COLD LAKE–BEAVER RIVER BASIN

GROUNDWATER QUALITY

STATE OF THE BASIN REPORT

Alberta
ENVIRONMENT

In partnership with Lakeland Industry and Community Association
and the Cold Lake–Beaver River Basin Advisory Committee

February 1, 2006

ISBN: 0-7785-4559-8 (Printed)
ISBN: 0-7785-4560-1 (On-line)
Pub No. T/848

For additional copies, please contact:

Alberta Environment Information Centre
Main Floor, 9820 – 106 Street
Edmonton, Alberta Canada T5K 2L6
Tel: 780-427-2700 (dial 310-0000 first for toll free)
Email: env.infocent@gov.ab.ca

Table of Contents

SECTION 1. PRELIMINARY INFORMATION

1.1 INTRODUCTION

This report is one of four State of the Basin reports described below. Each report gives specific information to provide a snapshot that illustrates the current condition of the Cold Lake–Beaver River (CLBR) Basin. The reports contain inventory and assessment information related to surface and groundwater quantity, quality and aquatic resources of the basin. Also identified are the management tools that are currently available to address water issues in the basin. In addition to providing background information and a knowledge base for the CLBR plan, the reports update information in the 1985 planning documents.

Developing the State of the Basin reports was a collaborative team effort using expertise from Alberta Environment, Sustainable Resource Development, Alberta Agriculture, Food and Rural Development, Prairie Farm Rehabilitation and Administration, Department of Fisheries and Oceans, and the Lakeland Industry and Community Association (LICA).

The four State of the Basin reports prepared for the CLBR Basin Plan Update are as follows:

- *Surface Water Quantity and Aquatic Resources State of the Basin Report*: This document contains an overview of regional hydrology, lake-based water balance studies, an assessment of current and historical surface water allocation and uses, and best management practices for municipal, agricultural and industry water conservation. The report also contains an assessment and update of fish and fish habitat, wildlife and recreation in the basin.
- *Groundwater Quantity and Brackish Water State of the Basin Report*: This document contains an assessment of fresh and brackish groundwater uses, groundwater/surface water interactions, and the geological/hydrogeological framework of the basin.
- *Groundwater Quality State of the Basin Report*: This document contains an overview of groundwater quality in the basin, including indicator parameters, potential contamination point sources and aquifer sensitivity maps. The report presents a summary of the groundwater quality database developed for the basin, and contains a summary of deep well disposal regulations and practices in the province and the basin.
- *Surface Water Quality State of the Basin Report*: This document contains an overview of regional water quality in lakes and the Beaver River at the Saskatchewan border. Also included is an assessment of surface water quality changes over the past two decades and reasons for the changes. In addition, the report contains an assessment of the sources of drinking water and identifies data gaps.

1.2 NEED FOR THE PLAN UPDATE

The Cold Lake–Beaver River Water Management Plan was adopted in 1985 to provide direction for managing water resources in the Cold Lake and lower Beaver River Basin. The plan's intent was to ensure an adequate quantity and quality of water to meet long-term user requirements of the basin. Since that time, however, the region has generally experienced below-average runoff as well as increased industrial development and population growth. This has resulted in the need to reassess the demands on the CLBR Basin and update the 1985 plan accordingly.

The update of the 1985 plan is occurring in consultation with stakeholders and the public, and in partnership with LICA and agencies that have an interest or mandate affected by the plan. The initiative undertaken in 1994 to update the 1985 CLBR Water Management Plan was never finalized. The 1994 initiative focused on industrial water supply and allocations due to increased industrial development in the basin.

1.3 PURPOSE OF THE PLAN UPDATE

Water management plans provide a framework for decision-making by the Alberta government. In particular, Alberta Environment uses the plans to make water management decisions under the *Water Act* and the *Environmental Protection and Enhancement Act*. This update will provide a current look at the state of the CLBR Basin, and a strategy will be developed to meet the current and future water needs of the basin. The updated plan will strive to balance community, economic and environmental issues and values with government legislation and policy for protecting and managing water resources in this area.

The Water Management Plan Update will assess the following:

- Groundwater quality and quantity
- Surface water quality and quantity
- Groundwater and surface water flows and interactions
- Aquatic resources.

The plan update will be guided by the following principles:

- ► Water must be managed sustainably.
- ► Water is a vital component of the environment; all life depends on it.
- ► Water plays an essential role in a prosperous economy and in balanced economic development.
- ► Water must be managed using an integrated approach with other natural resources, resulting in a healthy aquatic environment.
- ► Water must be managed in consultation with the public.
- ► Water must be managed and conserved in a fair and efficient manner.

1.4 Planning Area

The Cold Lake–Beaver River planning area is part of the CLBR Basin located approximately 300 km northeast of Edmonton. The Cold Lake River Basin drains to the outlet of Cold Lake, while the Beaver River Basin drains to the Alberta/Saskatchewan boundary.

The plan update study area focuses on the following lakes and downstream rivers:

- Jackfish Creek
- Manatokan Creek
- Marie Creek
- Moose Lake River
- Muriel Creek
- Reita Creek
- Sand River
- Wolf River
- Cold Lake
- Moose Lake
- Muriel Lake
- Marie Lake

The surface waterbodies supply most of the water used by the municipalities, of which the City of Cold Lake and the Town of Bonnyville are the largest. Cold Lake was incorporated in 1996 through amalgamation of Grand Centre, Cold Lake and 4 Wing Cold Lake (military base). It serves a regional trading area of approximately 50,000 people. Statistics Canada recorded an official population for Bonnyville of 5,710 in 2001, but the town serves more than 10,000 people living within a 10 km radius.

1.5 Plan Update Goals and Objectives

The plan update goals and objectives were laid out in the approved Terms of Reference, and are listed below.

Goals

- Assess the state of regional ground and surface water supply, quality, use, and their interactions in the basin based on the most recent information.
- Provide a strategy to meet current and future water needs in the region and ensure a sustainable water supply.
- Provide a strategy to protect and ensure a healthy aquatic environment.

Objectives

- Water Allocation — Review current and historical water allocation in the region.
- Water Use — Review current and historical water uses in the region and their potential impact on local water resources.
- Water Demand — Identify existing water demands in the region and forecast future short-term, medium-term (2010), and long-term water (2020) use.

- Water Supply — Establish quantity and distribution of surface and groundwater supply in the region.
- Water Interactions — Identify/investigate groundwater and surface water interactions.
- Legal Mandate — Identify all laws and legal agreements that are used to manage water in the basin, and ensure the plan is consistent with them.
- Water Conservation Objectives — Establish water conservation objectives to protect aquatic environments, regional tourism and recreation.
- Water Quality — Review regional surface and groundwater quality, and establish procedures to prevent pollution and degradation of water quality.
- Education — Engage the community, share information, and promote awareness of issues and solutions, as well as understanding about activities that impact the CLBR Basin water quantity and quality.

1.6 Overview of Issues and Conditions

Key issues identified in the 1985 plan are listed below, along with their current status and related initiatives.

