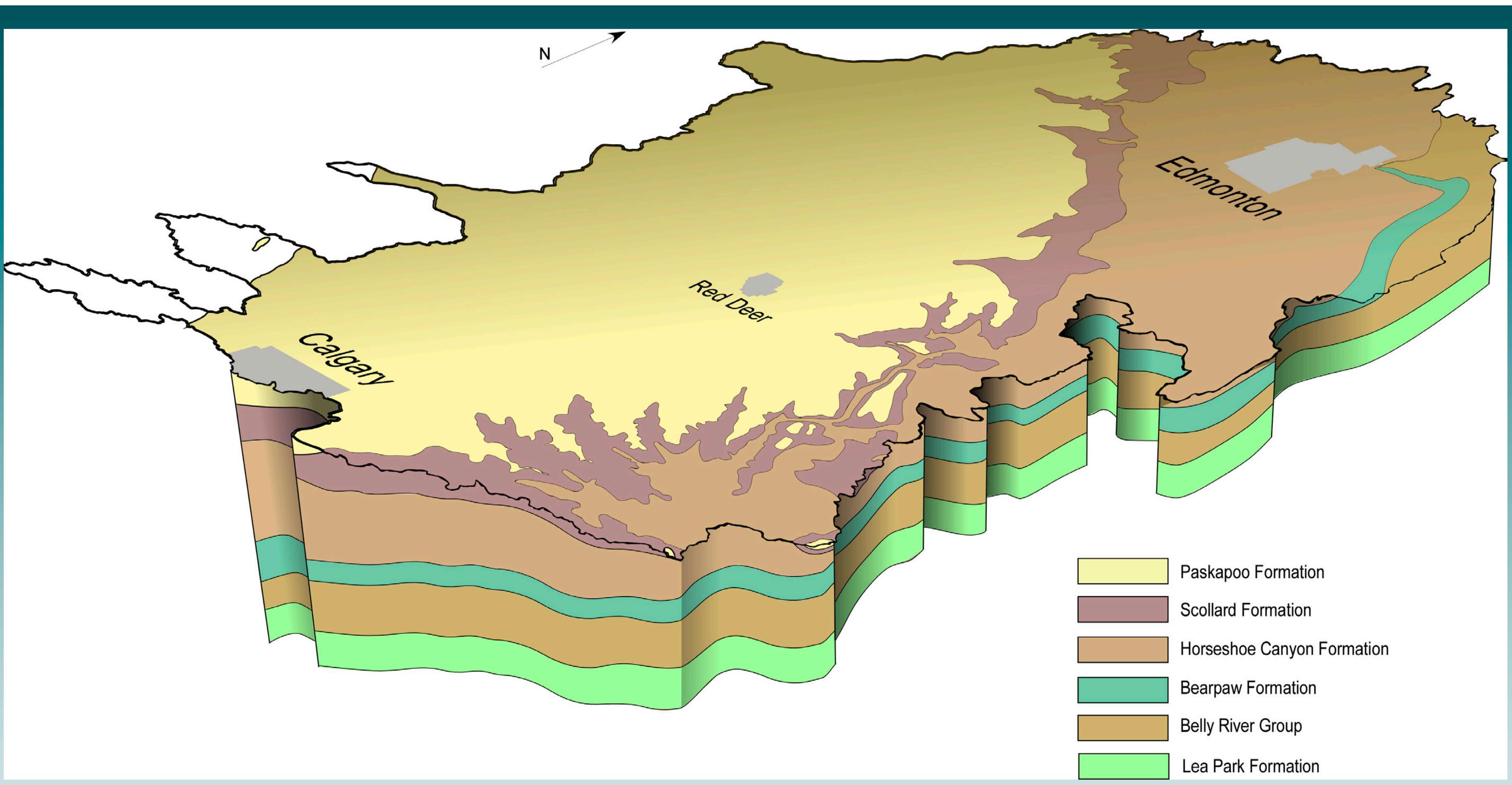


Figure 2.3. Model of the bedrock geology.

3. Geology above Bedrock

3. Geology above Bedrock

Alyssa Barker, Alberta Environment, measuring the thickness of gravel over bedrock in the central part of the ECC. The tip of the measuring stick is pointing at the bedrock overlain by gravel. In addition to looking at the gravel thickness, field parties will look at the types and shapes of rock materials that make up the gravel and the patterns these rock materials may make to understand how the gravel was deposited and from where it came. When saturated with water, thick gravel and sand deposits can form desirable aquifers, so mapping their occurrence is an important task.

Regional Surficial Geology and Geology above Bedrock

In the ECC, sediments lying above the bedrock surface vary in thickness and age. Most sediments at ground surface (surficial sediments) were deposited sometime during the Quaternary (this period began 2.6 million years ago and ended 10 000 years ago). A minor percentage of surficial sediments were deposited sometime during the Paleogene (this period began 36 million years ago and ended 5 million years ago) or were deposited less than 10 000 years ago. Alberta Geological Survey previously mapped the surficial geology of most of Alberta, including the central and southern portions of the province at various scales.[7, 8, 9]

Figure 3.1 shows a compilation of these different mapping activities within the ECC. During the ECC program, AGS added to the understanding of these sediments by describing the sediments from the ground surface to the top of the bedrock surface. This section describes these sediments' grain size and how grain size is related to groundwater flow.

Recent Sediments

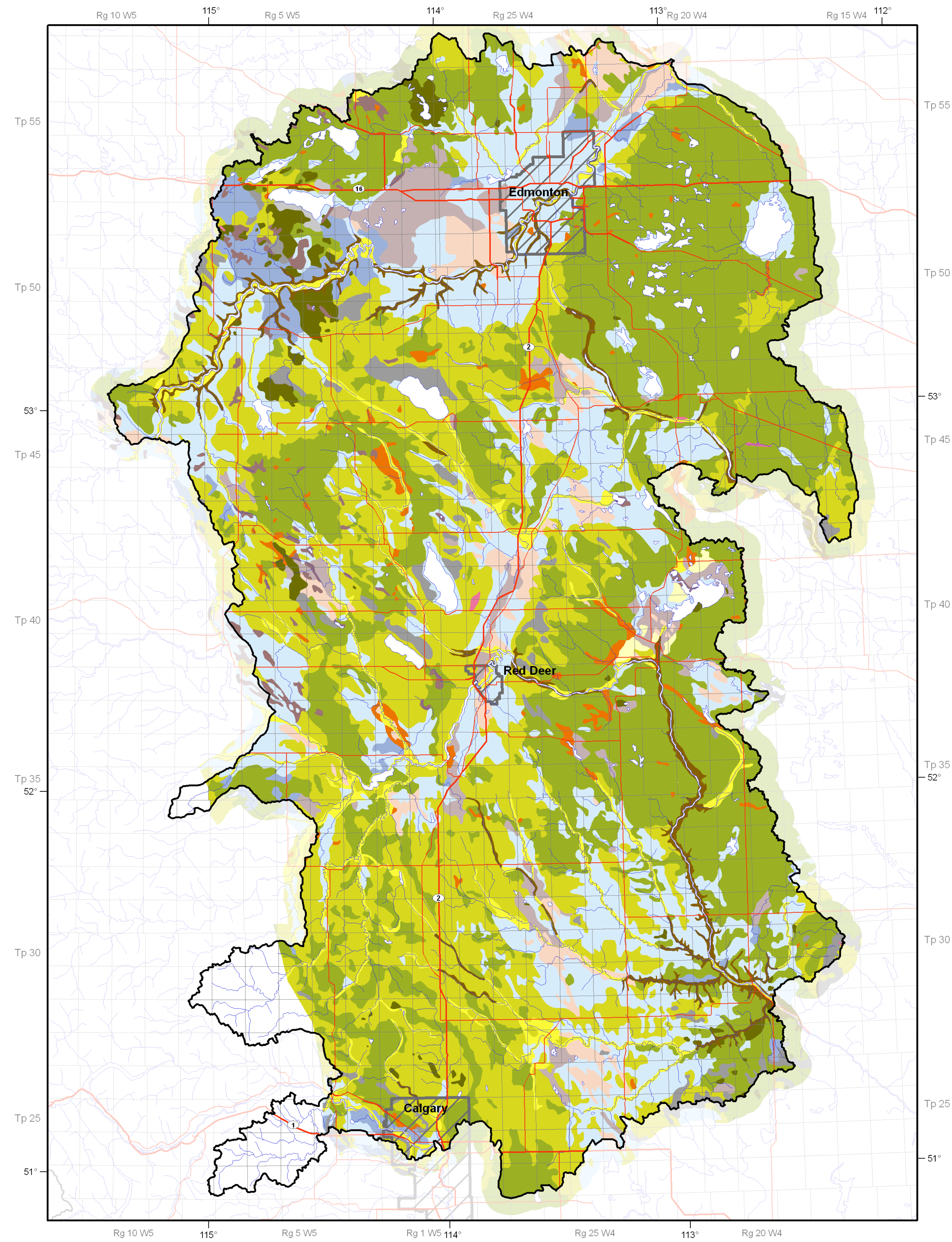
Recent sediments are less than 10 000 years old and were deposited after the most recent glacial event in Alberta ended. ***Eolian*** (wind), ***lacustrine*** (lake), ***fluvial*** (river) and slope-movement processes reworked glacial and bedrock materials and deposited or redeposited these sediments.

Eolian Deposits
Eolian deposits consist of fine- to medium-grained sand and silt that form elongated or curve-shaped dunes. Figure 3.1 shows many eolian deposits.

Lacustrine Sediments
Lacustrine sediments exist mainly in areas that had ***proglacial*** lakes, but also include recent lake sediments. Lacustrine deposits are generally composed of sand, silt and clay. They form flat to gently undulating topography. Figure 3.1 shows many areas with lacustrine deposits.

Gravel pit in central Alberta. Depending on the types of rock material in this gravel deposit, and the conclusions on how this gravel accumulation was deposited, this gravel deposit may have been laid down prior to the last glaciation in Alberta.

3. Geology above Bedrock



Surficial Geology (Figure 3.1)

Surficial Deposits

- Organic deposit
- Eolian deposit
- Lacustrine deposit
- Fluvial deposit
- Stream and slopewash deposit
- Eolian and fluvial deposit
- Glacial - draped moraine
- Glacial - stagnation moraine
- Glacial - ridged end moraine
- Glacial - ice-thrust moraine
- Ice-contact lacustrine deposit
- Ice-contact fluvial deposit
- Ice-contact fluvial and lacustrine deposit
- Glacial and fluvial deposit
- Fluvial deposit (Paleogene to Neogene)
- Bedrock with thin glacial cover
- Bedrock

0 12.5 25 50 75 100 km

Base Data Provided by Spatial Data Warehouse Ltd.

3. Geology above Bedrock

Fluvial Deposits
Fluvial deposits exist on the floors and terraces of present-day river valleys, in former ***meltwater channels*** and in ***deltas***. Fluvial deposits may be composed of gravel, sand, silt or clay. The composition of fluvial deposits depends on several factors, such as distance from the head of the river, location within the river channel and speed of the water flow. Fluvial deposits generally form flat to undulating topography. Figure 3.1 shows grainy areas with fluvial deposits.

Slope-Movement Processes
Slope-movement processes affect the slopes of river valleys and meltwater channels, causing unconsolidated sediments above bedrock and the bedrock to shift in a small area. The effects of these processes include the slumping of sediments and, more rarely, landslides.

Other Sediments
Other sediments include organic deposits, which exist in bogs, fens, swamps and marshes.

Quaternary Sediments

Glaciation
Glaciation produced most of Alberta's surficial sediments that were deposited sometime during the Quaternary Period. During this period, continental ice sheets covered large portions of North America at various times.

The western edge of the Laurentide Ice Sheet (which covered Greenland, all of Eastern and Central Canada and the northeastern U.S.) covered most of the ECC. At the same time, the Cordilleran ice sheet advanced from the mountains in the west toward the northeast extending into the western part of the ECC.

How Glaciers Deposit Sediments
A continental glacier mostly erodes the land and adds the eroded material into the ice at the base of the glacier. Erosion of bedrock or other pre-existing sediments at the base of the glacier occurs by two main processes: abrasion and plucking (or quarrying). Abrasion occurs as the rock fragments carried by the ice grind away at the ground surface. Plucking or quarrying occurs when the glacier removes blocks of material from the bedrock or other pre-existing sediments.

After a glacier collects debris, the debris can move within the glacier and travel with it. The debris can move between zones or remain in one of three zones as it moves along with the advancing ice:

- top of the glacier (supraglacial),
- middle of the glacier (englacial) or
- base of the glacier (basal).

The processes by which a glacier deposits debris are ***lodgement, melt-out*** and flowage. The way that a glacier deposits its debris determines the landforms left behind. One example of a common glacial landform in the ECC is a ***moraine***: a buildup of deposited glacial debris classified either by its origin or shape.

An example of a moraine classified by its origin is a ground moraine. A ground moraine is deposited over large areas but has no obvious shape. The sediments associated with this type of moraine can be deposited as meltwater washes out from under the glacier, or they can be the material dropped by the glacier as it melted.

An example of a landform classified by its shape is an end moraine. An end moraine forms along the margins of glaciers. When the glacier melts, a ridge of sediments is left where the margin of the glacier was. Glacial sediments fall into three broad categories: ***till***, ***glaciofluvial*** deposits and ***glaciolacustrine*** deposits.

Till
Till is sediment a glacier has transported and deposited with little or no sorting by water. Because it is poorly sorted (contains a mix of materials of different sizes), till often contains rock fragments (***clasts***) of many sizes in a

Sand and gravel fluvial deposits along the North Saskatchewan River. Notice the layers of light and dark material near the top of the photo. Examining these features help us understand how these materials were deposited. Also notice the slope failure that caused trees to slide toward the river.

Alyssa Barker, Alberta Environment, and Tony Lemay, Alberta Geological Survey, examine sediments from above bedrock in a core sample. This coring run collected material from the land surface (note the grass) down to approximately 2 m below ground surface. Notice how the colour changes with depth. Information on the colour along with the types of sediment present can tell us about the history of the site.

Keillor Road landslide along the North Saskatchewan River in Edmonton, Alberta.

3. Geology above Bedrock

fine-grained ***matrix***. The map of the ECC's surficial geology (Figure 3.1) shows four types of till deposits (draped moraine, stagnation moraine, ridged end moraine or ice-thrust moraine.

Glaciofluvial Deposits
Deposits that came from ***meltwater*** in rivers or streams that flowed on, within, beneath or out of a glacier are called glaciofluvial deposits. The ECC surficial geology map (Figure 3.1) shows glaciofluvial deposits as coarse- or fine-grained ice-contact sediments (sediments deposited beneath, on, within or immediately adjacent to the glacier).

Glaciolacustrine Deposits
Sediments that glacial meltwater has carried and then deposited into lakes are called glaciolacustrine deposits. The ECC surficial geology map (Figure 3.1) shows glaciolacustrine deposits as coarse- or fine-grained ice-contact sediments. Ice-contact glaciolacustrine sediments are lake sediments that had been directly in contact with a glacier.

Paleogene- to Neogene-Aged Sediments

The oldest unconsolidated sediments in the ECC were deposited sometime during the Paleogene. They generally consist of gravel and sand with minor amounts of silt. Fluvial systems transported and deposited these sediments before glaciation. These deposits remain preserved in a few places in the ECC. In some areas, these sediments are preserved on topographic highs (called *uplands*) or in channels that ancient rivers cut into the bedrock. The sediments are generally covered by till.

These sediments have not been mapped across all of Alberta, and AGS is working to fully understand the complex history of how they were deposited.

Sediment Thickness Mapping

Figure 3.2 shows the thickness of sediment between the ground surface and the top of the bedrock throughout the ECC. Sediment thickness in the ECC varies, ranging from less than one metre to more than 100 metres. We have identified trends between sediment thickness, land-surface topography, bedrock-surface topography and physiography.[10, 4]

In general, the Rocky Mountains, Rocky Mountain Foothills, benchland and upland physiographic regions have thin sediment cover (less than five metres thick), and the ground surface mimics the bedrock topography that lies underneath. Exceptions to this pattern include the Cooking Lake Uplands west of Edmonton and the Cherhill Uplands east of Edmonton. In these uplands, glaciers deposited more than 50 metres of sediment. Areas of thick sediment cover (greater than 10 metres) are generally associated with the Eastern and Western Alberta plains physiographic regions where they occur in the ECC.

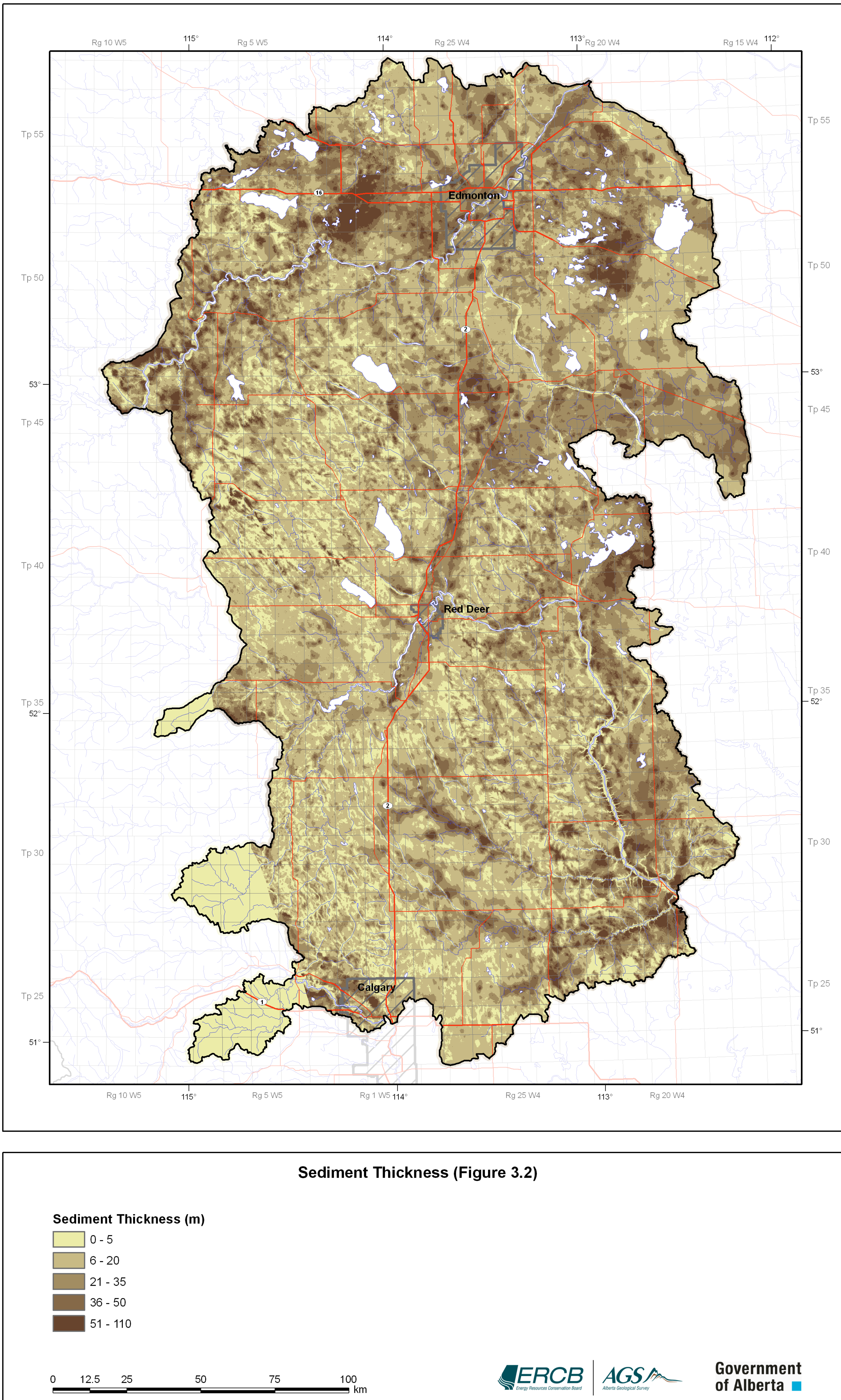
Three-Dimensional Geological Model

To better understand the movement of groundwater through the sediments above bedrock, we completed a preliminary, three-dimensional model of the sediments above bedrock in the ECC. We modelled the distribution and physical characteristics of these sediments (such as grain size and ***permeability***) within the ECC. We assigned values of low, medium or high ability for water to flow through the sediments by analyzing ***lithologs*** of the geological materials encountered during drilling. ***Lithological*** refers to the physical characteristics of a sediment or rock, including colour, mineral composition and grain size. A litholog describes the sequence of sediment and rock characteristics that a drill encounters as it drills downward.

Gordon Jean, Alberta Geological Survey, documenting fluvial sediments along the North Saskatchewan River near Edmonton. The sand he is pointing at shows the presence of bedding. Above the sand is gravel.

Abhijit Mukherjee and Sheila Stewart, Alberta Geological Survey, examining core samples of sediments from above bedrock. By examining the sediments we begin to understand where aquifers are and their extent.

Contact between bedrock and sediments above bedrock exposed along a stream. The bedrock can be identified by its rusty-orange colour in places and the horizontal layers of darker and lighter rock material. The sediments above bedrock are light grey-brown and do not have any noticeable layering.


Rg 10 W5
115°
Rg 5 W5
114°
Rg 25 W4
113°
Rg 20 W4
Rg 15 W4
112°
Tp 55
Tp 50
53°
Tp 45
Tp 40
Tp 35
52°
Tp 30
Tp 25
51°
Edmonton
Red Deer
Calgary
16
2
1
Rg 1 W5
Sediment Thickness (Figure 3.2)
Sediment Thickness (m)
0 - 5
6 - 20
21 - 35
36 - 50
51 - 110
0
12.5
25
50
75
100
km
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AGS
Government of Alberta
Base Data Provided by Spatial Data Warehouse Ltd.

3. Geology above Bedrock

Alberta Geological Survey geologists simplified the drilling descriptions of the sediments in the lithologs and rated the descriptions according to relative permeability based on grain size. As a starting point, we divided the litholog into 5 m intervals starting at the land surface. Then, we examined the descriptions of the geological materials encountered in each interval. Based on the dominant grain size of the geological materials in each interval, we assigned a relative permeability value to each five metre section in the lithologs so we could model permeability across that interval. For instance, if a driller encountered 5 m of gravel in the interval, we would give that a high value for permeability. If a driller encountered clay in a 5 m interval, we would give that a low value for permeability. Figure 3.3 shows examples of the results. We used these results to model groundwater movement.

To create this geological model of the ECC's sediment, we used subsurface data from various sources. These sources included water-well records, geological maps produced by AGS and geological data from field observations.[6] Alberta Geological Survey will release a detailed report outlining the modelling process in 2011.

Paleogene sand and gravel overlain by dark grey-brown till. The occurrences and thicknesses of the various sand and gravel layers along with the types of rock materials in the gravel tell us how these sand and gravel layers were deposited. Initial interpretations indicate the sand and gravel layers at this location were deposited prior to the last glaciation.

Till sample recovered during the drilling program in the ECC. The coin is included for scale. The till in this instance is light grey-brown with some rusty colouration. The colour is an important tool in mapping the occurrence of till from place to place in the subsurface.

Borehole drilling site in the ECC at day break. This site is near the top of a hill. Hills on the landscape of the ECC can be related to underlying bedrock topography highs or thick accumulations of sediments above bedrock. In choosing sites for drilling, we chose some hilltops to better understand these highs on the landscape.

Shawn Slattery, Alberta Geological Survey, examines a fluvial sand exposure. The grain size of the sand and any layering within it can help reconstruct the depositional history of the area. This exposure has many burrows, indicating it is a relatively soft material. However, it has a cliff-like form; therefore, it has some structural strength.

3. Geology above Bedrock

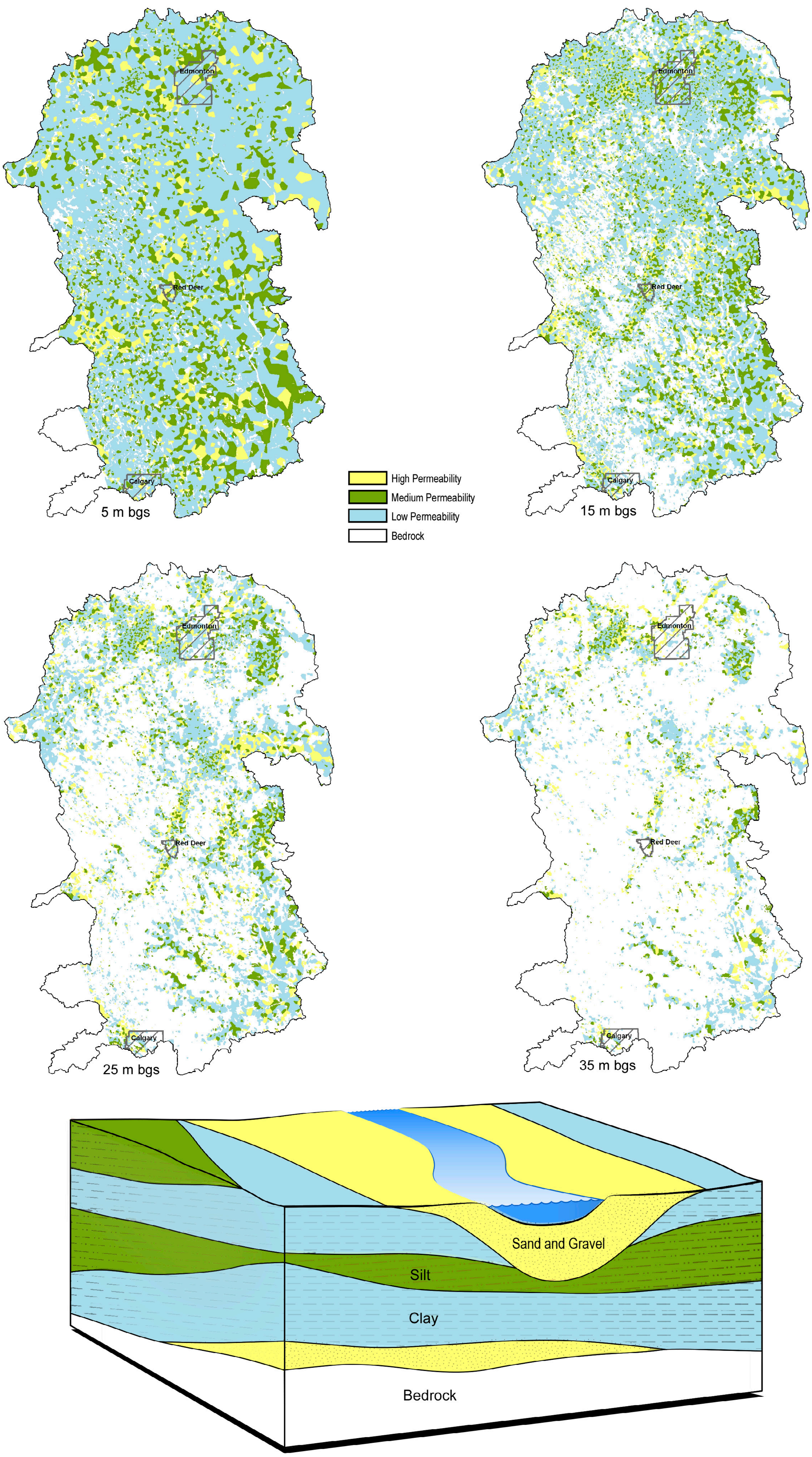


Figure 3.3. Permeability of the sediments above bedrock. The ECC figures show the permeability of the sediments at different depths below ground surface (bgs), as determined by water-well lithologs. The block diagram shows how these sediments may look in three-dimensional space.

4. Hydrology

4. Hydrology

What is Hydrology?

Hydrological Cycle
Hydrology is the science of water: its properties, movement and location on and under the Earth's surface and in the atmosphere. We study hydrological processes because they show us where and how water enters groundwater-flow systems. The hydrological cycle includes the following water components (Figure 4.1):

Precipitation
Precipitation happens when water vapour in the atmosphere condenses and is deposited on the Earth's surface. Precipitation includes rain, snow, hail, sleet and dew.

Evapotranspiration
Evapotranspiration is the reverse of precipitation. It is all of the water that the Earth's surface loses to the atmosphere. Evapotranspiration is a combination of ***transpiration***, when plants release water vapour to the atmosphere, and ***evaporation***, when water evaporates from the soil and from surface-water bodies, such as lakes and ponds.

Runoff
Runoff is water that travels either on top of or slightly below the land surface. Runoff occurs when the amount of water from precipitation or snowmelt exceeds the rate at which water can seep into the soil. Runoff flows into surface-water bodies, such as rivers and lakes.

Recharge
Recharge is the water that enters the underground environment and becomes part of the groundwater system. Recharge water typically comes from precipitation that seeps into the ground.

Storm clouds with precipitation falling in the distance. Precipitation in the form of rain and snow are the primary means that water enters the groundwater environment.

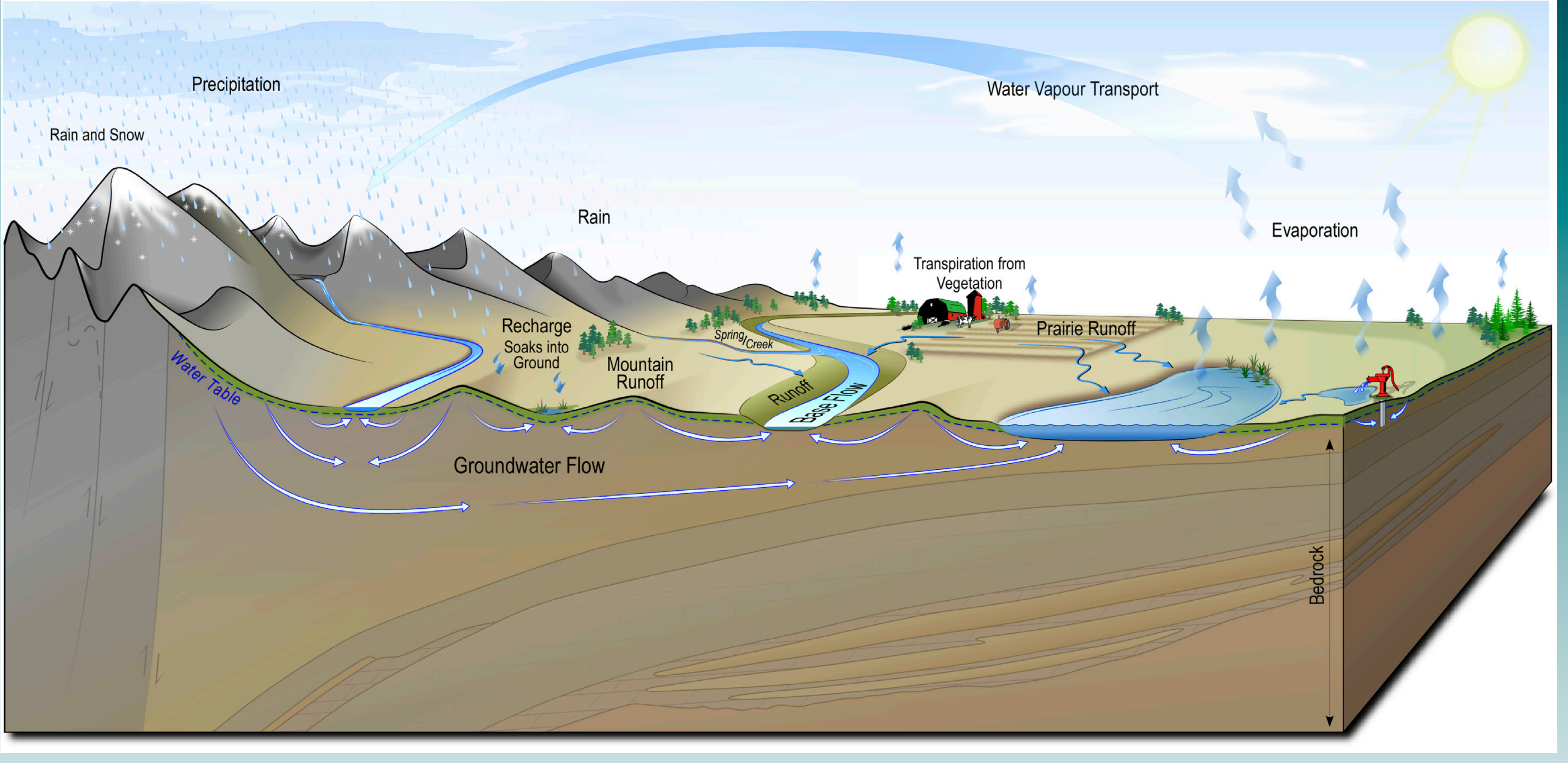


Figure 4.1. Hydrological cycle in the ECC.

4. Hydrology

Base flow
Base flow is groundwater that moves out of the underground environment, adding water to rivers and streams.

The ECC's Complex Hydrology

Figure 4.1 shows the general hydrological processes occurring in the ECC. The ECC's hydrology is very complex because of

- its diverse landscape;
- its location within four major river basins;
- the mountains' influence on the weather;
- the diverse properties of the geological materials that affect how groundwater moves through them; and
- the extensive interactions between groundwater and surface water in the plains.

Alberta's Precipitation and Evapotranspiration

Weather and landscape strongly influence the hydrological cycle. Alberta's climate is classified as *continental at a provincial scale*, with cold winters and warm summers. This provides a very high-level description of Alberta's weather. Because of the ECC's location, we had to consider additional factors, such as how geography influences weather in northern Alberta versus southern Alberta.

Southern Alberta
In southern Alberta, the Rocky Mountains create a rain shadow. Weather systems rise as they move eastward over the mountains and deposit most of their precipitation (such as snow and rain) at high elevations in the mountains and foothills. As a result, areas to the east of the mountains tend to receive less precipitation.

Southeastern Alberta
Southeastern Alberta is semi-arid. Here, evapotranspiration tends to be slightly greater than precipitation, mainly because of the rain shadow created by the Rocky Mountains. As a result, the air and soil are fairly dry.

Northern Alberta
Northern Alberta, which is farther from the rain shadow created by the mountains, has a sub-humid climate, with greater precipitation than evapotranspiration. This means that the air and soil here are moister than in southern Alberta.

The ECC is Water Neutral
The ECC sits in a transitional area between these different climatic regions. The ECC is almost water neutral over the course of one year. This means that, over one whole year, the ECC's precipitation is about equal to its evapotranspiration. However, Alberta's climate varies widely from year to year, which makes all of Alberta's hydrological processes vary as well, including those in the ECC.

Water Balance

Water balance refers to water's overall movement in and out of an area. To understand the ECC's water balance, we did a hydrological study using a simple water-balance equation. This showed the importance of each of the ECC's hydrological processes in the overall water balance.

Water-Balance Equation
The overall water-balance equation we used states that the change in the amount of water (surface water and groundwater), on a yearly basis, must equal the amount of precipitation, surface water and groundwater flowing into the ECC minus the amount of evapotranspiration and the amount of water flowing out of the area (surface water and groundwater).

We can assess the change in how much water is stored in an area's surface-water bodies and groundwater by subtracting all of the water leaving the area from the precipitation and groundwater the area receives.

This water-balance equation helps us understand the average hydrological conditions across the ECC. In this equation, we assume that the total volume of surface water and groundwater stored in the ECC does not change from year to year. We find that, because the ECC is in an almost water-neutral area, small differences between precipitation and evapotranspiration drive the hydrological

Wetland area in the ECC, south of Sherwood Park, Alberta. The physical and chemical relationships between wetlands, surface water and groundwater are important in understanding the overall hydrological cycle and therefore important in our groundwater inventory program.

Medicine River near Benalto, Alberta. Although this river is a smaller river within the study area, understanding the relationship between smaller rivers and groundwater systems is important in developing a complete picture of the hydrology of the study area.

Erosion of sediments caused by runoff. The various layers of the Horseshoe Canyon Formation show different patterns of erosion. More resistive layers will show less erosion.

4. Hydrology

Medicine River eroding into Quaternary sediments. Note the rapids in the bend. The rapids could be due to many factors, including the river-bed gradient (steeper gradients can form rapids), the material in the river bed (rocks and boulders make the flow of water over them less smooth), the width changes of the river (water moving from a wider to a narrower part of the river moves faster, possibly forming rapids), the rate of water flow (faster moving water can form rapids), and the obstructions in the river (water flowing over a rock ledge can form rapids downstream of the ledge). Although it is difficult to say with certainty, the river channel could be narrowing in the bend, and there are indications that the river-bed material could contain more rocky material in the bend than in the area in the foreground of the photo, resulting in the formation of rapids.

responses to these changes and are the most important hydrological factors in the ECC's water balance.

The ECC's Groundwater Recharge

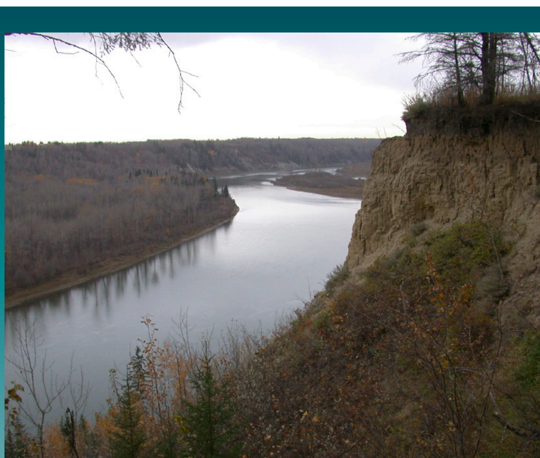
We did this hydrological assessment to find out how much water is entering the ECC's groundwater-flow system. We call this water recharge**.** We used precipitation, evapotranspiration, runoff and base-flow information to figure out the recharge. We estimated the amounts of each of the hydrological component based on mathematical relationships, measured hydrological data (such as stream flow) and climate data.

In the ECC, ***evaporative demand*** is generally similar to precipitation, except during spring snowmelt and summer storm events, when there is excess water available for evaporation. Therefore, short-term differences between precipitation and evapotranspiration tend to control when and how much recharge occurs. The following sections show maps that the AGS created for precipitation, evapotranspiration, runoff and base flow. Using these maps and our understanding of hydrological relationships, we were able to create a recharge map for the ECC.

Annual Total Precipitation

Environment Canada operates 147 climate stations across Alberta that measure total annual precipitation. About 50 of these stations are within or near the ECC boundary. We obtained the climate stations' data from Environment Canada's website.[11]

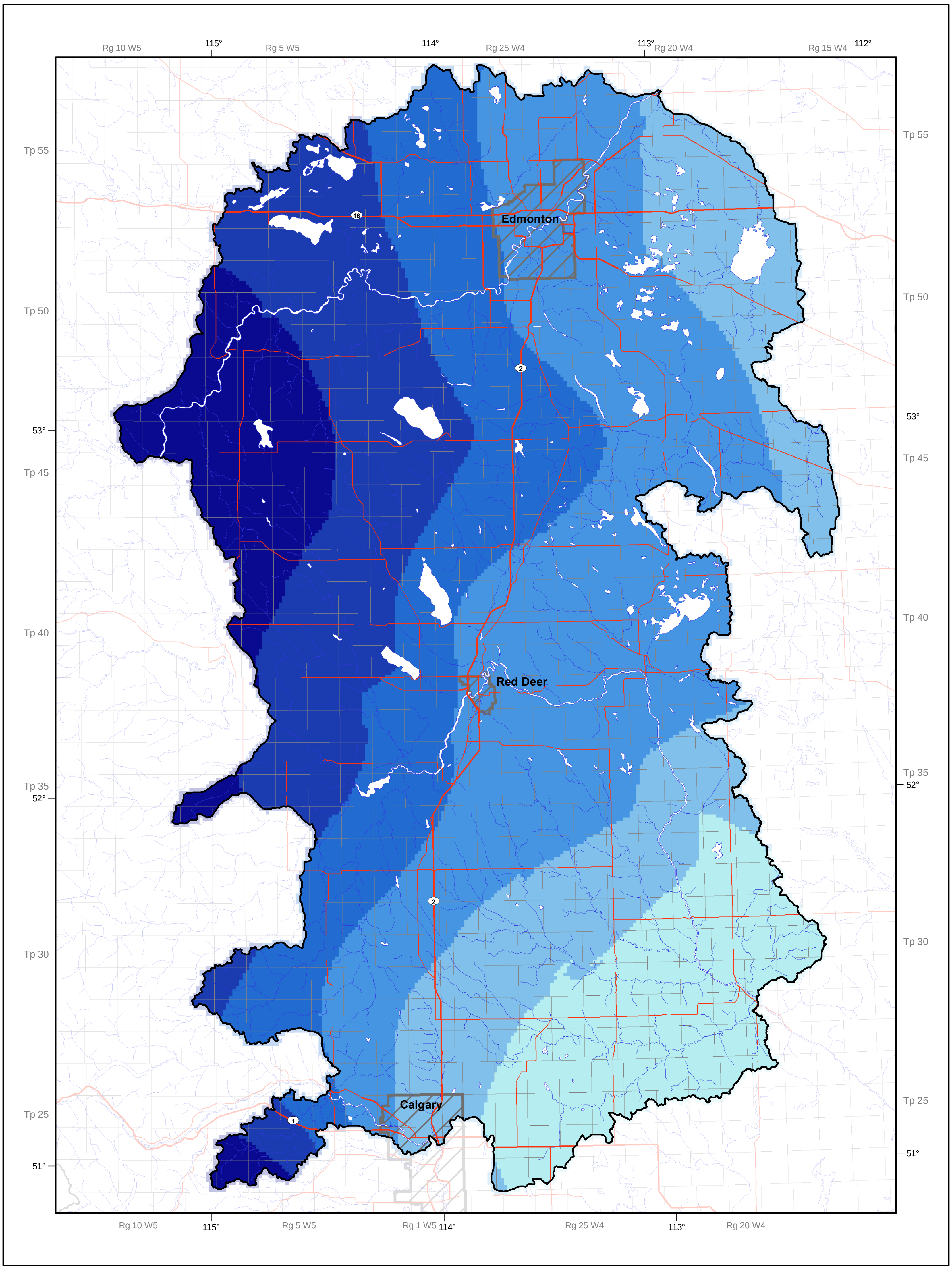
Figure 4.2 shows the 30-year average of annual total precipitation in the ECC between 1970 and 2000. The map shows six zones of long-term, average and annual total precipitation, ranging from 350 to 650 mm per year. The trends in the zones show that there is less precipitation in the southeast of the ECC than in the west or northwest.



North Saskatchewan River near Devon, Alberta. The North Saskatchewan River is one of the major river systems within the ECC. In this photo, we can see its broad flood plain and how deeply it has cut down through the sediments above bedrock and the bedrock to form its river valley.

Hydrometric station on the Blindman River, near Bluffton, Alberta. These hydrometric stations provide valuable information upon which we can base our calculations of how groundwater and surface water interact, and how much water is moving through river systems in the ECC.

Dickson Dam, near Gleniffer Lake, Alberta. The Dickson Dam generates electricity from the Red Deer River by impounding water in an upper reservoir. The effects of such structures must be considered in certain hydrology calculations.



Average Annual Total Precipitation (1970-2000) (Figure 4.2)

Precipitation (mm/year)

- 350 - 400
- 401 - 450
- 451 - 500
- 501 - 550
- 551 - 600
- 601 - 650

0 12.5 25 50 75 100 km

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4. Hydrology

Potential Evapotranspiration

The Earth's surface loses water via evaporation from surface-water bodies, evaporation from the soil and transpiration of plants. Evapotranspiration is the sum of all of the water that the Earth's surface loses to the atmosphere. Potential evapotranspiration is the amount of water that would evaporate or transpire from a land surface if water were available in an unlimited supply.[12]

Typically, potential evapotranspiration is not used in water-balance equations. However, potential evapotranspiration can help show a maximum estimate of evapotranspiration. This can be useful in relatively dry climates, such as Alberta, to assess how much water would evapotranspire in an area that was irrigated or had small surface-water bodies.

Determining Potential Evapotranspiration
We can estimate potential evapotranspiration by measuring the amount of water that evaporates from a container over time or using mathematical relationships based on basic climate data. To calculate potential evapotranspiration in the ECC, we used the Thornthwaite method.[13] Figure 4.3 shows the average annual potential evapotranspiration for the ECC from 1970 to 2000. Potential evapotranspiration is greatest south of Red Deer and toward the northeast of the ECC with the lowest values found in the south of the study area.

Actual Evapotranspiration

Actual evapotranspiration is the amount of water that the Earth's surface loses through evaporation from surface-water bodies, the soil and through transpiration by plants. Unlike potential evapotranspiration, actual evapotranspiration takes into account that an unlimited supply of water is not available for evaporation or transpiration (under natural climatic conditions). Therefore, if there is no water, no evaporation or transpiration can occur. Actual evapotranspiration is an important part of the water balance, especially in drier climates. In central Alberta's relatively dry climate, actual evapotranspiration rarely approaches calculated potential evapotranspiration values.

Calculating Actual Evapotranspiration for the Entire ECC
The task of accurately predicting actual evapotranspiration is complex. It often requires a lot of data and generally only shows the actual evapotranspiration for specific locations. To calculate average actual evapotranspiration for the entire ECC, we used the Turc equation,[14] which required only a small amount of data, such as temperature, humidity and solar radiation.

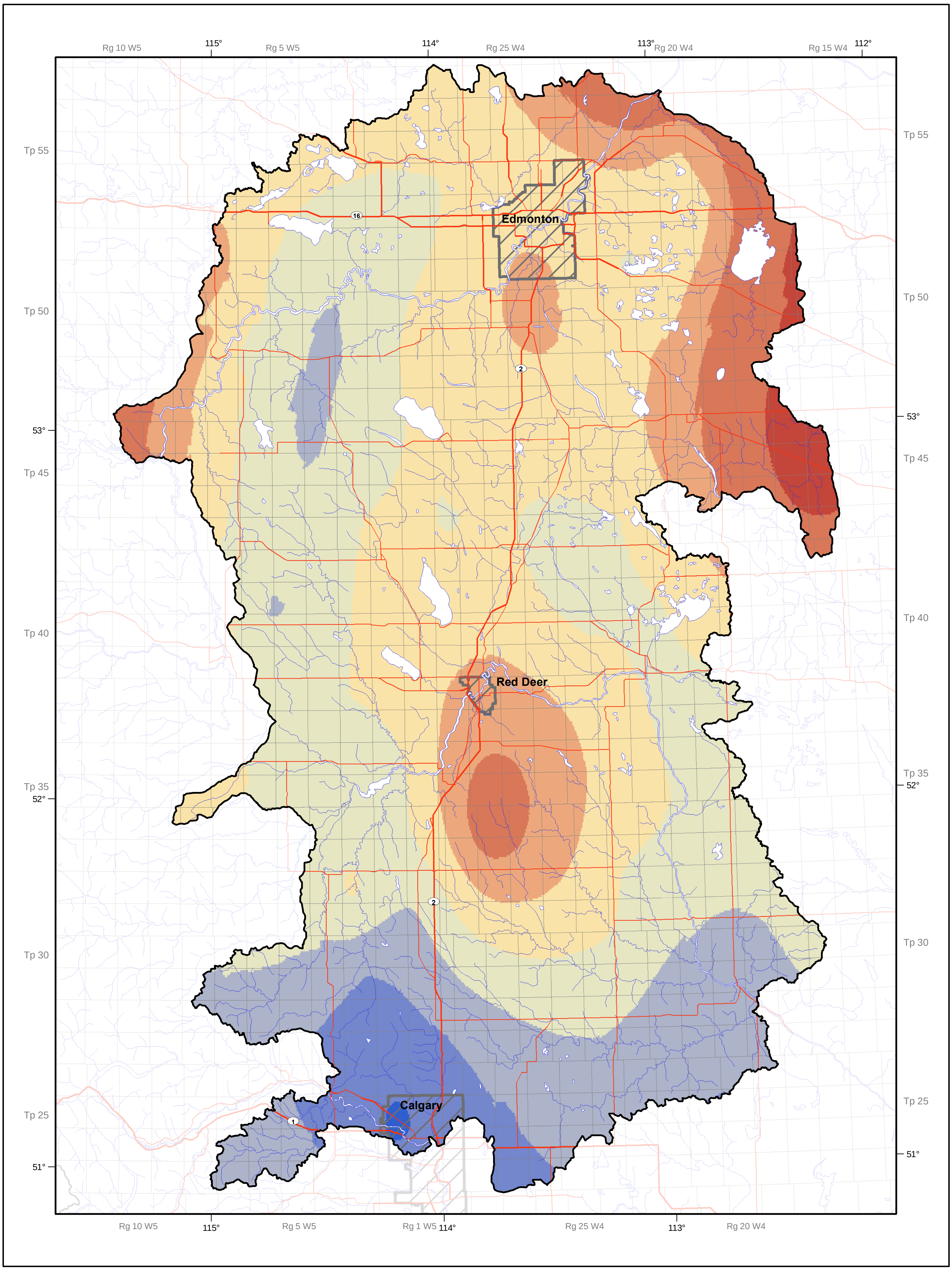
Using the Turc equation, we calculated actual evapotranspiration across the ECC. Not all temperature stations had precipitation data, so we used values from the precipitation map (Figure 4.2), as necessary. Figure 4.4 shows the actual evapotranspiration values we calculated and the map we made based on those values. Actual evapotranspiration is greatest in the western portion of the ECC, decreasing toward the east and southeast.

Total Surface Drainage

Unlike the atmospheric components of the water budget (precipitation and evapotranspiration) that are calculated at the scale of the entire ECC, total surface drainage and its subcomponents (baseflow and runoff) are calculated at a more detailed level, such as the drainage basin scale. Environment Canada and Alberta Environment measure stream flow (the amount of water travelling in a stream at a given time), also known as total surface drainage, using stream gauges installed and monitored in various parts of Alberta. Stream flow indirectly gives us a record of a drainage basin's runoff and base-flow data. Base flow and runoff are important in a groundwater study because they allow us to estimate groundwater recharge.

Base Flow
Base flow is groundwater that flows from underground into a streambed or river bed. Alberta Environment sometimes uses base-flow information to help decide how much water from a certain stream or river it will allow various users to use.

Travelling by raft in the headwaters of the North Saskatchewan River. Note the different characteristics of the river here as compared to the previous photo near Devon. Changes in the river-flow system affect how surface water and groundwater interact.



Average Annual Potential Evapotranspiration (1970-2000) (Figure 4.3)

Potential Evapotranspiration (mm/year)

- 315 - 375
- 376 - 400
- 401 - 425
- 426 - 450
- 451 - 475
- 476 - 500
- 501 - 550
- 551 - 575

0 12.5 25 50 75 100 km

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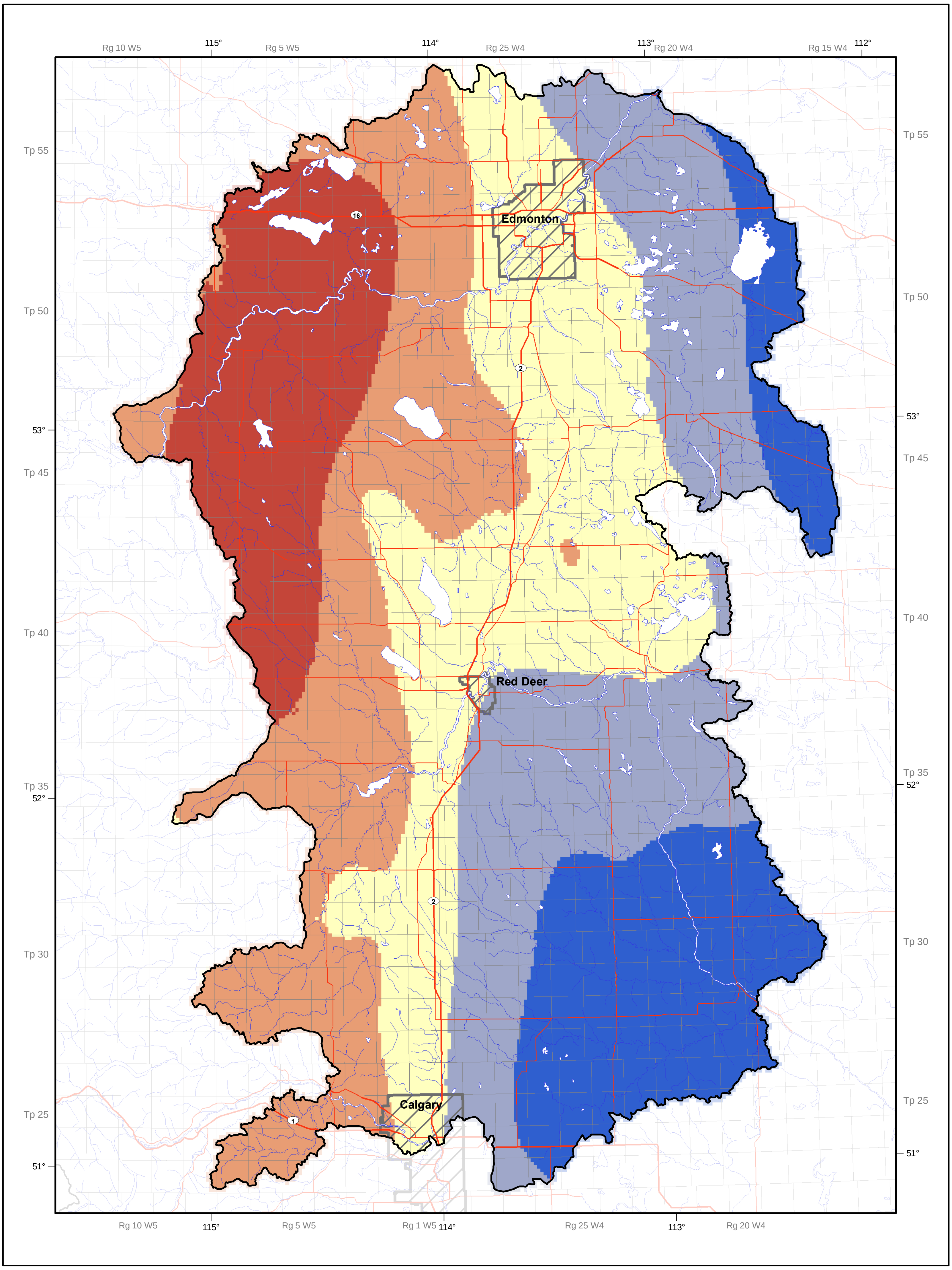

Average Annual Actual Evapotranspiration (1970-2000) (Figure 4.4)

Actual Evapotranspiration (mm/year)

- 275 - 285
- 286 - 295
- 296 - 305
- 306 - 315
- 316 - 325

0 12.5 25 50 75 100 km

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4. Hydrology

Measuring Base Flow
Alberta Geological Survey conducted base-flow separation analysis on data from Environment Canada and Alberta Environment's stream-gauging stations in the ECC. We plotted stream-flow measurements on ***hydrographs***, which show flow volume at certain times (Figure 4.5). We used a simple approach to figure out base flow using hydrographs in the ECC. We looked at the average flow volumes from November through to February. We then assumed that these flow volumes represented 100 per cent base flow. Because we believed that recharge is about zero during winter, this approach reasonably estimates minimum base flow. This approach showed us that base flow is at least 30 per cent of total surface drainage across the ECC. The base-flow map (Figure 4.6) shows the ECC's minimum annual base flow. Base flow is greatest in the west of the study area and decreases toward the east.

Runoff
Runoff happens when so much rain falls or so much snow melts that the soil can not absorb all of the resulting water. Frozen ground is one example of a condition that creates runoff. Runoff rapidly travels either across the land surface as overland flow, or it travels just below the ground's surface through the upper part of the soil zone. Runoff neither penetrates below the ***rooting zone*** in the soil nor enters the groundwater environment. Runoff flows directly into surface-water bodies.
We calculated runoff volumes during the base-flow separation analysis. Because base flow represents about 30 per cent of the total surface drainage, the rest of the annual flow volume represents maximum annual runoff. To better show runoff volumes, we mapped watershed boundaries for named rivers and streams. We then divided runoff volumes from each basin by the basin's surface area to get runoff values in millimetres per unit area. The runoff map (Figure 4.7) shows the maximum annual runoff across the ECC. Runoff is greatest in the western portion of the study area, decreasing toward the east.

Groundwater Recharge

Groundwater recharge is water from precipitation or snowmelt that penetrates the ground and reaches the ***saturated zone*** or ***water table***. Recharge occurs if groundwater is flowing down, away from the land surface. Recharge at any particular location depends on soil characteristics, vegetation, how long the rain falls, how much rain falls and the location's position within a groundwater-flow system. These factors make it difficult for us to estimate or evaluate recharge over large areas and across different landforms. However, we created a minimum annual recharge map (Figure 4.8) using a water-balance method. This method uses precipitation, evapotranspiration and runoff data to calculate recharge. Recharge values are greatest for the western portions of the ECC, decreasing toward the east.

We need to understand the quantity of recharge to understand groundwater-flow systems. Knowledge of groundwater-flow systems can help us manage our groundwater by telling us how quickly groundwater is replenished and how our groundwater withdrawals (through pumping) affect the system.

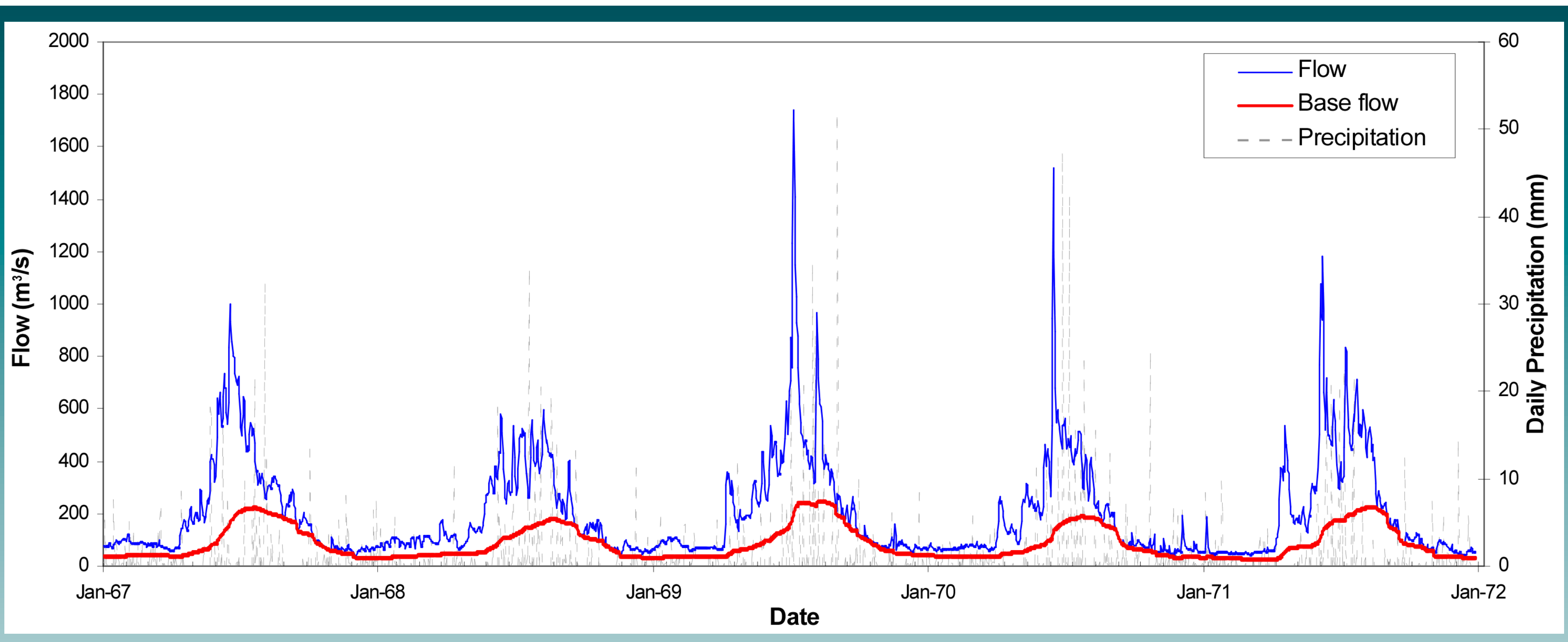
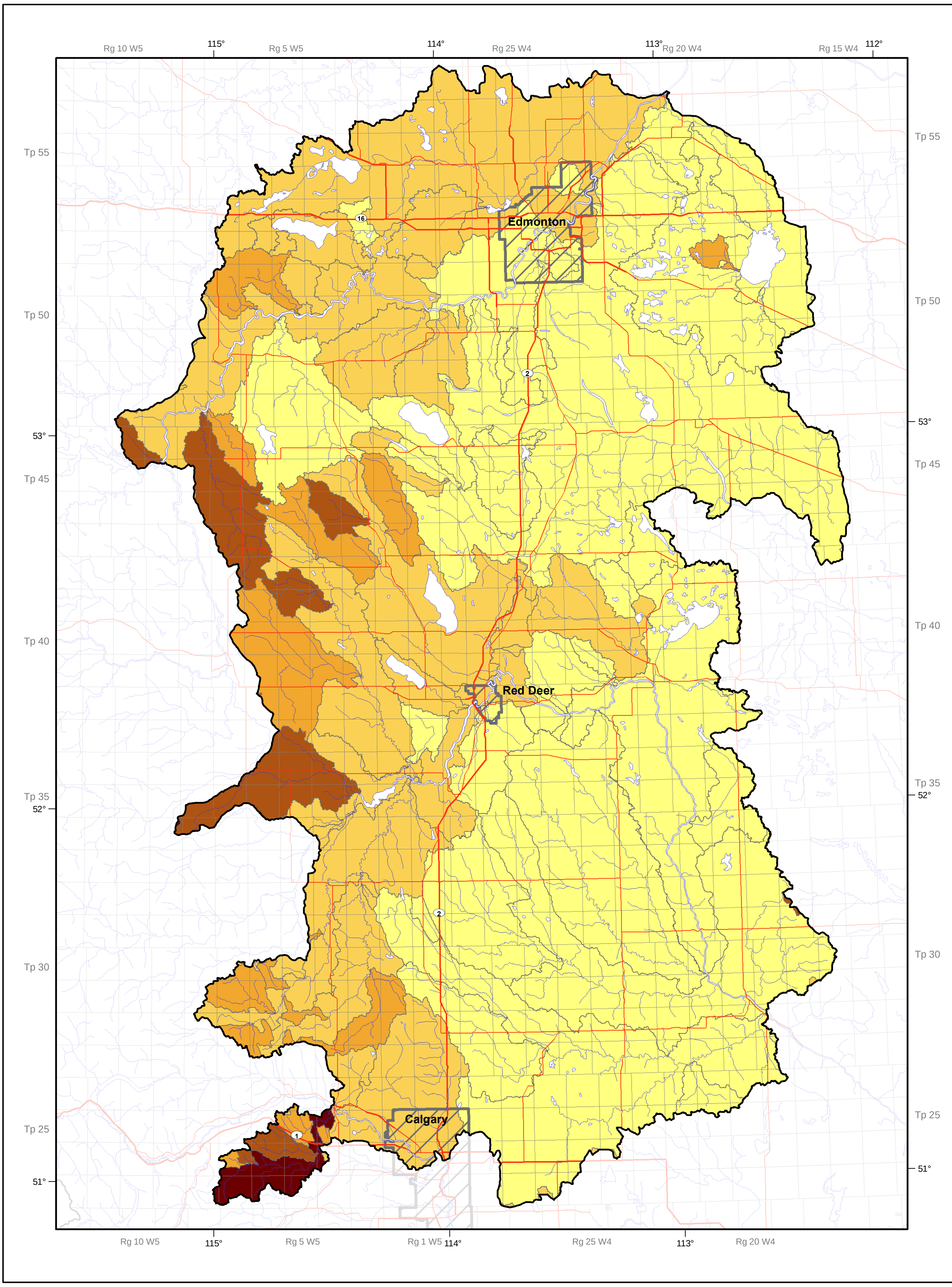


Figure 4.5. Hydrograph of the North Saskatchewan River in Edmonton (1967–1972).



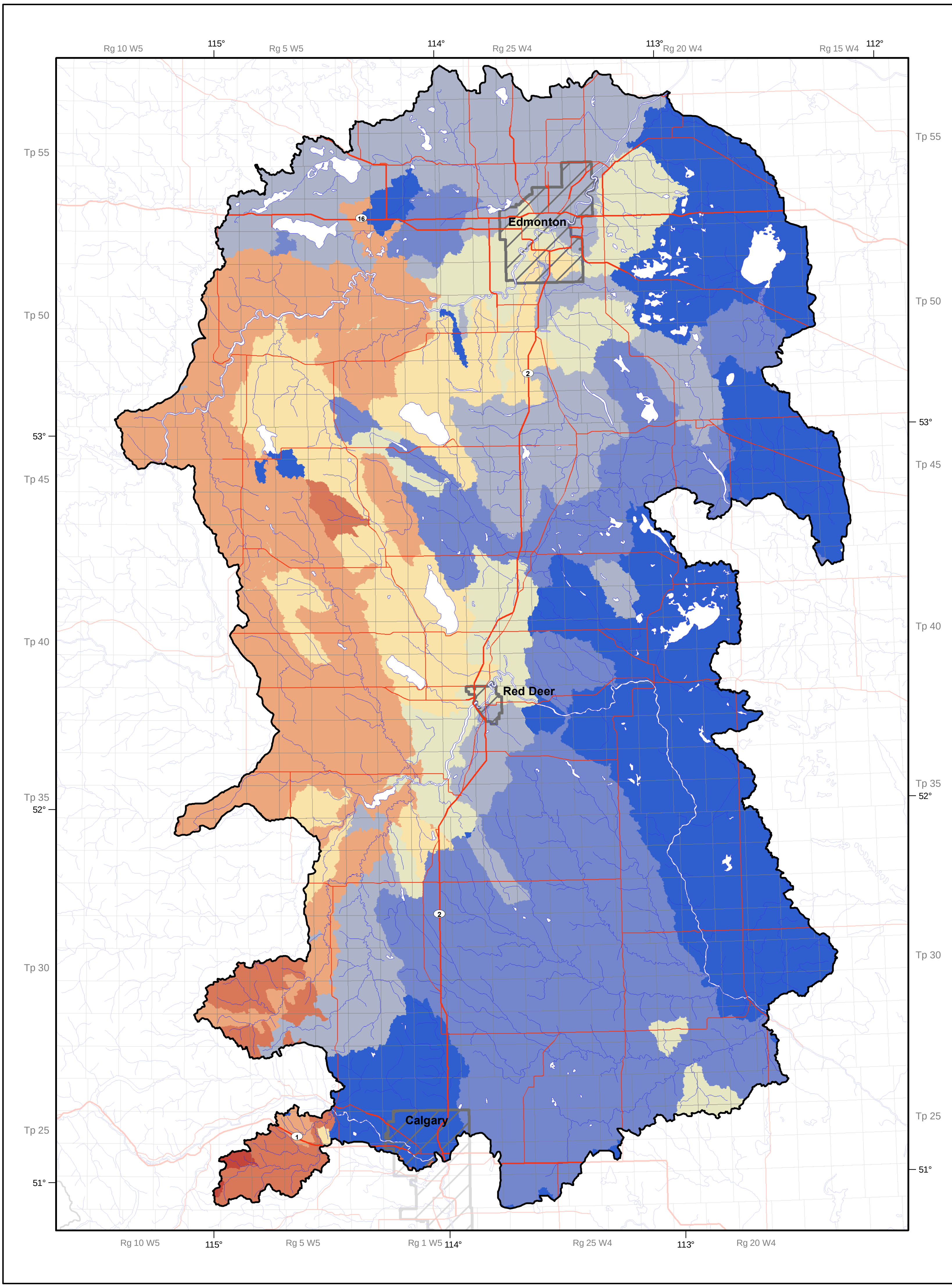
Average Annual Minimum Base Flow (Figure 4.6)

Minimum Annual Base Flow (mm/year)

- 0 - 4
- 5 - 12
- 13 - 43
- 44 - 72
- 73 - 127

0 12.5 25 50 75 100 km

Base Data Provided by Spatial Data Warehouse Ltd.