Industrial Water Supply

- Current industry use of freshwater is less than that predicted in 1985; however, allocation limits established in the plan are now being approached. *(Note: Allocation limits do not reflect actual use.)*
- Construction of a pipeline from the North Saskatchewan River was recommended as a way to secure a supply of freshwater for future use. This recommendation was based on a prediction that industrial freshwater requirements would become much larger than in 1985. Because of increased recycling of produced water and the use of brackish water by industry, the actual water use is only a fraction of the amount projected in the 1985 plan. Thus the pipeline has not been built. In addition, legislation now in place does not allow inter-basin transfer of water, which would be necessary should the pipeline be constructed. Some stakeholders, however, continue to view the pipeline as the preferred option for securing a long-term water supply for industrial use.
- Since 1985, industry has improved the efficiency of their operations through the use of produced water and recycling technology. Industry has also been supplementing make-up water needs by using brackish water for existing operations and future growth.
- Brackish water studies conducted by Imperial Oil and CNRL as part of their industrial expansions suggest the brackish water supply is sustainable and its use will not have a significant impact on fresh surface and groundwater resources.

Cold Lake Water Levels and Water Levels of Other Lakes in the Basin

- Cold Lake and Moose Lake are the water supply sources for the City of Cold Lake and the Town of Bonnyville, respectively. Cold Lake is also one of the water supply sources for

CNRL's Burnt Lake operations, Imperial Oil's operations, as well as the Cold Lake Fish Hatchery.

- Cold Lake and other lakes in the basin are important recreational lakes and provide vital fish and wildlife habitat.
- The water flowing from Cold Lake into Saskatchewan is managed under the Apportionment Agreement between Alberta and Saskatchewan.
- There is ongoing concern related to securing municipal and domestic water supplies owing to fluctuating water levels.
- There is concern regarding potential decreases in water levels in local lakes, streams and wetlands due to diversions, particularly during periods of drought.

Effect of Industrial Groundwater Use on Quantity

- Historically, conflicts have arisen between local residents and industry over the perceived interference with water quantity, both as it affects lake levels and shallow groundwater levels.
- Several years of drought-like conditions related to low runoff levels in 1999-2002 resulted in low lake levels and local opposition to further industrial surface water withdrawals in the basin.
- Some local residents believe industrial pumping from deep useable aquifers has added to the impacts of the drought cycle, and point to the decline in some water levels as evidence of the interconnection between deep and shallow aquifer systems.
- Nine options for water supply alternatives were examined and evaluated in the 1994 Cold Lake–Beaver River Water Management Study Update using a number of criteria, including reliability of supply, economic factors, and impacts on other users and the environment. The preferred source for industrial water continued to be the proposed North Saskatchewan River water supply pipeline.
- The second, although less desirable, source of water was a system of weirs on Cold Lake or Primrose Lake and Wolf Lake, supplemented by the use of brackish water to the maximum extent possible. The reasoning at the time (1994) was that in the interim, while the long-term alternative (pipeline) was being constructed, industry could maximize its use of brackish water and continue using surface and groundwater within the existing license limits.

Groundwater Quality

- Groundwater protection is one of the most significant issues arising in the Cold Lake area. There is ongoing public concern that thermal, geomechanical or geochemical effects of oil production techniques may be releasing contaminants into useable aquifers.
- Available data for some contaminant indicators (e.g., arsenic, phenols, dissolved organic carbon) showed they tend to be clustered around industrial developments; little data are available for the rest of the basin. It should be noted that groundwater monitoring is most extensive near industrial developments, and measures additional and different chemical parameters than through standard water monitoring used in the rest of the basin.
- Residential well data tend to be clustered around Bonnyville and Cold Lake.
- No baseline groundwater quality data were included in the 1984 Cold Lake groundwater study for comparison purposes.

- Alberta Environment (AENV) contracted the Alberta Geological Survey (AGS) to compile a database of groundwater quality in the study area, including developing maps of all potential contaminant sources. This information will be used to help develop a comprehensive, long-term groundwater monitoring strategy that will address data gaps identified by AGS.

Protecting Sources of Drinking Water

- The potential impacts of industrial or other land-based activities on drinking water quality (both municipal and domestic wells) have been an ongoing concern in the CLBR Basin.
- Protecting the sources of drinking water was not specifically addressed in the 1985 plan or the 1994 study update.
- The Department of Environment is developing a provincial strategy to address "Protection of Sources of Drinking Water" as a follow-up action under the *Water for Life Strategy*.
- The CLBR Plan Update will assess municipal drinking water quality and general lake water quality. Investigation of private drinking water systems is outside the scope of this plan and is the responsibility of the individual owner. However, it must be recognized that private wells exist in large numbers and have the potential to serve as conduits for surface contaminants if they are not well maintained and abandoned correctly when no longer in use.
- Non-point source pollution is better assessed by monitoring runoff, identifying hot spots and developing management strategies at the watershed level through specific watershed management plans (e.g., the stakeholder-led *Water for Life* plan for Moose Lake).
- Contaminant prevention is the most effective strategy for dealing with water quality issues.

Surface Water Quality

- Some stakeholders in the planning area believe oil production is causing the following:
  - increased surface water salinity due to groundwater contamination; and
  - reduced water levels, which in turn are decreasing water quality.
- The increased shoreline and basin development is decreasing the quality of surface and drinking water, as well as recreation potential.
- There is a concern that water quality is negatively impacted by decreased water levels.
- There is a lack of water quality data prior to the 1980s. As such, comparisons with pre-development water quality cannot be made.
- There is a lack of water quality data for some lakes.
- Insufficient river/stream water quality data has made it difficult to detect change.
- Support of long-term monitoring sites for lakes and rivers is essential.
- Water quality in the CLBR Basin is above average compared to the rest of Alberta; however, areas of concern were identified in heavily developed sub-basins.

1.7 Organization of Technical Studies

Collecting and analyzing data is an essential part of updating the 1985 Plan. Four Technical Advisory Teams provided baseline information for the Cold Lake–Beaver River Water

Management Plan Update: the Groundwater Quality Team, Groundwater Quantity Team, Surface Water Quality Team, and Surface Water Quantity and Aquatic Resources Team.

The technical teams reviewed existing information on water resources, identified information gaps, collected new information to address specific objectives, and provided advice on recommendations for the plan update. The teams and their responsibilities are listed below.

Groundwater Quality Team

- Evaluation of existing groundwater quality monitoring and data.
- Recommendations on a program to monitor and assess future groundwater quality.
- Overview of existing data on deep well disposal.

Groundwater Quantity Team

- Hydrogeological framework.
- Numerical flow model.
- Assessment of brackish water supply.
- Overview of groundwater flows and interactions with surface water.

Surface Water Quality Team

- Assessment of existing surface water quality monitoring data, including developing nutrient budgets for select lakes.
- Assessment of sources of drinking water quality.
- Assessment of municipal water quality data.
- Recommendations for long-term monitoring program.

Surface Water Quantity and Aquatic Resources Team

- Assessment of water availability at key locations (water balance).
- Assessment of actual regional water allocations and uses.
- Estimate of future water demands.
- Assessment of fisheries, water-based wildlife and recreation.
- Recommendations for water conservation objectives and strategies to protect the aquatic environments.