Average Annual Maximum Runoff (Figure 4.7)

Maximum Annual Runoff (mm/year)

0 - 11
12 - 18
19 - 25
26 - 35
36 - 45
46 - 65
66 - 125
126 - 300

0 12.5 25 50 75 100 km

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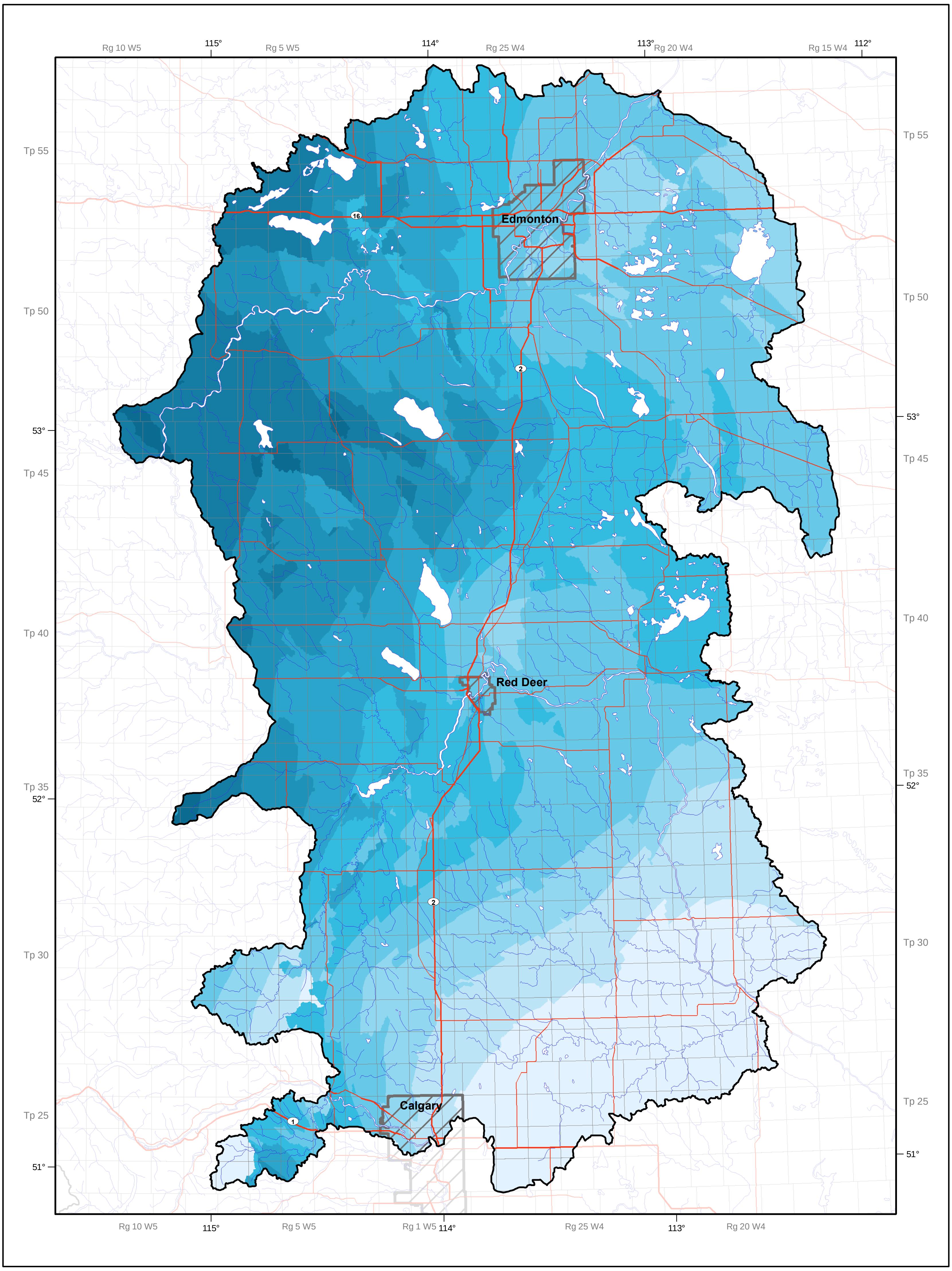

Average Annual Minimum Recharge (Figure 4.8)

Recharge (mm/year)

0 - 25	76 - 100	151 - 175
26 - 50	101 - 125	176 - 200
51 - 75	126 - 150	201 - 225

0 12.5 25 50 75 100 km

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5. Hydrogeology

5. Hydrogeology

Hydrogeology Basics

Hydrogeology is the subdiscipline of geology that deals with the interactions between groundwater, surface water, and sediments and rocks. Hydrogeology uses concepts from geology, biology, physics and chemistry to help us understand groundwater movement and the chemical reactions that occur as groundwater moves in the Earth's subsurface.

Groundwater Movement

Groundwater movement is driven by differences in the elevation of ***hydraulic heads*** in the subsurface. The hydraulic head is the level that groundwater rises to within a well. Hydraulic head is a measure of the potential energy that drives the flow of groundwater. Groundwater flows from areas with higher hydraulic-head elevations to areas with lower hydraulic-head elevations to equalize the head water pressures between the two areas. Figure 5.1 shows that groundwater flow may take place over short distances and time spans (local flow) or long distances and time spans (regional flow). Groundwater-flow systems and hydraulic-head elevations are influenced by natural factors (drought or flooding) or by man-made stresses (groundwater pumping or alteration of the land surface).

Groundwater follows the path of least resistance through the subsurface. The properties of the geological layers determine this path.[15] These properties include the geological layers'

- geometry (orientation and shape of the layer),
- ***porosity*** (how much open space exists in the sediments or rocks), and
- permeability (how easily a fluid can move through the sediment or rock).

When we understand the properties of the geological layers in the subsurface, we can figure out which layers will conduct groundwater (aquifers) and which will hinder it (aquitards).

Aquifers are geological layers that are water-saturated, have high permeabilities and can yield significant quantities of water to wells or springs.

Thomas Graf, Alberta Geological Survey, measuring Paskapoo Formation sandstone thickness near Drayton Valley. The Paskapoo Formation is an important source of groundwater in Alberta. Understanding its properties and subsurface extent helps us map those portions of the Paskapoo Formation best suited for use as sources of groundwater.

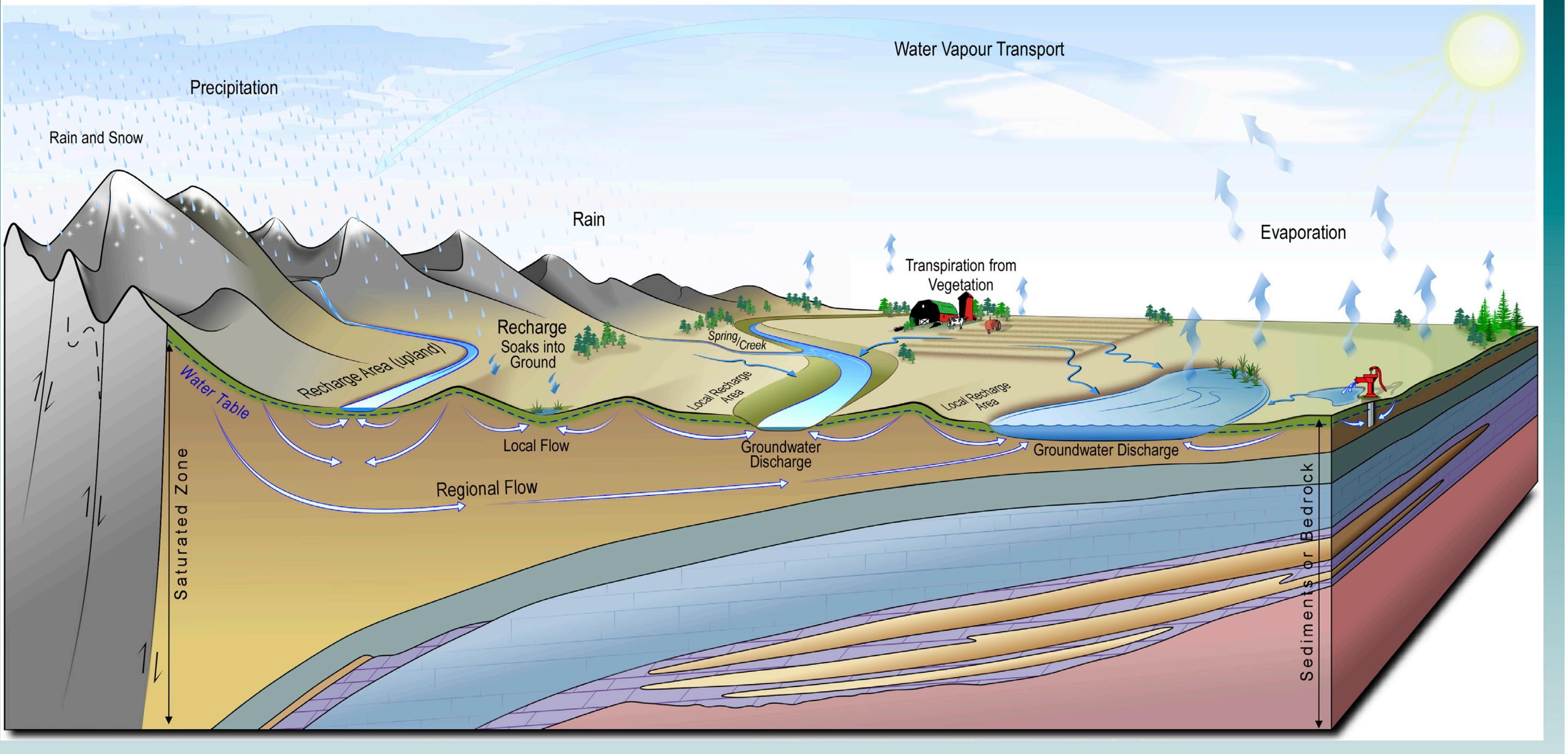


Figure 5.1. Hydrogeological cycle in the ECC.

5. Hydrogeology

Aquitards (or confining layers) are geological layers that are water-saturated, have low permeabilities, but cannot transmit significant quantities of water. Aquifers can be confined—enclosed above and below by aquitards—or unconfined, with no aquitard above the aquifer.

How We Gain Access to Groundwater
Groundwater flows to the land surface to form springs, flows into surface-water bodies (like rivers, streams, lakes and wetlands) and can be sampled or monitored in wells (Figure 5.1).

A spring is typically a small point on the Earth's surface where groundwater moving through the subsurface intersects the land surface. Groundwater that feeds into surface-water bodies helps maintain the water levels in streams, rivers and lakes. Wells allow us to extract groundwater from, or monitor the water levels in, the geological layer in which a well is completed.

Groundwater mapping almost exclusively relies on data from boreholes, like wells, since the movement of groundwater is not usually visible or measurable at the land surface without them. The maps in this section use these data to estimate both the parameters being mapped for which we have borehole information and the areas where no wells exist. This is done with statistical mapping techniques. It is very important to know that all maps have some level of uncertainty in them, as described in Section 1.

Understanding the ECC's Hydrogeology

The following sections outline the work AGS completed to understand the ECC's hydrogeology. The primary data source was the Alberta Water Well Information Database, supplemented by AGS data. We summarize the work in this section and provide detailed information later in this chapter.

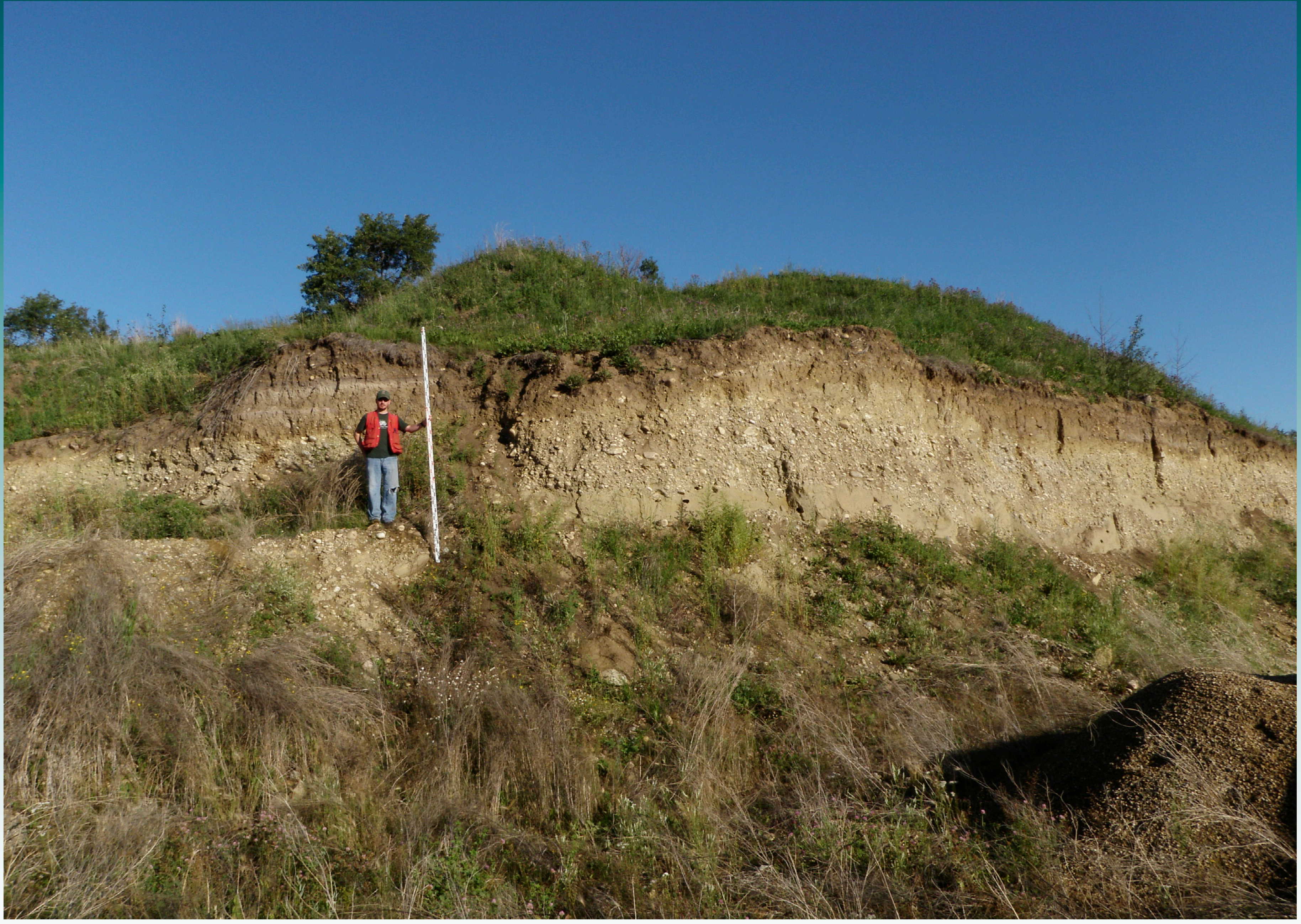
The ECC's Hydrogeological Framework
We used our understanding of the sediments above bedrock and of the bedrock units to construct models showing the hydraulic properties of the ECC's major geological units. Figure 5.2 shows a cross-section of the bedrock formations with a chart showing which sediments are aquifers and which are aquitards. Figure 5.3 shows the possible geometry of the sediments above bedrock with a chart showing which sediments are aquifers and which are aquitards.

Well Density
Well density shows us where the ECC's wells are and which areas have more wells than other areas. We consider this information when interpreting maps based on the water-well data. Areas with more water wells generally give us a more accurate understanding of hydrogeological parameters. In areas with low well density, greater uncertainty exists in the accuracy of the estimates. When examining any map, it is good practice to also review the data density to understand which estimates are based on data and which estimates are based on calculations.

Hydrogeological Parameters

Water Table
The water table is where fully saturated groundwater conditions are first encountered below the surface of the Earth if we were to dig or drill downward from the Earth's surface. The whole subsurface is saturated below the water table. Therefore, the water table is the surface between the ***unsaturated zone*** and saturated zone (Figure 5.1). The water table is a three-dimensional surface and usually follows the surface topography in a subdued manner. We typically use the elevation of the water-table surface to estimate local groundwater-flow directions, identify shallow aquifers and determine the depth to groundwater in an area.

Groundwater Flow
We looked at the hydraulic-head elevations in wells to understand how groundwater is moving in the subsurface. Recall that groundwater flows from higher to lower hydraulic-head elevations. This flow has a component that moves in a horizontal direction and a component that moves in a vertical direction. When you add the horizontal and vertical components together, you have the overall direction of groundwater flow. Groundwater moving between aquifers typically travels slower than groundwater moving within an aquifer, because the



Steven Lyster, Alberta Geological Survey, measuring thin till cover on unconsolidated sand and gravel. The till-sand and gravel contact is best seen in the leftmost portion of the photo where the lighter and darker grey-brown till overlies the sand and gravel. You can follow this contact across the photo. This sharp contact is also marked in many places by a zone of rusty colouration. Sand and gravel deposits can also be important sources of groundwater. By mapping them near the land surface and in the subsurface, we gain a better understanding of their potential as sources of groundwater.

5. Hydrogeology

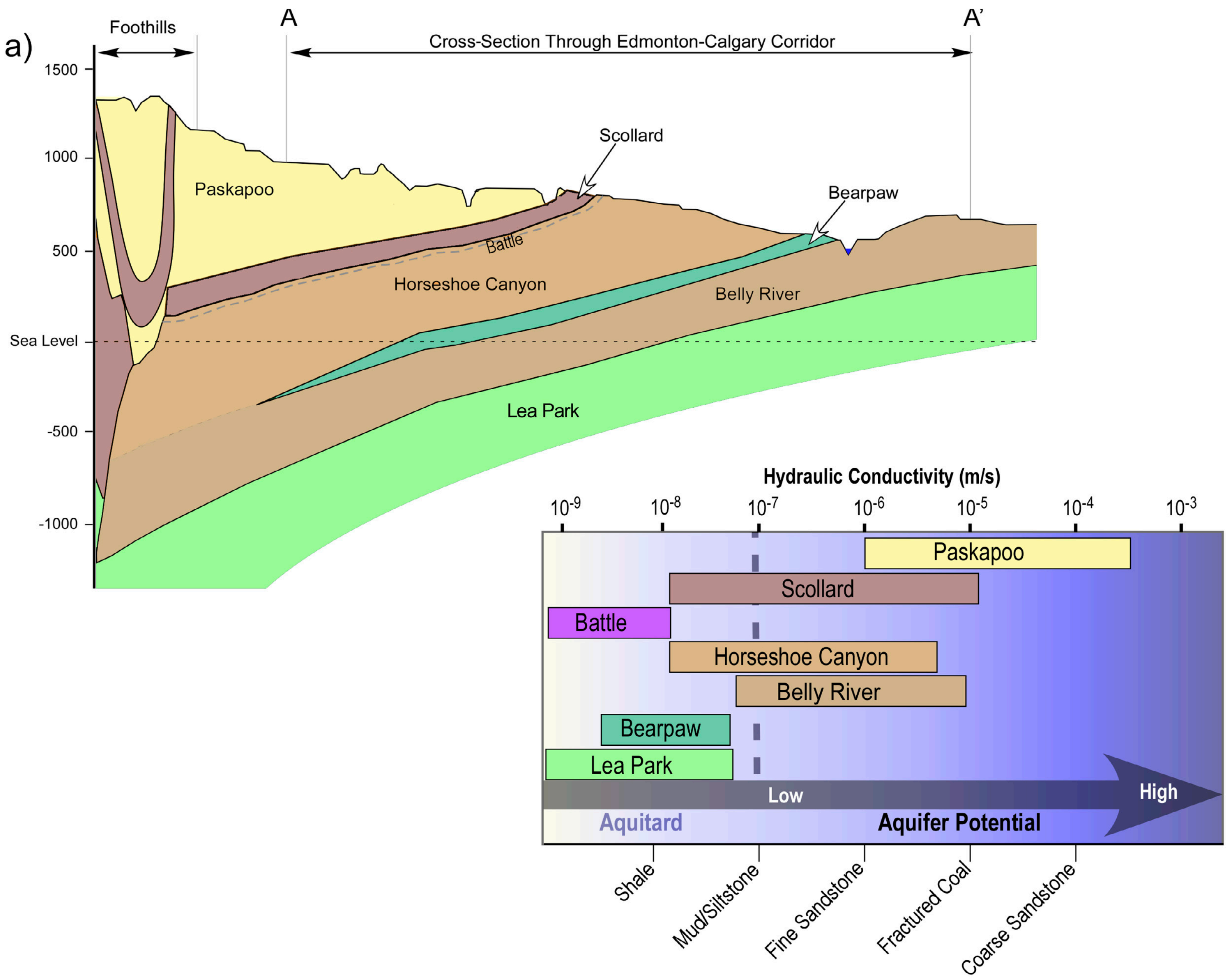


Figure 5.2. Cross-section through the ECC and the aquifer potential of the bedrock formations in the ECC.

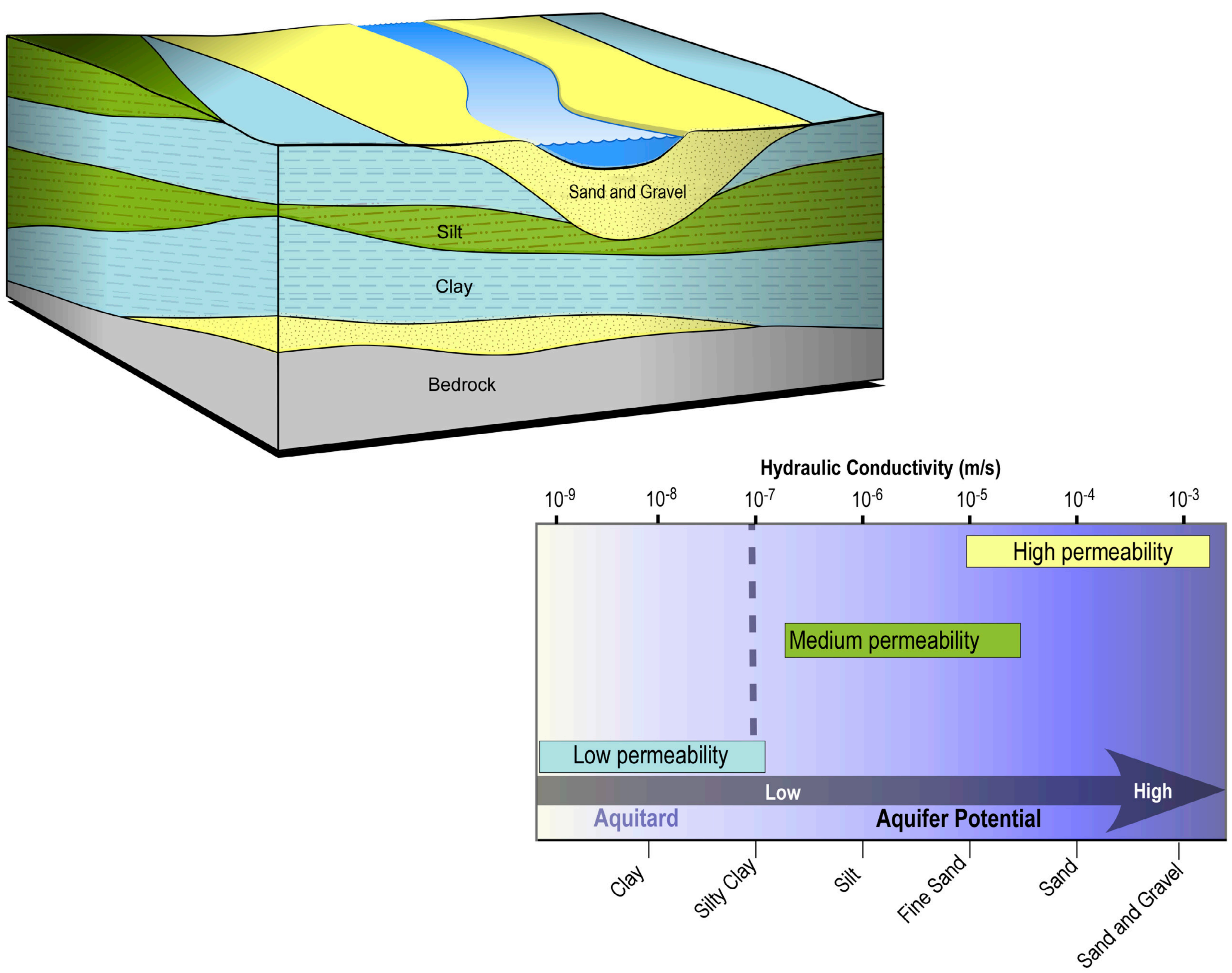


Figure 5.3. Conceptual model of the sediments above bedrock in the ECC and the aquifer potential of those different sediments.

groundwater moving between aquifers has a much greater chance of being slowed by aquitards as it travels vertically. In general, groundwater in aquifers tends to flow horizontally within the aquifer, whereas groundwater in aquitards tends to flow vertically across the aquitard.

We use the hydraulic-head elevations to produce ***water-level surfaces*** (which show elevations of the hydraulic head in a particular subsurface zone) for various zones in the subsurface. We then use these surfaces to figure out the directions of groundwater flow.

Recharge and Discharge
We also used water-level surfaces to locate ***recharge areas*** (where groundwater flows down into the groundwater system) and ***discharge areas*** (where groundwater flows up into springs or surface-water bodies).

Potential-Yield Mapping
Potential-yield mapping displays the maximum amount of groundwater potentially available in the upper 100 to 200 m of geological media at any location in the ECC.

Groundwater Susceptibility
Groundwater susceptibility refers to how easily groundwater can be contaminated from surface sources. It depends on how easily water enters and moves through a particular subsurface area, and is a function of the overlying material and the hydrogeological conditions of the area.[16] We used information on aquifer properties, water levels and climatic conditions to understand susceptibility.

Well Density

In Alberta, most urban areas are on or near major river systems and use surface water as their water source. In contrast, rural residents, who generally do not have access to the water infrastructure available in urban areas, tend to use groundwater as their water source. The most common way to access groundwater is to drill wells and pump the water. People generally prefer deeper wells drilled into the bedrock instead of shallower wells drilled only into the sediments above the bedrock. This is because bedrock wells tend to produce more water and tend to have water whose chemical composition is better suited for human, household or agricultural use.

The water-well density map (Figure 5.4) shows that rural areas surrounding major urban centres and around lakes in the ECC have many wells. Some are in use, some unused and some are reclaimed. These areas are mainly populated by acreage owners. The rest of the ECC is generally agricultural land or forested areas where wells are farther apart.
Anyone looking at maps derived from the water-well database should consider the well density when evaluating the results of the work. When we create maps, we use mapping techniques to estimate the values of what we are mapping for areas where we do not have data points. For these areas we are less certain that the estimates we make are correct. For areas where we have more data, we can be more certain of the mapped values and, therefore, more confident that the map represents the actual conditions of the area.

Mapping the Water Table

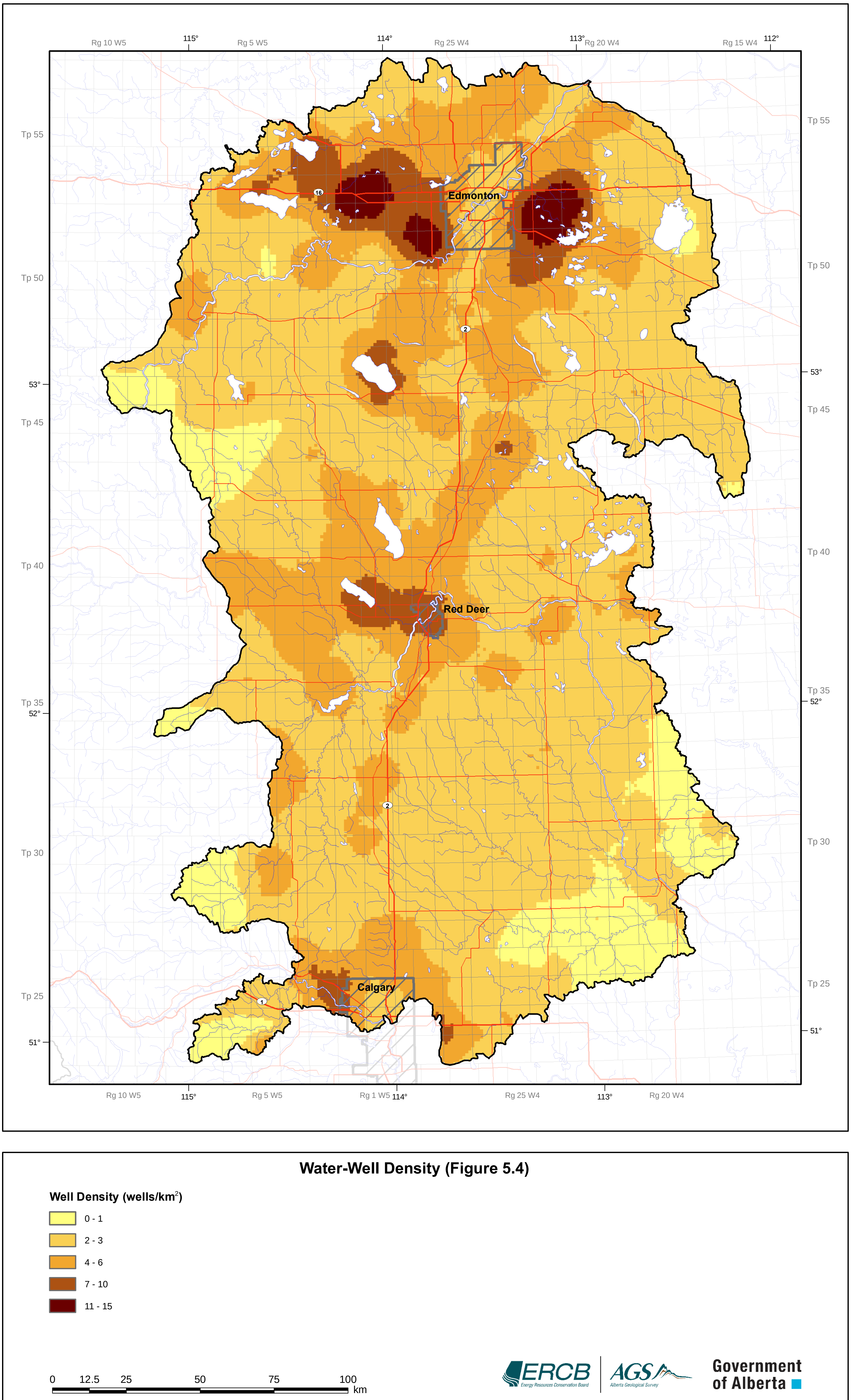
The water table

- generally follows land-surface topography but with less abrupt changes in elevation;
- tends to be closer to the land surface in low-lying areas and farther from the land surface in upland areas;
- is affected—in terms of position within the ground—by sediment type. Water flows through permeable sediments (such as sand and gravel) quickly, so the water table is typically farther from the land surface and flatter in these areas. Low-permeability sediments (such as clay) slow the downward movement of water, keeping the water table closer to the land surface;
- matches the elevation of the water along river or stream banks, lake shores, spring discharge points or wetland edges;
- changes elevation seasonally and annually, and is directly affected—in terms of elevation—by changes in the amount of

Fractured sand and gravel near Wabamun Lake. Fractures can increase a rock's permeability making it easier for water to flow through the rock. However, sometimes fractures can be filled, effectively sealing them. These fractures appear filled in. Note the white material.

Spring discharging to form a pond in the central part of the ECC.

Measuring the permeability of a rock sample collected during the ECC drilling program. A tool called a mini-permeameter determines the permeability of a rock sample by measuring how much nitrogen gas can be injected into the rock over time.



Water-Well Density (Figure 5.4)

water entering and leaving the groundwater system; and

- may lie in the bedrock, especially in upland areas where bedrock is near the land surface (and the land surface has thin sediment cover) or where river valleys have cut into the land and lowered the water table.

We map the water-table surface because we can use it to estimate other hydrogeological characteristics, such as the thickness of the interval between the land surface and the water table (the unsaturated zone), local groundwater-flow directions or the positions of shallow aquifers.

How We Mapped the Water Table
To create the map of the water-table surface we used

- elevations of permanent water bodies (such as wetlands, lakes and rivers);
- elevations of springs; and
- water levels from wells that have screened intervals in the sediments above the bedrock or screens in bedrock (if the bedrock is within 5 m of the ground surface).

Figure 5.5 (next page) shows the water-table surface, which looks very similar to the present-day land surface. When we look at this map and talk about groundwater flow, we expect groundwater to move from areas of higher elevation to areas of lower elevation.

Groundwater Flow

Groundwater flow is the movement of water in the saturated zone, which is everything below the water table. Groundwater flow occurs because of elevation differences in hydraulic heads from one point to another in the same aquifer or between overlying aquifers.

Groundwater flow can

- be local to regional in scale;
- be constrained horizontally by boundaries known as groundwater divides: groundwater moves in one direction on one side of the boundary and in the opposite direction on the other side of the boundary;
- be constrained vertically or horizontally by boundaries that groundwater cannot flow through (aquitards); and
- contain one or more recharge and/or discharge areas.

Our understanding of groundwater flow in the ECC comes mainly from work done by József Tóth[17] on flow in small drainage basins in prairie environments. Tóth's work described local groundwater flow versus regional groundwater flow and changed the way hydrogeologists understand these concepts.

When we use these concepts of flow with our knowledge of the type of sediment that the various geological units are composed of, we can refine our interpretation of groundwater flow within the ECC.

For the purposes of this atlas, we wanted to understand groundwater flow in a broad, regional sense across the ECC. Because we cannot measure the direction of groundwater flow directly, we use the hydraulic-head elevations in wells to figure out flow direction (Figure 5.6). We use the hydraulic-head elevations from the wells completed in various subsurface zones to generate water-level surfaces for these zones. We then use the information from these surfaces to understand groundwater-flow directions within and between subsurface zones.

Groundwater flows in three dimensions. To understand this three-dimensional flow, we look at the horizontal (groundwater flow within the same subsurface zone) and vertical (groundwater flow across subsurface zones) components of groundwater flow. As groundwater flows from higher hydraulic-head elevations to lower hydraulic-head elevations, groundwater moves toward or away from a well depending on that well's hydraulic-head elevation compared to surrounding wells. Within aquifers, flow is mainly horizontal. Within aquitards, flow is mainly vertical.

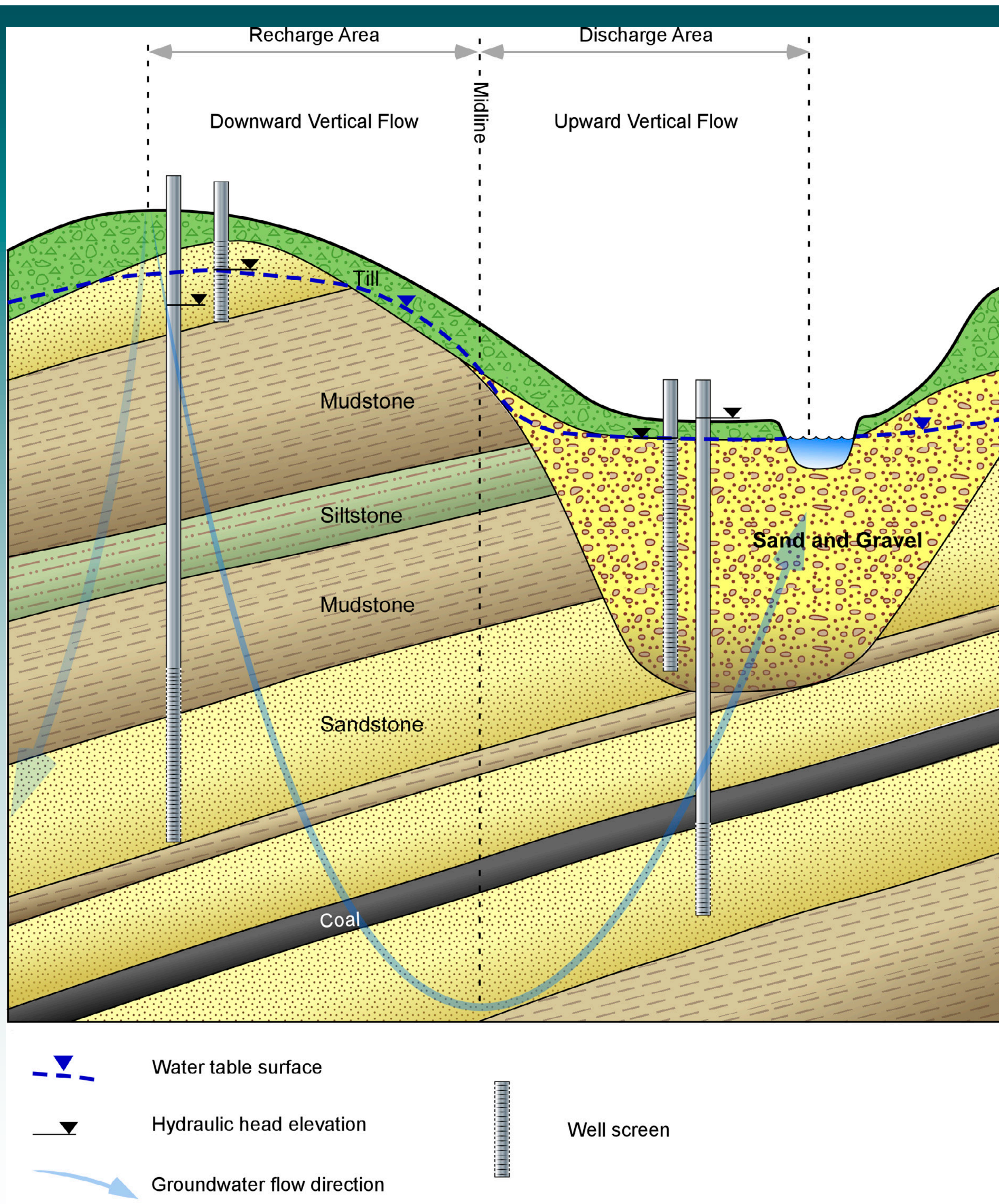
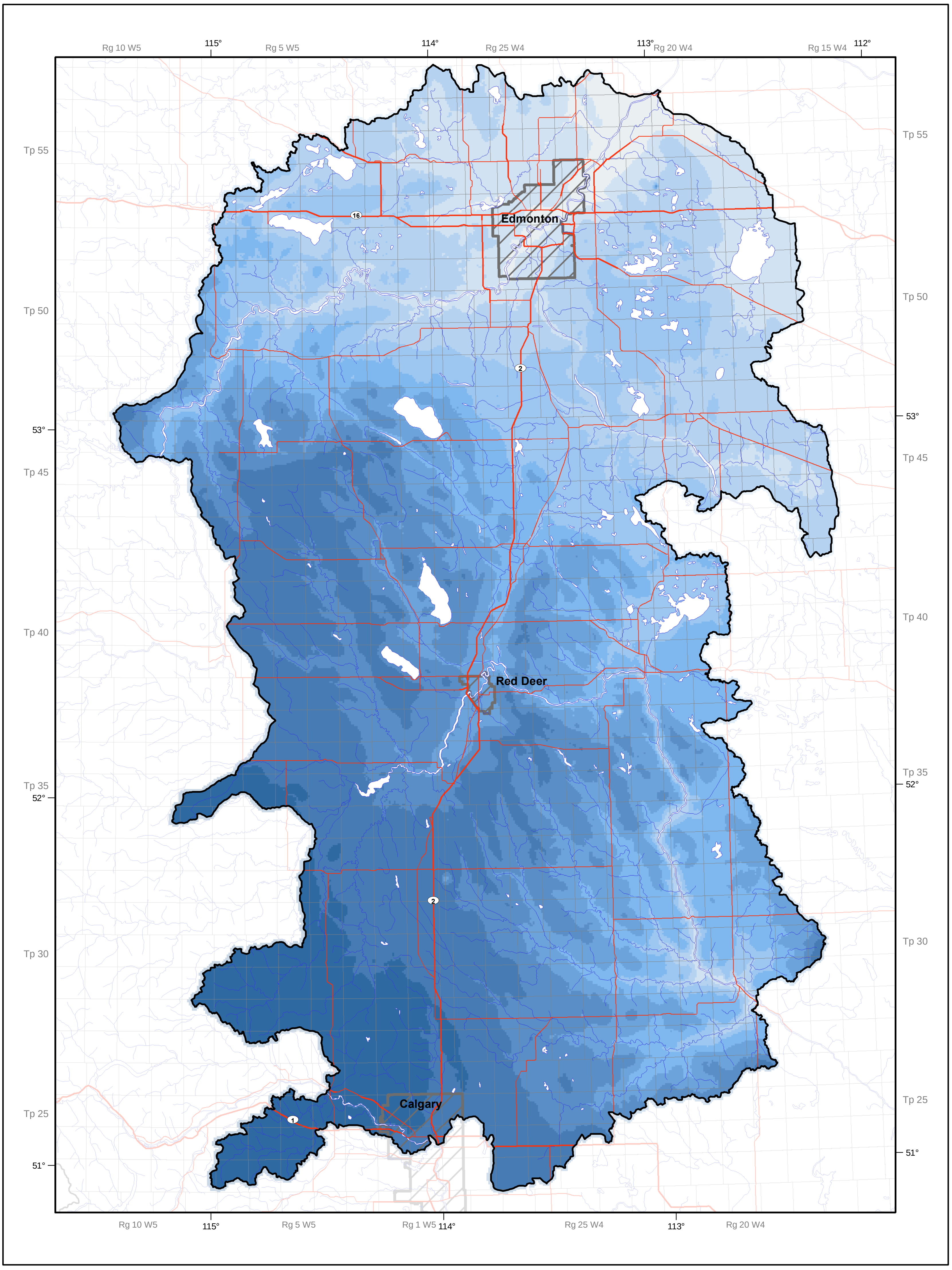


Figure 5.6. Two-dimensional schematic of a groundwater-flow system showing the water-table surface, recharge and discharge areas and the associated hydraulic-head elevations in the groundwater wells installed in different parts of the flow system and groundwater-flow direction.



Water-Table Surface (Figure 5.5)

Elevation (metres above sea level)

- 516 - 650
- 651 - 700
- 701 - 750
- 751 - 800
- 801 - 850
- 851 - 900
- 901 - 950
- 951 - 1100
- 1101 - 2254

0 12.5 25 50 75 100 km

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The vertical movement in aquifers and aquitards also have a downward or upward component. When the horizontal and vertical components are combined, the result is a picture of the overall direction of flow.

Water-Level Surfaces

A water-level surface is an estimate of the hydraulic-head elevations within the same aquifer or in the same subsurface zone. The water table is an example of a water-level surface. We used the available hydraulic-head data from the Alberta Water Well Information Database to create the water-level surfaces referred to in this section. Water-level surfaces show how hydraulic-head elevations vary across an area.

In this section, we focus on the hydraulic-head information available for the various bedrock formations in the ECC. We created water-level surfaces using wells completed in bedrock that had measured hydraulic-head values. We sorted the wells into ten metre intervals below the ground surface, based on the depth of the completion. Table 5.1 shows the number of wells at each depth interval. (For example, in the ECC, there are 11 152 wells in bedrock whose completions are between 10 metres and 20 metres below the ground surface (m bgs)).

We created 10 water-level surfaces to show groundwater flow within and between the various bedrock formations in the ECC, one for each of the intervals listed in Table 5.1. An upcoming AGS report will provide the full analysis of the results. However, for this atlas, we will show a summary of the findings using one example of the created surfaces.

Table 5.1. The number of well records used to create water-level surfaces for each subsurface zone.

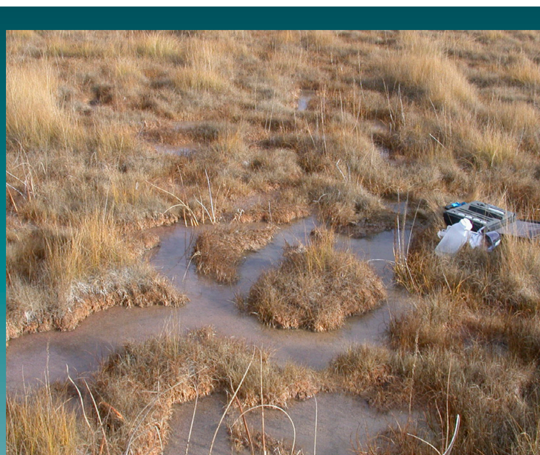
Depth Interval (m bgs)	Well Records
10–20	11 152
20–30	11 121
30–40	10 824
40–50	6445
50–60	3730
60–70	2430
70–80	1618
100–125	432
100 +	636
200 +	40

Figure 5.7 shows the water-level surface of the 30–40 m bgs interval. We chose this water-level surface as an example for the atlas because the data density in this interval is high (10 824 wells), suggesting that it represents a common target depth for wells within the ECC.

When we look at the map, we can comment on general patterns of horizontal flow within the ECC in this depth interval. Flow will be from the darker colours toward the lighter colours. We can see the important role that the major rivers play in controlling groundwater flow, as many of the lowest elevations coincide with the North Saskatchewan, Battle and Red Deer rivers.

To figure out the direction of the vertical groundwater-flow component, we used the differences between the hydraulic-head values in a given interval and the hydraulic-head values in the interval immediately above or immediately below that interval.

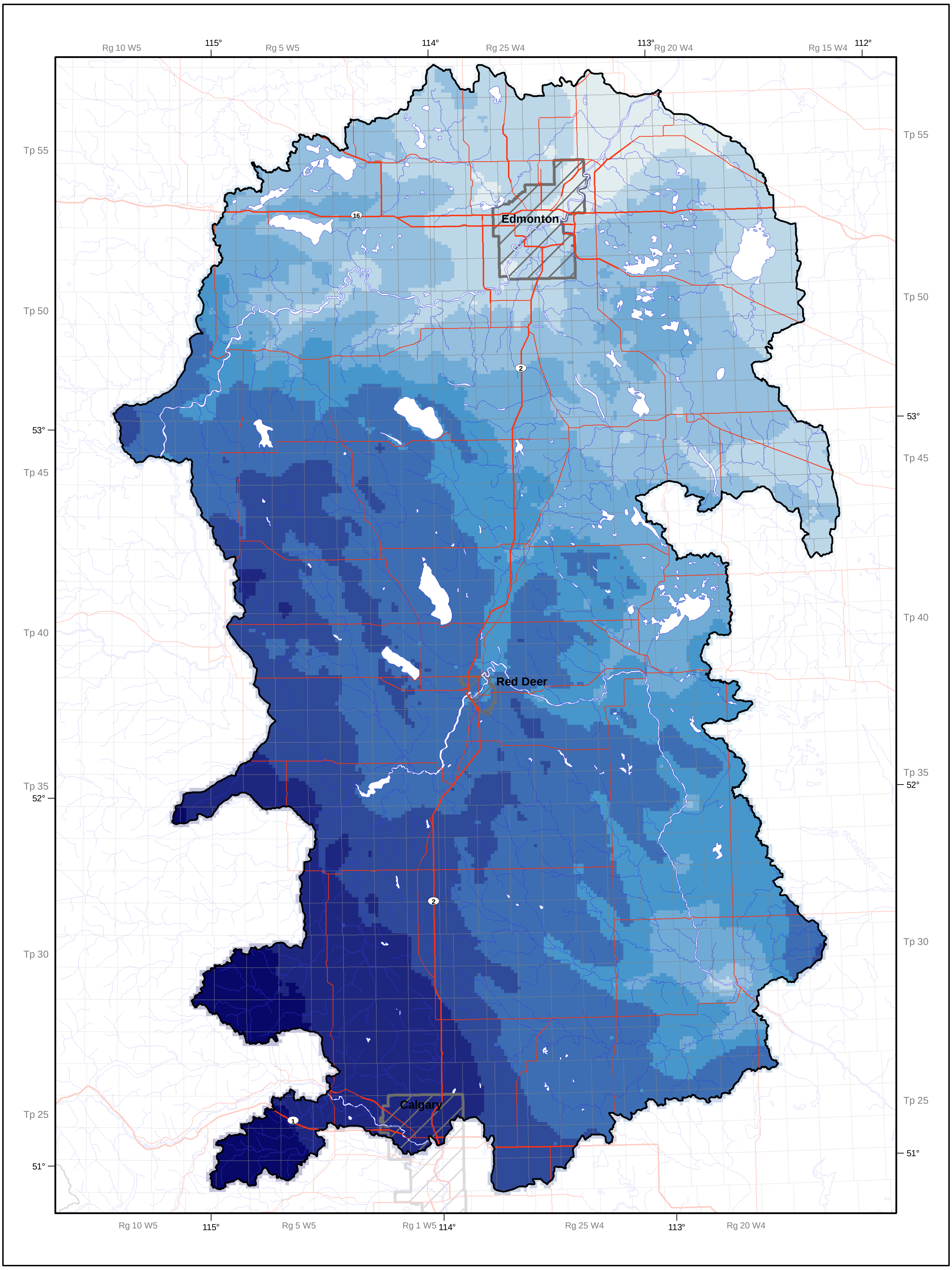
Usually, maps showing the vertical groundwater-flow component use arrows showing the difference in hydraulic-head values at a particular point in successive layers. This value is called the



Groundwater discharge at the land surface near Fort Saskatchewan, Alberta. Where the land surface is lower than the water table elevation, groundwater can discharge at the land surface forming wet areas that, over time, can change in size and depth depending on changes to the water table.

Measuring groundwater discharge from a spring near Rocky Mountain House. Springs represent discrete points on the landscape where groundwater leaves the subsurface environment to flow out of the rock or other sediments. They can be caused by many factors, including the geology and hydrogeology of the area.

Groundwater discharge from a flowing well in the central portion of the ECC. The well water has risen above the top of the casing, forming a pond adjacent to the well.



Potentiometric Surface (for wells screened 30-40 metres below ground surface) (Figure 5.7)

Elevation (metres above sea level)

581 - 650	751 - 800	951 - 1050
651 - 700	801 - 850	1051 - 1300
701 - 750	851 - 950	1301 - 1895

0 12.5 25 50 75 100 km

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vertical gradient. The ECC is too large of an area for us to use arrows to display the vertical gradient, so we mapped the vertical gradient as a series of surfaces using the information from two successive layers. Figure 5.8 shows the vertical gradients across the ECC based on the differences between the 20–30 m bgs and the 40–50 m bgs water-level surfaces. This map shows us where groundwater flow is mainly downward (mapped in blue) or upward (mapped in red). A vertical gradient close to zero means little to no vertical flow.

Recharge and Discharge Areas

Recharge areas are the parts of the landscape where water moves from the land surface into the groundwater-flow system. Recharge areas are typically elevated areas where the main groundwater flow direction is downward. Chapter 4 discusses how we figured out the amount of recharge entering the groundwater-flow system (Figure 4.8).

Discharge areas are where groundwater flows upward to the land surface. Discharge areas are generally in low-elevation areas where lakes, rivers or wetlands exist. Discharge can occur in isolated areas (such as springs) or over broad areas (such as lake and river beds). Discharge areas, especially those in regionally low-elevation areas, may receive a mixture of groundwater from local flow systems (in which the groundwater takes tens of years to travel from recharge to discharge) and regional flow systems (in which the groundwater takes hundreds or thousands of years to travel from recharge to discharge areas).

We mapped the recharge and discharge areas to see where they exist in the ECC and to understand the various flow systems in the ECC.

How We Mapped Recharge and Discharge Areas

We mapped recharge and discharge areas by subtracting water-level surfaces from the land surface. Figure 5.9 shows the difference between the 10–20 m bgs water-level surface and the land surface. The results of this subtraction should show the influence of recharge (green areas on the map) and discharge (red areas on the map) associated with local flow systems.

Figure 5.10 shows the difference between the 70–80 m bgs water-level surface and the land surface. The results of this subtraction should show the influence of the recharge (green areas on the map) and discharge (red areas on the map) associated with regional flow systems.

Of the mapped values, the larger, negative numbers mean strong discharge conditions, and the larger, positive numbers mean strong recharge conditions.

What These Maps Show Us

The local recharge and discharge areas in Figure 5.9 show that recharge and discharge generally occur between adjacent high and low land-surface elevation areas. We compared known spring locations to this map, and they show a strong match with the discharge areas. Figure 5.10 suggests that only a few areas receive discharge from regional flow systems. These tend to be regionally low-elevation areas.

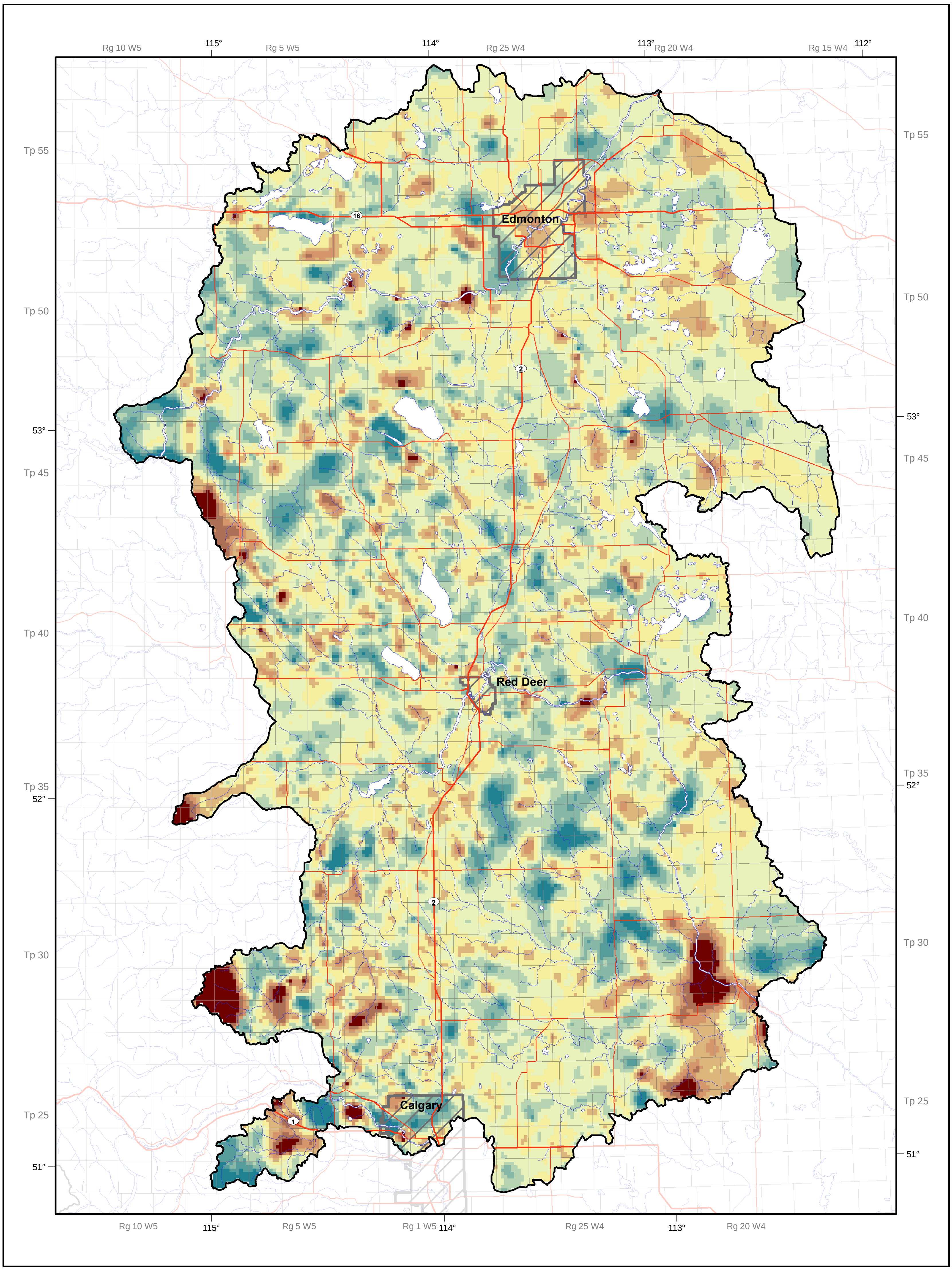
Potential-Yield Mapping

Many people ask how much groundwater is available at a given location when they are trying to decide where to drill a well. Between 1968 and 1983, the Alberta Research Council (now Alberta Innovates–Technology Futures) mapped the hydrogeology of most of Alberta. One thing these maps showed was how much water would be available to a well from the upper 300 m of geological media for each map area. In 2009, AGS digitized and compiled these original hydrogeological maps.[18] These maps provided estimates of how much groundwater could be pumped out of the sediment units by wells completed within a given area.

Updating the Potential-Yield Map

With this atlas, we wanted to update our understanding of the ECC's potential water yield by adding to our mapping process the

Spring flowing out of sediments above bedrock near Bluffton, Alberta. Note the high flow of water and the abundant vegetation where the spring flows out of the ground.



Vertical Gradients (difference between 20-30 and 40-50 metres below ground surface)
(Figure 5.8)

Potential for Upward Flow	Potential for Downward Flow
Strong	Weak
Weak	Strong

0 12.5 25 50 75 100 km

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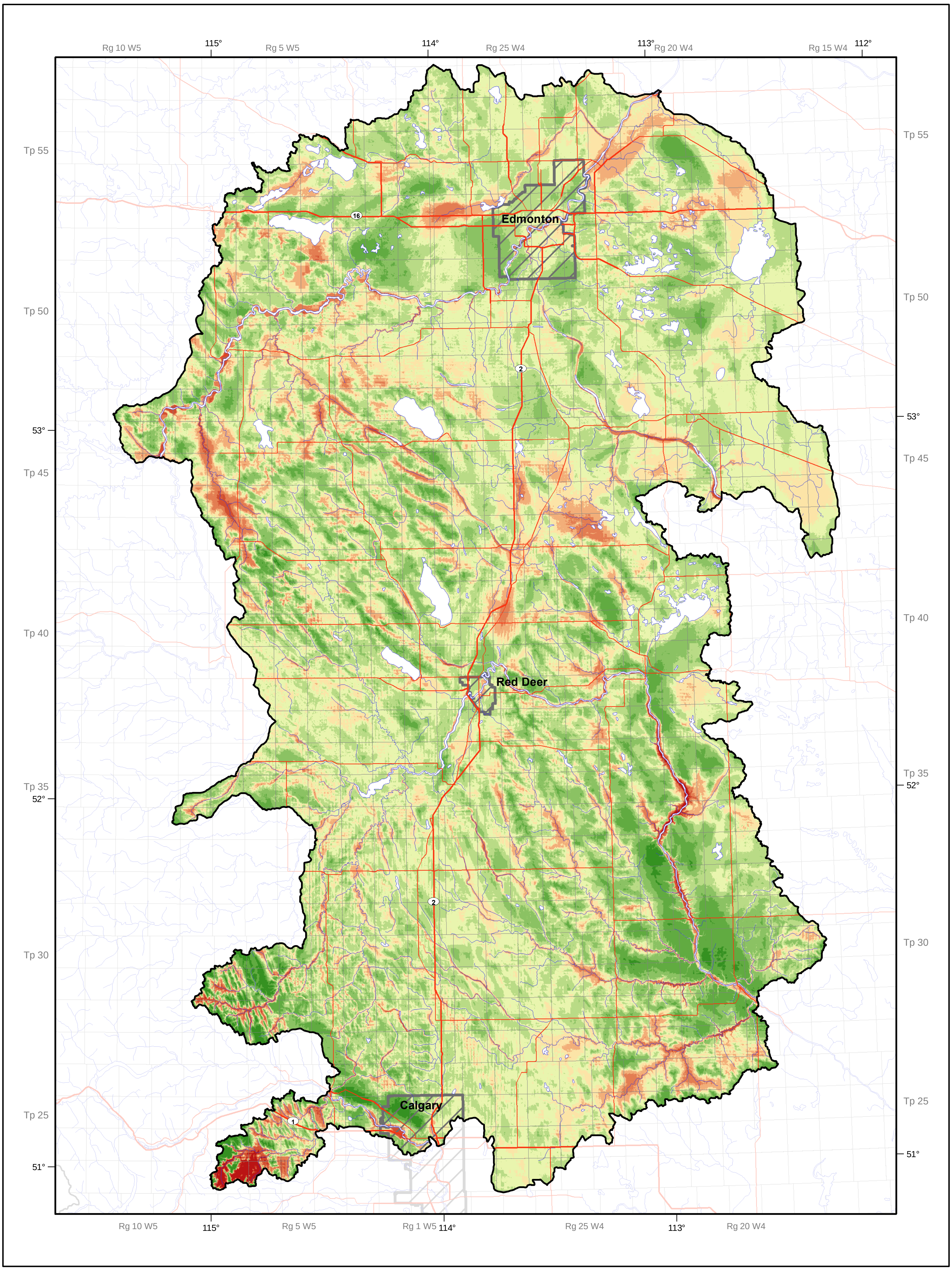

Local Recharge and Discharge Areas (Figure 5.9)

Distance of potentiometric surface above (-) or below (+) land surface (m)

Discharge Areas	Recharge Areas
<-150 to -100	0 to 10
-99 to -50	11 to 25
-49 to -25	26 to 50
-24 to -10	51 to 100
-9 to 0	101 to >150

0 12.5 25 50 75 100 km

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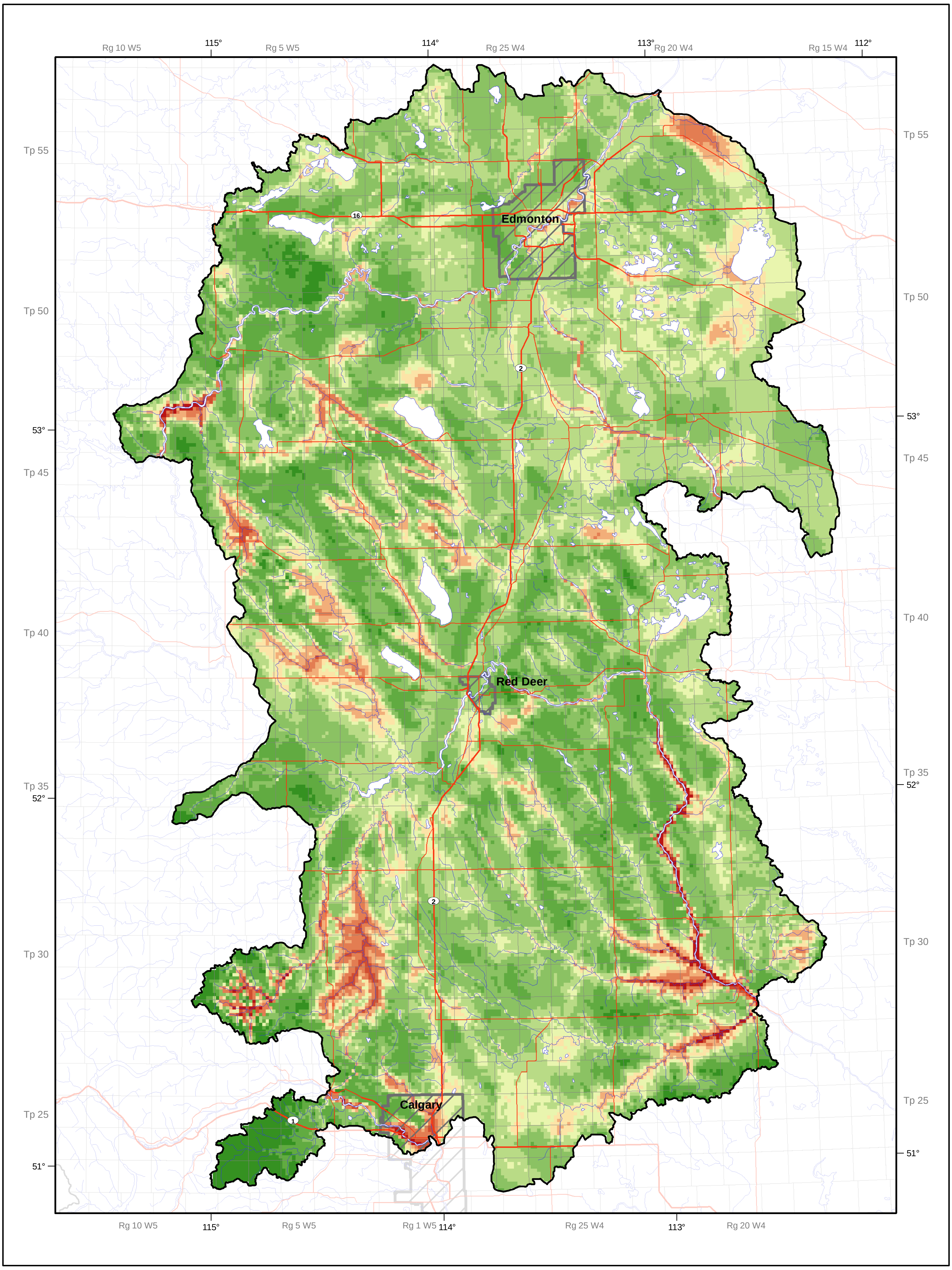

Regional Recharge and Discharge Areas (Figure 5.10)

Distance of potentiometric surface above (-) or below (+) land surface (m)

Discharge Areas
- -125 to -75
- -74 to -50
- -49 to -25
- -24 to -10
- -9 to 0

Recharge Areas
- 0 to 10
- 11 to 25
- 26 to 50
- 51 to 100
- 101 to >250

0 12.5 25 50 75 100 km

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information now available in the Alberta Water Well Information Database since the completion of the Alberta Research Council's hydrogeological maps. The potential yield values that we mapped are based on the extraction rates (how much water should be removed and how fast, based on the geological material in which the well was completed) that well drillers recommend after they install a well. These values are based on the driller's assessment of the sediment in which the well is completed and not necessarily on a test to determine the rate at which water can be pumped out over the long term. It should also be noted that the driller's assessment likely does not take into account the possible effects that neighbouring wells could have on the long-term yield of a specific well. Therefore, we must view the results of the mapping work as potential yield, not as definitive values.