1.8 REPORT FOCUS

This state of the basin report describes groundwater quality in the CLBR Basin. Graphics are provided showing the TDS concentrations by aquifer group, as well as arsenic, chloride and phenols. Aquifer sensitivity maps are also included. Although this state of the basin report focuses on groundwater quality issues in the CLBR Basin, the issue of water quality is intertwined with other basin issues such as groundwater quantity and surface water quantity and quality.

SECTION 2. OVERVIEW OF THE BASIN

2.1 PHYSICAL SETTING

The Cold Lake–Beaver River Basin is located approximately 300 km northeast of Edmonton (Figure 2-1). Most of the basin lies within Alberta, covering about 2% of Alberta's surface area, with a small portion extending into Saskatchewan. The basin is within the Boreal Forest Natural Region of Alberta, with undulating to moderately rolling topography and elevations ranging from about 500 m to 750 m above sea level (ASL). Boreal forest and aspen parkland vegetation communities dominate this region, consisting primarily of aspen, balsam poplar, white birch and white spruce. Jack pine is found in the more sandy areas, while black spruce and tamarack are found primarily in low-lying, poorly drained locations.

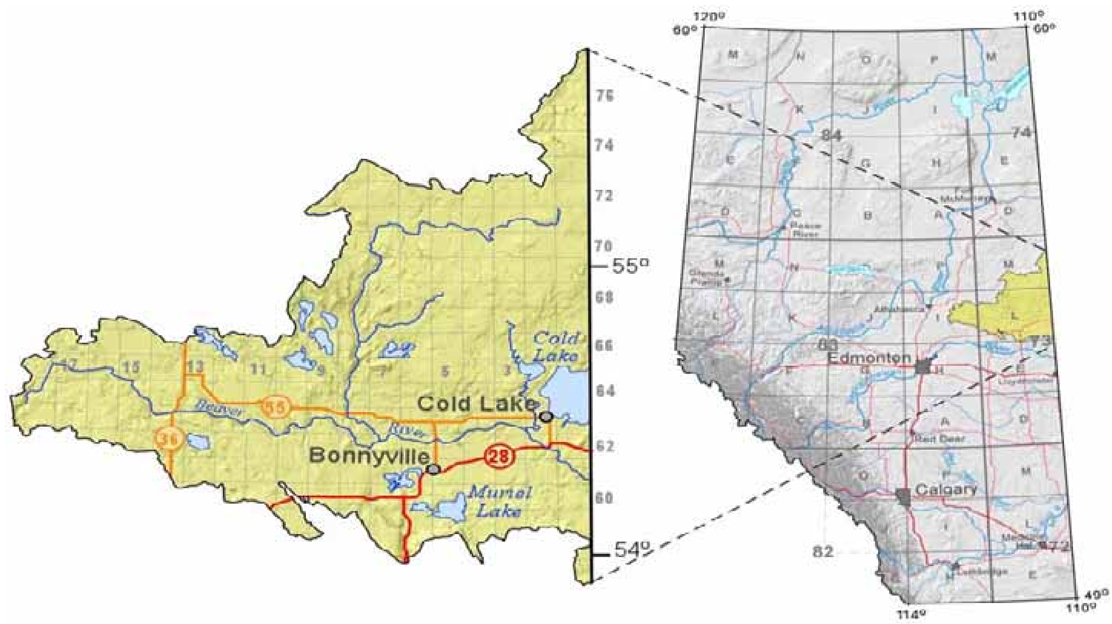


Figure 2-1. Cold Lake and Beaver River Basins within the Province of Alberta.

Figure 2-2 shows the entire basin has a total drainage area of 22,000 km^2, and comprises the Beaver River Basin (15,500 km^2) and the Cold Lake drainage system (6,500 km^2). The Beaver River originates near the Town of Lac La Biche as the outflow from Beaver Lake, and flows eastward. Cold Lake is the largest water body in the planning area, with a surface area of 350 km^2. A small portion of Primrose Lake falls within the planning area. Primrose Lake drains into Cold Lake through the Martineau River, and Cold Lake drains into the Beaver River through the Cold and Waterhen Rivers. The Cold Lake and Beaver River Basins then flow into the Hudson Bay through the Churchill River system.

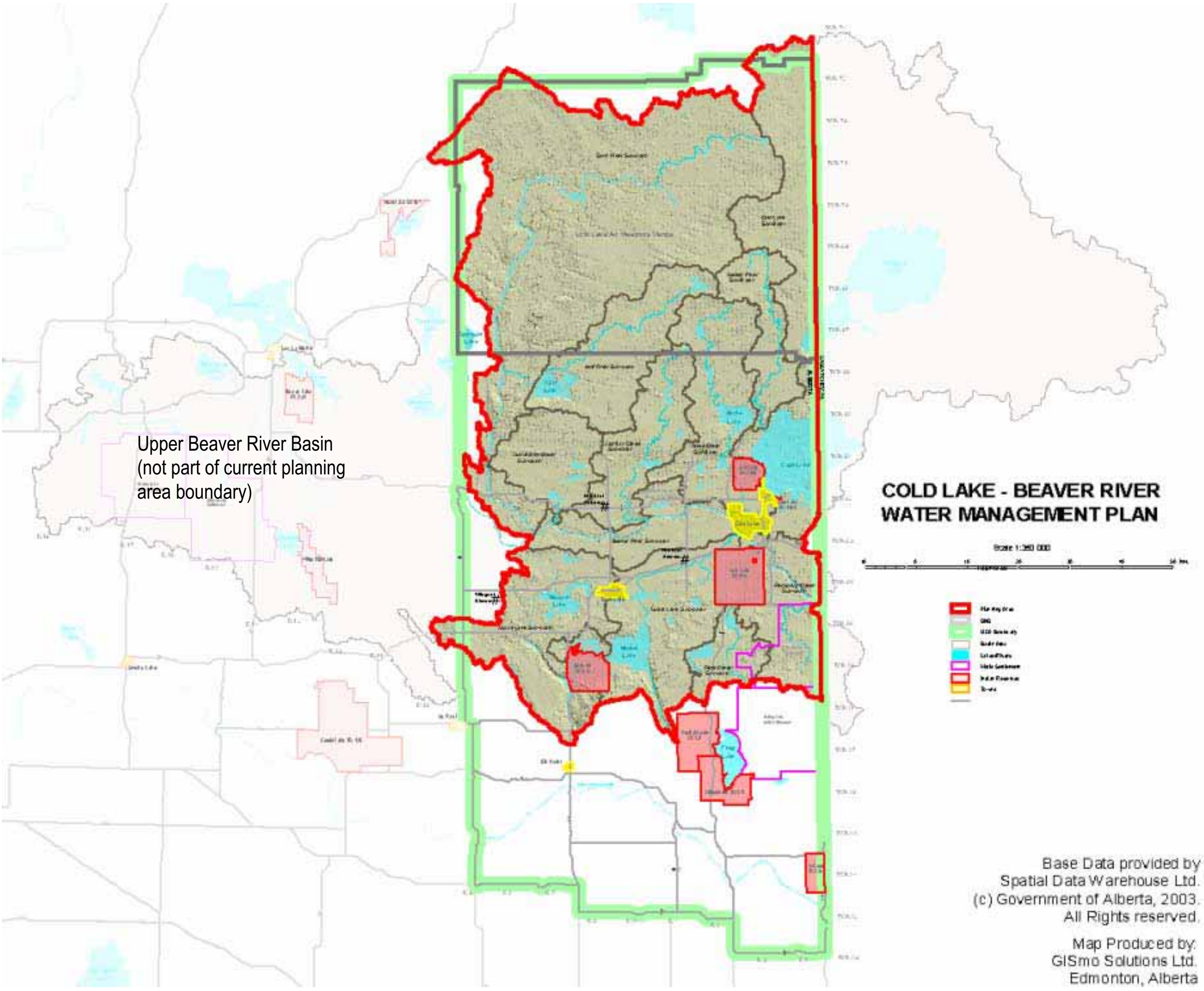


Figure 2-2 Cold Lake and Beaver River Basins with CLBRWMP Planning Area.