The resulting yield map, Figure 5.11, shows the well driller recommended extraction rate of groundwater in imperial gallons per minute (igpm – a standard unit of measure in the well-drilling industry; 1 igpm = 0.000076 m^3/s) for the ECC. We refer to this map as the potential water yield because these values do not represent yield over a specific time, nor do they represent the actual groundwater yield possible for each geological formation. This map is a guideline for the potential water yield that one may find in the upper 100 to 200 m of sediment at any given location.

Groundwater Susceptibility

By definition, intrinsic aquifer susceptibility (or groundwater susceptibility) "is a measure of the ease with which water enters and moves through an aquifer, it is a characteristic of the aquifer and overlying material and hydrologic conditions, and is independent of the chemical characteristics of the contaminant and its sources."[16] We considered this definition of groundwater susceptibility when we chose to use the DRASTIC mapping method[19] to map groundwater susceptibility in the ECC.

The DRASTIC method lets us consider the ECC's diverse hydrogeological conditions in our assessment of susceptibility. It also uses information (such as type of geological material and measured water levels) to better limit our assessment.

Each letter in the DRASTIC acronym identifies an aspect of the groundwater system that is part of the susceptibility assessment. The process includes a weighting factor to signify the importance of each component in calculating susceptibility (a higher weighting factor means that that aspect has more influence on the outcome of the calculation). Table 5.2 shows our data sources for each variable, and Figure 5.12 schematically shows what the data represent.

We made minor changes to the method to calculate aquifer susceptibility so that it would better reflect the ECC's range of conditions. The modifications were generally based on the hydrological and hydrogeological work we have done on the ECC. The DRASTIC index values we obtained for each of the method's parameters were multiplied by their respective weighting factors and then added to obtain the ECC's DRASTIC groundwater susceptibility index. Figure 5.13 shows the mapped DRASTIC index values.

The DRASTIC index has eight categories as shown in Table 5.3. The DRASTIC index values that we calculated for the ECC ranged from 38 to 160. These values fit into the classification scheme's extremely low to medium range. The low index values are primarily due to the ECC's low recharge rates and relatively deep water tables. The medium DRASTIC index values suggest a more humid climate or areas with geological formations of higher permeability.

Aquifers in the ECC

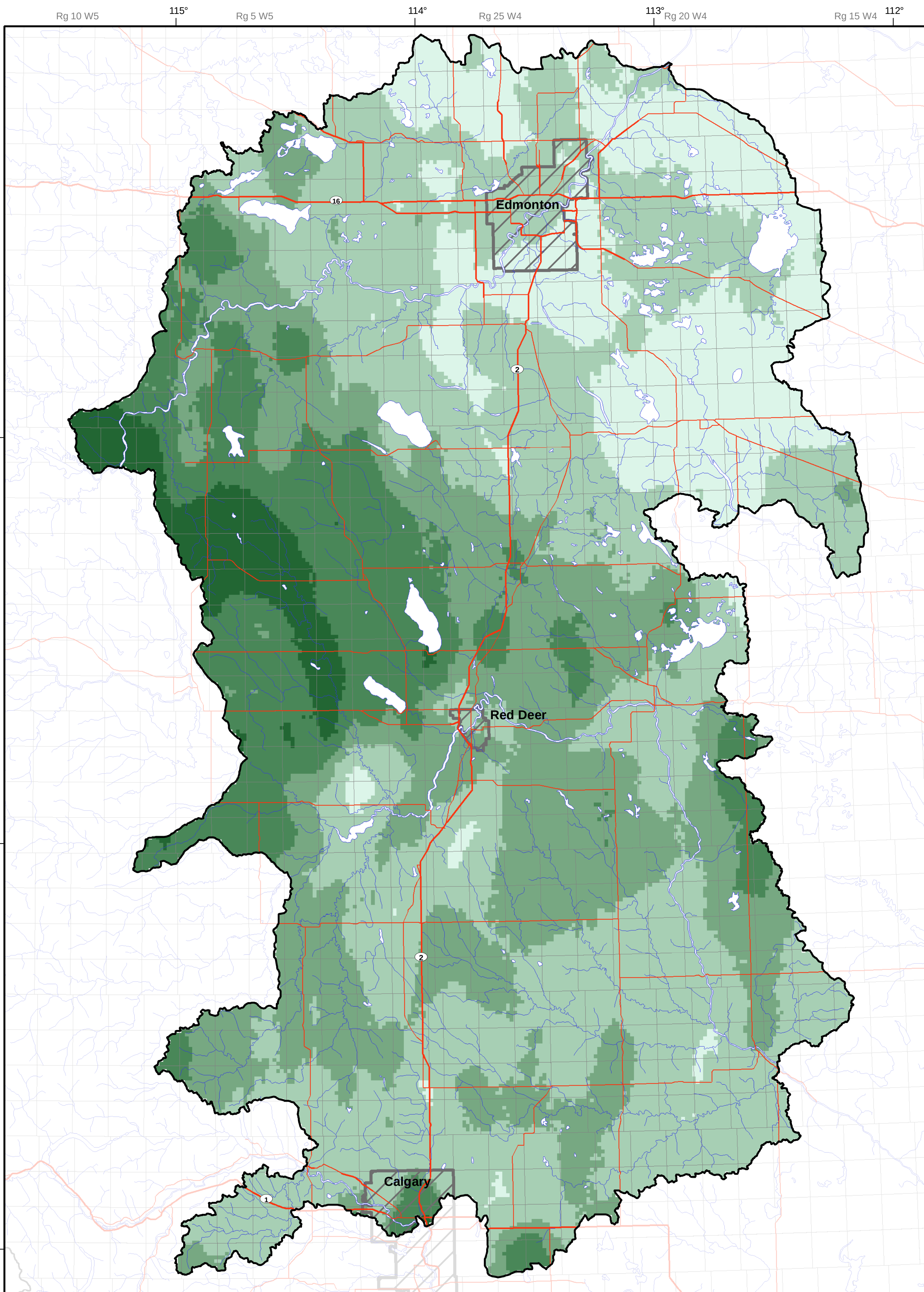
To further our assessment of the regional hydrogeology, we highlighted the types of aquifers and their probable locations in the ECC.

As mentioned, aquifers are geological layers that are water-saturated, have high permeabilities and can yield large quantities

Table 5.2 Description of the DRASTIC parameters.*

Letter	Parameter	Weighting Factor	Data Source
D	Depth to ground water	5	Water-table surface (Figure 5.5)
R	Net Recharge	4	Groundwater recharge values from the water-budget analysis (Figure 4.8)
A	Aquifer materials	3	Types of materials present in the subsurface as reported by well drillers for wells in the Alberta Water Well Information Database
S	Soil materials	2	Descriptions of soils found in the AgraSID soils database[20] released by Alberta Agriculture, Food and Rural Development, (now Agriculture and Rural Development)
T	Topography	1	Land-surface elevation (as seen on Figure 1.1)
I	Impact of vadose zone	5	Types of materials in the subsurface above the water table, as reported by well drillers for wells in the Alberta Water Well Information Database
C	Hydraulic Conductivity	3	Values from published tables summarizing the rate at which water moves through the types of materials found in the ECC

* This assessment was done for a regional project. Local-scale assessments can use Figure 5.13 generated from these data as a starting point for further site-specific mapping to determine risks to groundwater resources.



Potential Groundwater Yield (Figure 5.11)

Recommended Extraction Rate (imperial gallons per minute)

- 1.5 - 5
- 6 - 10
- 11 - 15
- 16 - 25
- 26 - 42

0 12.5 25 50 75 100 km

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of water to wells or springs. A geological layer that forms an aquifer can be made up of rock or loose sediment, like gravel, sand, silt or combinations of these materials.

There are two general types of aquifers in the ECC, ***unconfined aquifers*** and ***confined aquifers***.

Table 5.3 DRASTIC index values.

Extremely Low	Less than 79
Very Low	80–99
Low	100–119
Medium-Low	120–139
Medium	140–159
High	160–179
Very High	180–199
Extremely High	200+

Unconfined aquifers are near the land surface, and the water table defines the tops of these aquifers. They are in the sediments above bedrock, in bedrock units or in a combination of sediments above bedrock and bedrock units, depending on how the materials are stacked.

Confined aquifers are permeable, saturated, geological layers found between other geological layers that impede the flow of water through them. As mentioned, geological layers that impede the flow of water are called aquitards. Water does flow through aquitards, but the movement is very slow, so aquitards are unable to transmit water in sufficient quantities to allow them to produce any reliable, substantial volumes of water over time.

How We Mapped Potential Aquifers

We used AGS maps of the surficial geology and known sand and gravel deposits, geological data from well drillers and oil and gas wells, and airborne geophysics to map where potential aquifers could be in the ECC. The airborne geophysics provided us with new data to help us map aquifer locations. The geophysical survey measures the differences in the electrical properties of the various geological layers. These differences can be interpreted by geologists and used to determine which layers are mainly sand instead of clay. This combination of geological and geophysical information allows us to better map aquifers.

Potential Unconfined Aquifers

Figure 5.14 shows the locations near the land surface where coarse-grained materials, like sand and gravel, have been mapped by AGS and the results of the airborne geophysics for the upper 10 m of the subsurface. Several areas show overlaps between where coarse-grained materials are mapped and where the geophysical results suggest coarse-grained materials exist. The areas of overlap show us where we can focus future work to confirm the extent of near-surface, coarse-grained materials and if they contain water.

Depending on the thickness of near-surface, coarse-grained materials and the water-table depth, these areas of coarse-grained materials could make up the best unconfined aquifers in the ECC. Alberta Geological Survey is currently working on mapping the major aquifers across Alberta and will take into account the information from our ECC work as we continue this province-wide work. The nature of these potential unconfined aquifers will be determined once the mapping work is completed.

There are other areas where geophysical signatures suggest that coarse-grained materials may be present. As we look at other depth slices and at what we know geologically about the deeper depths, we can decide if these other areas could be additional buildups of near-surface, coarse-grained sediment, or deeper buildups of coarser-grained sediment.

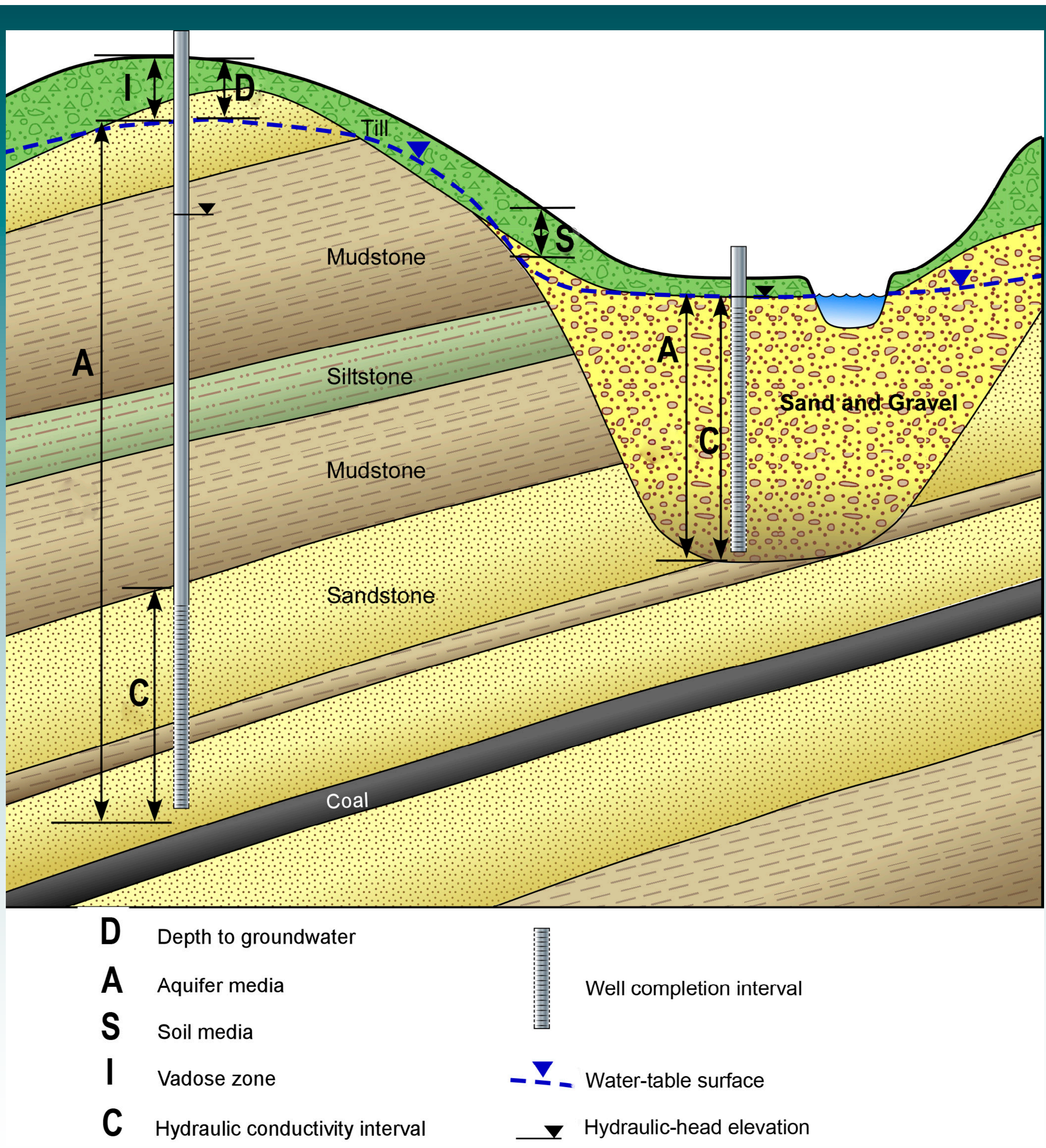
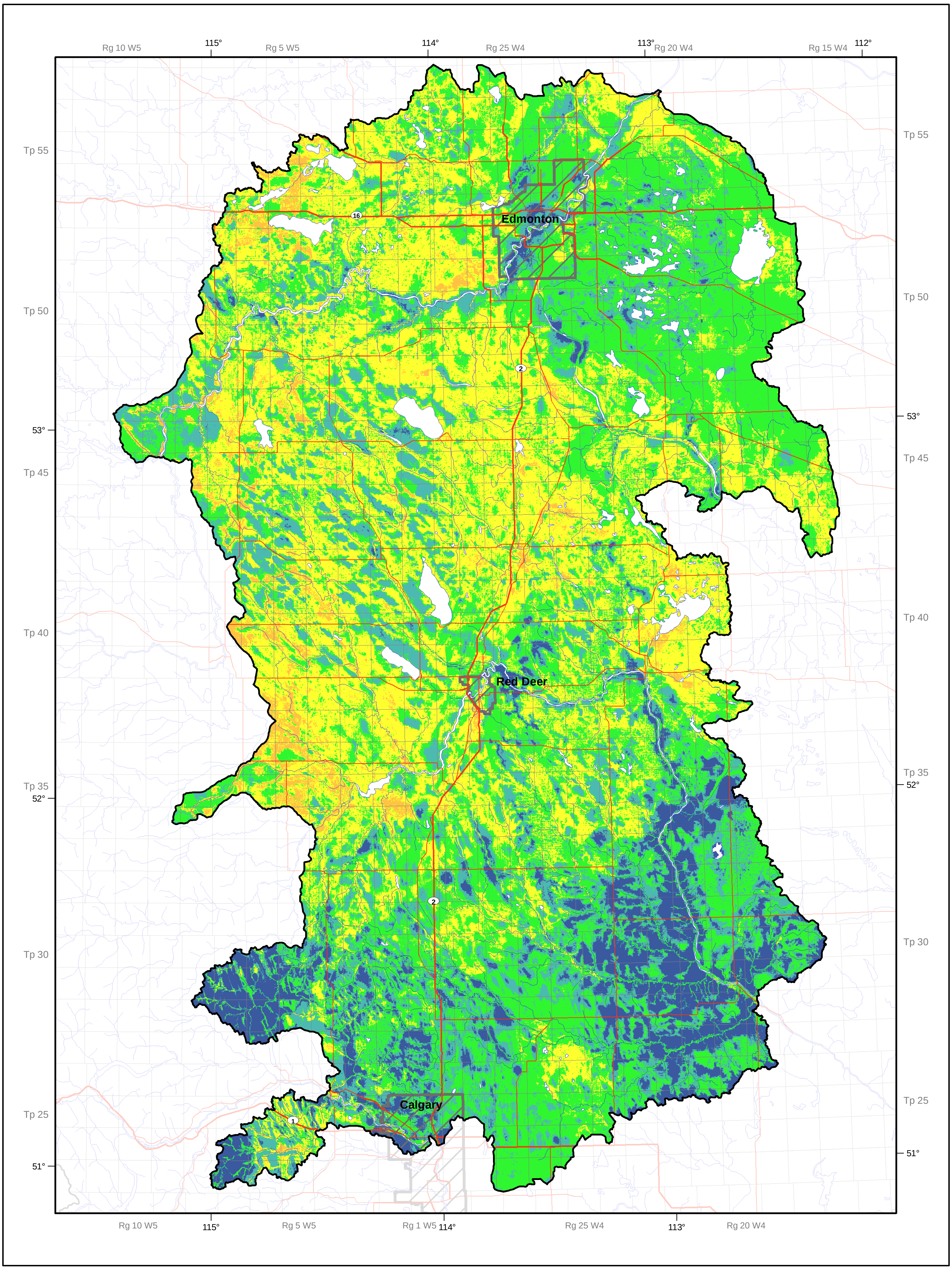


Figure 5.12. Schematic showing which part of the borehole or water-well lithological logs was used for the D (Depth to groundwater), A (Aquifer media), S (Soil media or the top metre of material), I (Impact of the vadose zone), and C (hydraulic Conductivity of aquifer media) parameters used for the DRASTIC Intrinsic Aquifer Susceptibility analysis. The other parameters in the DRASTIC acronym are T (Topographic slope) and R (groundwater Recharge rate), which do not rely on borehole information.



Groundwater Susceptibility (Figure 5.13)

DRASTIC Index Values

< 79	Extremely Low
80 - 99	Very Low
100 - 119	Low
120 - 139	Medium Low
140 - 159	Medium
>160	High

0 12.5 25 50 75 100 km

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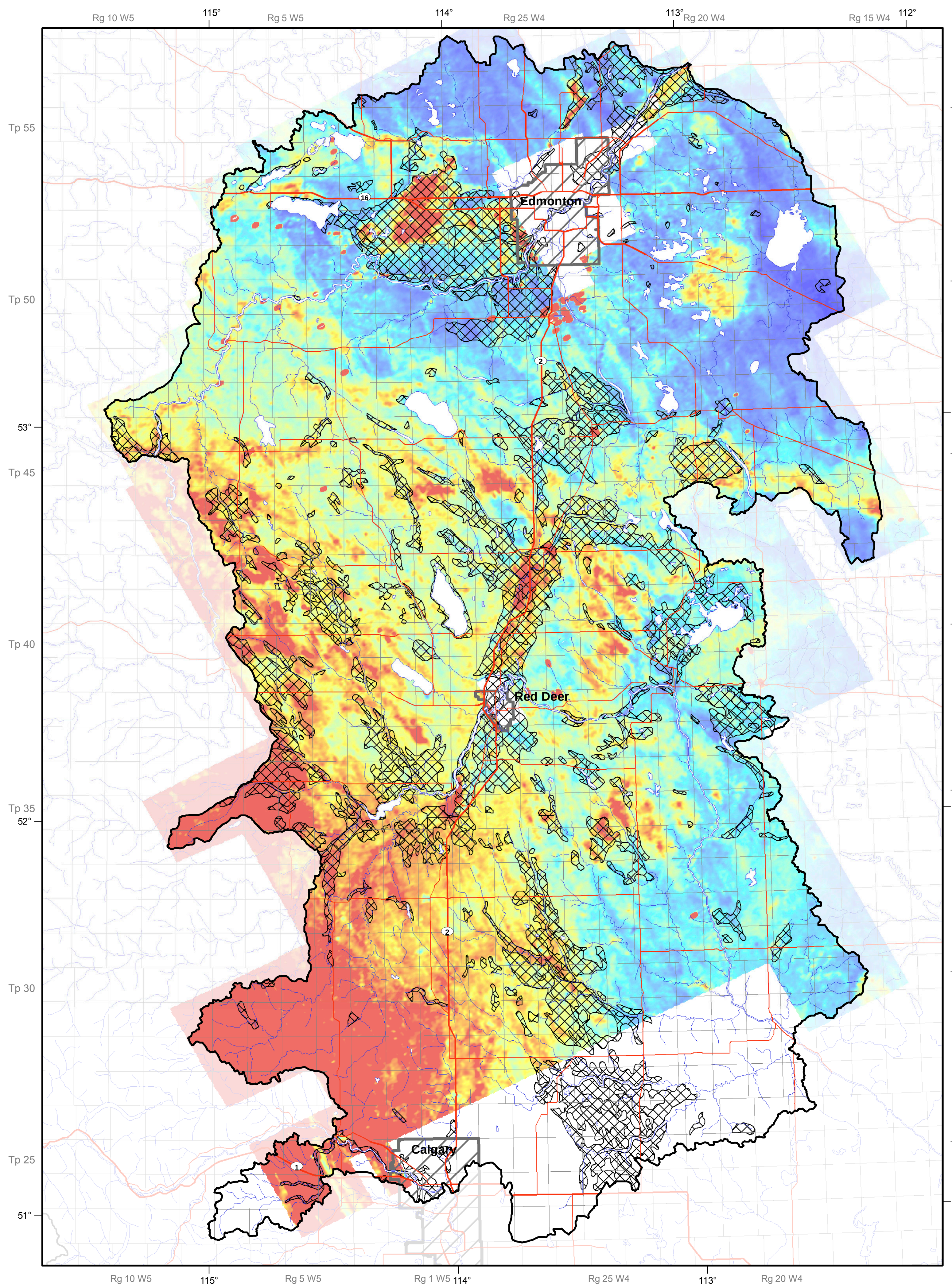

Geophysics and Mapped Coarse-Grained Materials near the Land Surface (Figure 5.14)

Coarse-grained material

Geophysics near Land Surface

High Resistivity

Low Resistivity

0 12.5 25 50 75 100 km

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Potential Confined Aquifers in the Sediments above Bedrock

The most extensive confined aquifers in the sediments above bedrock are associated with buried-valley aquifers and are found in channel complexes. We identified three channel complexes in Chapter 2: the Beverly-Onoway complex, the Red Deer River complex and the Drumheller complex (Figure 5.15). Just like current river systems, these ancient systems can contain substantial buildup of sand and gravel along the lengths of the channels. Filled with water, these deposits can yield large amounts of groundwater to wells. Figure 5.15 shows where these channels appear to have the highest potential to be aquifers based on the mapping work and the geophysical surveys.

Another potential confined-aquifer system in the sediments above bedrock is in the Cooking Lake area. Figure 5.16 shows the buildup of coarser grained materials at different depths within this area, which indicates that the potential aquifers in this area are stacked. We can use the geophysical survey results to clarify the extent of these deposits and show us where to focus any future work to map the extent of these systems.

There are other potential aquifers within the sediments above bedrock, but they are smaller than the buried-valley deposits and those near Cooking Lake. They may form important sources of water to local users, but their size makes them minor aquifers in the context of the larger ECC.

Potential Bedrock Aquifers

Based on our understanding of the bedrock units in the ECC (see Chapter 2), one unit has the highest potential to host aquifer systems: the Paskapoo Formation. We mapped the extent and thickness of the Paskapoo in the ECC and looked at where the coarser grained materials versus the finer grained materials exist and how these materials relate to one another. By mapping where the coarser grained materials occur, we get a sense of where the Paskapoo Formation has the potential to produce the most water. Figure 5.17 shows where the coarser grained parts of the Paskapoo Formation are within 150 m of the land surface. These are the areas where the Paskapoo Formation has a higher potential for hosting aquifers that would most commonly be used by domestic and agricultural users.

The other bedrock formations in the ECC are used as sources of groundwater but generally for low-volume household or agricultural needs. These formations generally have finer grained rocks than those in the Paskapoo Formation. In the ECC, they do not typically host large, regional aquifers that produce large volumes of groundwater.

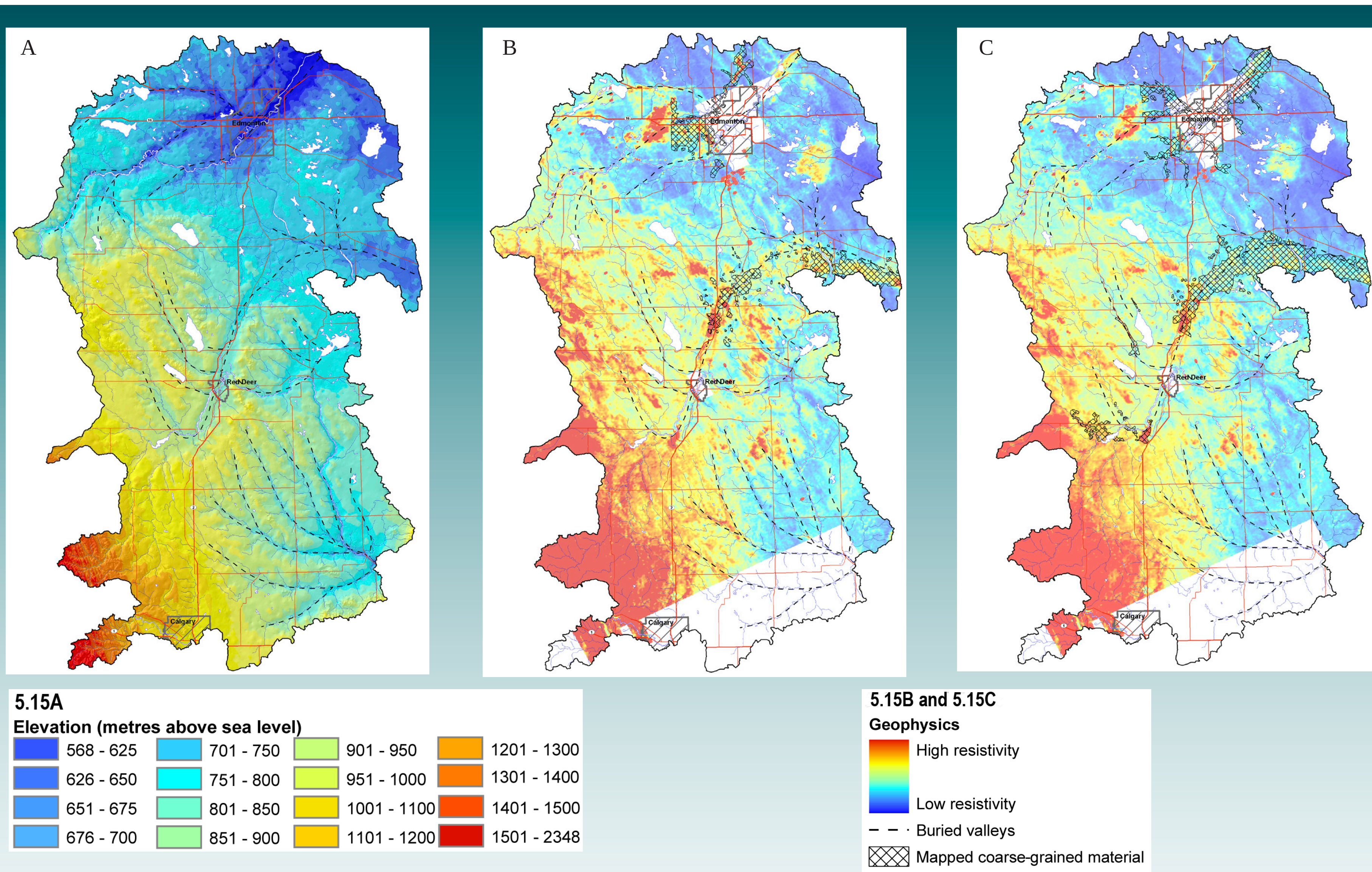
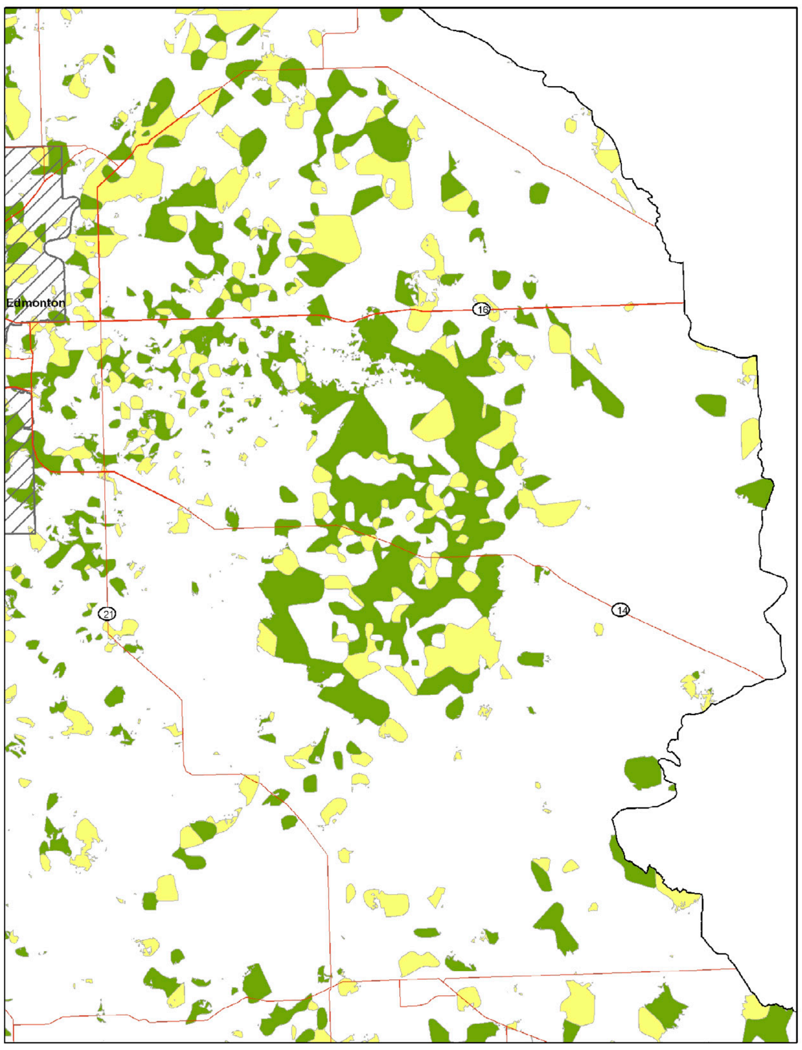
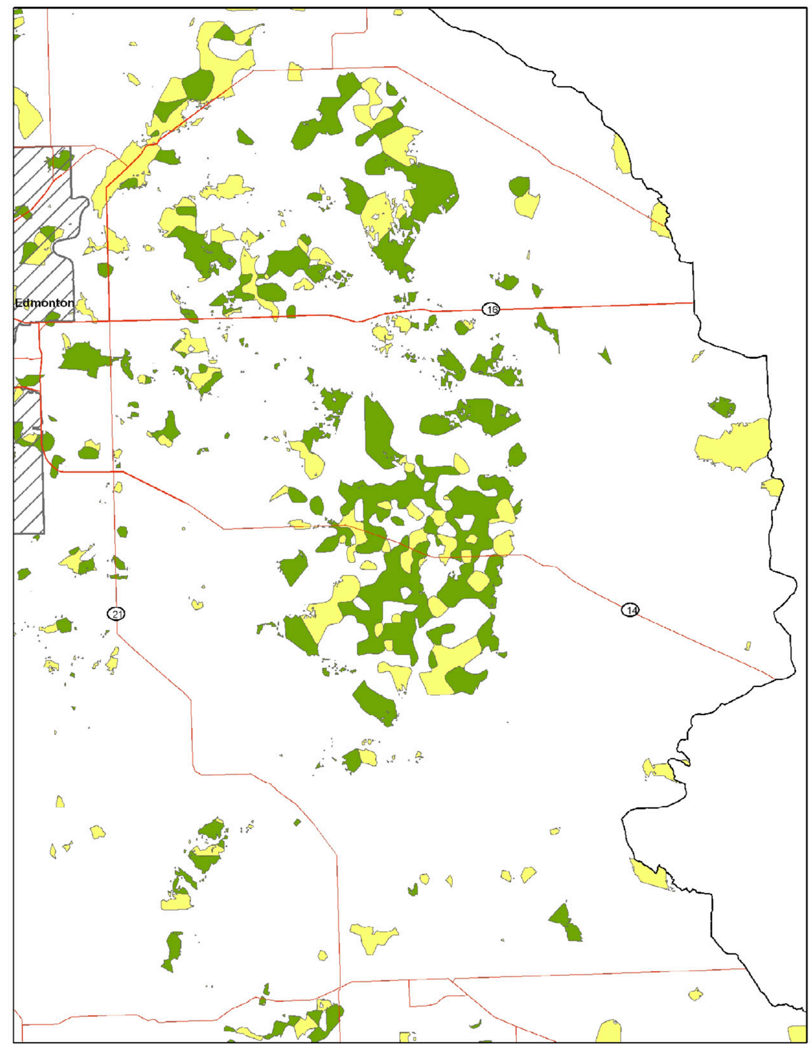


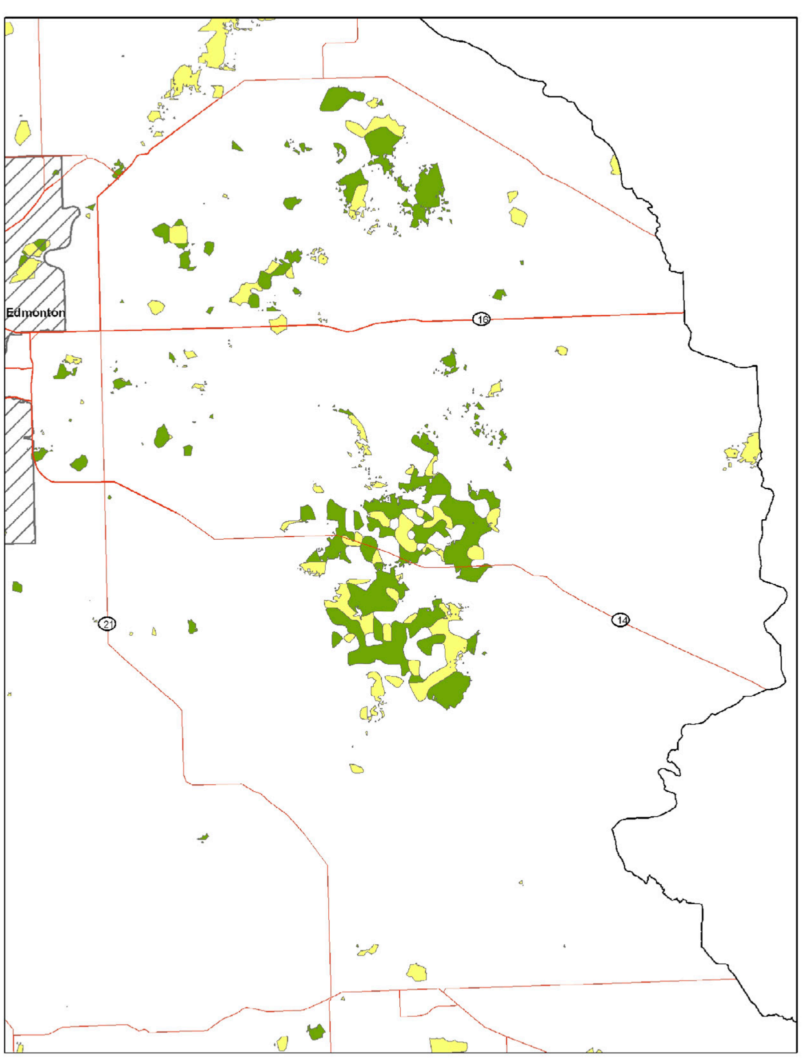
Figure 5.15. Location of buried channel complexes in the ECC and the outlines of the potential confined aquifers associated with the buried channels. A) Bedrock elevation (metres above sea level) with the location of the buried channel complexes in the ECC. B) Potential confined aquifers in the sediments above bedrock, as outlined by the mapped, coarse-grained material. These boundaries were determined using lithologs and the geophysical results 20 metres below ground surface. C) Potential confined aquifers that lie on the bedrock surface, as outlined by the mapped, coarse-grained material. These boundaries were determined using lithologs and the geophysical results 30 metres below ground surface.