2.2 OVERVIEW OF BASIN WATER RESOURCES

In addition to the vital role of sustaining ecosystems, surface and groundwater in the Cold Lake–Beaver River Basin is used for many purposes including domestic and municipal uses, industrial and agricultural water supplies, and recreation. Understanding and managing regional water resources is essential in order to ensure the water resources are sustainable for both current and future uses. This section provides a brief overview of the basin's water balance, surface water and groundwater resources, regional hydrology and current water allocations. A general discussion on groundwater and surface water interactions is also presented.

2.2.1 Basin Water Balance

Figure 2-3 shows the average Cold Lake–Beaver River Basin annual water balance. The basin cycle is part of the global hydrologic cycle mediated by weather systems and predominantly driven by the sun. Solar power evaporates water from the oceans, and a portion of this water precipitates as freshwater in the CLBRB. On average, 8292 million m^3 (8.3 billion m^3) of water falls as rain and/or snow in the basin each year. Most of this water (7.6 billion m^3) evaporates or transpires through vegetation back into the air and leaves the basin. Some of the water drains from the land as surface water run-off into the Beaver River and some enters the subsurface as groundwater recharge.

About 650 million m^3 of water flows out of the basin through the Beaver River each year. The combined flow out of the basin, including Cold Lake/Cold River (about 350 million m^3), is about 1015 million m^3 (1 billion m^3) of water each year. This water ultimately flows toward the Churchill River system and back to the ocean.

An estimated 166 million m^3 of water enters the subsurface on the Alberta side of the basin as groundwater recharge each year. This water slowly percolates into the ground over time and results in fresh groundwater aquifers. It also discharges to lakes and streams in about the same amount each year. In other words, the amount of water entering as groundwater recharge equals the amount flowing into streams and lakes less the small amount pumped by groundwater users.

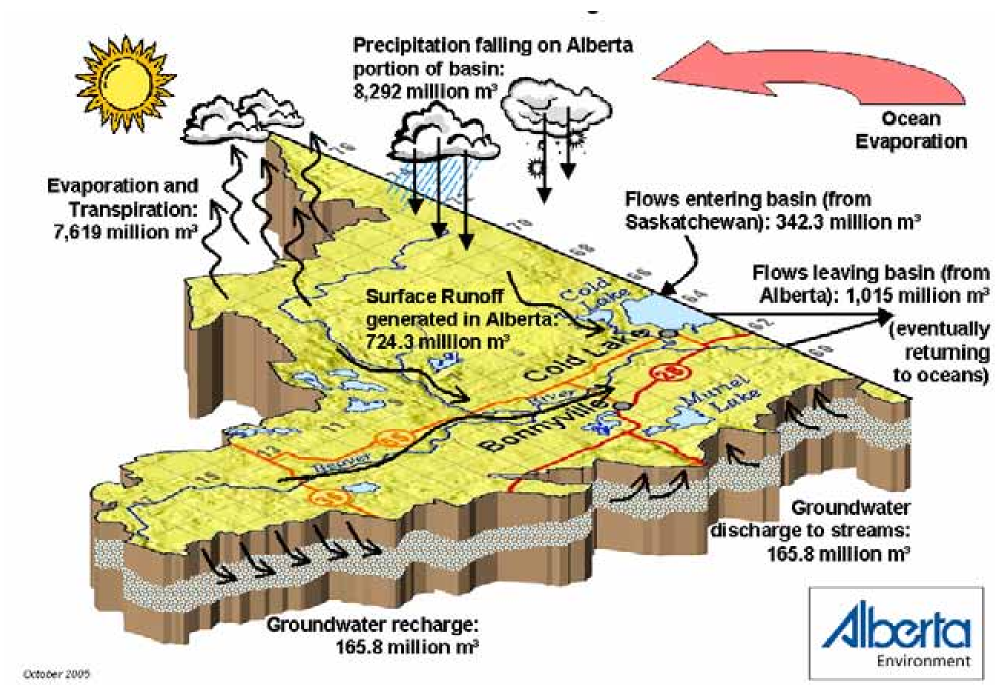


Figure 2-3. CLBR Basin average annual water balance.

2.2.2 Surface Water Resources

The Cold Lake–Beaver River Basin is well known for its abundant surface water resources that have supported a strong recreation and tourism industry for many years. The combined drainage area of the Beaver River and Cold Lake Basins is about 22,000 km^2 (about 8,500 sq. mi.). Compared to other major river basins in the province, the Beaver River is a relatively small river with a mean annual discharge of about 650 million m^3 per year. From the north, the Beaver River drains the Sand and Amisk Rivers as well as Manotokan, Jackfish and Marie Creeks. Tributaries from the south include Moose Lake River and Muriel and Reita Creeks.

The Cold Lake drainage system includes the Martineau River and the Medley River. Flow through the Cold Lake drainage portion of the basin (342 m^3) does not flow into the Beaver River within Alberta. The majority of the flow in this basin is surface water from Saskatchewan, which flows into Cold Lake and drains from the lake eastward via the Cold River. The combined total average discharge from the Beaver River and Cold Lake Basin is approximately 1 billion m^3.

There are over 2000 lakes in the CLBR Basin. Many of these lakes are popular recreational destinations, and all are important elements of the basin's aquatic ecosystem. Table 2-1 summarizes the characteristics of some major lakes in the basin. These lakes contain over 20 billion m^3 of water.

Table 2-1. Characteristics of major lakes.

	Cold Lake	Moose Lake	Marie Lake	Muriel Lake	Wolf Lake	Ethel Lake	Moore Lake
Drainage Area (km^2)	6140	775.2	380.6	384	693	542	37.12
Lake area (km^2)	373	40.8	34.6	64.1	31.5	4.90	9.28
Ratio of drainage area and Lake area	16.5:1	19:1	11:1	6:1	22:1	110:1	4:1
Volume (m^3)	18600×10^6	230×10^6	484×10^6	424×10^6	289×10^6	32.2×10^6	77.4×10^6
Max. depth (m)	99.1	19.8	26	10.7	38.3	30	26
Mean depth (m)	49.9	5.6	14	6.6	9.2	6.6	8.3
Shoreline length (m)	90	64	29	50	49.8	11	16.7
Mean residence time (years) [1]	33	7.5	47.5	>100	6	2.5	>100

Source: Atlas of Alberta Lakes

[1] Average time required to completely replace the total volume of the lake with inflowing water.

The lakes in the basin have three distinct origins. The first type are typical prairie lakes characterized by shallow depth and a gently-dipping lake-bottom. These lakes are sensitive to seasonal and climate variations. The second type is deep lakes with steep sides. In general, these lakes do not tend to fluctuate widely in lake levels from year to year. They are also likely to intersect and interact with some groundwater aquifers. Cold Lake is an example of this kind of lake since it is about 100 m deep in places. The third group is formed by impoundments of surface water in the bottom of abandoned glacial melt water channels.

The ratio between drainage area to lake surface area is also an important indicator of how lakes will respond to local climate fluctuations. Typically, lakes with a small drainage area are more sensitive to climate variations. This is because these lakes have lots of area for water evaporation but do not drain very much land. These lakes are also more sensitive to land clearing and changing land practices within the lake's drainage area. The table above shows that Muriel Lake has a small drainage area compared to the size of the lake. Muriel Lake has been steadily declining during the last 25 years and did not respond substantially to the high precipitation events of 1996-97. In comparison, Moose Lake, which has a relatively large drainage basin, recorded its highest water levels in 1997. In some cases, groundwater inflows also play a role in lake level. For example, the water level of Moore Lake does not fluctuate substantially despite having a relatively small drainage basin. In this case, it is possible that Moore Lake receives substantial inflow from groundwater.

2.2.3 Groundwater Resources

Groundwater is an important component of water resources in the CLBR Basin. While groundwater volumes do not fluctuate from year to year as much as surface water, there are vast quantities of stored groundwater beneath the ground. A detailed assessment of regional geology and groundwater flows was conduct by Alberta Geological Survey (2005). The findings of this study are summarized in the *Groundwater Quantity and Brackish Water State of the Basin Report*. This section presents a brief overview of the regional geology and groundwater resources.

The subsurface beneath the CLBR Basin consists of a succession of geological units. From deeper intervals to shallow intervals, these include Cambrian sandstone and Devonian limestone and evaporates overlain by Cretaceous sands and shales and Quaternary sand and gravel glacial deposits. Fresh groundwater resources are shown in the Quaternary aged strata in Figure 2-4. These six main aquifers are listed on the right side of the diagram. Groundwater is mostly used in the basin by domestic/livestock users and by industry. Typically, domestic users are concentrated in the medium to shallower aquifers while industry mainly uses the deeper aquifers. Water below the Quaternary aged aquifers is usually saline. The deepest water used in the basin is from the McMurray Formation, which is a saline source.

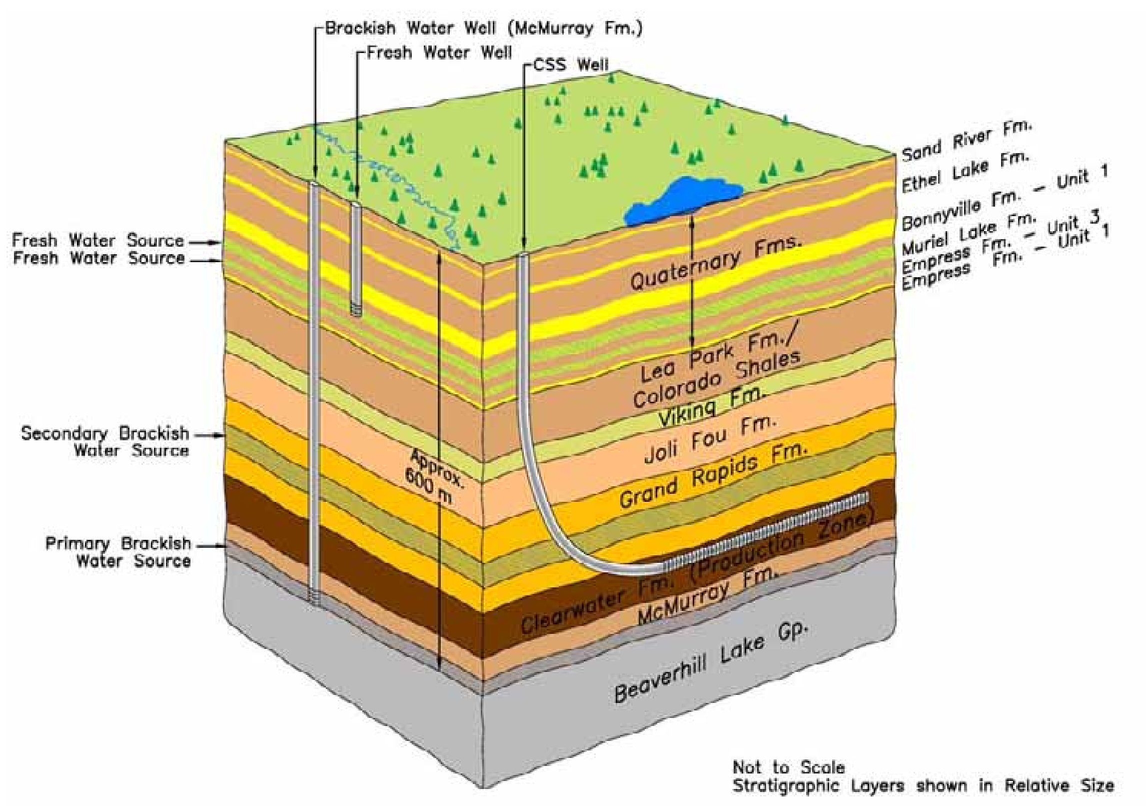


Figure 2-4. Schematic diagram of Cretaceous, Tertiary and Quaternary stratigraphy in the Beaver River Basin.

An estimated 166 million m^3 of water recharges groundwater resources each year. This amount may vary from year to year depending on climate. The amount of water estimated to be present as groundwater within Quaternary and Tertiary aquifers in the basin is an estimated 50 billion m^3 (AGS 2005).

2.2.4 Surface and Groundwater Interactions

The interaction between groundwater and surface water has become a public concern in the CLBR Basin, particularly during below normal run-off years. Some public and local stakeholders have become concerned that groundwater pumping has reduced the water levels of local lakes, streams and wetlands. In order to assess this concern, it is necessary to understand the volumes of water pumped in the context of the basin water balance. A summary of this water balance information is presented in this section.

Most surface water features, including lakes, rivers and wetlands, interact with groundwater to some extent. When lakes receive groundwater inflow via groundwater discharge, they are commonly called “gaining lakes”. The lakes referred to as “losing lakes” can lose water into the subsurface, thereby recharging groundwater. Many lake levels are not effected by groundwater influences. Although these lakes may receive water from or lose water to the subsurface, their water levels are generally not changed significantly due to the much larger influences of surface water flow.

Evaporation and precipitation have a greater effect on lake levels and for this reason, groundwater contributions are considered negligible in many studies. To put this in perspective, over 8 billion m^3 of water are in play in the basin each year. Of this amount, about 7 billion m^3 evaporates from lakes and the ground surface. One billion m^3 ultimately flows out of the basin through the Beaver River and Cold River. With respect to groundwater, 166 million m^3 enters the subsurface to become groundwater, and over time flows into the lakes and rivers. Thus while there are vast supplies of groundwater present in the basin, the amount that cycles annually is quite small compared to surface water.