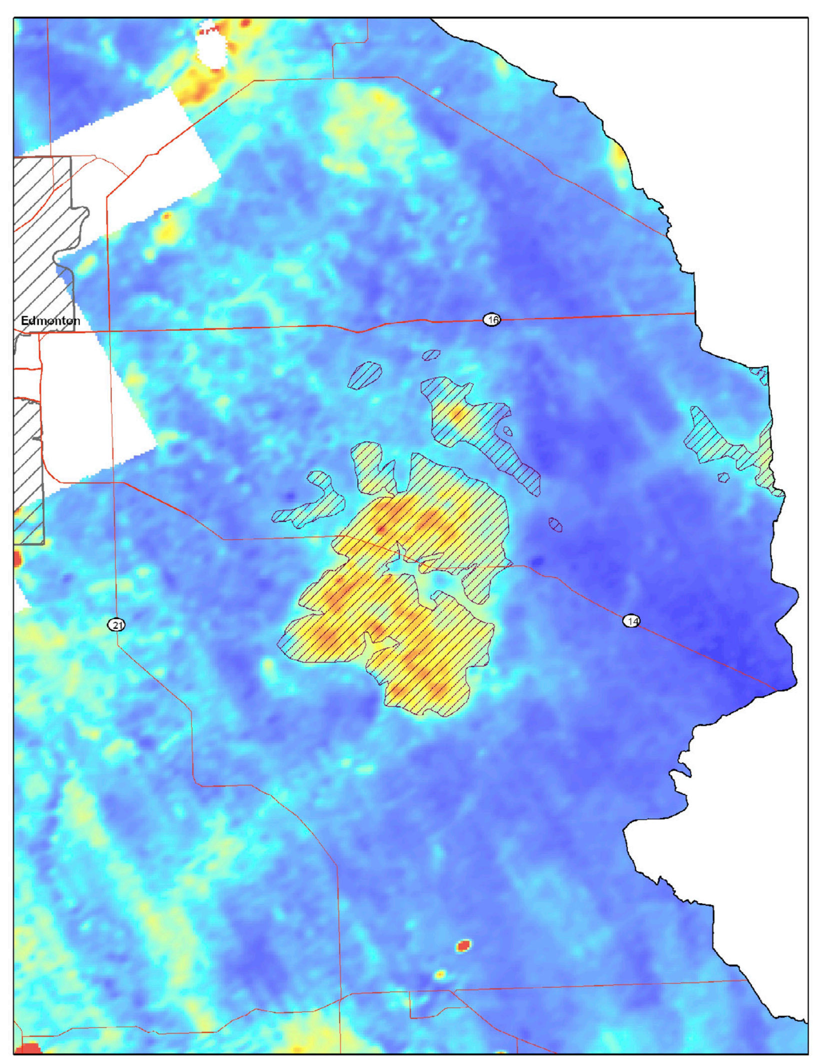
a) Sediment permeability at 20 metres below ground surface



b) Sediment permeability at 30 metres below ground surface



c) Sediment permeability at 40 metres below ground surface



d) Area of interpreted medium to high sediment permeability based on the airborne geophysics for the 20-30 metres below ground surface interval

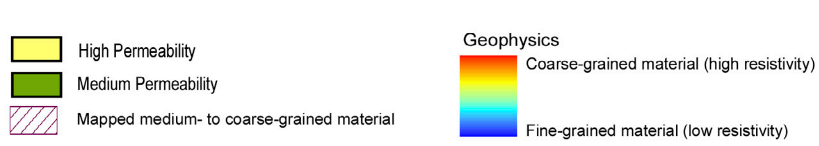


Figure 5.16. Potential confined aquifers for the Cooking Lake moraine as mapped from lithologs (a to c) or interpreted from the geophysics (d). All figures show sediments that have been mapped as having medium to high sediment permeability.

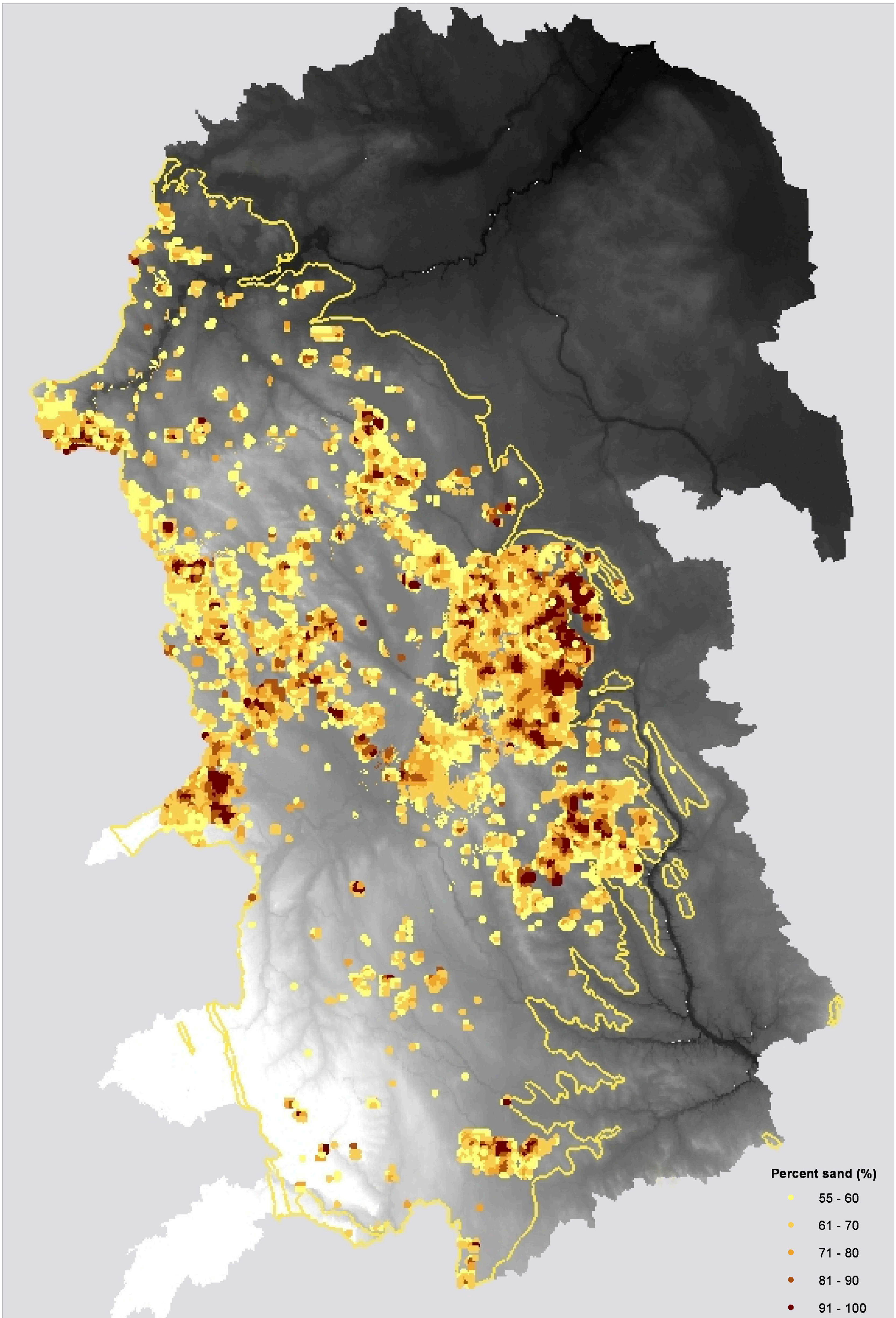


Figure 5.17. Sandiness of the Paskapoo Formation from 0–150 metres below ground surface. The map shows areas that have 55% or greater sand content. These sandy areas represent the potential aquifers in the upper 0–150 metres of the Paskapoo Formation. The surface is DEM -150 metres and the yellow line is the boundary of the Paskapoo Formation.

6. Hydrochemistry

6. Hydrochemistry

What is Hydrochemistry and Why Did We Study It?

Hydrochemistry is the study of chemical reactions and conditions in groundwater. Water interacts with the underground environment by dissolving solids and gases or by forming solids, causing changes to the chemical composition of the water. When we analyze and interpret groundwater's chemistry, we learn

- from where the water came;
- through which type(s) of materials it has travelled and for how long; and
- if it has mixed with other types of water.

Hydrochemistry helps us complete the groundwater model of the ECC by filling in details about how groundwater moves through the underground system. Knowledge of groundwater chemistry is also important when we want to decide which groundwater is suitable for drinking, agriculture or industrial use.

General Principles of Hydrochemistry

As mentioned above, many factors affect the chemical composition of groundwater. The first control on groundwater chemistry is the source of the water in the groundwater system. Water that makes up the shallow groundwater system largely comes from precipitation that falls on the land surface as rain or snow. The properties of rain and snow can dissolve and alter the geological materials they contact as they move from the land surface down to the water table. These reactions change the chemistry of the water and the geological materials. Once water that recharges the groundwater system moves below the water table, it mixes with the existing water in the subsurface, making mixing an important consideration as we evaluate water chemistry.

Dissolution reactions continue to occur below the water table, but increasingly, other types of water-rock interactions happen as water moves from its recharge zone toward its discharge zone. Depending on the amount of certain

Measuring the water level using a water-level tape and collecting groundwater samples from a well in the central portion of the ECC.

Creative water-well construction. Wells we sampled in the ECC came in all shapes and sizes. In this case, the well owner constructed the pump with parts on hand.

The Alberta Geological Survey sampling team visited a site in conjunction with Alberta Environment. The equipment inserted into the well includes a submersible pump to conduct a pump test, a water-level tape to measure the water level and sampling tubing to collect a water sample.

Landon Wood (Alberta Geological Survey summer student) processing water samples collected in the central portion of the ECC. Water samples are collected for different types of analysis. The collection protocols for each sample type are carefully developed to avoid contamination during sampling. Landon is wearing gloves to not contaminate the sample, and the sampling materials are relatively inert to not contaminate the sample during collection.

6. Hydrochemistry

elements dissolved in the water, and things like pH and water temperature, instead of dissolving material, material may be formed, or certain elements dissolved in the water may react with the geological material and take the place of elements that were part of the geological material. These previously attached elements are then released from the geological material and dissolve in the water. The amount of dissolved material in the water typically increases along the flow path and with depth, and the types and amounts of constituents typically change as well.

What We Studied in the ECC
This atlas contains maps showing total dissolved solids and hardness, because these two chemical parameters often let us quickly decide which groundwater is suitable for which use (such as drinking instead of agriculture). Health Canada's water-quality guidelines[21] provide ranges of chemical concentrations it considers acceptable for different uses of water.

Total dissolved solids express the quantity of dissolved minerals in a sample of water. Hardness is a property of water that causes residue to form when the water is used with soap or forms a deposit when water evaporates. Water hardness is determined by a combination of calcium and magnesium concentrations but is expressed as *hardness as* $CaCO_3$ (calcium carbonate).

We looked at how groundwater chemistry relates to different geological units, the sediments above bedrock and the bedrock units. We used this approach because the characteristics of the materials that groundwater flows through is one of the primary influences on groundwater chemistry.

Hydrochemical Mapping

Data Sources
The AGS gathered more than 20 000 analyses of groundwater chemistry within the ECC. These analyses came from several sources:

- Alberta Environment's Alberta Water Well Information Database: These are samples that
  - well drillers collected when they installed wells; and
  - well owners submitted to provincial laboratories for analysis.
- Alberta Research Council (now Alberta Innovates – Technology Futures): These are samples Alberta Research Council collected from water wells or from wells it drilled.
- Energy Resources Conservation Board and Alberta Geological Survey: These are samples AGS collected from Alberta Environment observation wells, water wells or wells that AGS drilled.

Deciding Which Data to Use
A groundwater analysis shows the chemical composition of groundwater at a particular time, place and depth. We chose the most suitable of the 20 000 available analyses by considering

- **Age**: We chose only analyses performed after 1980 because we wanted information about relatively recent groundwater conditions:
- **Completion length**: Wells are pipes with slots or perforations cut into the well-casing walls, or with separate lengths of pipe with finely slotted intervals attached to the well casing, that are installed (referred to as completions) at the depth the well driller thinks groundwater will flow into the well. We required samples from wells with completions 15 m or shorter in length to find samples from a single geological layer. If a water sample comes from multiple geological layers, the groundwater from the multiple layers mixes and gives us less accurate chemistry data.
- **Complete dataset and charge balanced**: For mapping purposes, we used only analyses with a selected set of inorganic chemical parameters. We then performed a quality-control assessment, called a charge balance, on the analyses. The

Typical groundwater sampling set up. Prior to sampling, all bottles are labelled, the equipment is connected to a sampling point, or lowered down the well, and any equipment that measures the physical or chemical properties of the water are calibrated.

Measuring the water level in a well prior to collecting groundwater samples. The water-level tape is lowered into the well until it touches the water. The depth is determined using the measurement scale on the tape.

Spring discharge in Big Hill Springs Provincial Park, near Cochrane, Alberta. Groundwater samples were collected from wells and springs within the ECC. Discharge from springs can be substantial, as we see here, or form just a trickle.

charge-balance calculation lets us know if the electrical contributions of cations (positively charged parameters) and anions (negatively charged parameters) are nearly equal in the water sample. In theory, cations and anions must balance in all solutions. Therefore, to account for reasonable errors in analysis practices, we accepted charge balances that were within +/- 5% of neutral.

- **Total dissolved solids compared to the base of groundwater protection**: The Alberta Government considers groundwater with total dissolved solids of more than 4000 milligrams per litre (mg/L) to be saline (salty water). We know most wells in the ECC are screened in intervals that tend to be categorized as non-saline. When we looked at the overall percentage of water samples with a total dissolved solids concentration equal to or greater than 4000 mg/L, we saw that only a very low overall percentage of the samples fell into the saline category. Thus, because we are mapping the overall characteristics of groundwater chemistry, and not isolated anomalies, we decided not to use analyses that had a total dissolved solids greater than 4000 mg/L.

After applying all of these criteria to the data, we had 4835 analyses to map.

How We Mapped the Hydrochemistry

Our first step in mapping the ECC's hydrochemistry was to choose from which of the ECC's geological units each analysis came. To do this, we considered well locations and the depths of the well screens, and we used the geological model that we had constructed previously. Figure 6.1 shows where wells are in relation to each bedrock unit. After all of the data were examined, we found that few data were available to characterize water chemistry in the Scollard. Therefore, we chose not to include descriptions of its water chemistry in the atlas. Figure 6.2 shows where wells are in the sediments above bedrock.

After we split the analyses based on which geological unit they came from, we analyzed each set of chemical constituents. The results of the analysis gave us an initial picture of the distribution of concentrations of each chemical constituent. Alberta Geological Survey hydrogeologists then adjusted this representation manually to map the ranges of concentrations for each chemical constituent in each geological formation. More information on this process will be available from AGS in an upcoming report.

Hydrochemistry Maps

This atlas shows total dissolved solids and hardness as calcium carbonate for the sediments above bedrock and for the Paskapoo, Horseshoe Canyon and Bearpaw formations and the Belly River Group.

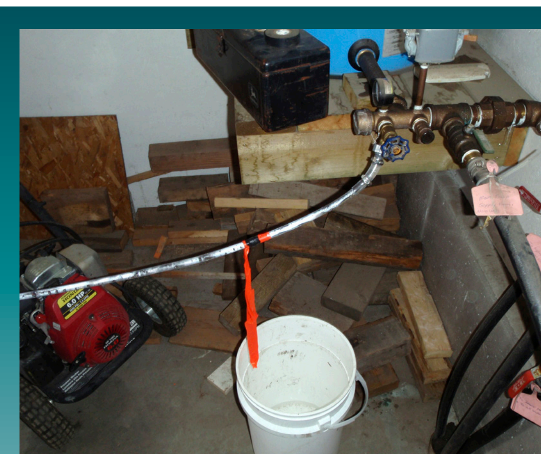
Sediments above Bedrock

We used the sediment thickness map (Figure 3.2) to determine where the sediment was mostly thicker than 10 m, and we drew boundaries around these areas. We then mapped the groundwater chemistry within these boundaries. Figure 6.3 shows the total dissolved solids concentration ranges, and Figure 6.4 shows the hardness concentration ranges.

Total dissolved solids concentrations are generally less than 1500 mg/L except in certain areas south and east of Edmonton, and in the southernmost portion of the study area. Hardness values are greatest near Edmonton and in distinct areas along the eastern edge of the study area. According to Health Canada,[22] the hardness values shown on Figure 6.4 places the water in the very hard category.

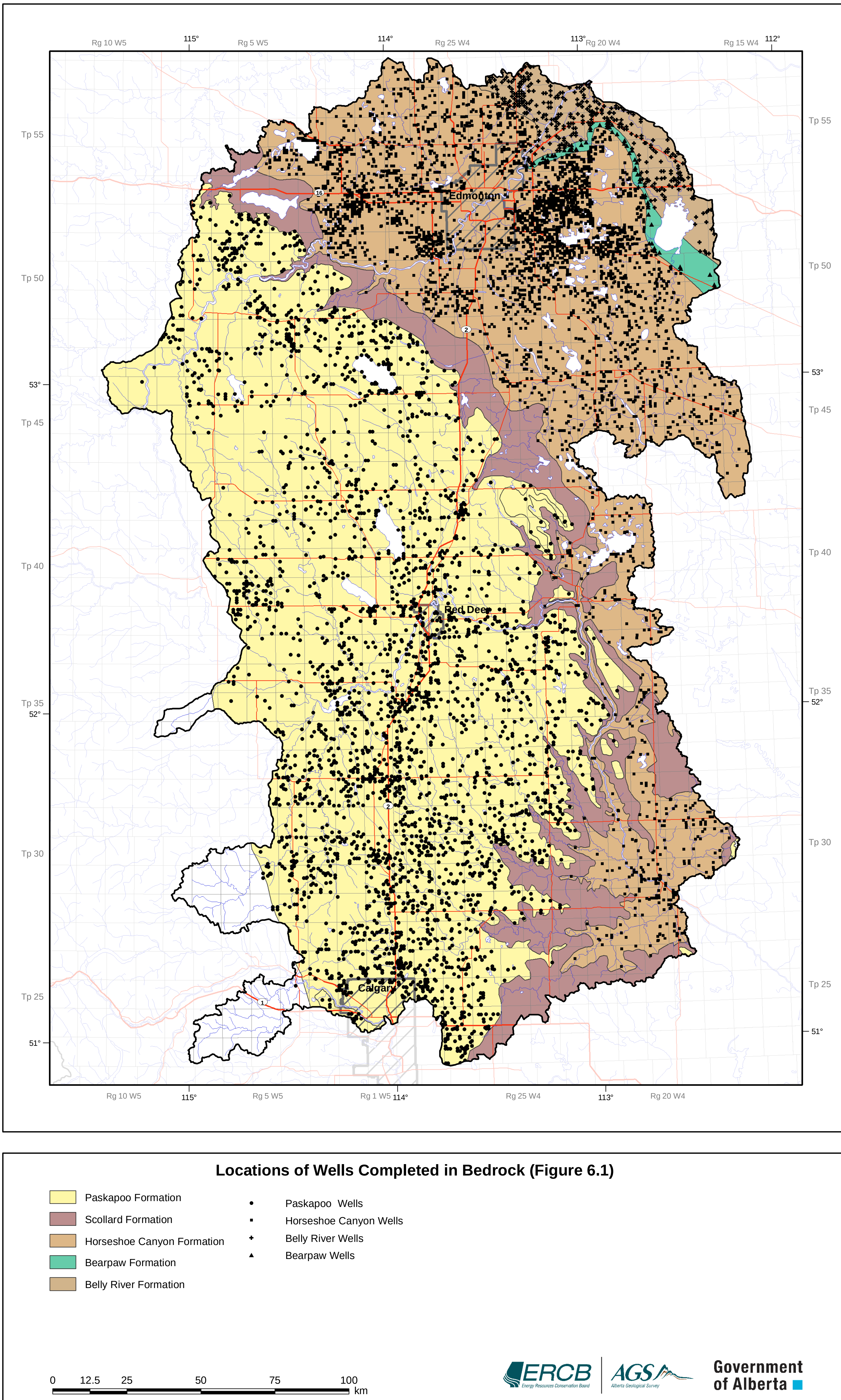
Different samples are collected at each site for different types of analyses. Each analysis has different requirements, including the type of bottle used to hold the sample. This photo shows the various types of bottles used in sampling work.

Flowing well in the central ECC encountered during sampling. Some wells, like this one, do not require us to connect our sampling equipment to the water well's plumbing system. The natural groundwater in the area has raised the water level above the top of the casing.

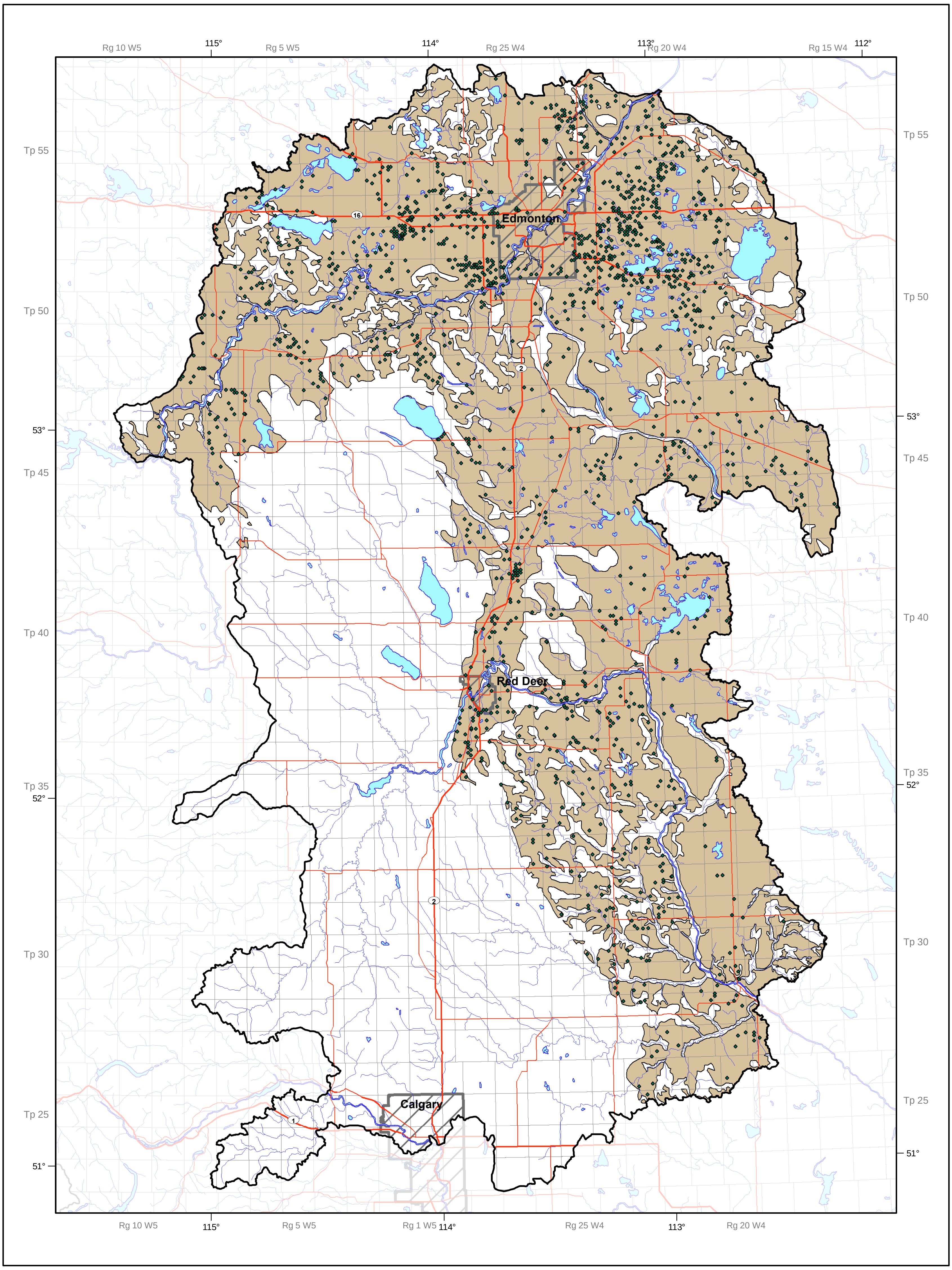


Collecting a water sample from a well with a manifold (upper right). Because of the types of analyses performed on the groundwater samples we collect, it is important for the sample to be collected prior to it entering any pressure tank or treatment system. In this case, the manifold has a connection point prior to the groundwater from the well entering a pressure tank.

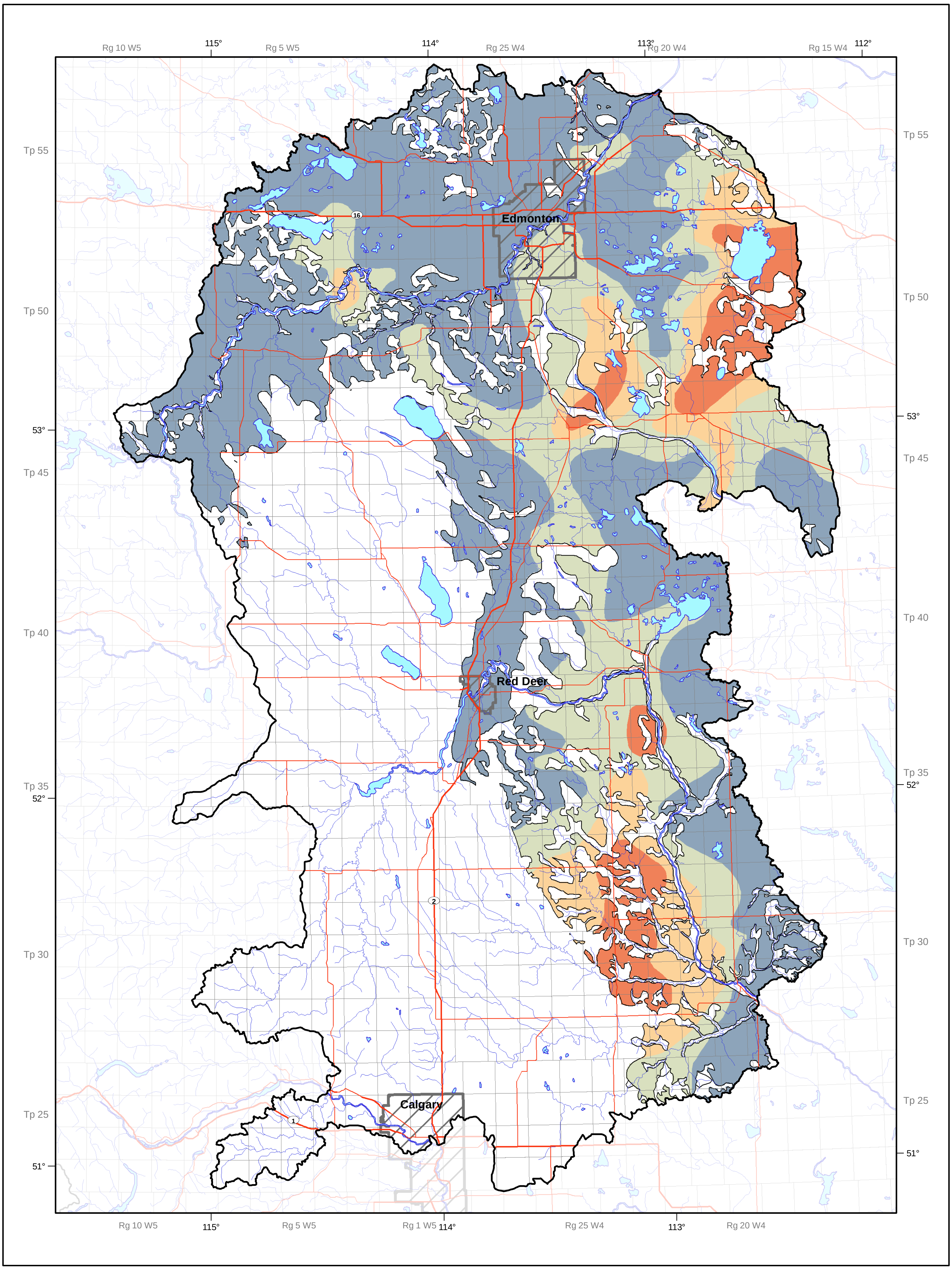
6. Hydrochemistry



Locations of Wells Completed in Bedrock (Figure 6.1)



Locations of Wells Completed in the Sediments above Bedrock (Figure 6.2)



Total Dissolved Solids Concentration in the Sediments above Bedrock (Figure 6.3)

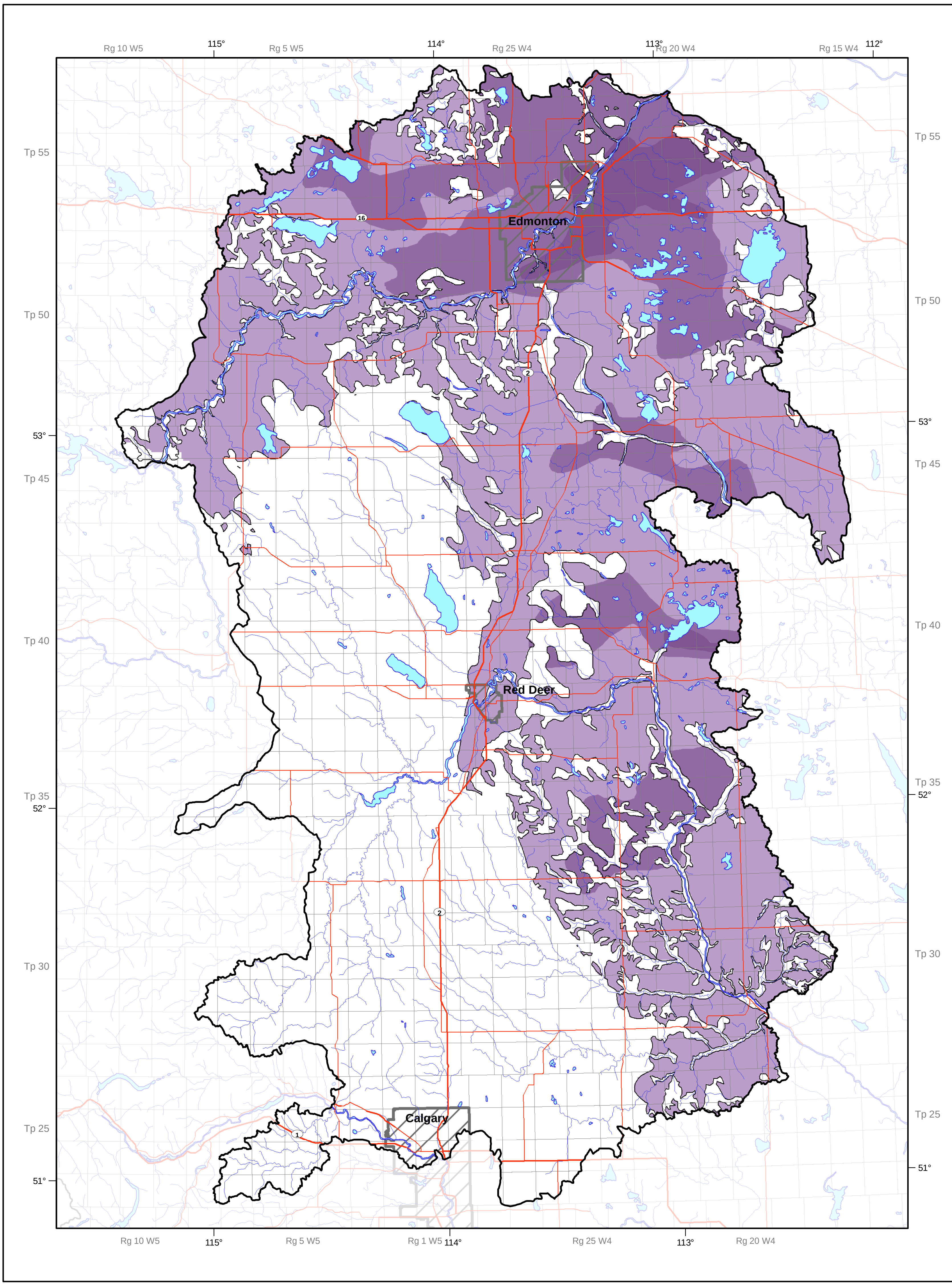
Total Dissolved Solids (mg/L)

- <1000
- 1000.1 - 1500
- 1500.1 - 2000
- >2000

0 12.5 25 50 75 100 km

Government of Alberta

Base Data Provided by Spatial Data Warehouse Ltd.