Both natural processes (climate changes) and human activities (groundwater pumping, land use/land cover changes) affect the interaction mechanism of groundwater and surface water. For example, groundwater pumping initially captures water from aquifer storage. As pumping continues, the groundwater table declines and begins to affect the natural state of groundwater and surface water interactions by either decreasing the discharge to surface water bodies or inducing additional recharge until the pumping losses are balanced out.

Despite the connections between groundwater and surface water features, it is often difficult to determine the timing, location and magnitude of these interactions. At this time, an accurate assessment of groundwater and surface water interactions at specific locations is not possible within the CLBR Basin. In part, this is due to the relatively small contributions of groundwater cycling in the basin compared to surface water cycling. A regional groundwater numerical model, developed by the Alberta Geological Survey (AGS 2005) has been used to simulate groundwater and lake interaction in the basin. The model has the capacity to show general trends that would occur during a pumping situation, and can indicate where more conservative management guidelines and more extensive monitoring might be required.

As suggested in the Komex reports of (2002) and (2004), climate changes alone may not be solely responsible for changes to the hydrological cycle in the basin. Human-induced factors such as water withdrawal and land use and land cover changes (from forest clearing) may also have the potential to affect localised or regional water balances. The southern portion of the Beaver River Basin has seen a large amount of forest clearing for agricultural development.

2.3 Basin Allocations and Comparison to Other Alberta River Basins

This section presents an overview of the current water allocations in the basin and makes comparisons with other major river basins in the province. It should be noted these gross allocations do not represent actual water use in the basin. Total allocations indicate the maximum amount of water that has been granted for use by Alberta Environment and are often double actual water use. In addition, some water license holders return water directly back to the environment. While allocations have risen with population growth, increased industry and increased agricultural activity, the allocation amounts are small in comparison to other basins in the province.

As of December 2003, a maximum of 44 million m^3 of groundwater and surface water were allocated in the basin. This represents about 4% of the average 1 billion m^3 of surface water that leaves the Beaver River Basin each year and about 0.5% of the average annual precipitation of the basin. Of the 44 million m^3 of allocations in the CLBR Basin, surface water allocations represent about 62% (27 million m^3) and groundwater about 38% (about 17 million m^3). Therefore, groundwater allocations are about 1.5% of the average annual flow that leaves the CLBR Basin each year. The actual use is about 0.5% the average annual flow.

On a provincial scale, about 9 billion m^3 of water are allocated for use in Alberta with less than 300 million m^3 of that consisting of groundwater. Thus the CLBR Basin allocations represent less than half of one percent of the water allocated for use in Alberta.

Figure 2-5 shows surface and groundwater allocations compared to average natural flow for Alberta river basins. With this update of the CLBR Basin plan, it has been determined the actual allocation in the Beaver River Basin is less than that shown in the figure since the allocation (as a percentage of the flow leaving the CLBR Basin) is about 4%. However, the figure generally shows the southern basins are more heavily used than the northern basins, and demonstrates the relative abundance of water in the Beaver River Basin compared to others in the province.

One difference in water use in the CLBR Basin compared to other basins is the percentage of groundwater compared to surface water used in the basin. In the CLBR Basin, groundwater is about 33% of the total water allocation compared to less than 3% at the provincial level. In a large part, this is due to low overall water usage and not due to large groundwater usage.

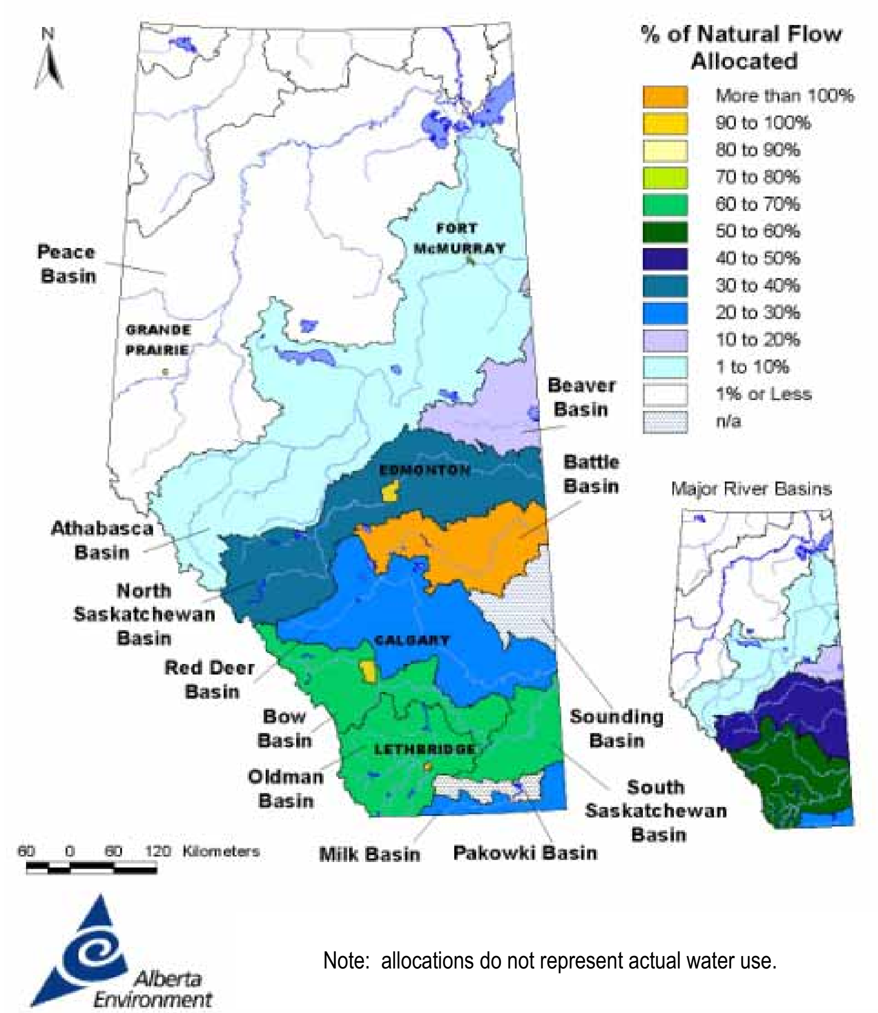


Figure 2-5. Surface and groundwater allocations in 2004 by river basin compared to average natural flow.

2.4 Climate and Recent Regional Hydrological Trends

2.4.1 Climate

The climate in the CLBR Basin is generally described as continental with short, cool summers and long, cold winters. The weather patterns are usually influenced by maritime air masses moving east from the Pacific Ocean, and continental air moving south from the Arctic. In winter, the westerly winds are pushed southward, allowing cold arctic air to invade the region. These cold, heavy air masses frequently stagnate over this area for weeks at a time, often causing fog or ice fog.

Continuous year-round regional climate data has been recorded at the Cold Lake weather station since 1951. A detailed assessment of regional climate changes was conducted by Alberta Environment (1997), and in a Komex study (2003) commissioned by LICA. The mean annual temperature measured at the Cold Lake station from 1956 to 2003 was 1.65°C. The mean annual temperature observed at the same station from 1986 to 2003 was 2.2°C. This suggests the annual mean temperature in the last 20 years has increased by 0.6°C compared to the longer–term average temperature. The Komex (2002) study found a temperature correlation with an El Niño-like phenomena in the North Pacific called the Pacific Decadal Oscillation (PDO) which cycles every 20-30 years. The PDO had a warming effect in the Cold Lake region from about 1980-2000. There is some evidence to suggest this warming trend is beginning to enter a cooler and therefore wetter cycle. Warm and cool periods not only affect the amount of precipitation in the region but also the amount of evaporation in the basin.

The average annual precipitation measured at Cold Lake station from 1953 to 2003 was 433.5 mm. Between 1986 and 2003, the average annual precipitation was 15 mm less than the long-term average, and 22 mm less than the average amount for the previous 15-year period (1970-1985). It is interesting to note the record high annual precipitation of 1997 (record wet year) was 64 mm higher than the long-term average annual precipitation. Conversely, the record low precipitation of 1992 (driest year) was 62 mm lower than the long-term annual amount. In 1997, the majority of the lakes and streams in the basin recorded historical high water levels while in 1992, the water levels were the lowest recorded. This suggests that climate and precipitation have the greatest long-term direct impact on the fluctuation of local lakes and groundwater levels.

2.4.2 Regional Hydrological Trends

There has been a warming trend in the CLBR Basin over the last 20 years. With the exception of 1996-97, the basin has, on average, experienced an increase in temperature and decreased flow in the Beaver River. These changes have an impact on other components of the regional hydrological cycle. Generally, increased temperature leads to changes in evaporation and precipitation that result in changes to lake levels, regional stream flows, runoff and groundwater recharge and discharge.

A detailed assessment of lake water balances is presented later in this report. This section presents only an overview of historical streamflow trends to determine the response to recent climate variations. Figure 2-6 shows the total average annual runoff of Beaver River at Cold Lake in cubic meters per second compared to total annual precipitation (in mm). Both precipitation and runoff shows a declining trend, particularly in the past 20 years. The slope of the annual runoff decline is more pronounced than the precipitation-declining rate. This demonstrates there may be other factors such as increased evaporation or land use/land cover changes in the basin that might also affect the flow of the Beaver River. The total allocated water withdrawals represent only 1.4 m^3/s and could not be responsible for this change, especially if one considers that only about one third of the allocation is being used ($<0.5\ m^3/s$).

Table 2-2 compares average annual flows with precipitation, evaporation from the Cold Lake surface and temperature. Under natural conditions, the regional hydrologic cycle tends to balance out. The difference between water input (precipitation) and water output (evaporation and runoff) provides an indication of moisture conditions in the watershed. During dry periods, the water output exceeds the water input, thus creating a natural “deficit” that will be balanced by the removal of water stored in lakes, streams, wetlands and soil in the watershed.

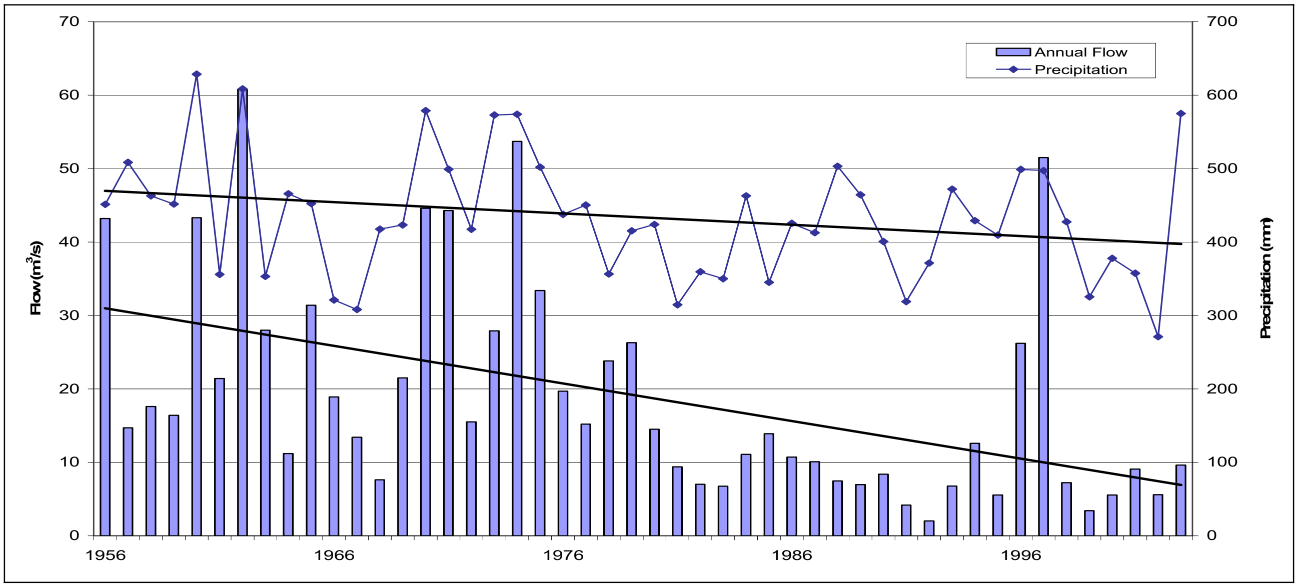


Figure 2-6. Annual flows of Beaver River and annual precipitation at Cold Lake.

Table 2-2. Cold Lake hydrological data.

Period	Average Annual Flows Beaver River at Cold Lake (m³/s)	Average Annual Precipitation	Average Annual Evaporation (mm)	Average Annual Temperature (⁰C)
1956 to 2003	18.90	433.5	618	1.65
1970 to 1985	22.90	441.3	630	1.37
1985 to 2003.	10.70	418.8	608	2.21
1996 – 1997	51.50	497.4	606	2.63
1991 – 1992	2.02	371.5	588	2.24

At first glance, this table suggests there is not a good relationship between precipitation and outflows. During the 1985 to 2003 period, annual average flows were reduced by 43% from 18.9 m^3/s to 10.7 m^3/s. In absolute terms, this represents an average reduction of about 260 million m^3 of water. Mean annual precipitation was only reduced from 433.5 mm to 418.8 mm (3.4%), which represents a reduction of about 280 million m^3 of water. The average evaporation from Cold Lake did not change much over this period. On average, the reduction in the amount of precipitation equalled the reduction in streamflow.

Groundwater levels also fluctuate with the climate over some time frame. Depending on how directly connected water wells are to the surface, they will respond to climate variation on different time scales. Surficial water levels sometimes respond almost immediately to large precipitation events. Other aquifers (e.g., Figure 2-7) show seasonal responses with a typical rise in levels around June followed by slowly decreasing levels until the next spring melt. Deeper aquifers may show less or delayed seasonal response, and demonstrate long-term variations from climate effects.

Figure 2-7 indicates water levels from a monitoring well completed across the water table in the area of Borque Lake, which shows clear seasonal responses due to groundwater recharge from precipitation.