Hardness (as Calcium Carbonate) Concentration in the Sediments above Bedrock (Figure 6.4)

Hardness as Calcium Carbonate (mg/L)

- <250
- 250.1 - 500
- >500

0 12.5 25 50 75 100 km

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6. Hydrochemistry

As we read in Section 3, glaciers deposited the majority of the unconsolidated sediments above bedrock in the area. The values of the total dissolved solids concentrations and hardness are in the range typical for areas affected by glaciation.[23] Specific reasons for the trends we see are related to the chemical composition of the geological materials that the water flows through, as well as the grain size of the sediments, which affects how easily water can move through the sediments. As a general principle, the longer the water remains in contact with geological materials, the more the water can react with those materials, changing the composition of the water and of the geological materials in the process.

Paskapoo Formation

We defined the Paskapoo Formation's western boundary as the edge of the ECC and the deformation belt. We defined the eastern boundary as the Paskapoo subcrop edge. Figure 6.5 shows the total dissolved solids concentration ranges in Paskapoo groundwater, and Figure 6.6 shows the hardness concentration ranges.

Total dissolved solids concentrations are lowest toward the north-central and western portions of where the Paskapoo Formation subcrops,

Sheila Stewart, Alberta Geological Survey, taking a groundwater sample from a well equipped with a hand pump. Although we encountered many different well construction types during the sampling program in the central portion of the ECC, few had hand pumps.

Sophisticated, high-capacity, water-distribution system.

Groundwater sampling in the central ECC from a well with a hand pump.

Ingenious design for a well. The pump mechanism uses many different components, including a wheel rim, a tire and a small engine. On the left side, you can see the pump's outflow in the white bucket.

6. Hydrochemistry

with the concentrations increasing toward the southeast. Groundwater flow in the Paskapoo Formation is generally away from the Foothills toward the subcrop edge.

Figure 6.5 shows how total dissolved solids concentrations increase along the flow path. Furthermore, in many places, the Paskapoo Formation total dissolved solids concentrations are less than those in the sediments above bedrock (Figure 6.3).

As we read in Sections 2 and 3, the composition of the Paskapoo Formation is quite different from that of the sediments overlying bedrock. Unlike the sediments above bedrock, the components of the Paskapoo Formation do not generally react to any great extent with water, so less are dissolved as water moves through the Paskapoo Formation as compared to water moving through the sediments above bedrock. The result is a lower total dissolved solids concentration in many parts of the Paskapoo Formation.

Water in the Paskapoo Formation is medium hard to very hard based on Health Canada documents.[22] Hardness is lowest in the central portions of the Paskapoo Formation subcrop area, increasing toward the subcrop edge and the Foothills. Hardness values in the Paskapoo Formation are generally less than those in the sediments above bedrock. As with the total dissolved solids concentrations, once again, the composition of the Paskapoo Formation compared to that of the sediments above bedrock is the likely reason for the differences.

Horseshoe Canyon Formation

To define the Horseshoe Canyon Formation's western boundary, we selected an area that would include all of the data, as well as provide a bit of a buffer to the west. We defined the eastern boundary as the subcrop edge and ECC boundary. We had enough data in the Horseshoe Canyon to split the data into two categories: wells completed between 0–50 m below land surface and wells completed between 51–100 m below the land surface.

For the 0–50 m interval, Figure 6.7 shows the total dissolved solids concentration ranges, and Figure 6.8 shows the hardness concentration ranges. For the 51–100 m interval, Figure 6.9 shows the total dissolved solids concentration ranges, and Figure 6.10 shows the hardness concentration ranges.

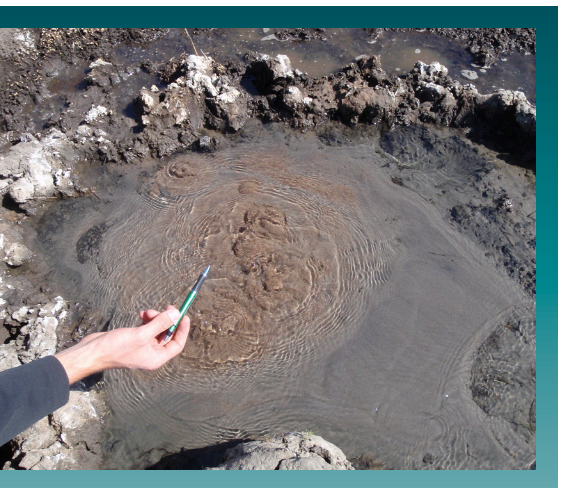
When comparing the total dissolved solids concentration maps, there appears to be a general trend of increasing total dissolved solids concentrations with depth. This is because water that is deeper below the surface has typically been in the ground longer than water closer to the surface. Therefore, the deeper water has had more time to react with geological materials through which it is moving.

We also noticed that the total dissolved solids concentrations are greater in the Horseshoe Canyon Formation than in the Paskapoo Formation. As we read in Section 2, the composition and grain size in the Horseshoe Canyon Formation are generally different from the composition and grain size in the Paskapoo Formation. The Horseshoe Canyon Formation is finer grained and has more variability in the types of sediments from which it is made. This means that water moves more slowly through the Horseshoe Canyon and can react with more types of materials over a longer time, resulting in greater total dissolved solids concentrations.

Water in the shallower portions of the Horseshoe Canyon Formation is of medium hardness to very hard. The water in the deeper interval of the Horseshoe Canyon that we examined is soft in many areas but very hard in the Edmonton area. A likely reason for these changes with depth is the composition of the Horseshoe Canyon Formation and the chemical reactions that take place as water moves through the rocks of the formation. The

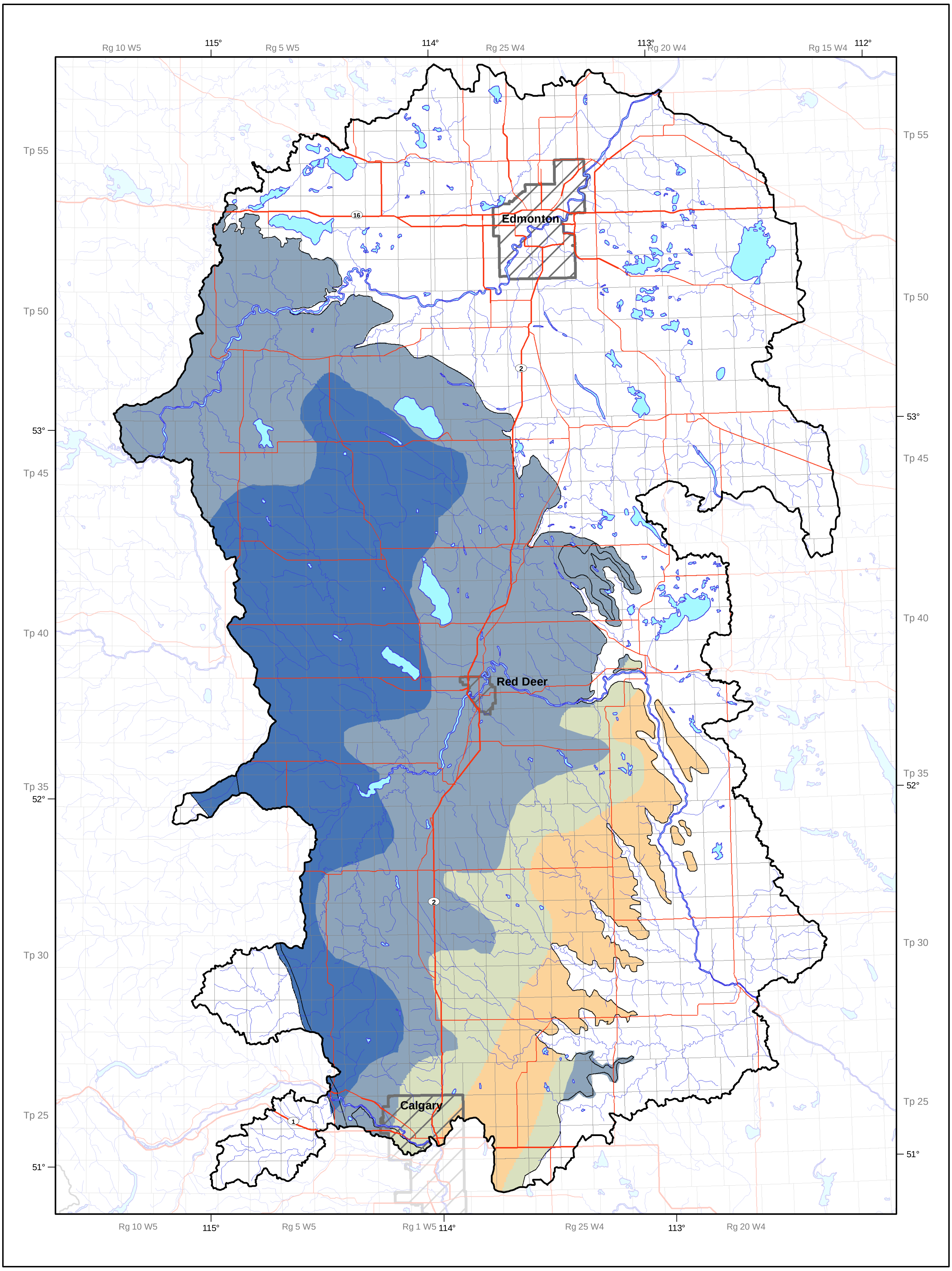
Alyssa Barker, Alberta Environment, collecting groundwater samples from a well in the central part of the ECC. Whereas the sampling protocols remained the same for each site, the geology of potential aquifers would change. The effects of the geological and hydrogeological settings on the hydrochemistry were key questions asked at the outset of the program. Answering these question dictated the details of the sampling program.

Hira Moktan, Alberta Environment, taking field notes during sampling. The information collected at each site includes site location, site description, physical and chemical measurements (like groundwater pH), and quality control-quality assurance details.



Upward groundwater discharge at a spring in the central ECC. The upward discharge is forcing sediment to become suspended in the water. The sediment was fine-grained, requiring careful processing of the sample to remove all of it.

6. Hydrochemistry



Total Dissolved Solids Concentration in the Paskapoo Formation (Figure 6.5)

Total Dissolved Solids (mg/L)

- <500
- 500.1 - 1000
- 1000.1 - 1500
- >1500

0 12.5 25 50 75 100 km

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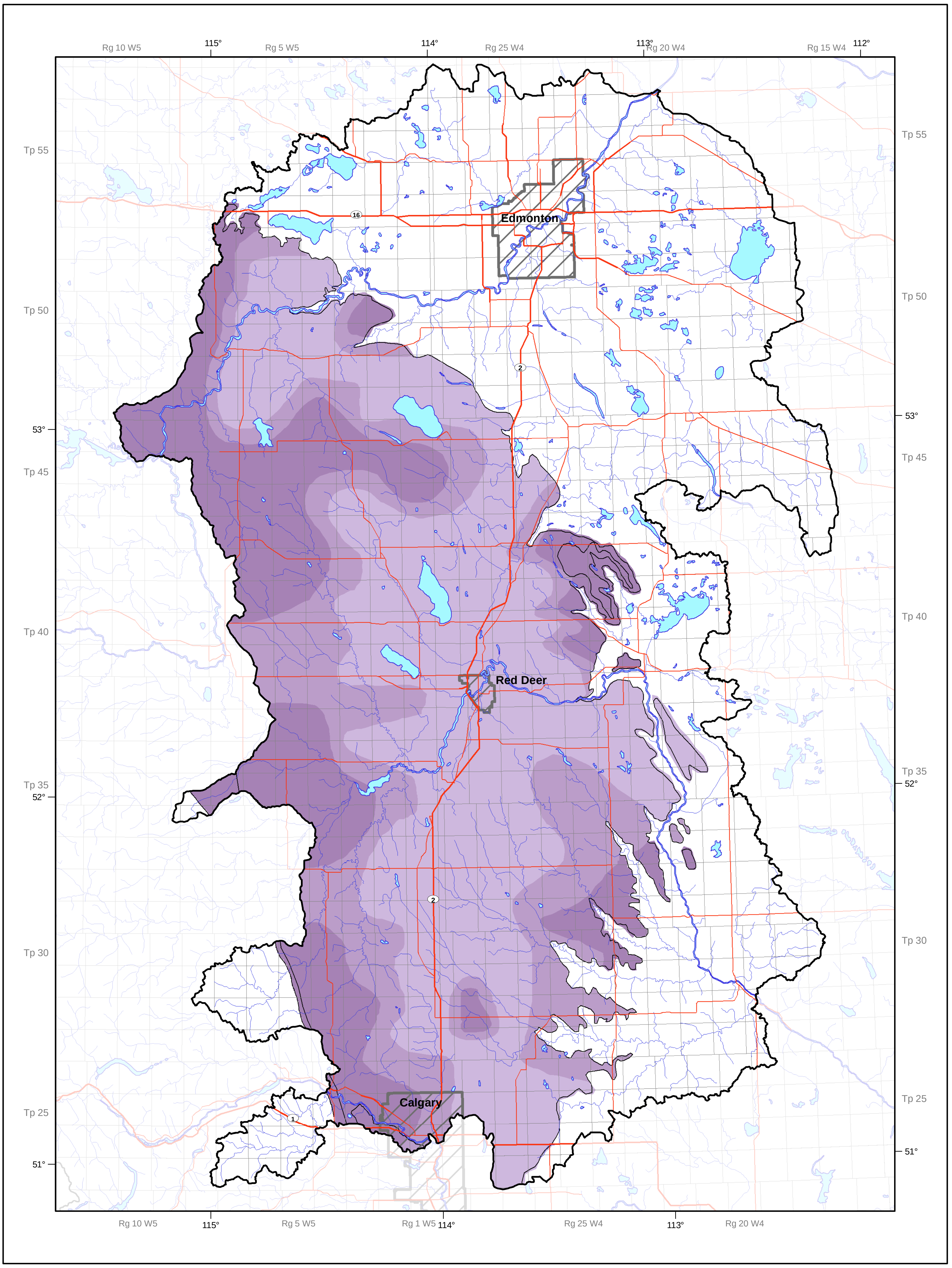

Hardness (as Calcium Carbonate) Concentration in the Paskapoo Formation (Figure 6.6)

Hardness as Calcium Carbonate (mg/L)

- <150
- 150.1 - 250
- >250

0 12.5 25 50 75 100 km

Government of Alberta

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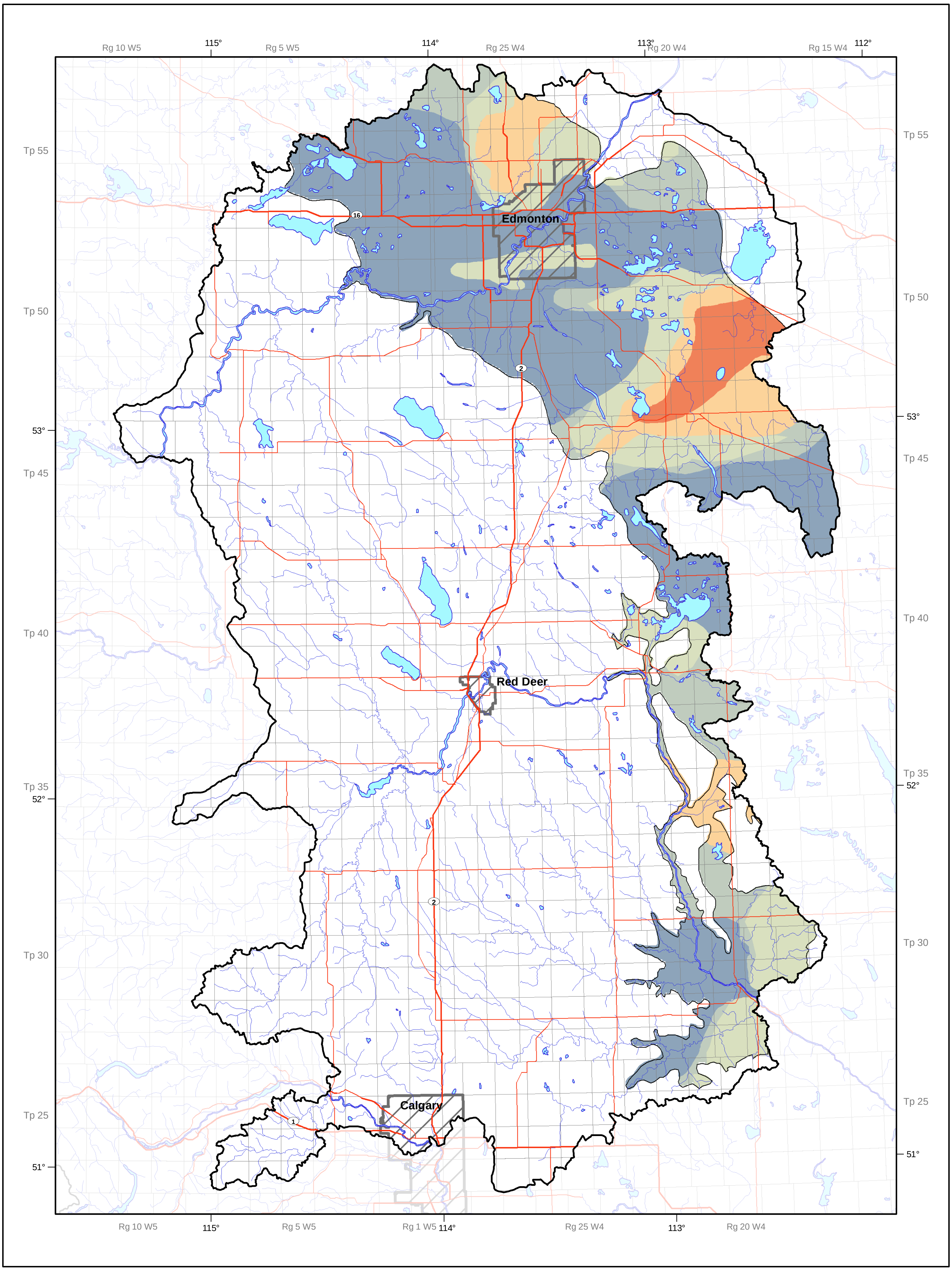


Total Dissolved Solids Concentration
in the Horseshoe Canyon Formation (0-50 m bgs) (Figure 6.7)

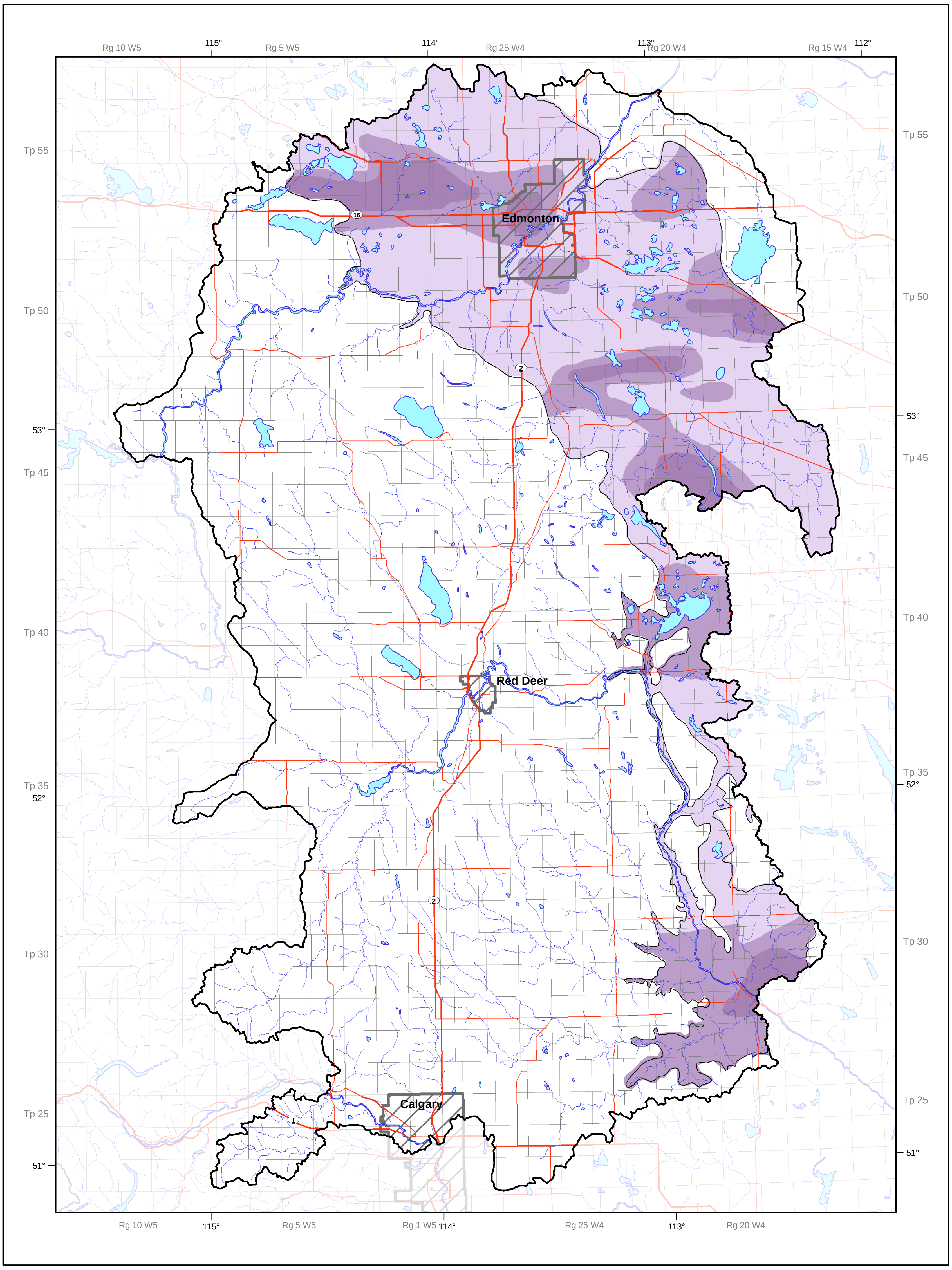
Total Dissolved Solids (mg/L)

- <1000
- 1000.1 - 1500
- 1500.1 - 2000
- >2000

0 12.5 25 50 75 100 km

Government of Alberta

Base Data Provided by Spatial Data Warehouse Ltd.



Hardness (as Calcium Carbonate) Concentration in the Horseshoe Canyon Formation (0-50 m bgs) (Figure 6.8)

Hardness as Calcium Carbonate (mg/L)

- <100
- 100.1 - 250
- >250

0 12.5 25 50 75 100 km

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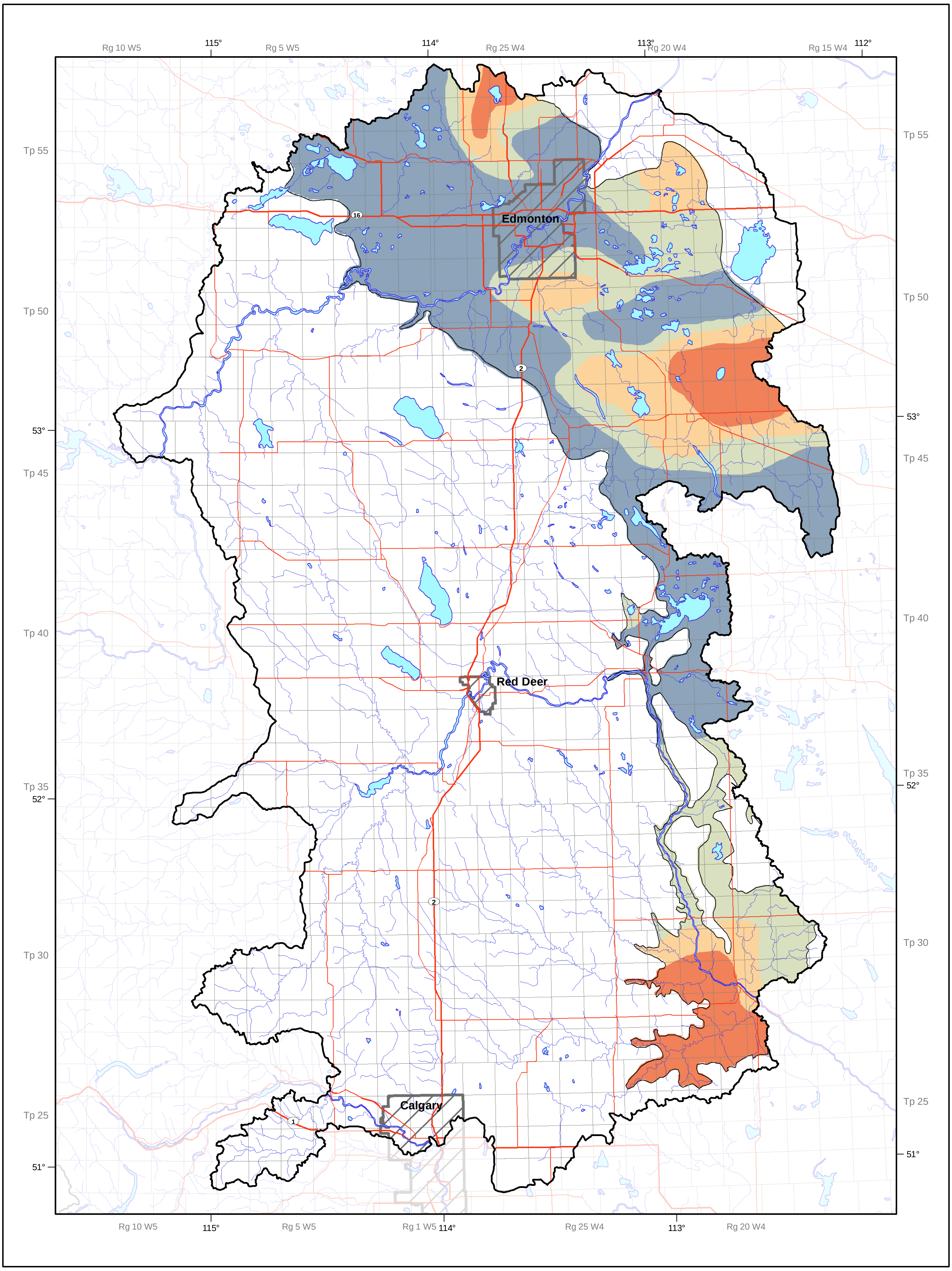

Total Dissolved Solids Concentration in the Horseshoe Canyon Formation (50-100 m bgs) (Figure 6.9)

Total Dissolved Solids (mg/L)

- <1000
- 1000.1 - 1500
- 1500.1 - 2000
- >2000

0 12.5 25 50 75 100 km

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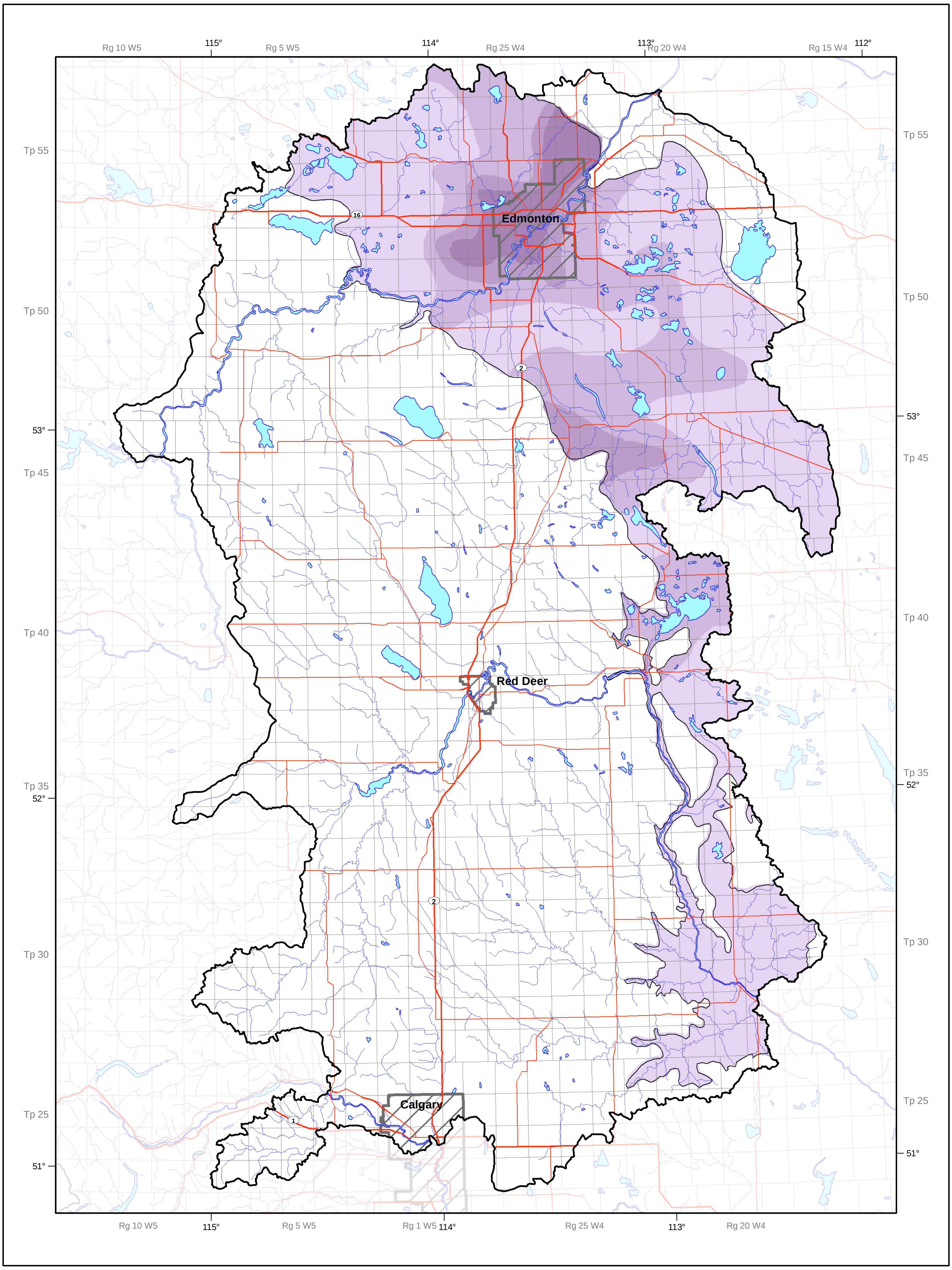
Base Data Provided by Spatial Data Warehouse Ltd.



Hardness (as Calcium Carbonate) Concentration in the Horseshoe Canyon Formation (50-100 m bgs) (Figure 6.10)

Hardness as Calcium Carbonate (mg/L)

- <50
- 50.1 - 150
- 150.1 - 250
- >250

0 12.5 25 50 75 100 km

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Base Data Provided by Spatial Data Warehouse Ltd.

elements responsible for making water hard react with the rocks, and these elements bind to the rocks. The elements that were bound previously to the rocks are released and enter the water. These released elements are different from those that made the water hard, thus making the water softer.

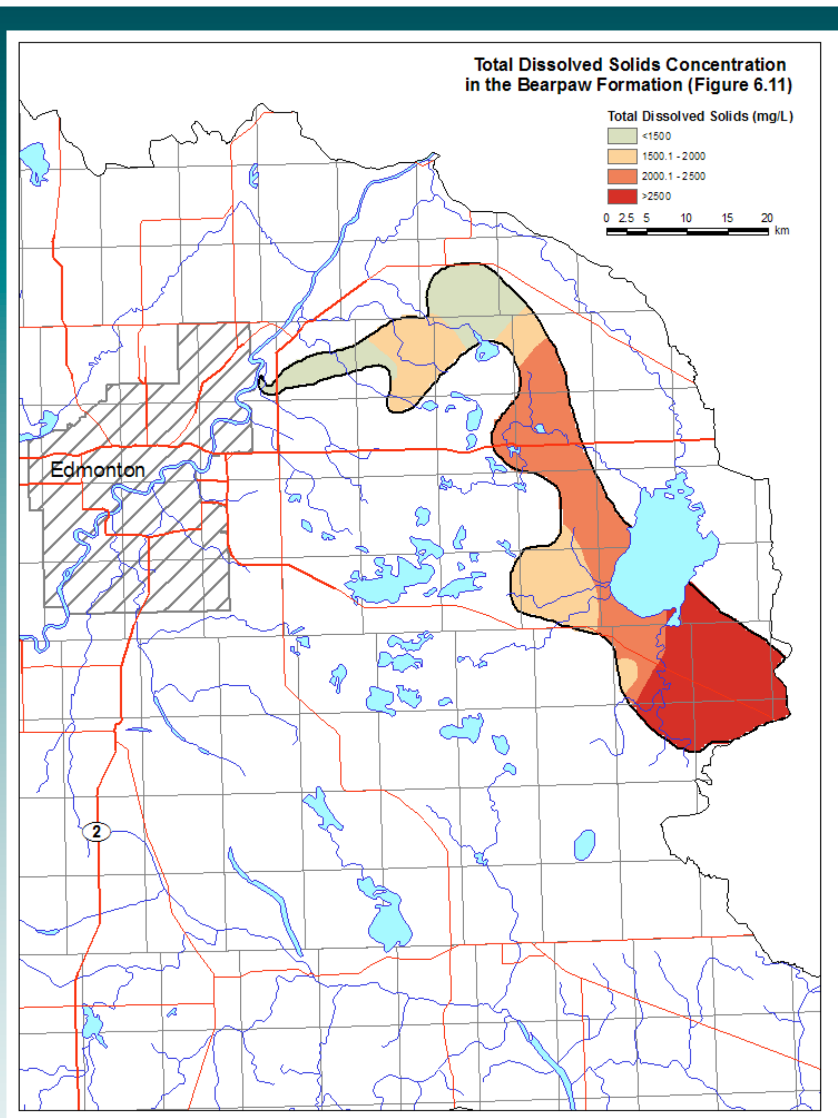
Bearpaw Formation

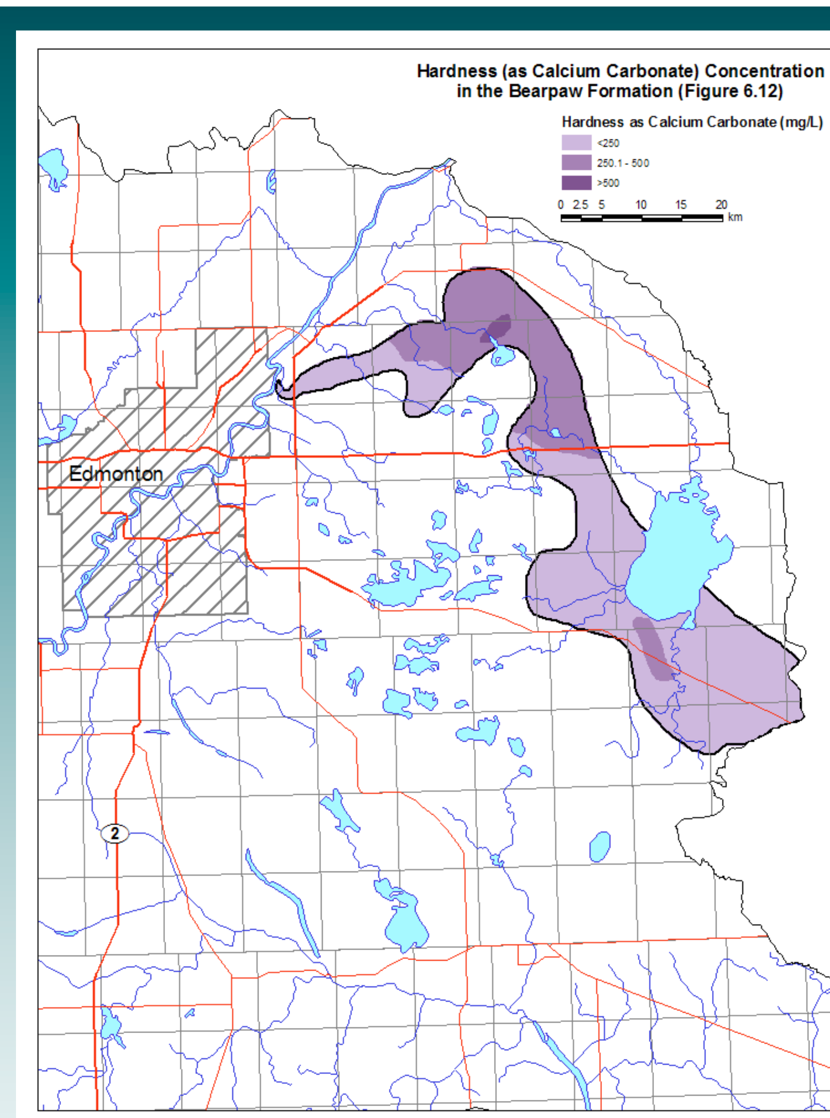
To define the Bearpaw Formation's western boundary, we selected an area that would include all of the data, including a bit of a buffer to the west. We defined the eastern boundary as the subcrop edge. Only a few of the wells in the ECC that are completed in the Bearpaw Formation have water chemistry information, so we had limited data to map the chemical concentration ranges. Figure 6.11 shows the total dissolved solids concentration ranges, and Figure 6.12 shows the hardness concentration ranges.

Total dissolved solids concentrations in wells completed in the Bearpaw Formation increase toward the southeast. Concentrations are somewhat higher than those in the Horseshoe Canyon Formation, suggesting that the link between an increase in depth and an increase in total dissolved solids concentrations exists here as well.

Water from the Bearpaw Formation is very hard. Hardness values in the Bearpaw Formation are similar to those in the sediments above bedrock. This could mean that we are witnessing mixing between water from these two intervals.

Spring at the Raven fish hatchery near Caroline, Alberta. The springs at the Raven fish hatchery form pools and straight channels, which are ideal habitats for the trout raised at the hatchery.





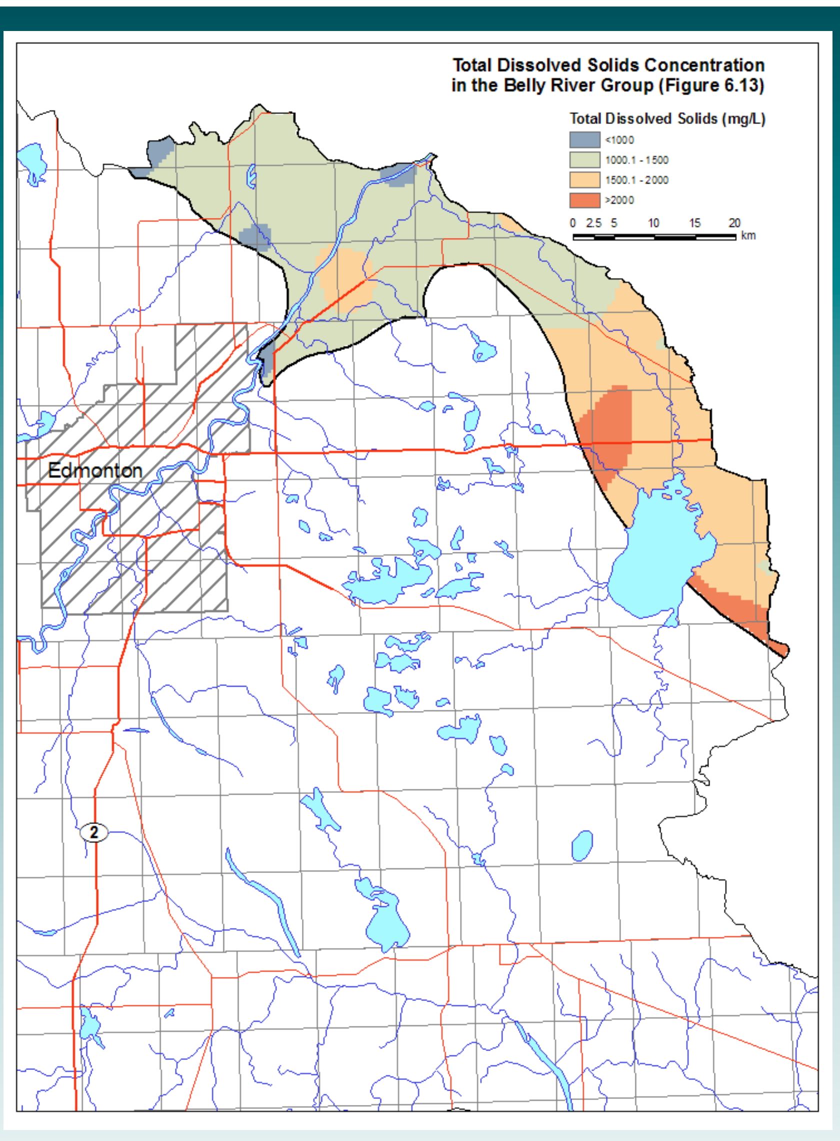
Belly River Group

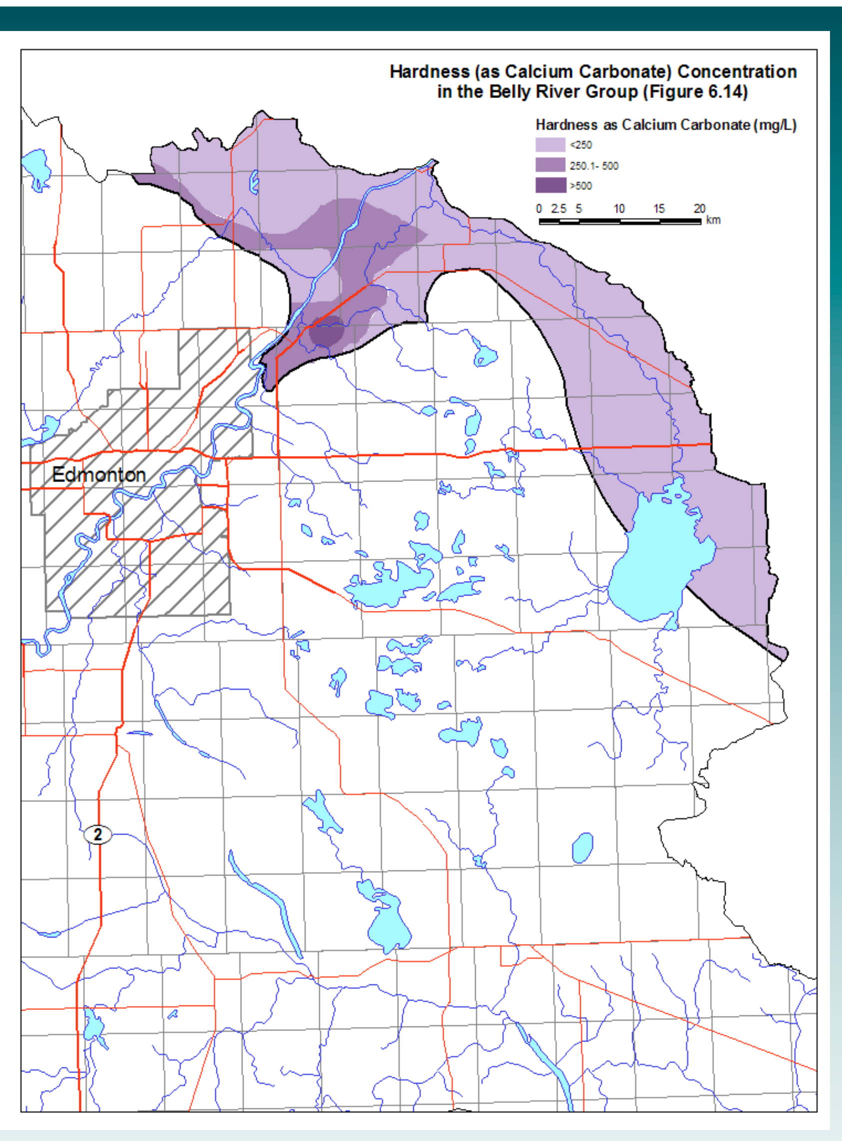
To define the Belly River Group's western boundary, we selected an area that would include all of the data, including a bit of a buffer to the west. We defined the eastern boundary as the ECC's boundary. Only a few of the wells in the ECC that are completed in the Belly River Group have water chemistry information, so we had limited data to map the chemical concentration ranges. Figure 6.13 shows the total dissolved solids concentration ranges, and Figure 6.14 shows the hardness concentration ranges.

Total dissolved solids concentrations increase toward the southeast. Concentrations in the Belly River Group are generally less than those in the Bearpaw Formation but greater than those in the Horseshoe Canyon Formation. These trends are related to differences in the sediment within each of these rock units and the amount of time water spends in flow systems within each of these units.

Water from the Belly River Group is very hard. Hardness values are greatest northeast of Edmonton.

Spring water flow forming a stream in the central part of the ECC.





7. Summary

What We Mapped in the ECC
How This Work Will Be Used
Where Do We Go From Here?

7. Summary

The *Water for Life* strategy[1] outlines the Government of Alberta's commitment to managing water resources in the province. This document identifies a number of key directions:

- Albertans will have access to the knowledge needed to achieve safe drinking water, healthy aquatic ecosystems and reliable, quality water supplies for a sustainable economy;
- *Water for Life* partners are empowered, informed and fully engaged in watershed stewardship; and
- All sectors understand how their behaviours impact water quality, quantity and the health of aquatic ecosystems. They will adopt a water conservation ethic and take action.

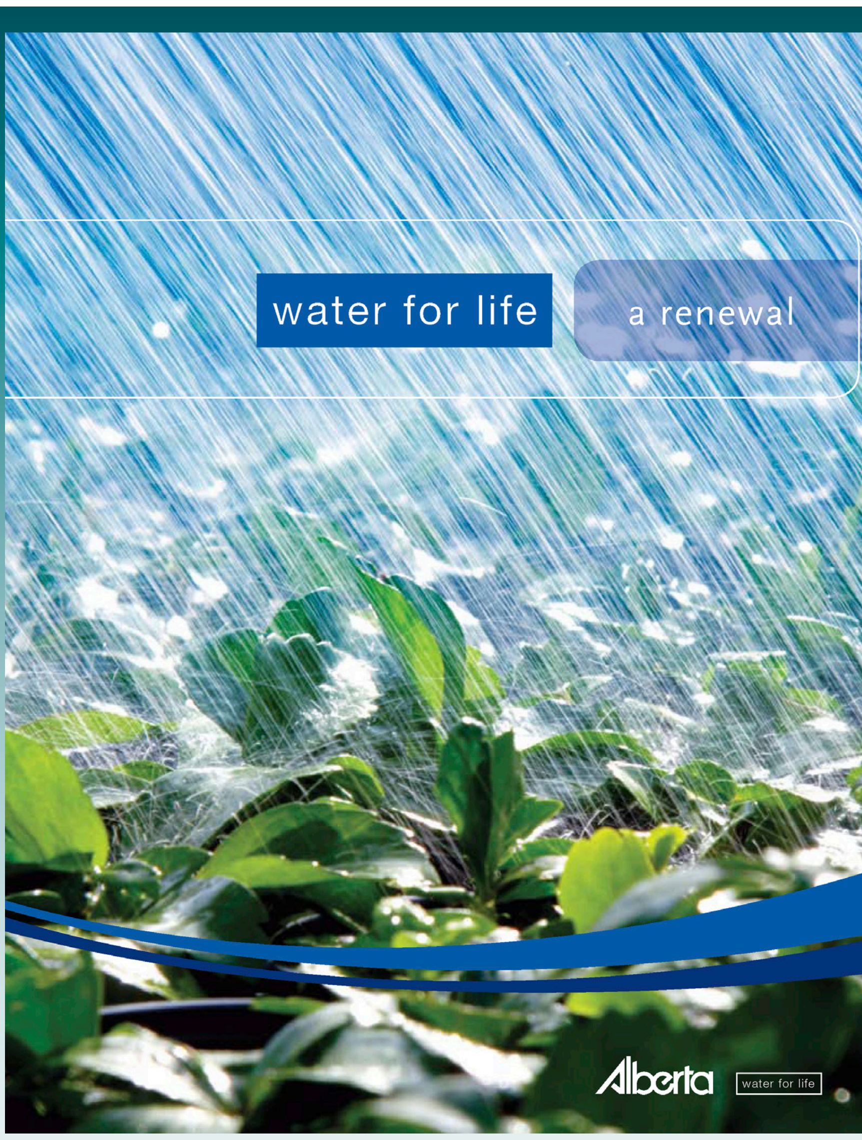
The groundwater inventory work we are conducting in the ECC provides the information and knowledge that can be used in achieving success in all three of these directions.

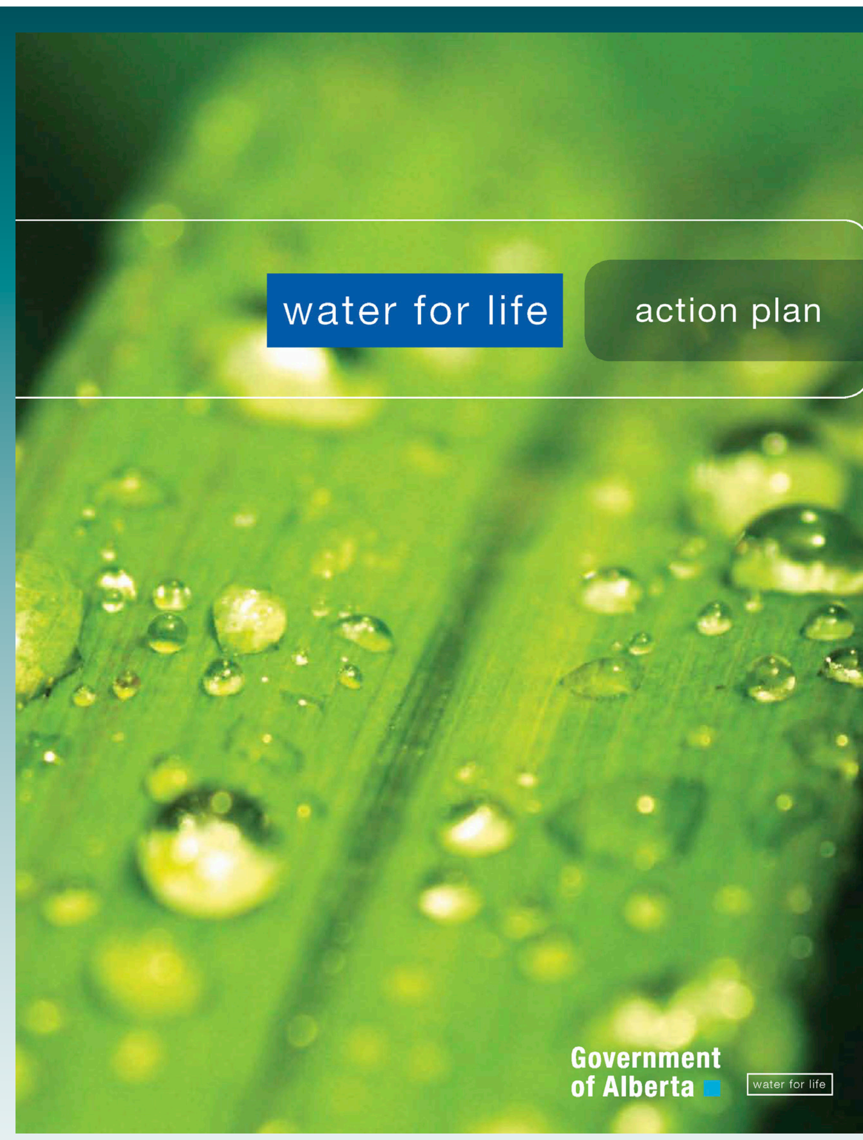
What We Mapped in the ECC

The AGS compiled and mapped the following information for the ECC:

- physical arrangement and composition of the sediments above bedrock;
- physical arrangement and composition of the bedrock units;
- hydrological parameters, such as precipitation, evapotranspiration, base flow, runoff and recharge;
- hydrogeological parameters, such as the water-table elevations, water-level surfaces, estimates of groundwater-flow directions, vertical gradients, recharge and discharge areas, potential groundwater yield, groundwater susceptibility, and the location of the major aquifer types in the area; and
- hydrochemistry (the range of chemical concentrations found in each geological formation).

Gordon Jean, Alberta Geological Survey, measuring the physical properties of the water in the North Saskatchewan River near Edmonton, Alberta. Measurements included pH, conductivity, dissolved oxygen and temperature. These water properties are used to report on the water quality in the study area.





7. Summary

How This Work Will Be Used

The mapping work provides us with an excellent overview of the climate and hydrology of the study area, as well as the geological and hydrogeological characteristics of the rocks and sediments that contain the groundwater resources of the ECC. This study confirmed and greatly improved our previous understanding of the waterscape of the ECC. However, some questions remain unanswered.

Specific questions include how groundwater is

- flowing through the study area, and how this flow may be altered given changes in the overall water system, such as increased use or decreased recharge;
- linking to surface-water bodies; and
- being used in the study area and is this use sustainable.

The mapping and calculations completed as part of this study form the basis for developing models of groundwater flow to answer these questions. The groundwater-flow models will forecast how changes in the use of groundwater can influence groundwater levels and surface-water bodies with which aquifers are in contact. It will also help regulators consider the cumulative effect of all of the groundwater users within an aquifer system when making water-allocation decisions.

Our understanding of the geology, climate, hydrology and hydrogeology in the ECC can be used by stakeholders and regulators to identify future water-monitoring needs and improve regional land-use planning initiatives. For instance, in places where recharge areas are known to exist, monitoring of groundwater levels may be included in monitoring programs to understand the rate of recharge to refine water-balance calculations. More refined estimates of recharge can improve the results of groundwater models. Areas where groundwater is more susceptible to contamination can be targeted for best management practices, educational programs or inspected more frequently for possible pollution sources.

Ultimately, our understanding will help water managers, land-use planners, stewards and other stakeholders focus on areas where the quantity and quality risks to groundwater are the greatest so they can protect this valuable, hidden resource.

Where Do We Go from Here?

The work in this first phase of the ECC project will be used to develop more sophisticated groundwater models to help us understand how much groundwater is available in the major aquifers. These groundwater models will aid us in deciding how best to manage water resources in the area. These tools will test different management options and scenarios so the Government of Alberta can develop water management policies that achieve the desired outcomes of the *Water for Life* strategy[1].

The physiography of the ECC is diverse, going from relatively flat-lying elements to steep-sided hills. This valley near Gwynne, Alberta, is just one example of that diversity.

Sylvan Lake, Alberta, is one of the largest lakes in the ECC. The linkages between surface water, groundwater and the geological setting are very important factors to understand as we build our groundwater inventory.

Groundwater discharge forming a pond in the central part of the ECC. The circle of ripples toward the far end of the pond marks the location of the discharge. Groundwater is always moving, albeit relatively slowly. We rarely witness this movement unless we spot discharge features like this or locate a spring.

Glossary

Glossary

aquifer – Body of rock or sediment that is water-saturated, made up of highly permeable material and can supply large quantities of groundwater to wells, springs or surface-water bodies.

aquitard – Body of rock or sediment that is water-saturated, made up of low-permeable material and cannot transmit large quantities of water.

base flow – Part of the stream flow in rivers and streams that comes from groundwater moving into a river or stream.

bedrock – General term for rock, usually solid, lying under soil or other loose surface materials.

bentonite (-ic) – Rock containing bentonite. Bentonite is a soft clay or claystone largely composed of the mineral smectite. Bentonite can absorb large quantities of water, which causes it to increase in volume.

calcareous – Rock or sediment containing calcium carbonate. When used with a rock name, it means that as much as 50 per cent of the rock is calcium carbonate.

carbonaceous – Rock or sediment rich in carbon. It may contain coal. It is also said of sediments containing organic matter.

chert (-y)– Hard, very fine grained sedimentary rock, often found as nodules in limestone or dolostone. Chert has also been called flint.

clast – Individual piece, grain or fragment of a sediment or rock produced by the mechanical or chemical disintegration of a larger rock mass.

clastic – Rock or sediment made of broken pieces from pre-existing rocks or minerals. This may also refer to the texture of a rock.

confined aquifer – Aquifer bounded above and below by confining beds (or aquitards).

delta – Low, nearly flat section of land at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of sediments. It is the result of the buildup of great quantities of sediment supplied by a river.

discharge area – Area where groundwater is being released from the saturated zone.

downhole geophysics – Geophysical data collected by lowering measurement tools (e.g., electric, gravity, magnetic) into and out of a borehole.

electromagnetic – Electrical exploration method measuring alternating magnetic fields from natural or artificially induced sources in the subsurface.

eolian – Erosion and deposition of sediments caused by the wind, usually forming deposits such as sand dunes.

evaporation – Process by which a substance passes from the liquid or solid state to the vapour state. In this case, the evaporation of water from surface-water bodies or the land surface.

evaporative demand – Rate of water loss from a wet surface.

evapotranspiration – Loss of water from a land area through the transpiration of plants and evaporation from the soil and surface-water bodies.

feldspathic – Containing feldspar, which is a group of rock-forming minerals comprising 60 per cent of the Earth's crust.

flow modelling – Groundwater-flow models are conceptual descriptions or approximations describing physical systems using mathematical equations.

fluvial – Of or pertaining to a river; sediments produced by the movement of a stream or river are 'fluvial sediments.'

formation – Body of rock identified by its physical characteristics and position in relation to other bodies of rock. It can usually be mapped at the Earth's surface or traced in the subsurface.

frequency-domain technology – Geophysical exploration method based on measuring magnetic fields created by an electromagnetic field with a fixed frequency.

geophysics (geophysical)– Study of the Earth by quantitative physical methods using physics principles.

geostatistics – Branch of applied statistics dealing with phenomena that fluctuate in two- or three-dimensional space. Statistics as applied to geology.

glaciation – Formation, movement and recession of glaciers or ice sheets.

glaciofluvial – Refers to the sediments from the meltwater streams flowing from melting glacier ice and especially to the deposits and landforms produced by such streams; the result of the combined action of glaciers and streams.

glaciolacustrine – Sediments from or deposited in glacial lakes, especially the deposits and landforms composed of material carried by meltwater streams flowing into lakes bordering a glacier.

groundwater – Water below the land surface and the water table; the source for springs and wells.

groundwater susceptibility – Ease with which water enters and moves through an aquifer. It is a function of the overlying sediment and the aquifer's physical characteristics.

hydraulic head – Elevation of water in a groundwater well. This elevation is related to the pressure acting on the water from within the aquifer in which the groundwater well is completed.

hydrochemistry – Study of chemical processes and conditions in groundwater.

hydrogeology – Study of subsurface water, its movements and its interactions with geological materials and surface water.

hydrograph – Graph showing characteristics such as the elevation or the rate of flow of water with respect to time.

hydrology – Science of global water (both liquid and solid), its properties, circulation and distribution on and under the Earth's surface and in the atmosphere.

inorganic chemistry – Chemistry of compounds that contain no carbon.

interbedded – Refers to geological layers or 'beds' that lie between or alternate with different types of geological layers.

isostatic rebound – Adjustment of the Earth's crust to the unloading from the removal of glacier ice or as sediments are eroded from the landscape.

lacustrine – Refers to sediments produced by or formed in a lake.

Laramide Orogeny – Time of geological deformation that occurred in the eastern Rocky Mountains. There were several phases that extended from the Late Cretaceous until the end of the Paleocene (about 80 to 50 million years ago).

litholog – Log describing the sequence of physical (lithological) characteristics of the sediments or rocks encountered while drilling a well or borehole. It is compiled from the examination of well cuttings or core.

lithology (lithological) – Description of sediments or rocks based on such characteristics as colour, mineral composition and grain size. The physical character of a sediment or rock.

lodgement – Process of depositing glacial debris from the base of a moving glacier through pressure melting and/or mechanical means.

matrix – Finer grained material enclosing or filling the spaces between the larger grains or particles of a sediment or sedimentary rock.

melt-out – Slow release of debris from ice that is not sliding or deforming.

meltwater – Water from the melting of snow or ice, used most often when referring to water from melting glacial ice.

meltwater channel – Channel eroded into the land surface by water from the melting of snow or ice, especially from melting glacier ice.

moraine – Mound, ridge or other distinct buildup of unsorted, not layered glacial materials, predominantly till, usually deposited by direct action of glacier ice. It can form a variety of topographic landforms independent of the land surface on which the moraine was deposited.

morphology (morphological) – Shape, form or arrangement of sediments and rocks as they relate to landforms on the Earth's surface. Areas defined by distinctive landforms are grouped together and called morphological elements or regions.

paleochannel – Remnant of a stream channel cut in older rock or sediment and filled by younger overlying rock or sediment. It often refers to buried stream channels.

permeability – Ability or capacity of a porous rock or sediment to transmit water. It is a measure of how easily water can move through a given material.

physiography (-ic) – Description of the physical nature (shape, composition and arrangement) of natural features on the Earth's surface.

Glossary

porosity – Percentage of the volume of a rock or soil that is occupied by void spaces. These spaces can be isolated or connected.

precipitation – Water that falls to the Earth's surface from the atmosphere as rain, snow, hail or sleet.

proglacial – Immediately in front of or just beyond the outer limits of a glacier or ice sheet. This is usually said of lakes, streams and deposits produced by or from the glacier ice.

recharge – Processes involved in adding water to the saturated zone. It occurs naturally via precipitation or runoff. It also refers to the amount of water added to the saturated zone.

recharge area – Area where water is being added to the saturated zone.

resistivity (electrical) – Electrical resistance of a material. This is used in geophysical explorations to describe the rock or sediment.

rooting zone – Soil in the immediate area of plant roots.

runoff – Water from precipitation or snowmelt travelling across the land surface, either on top of the land surface or slightly below it. This water contributes to stream flow.

saturated zone – Subsurface zone (area below the water table) in which all of the void spaces of the sediments and rocks are filled with water.

sediment – Material from the weathering of rocks transported and deposited by air, water or ice. This material is deposited in layers on the Earth's surface in a loose (unconsolidated) form.

sedimentary rock – Rock formed from the consolidation or compaction of loose sediments collected in layers on the Earth's surface.

siliceous tuff – Consolidated or cemented volcanic ash rich in the mineral silica.

subcrop – Subsurface outcrop describes the areal limits of a rock unit buried below other sediments. These limits are shown on subcrop maps.

surficial – Something occurring on the Earth's surface. A surficial deposit refers to the loose (unconsolidated) sediments lying on top of bedrock and generally represent the most recent geological deposits.

tectonic (-s) – Forces involved in moving geological plates around the Earth. Tectonics is a branch of geology dealing with the broad architecture of the outer part of the Earth.

till – Sediment dominantly unconsolidated, unsorted and not layered deposited directly by or underneath a glacier without being subsequently reworked by water. Till generally consists of a mixture of clay, silt, sand, gravel and boulders ranging widely in size and shape.

time-domain technology – Geophysical exploration method based on measurements of electromagnetic quantities with time.

topography – General configuration of a surface (either land surface or underground surface) as defined by its elevation.

transpiration – Water evaporated from a plant's surface.

unconfined aquifer – Aquifer near the land surface. The water table defines the top of these aquifers.

unconsolidated – Sediment loosely arranged or whose particles are not cemented together.

unsaturated zone – Subsurface zone whose void spaces are filled with a combination of gases or water. The top of this zone is defined by the land surface, and the base is defined by the saturated zone.

vertical gradient – Rate of change in the vertical direction. It can be calculated from the horizontal flow data. It suggests which direction groundwater is travelling in the vertical direction.

water-level surface – Surface representing the elevation of groundwater for a particular geological layer or aquifer. It is generated using the water levels measured in wells. The water table is an example of a water-level surface.

water table – Where fully saturated groundwater conditions are first encountered below the surface of the Earth. It also represents the surface between the saturated and unsaturated zones.

Endnotes

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