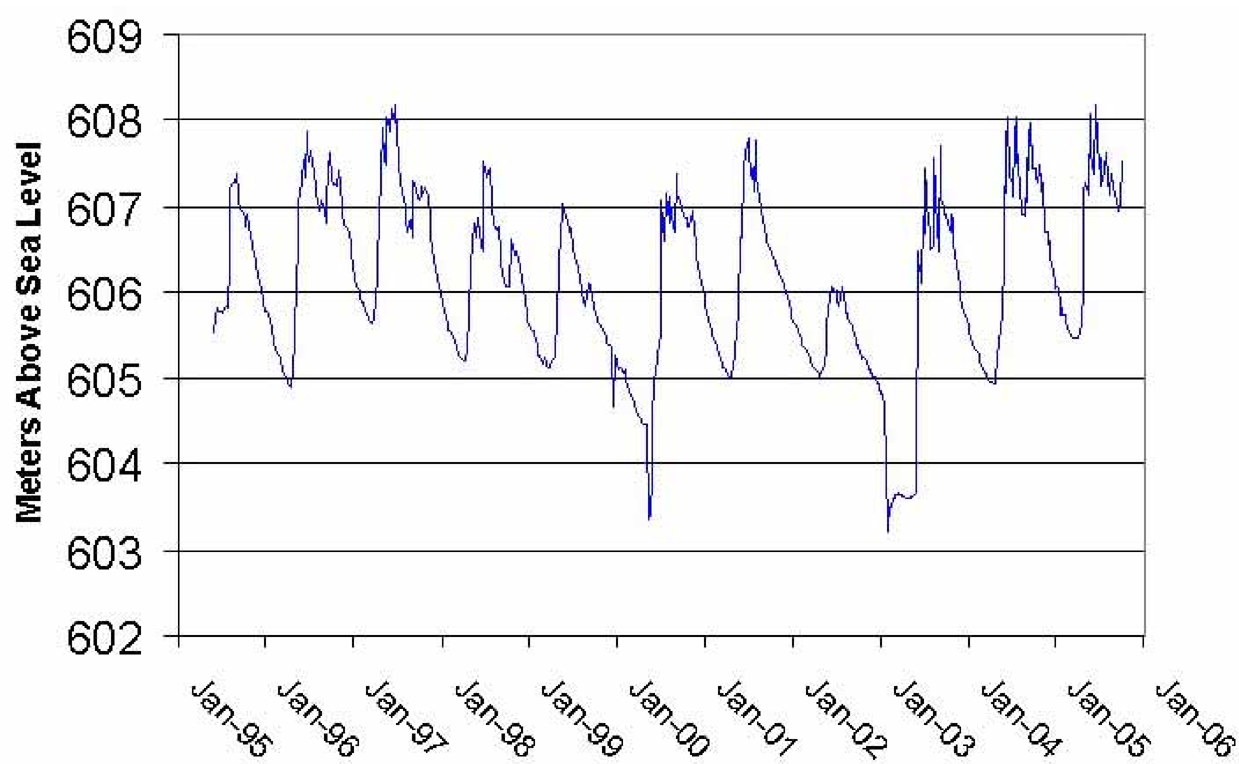


Figure 2-7. Hydrograph for monitoring well MAS92-1 (WT).

SECTION 3. GROUNDWATER QUALITY IN THE CLBR BASIN

3.1 INTRODUCTION

The short-term and long-term water management plans of 1983 and 1985 have been the basis for developing water management priorities and actions in the CLBR Basin over the past 20 years. These plans established water management alternatives and monitoring recommendations for streams and lakes.

Alberta Environment, in collaboration with stakeholders in the basin, has identified the need to update the existing water management plan within the context of the provincial *Water for Life Strategy* and the *Framework for Water Management Planning*. Other communities in Alberta have identified similar issues and concerns; however, the Cold Lake–Beaver River Basin is one of the first to have its water management plan updated in light of the *Water for Life Strategy*. One of the principles in the Strategy is “groundwater and surface water quality must be preserved in pursuing economic and community development.”

This State of the Basin report is a significant step toward addressing the goal of better understanding the quality of Alberta’s groundwater supply for the basin. It is the result of a collaborative effort of the Groundwater Quality Team of Alberta Environment, Natural Resources Conservation Board, Alberta Geological Survey, and LICA.

3.2 PURPOSE

The main purpose of this report is to provide a sound set of baseline data and information about the controls on distribution and mobility of naturally occurring contaminants in the CLBR Basin. The report allows for the design of a regional groundwater monitoring system that can distinguish groundwater quality changes due to natural variation from those attributed to human activities.

The main objectives are:

- Establish baseline groundwater quality characteristics of surficial aquifers in the study area.
- Provide a framework for evaluating potential changes in groundwater quality in surficial aquifers.
- Provide a publicly accessible groundwater quality database that all stakeholders can query regarding the distribution of groundwater quality in the study area.

Note: Because the baseline is being established after development has occurred in the basin, it includes data from sites with known anthropogenic (human-related) contamination.

3.3 Background and Issues

Industrial water use in the Cold Lake region became an issue in the late 1970s when Imperial Oil proposed to construct a 140,000 barrel-per-day in situ commercial oil sands plant in the region. In response to growing concerns regarding the demand for water and the impact from the expanding water diversion requirements for the oil sands industry, Alberta Environment initiated the Cold Lake–Beaver River Basin study in 1981. The 1981 study resulted in a short- and long-term water management plan for the basin. The short-term plan was adopted in March 1983, and set out consumptive withdrawal limits for surface and groundwater sources until the long-term plan was in place.

The 1983 and 1985 plans did not specifically address groundwater quality in the basin. Impacts on groundwater quality have now become a greater issue since industrial development is approaching populated areas in the southern and eastern portions of the basin. As well there is greater recognition that some industrial, commercial, municipal, agricultural and domestic practices can impact groundwater quality.

Within the regional groundwater system, the Beverly, Helena, Sinclair and Vermillion channels are the major buried valley aquifers. These aquifers are an important source of water for many rural Albertans who live along their paths. The channels comprise permeable gravels and sands overlain by a varying thickness of relatively impermeable glacial till. Since the till is not always continuous, the channels are susceptible to contamination from surface and subsurface activities.

The major regional aquifers identified in the study area include the Empress Formation Unit 1, Empress Formation Unit 3, Muriel Lake Formation, Ethel Lake Formation, Sand River Formation and Grand Centre Formation.

Current and Emerging Issues

Increasing development and production of oil and gas resources, combined with increased agricultural and domestic activity in the CLBR area, has triggered the need to thoroughly evaluate groundwater quality and ensure protective measures are implemented. Groundwater protection is one of the most significant issues in the CLBR area. There is ongoing public concern that thermal, geomechanical, or geochemical effects of oil production techniques may be releasing contaminants into useable aquifers.

In consultation with the regional regulators, industrial operators, local governments, aboriginal groups and stakeholders in general, the following key issues and priorities were identified regarding groundwater quality and the protection of groundwater resources:

- Potential impacts to groundwater from industrial activities.
- Protection of groundwater sources currently being used.
- Protection of useable groundwater resources for future use.

3.4 Methods

Alberta Environment partnered with the Alberta Geological Survey (AGS) to compile and analyze shallow groundwater quality data in the CLBR drainage basin. The scope of the AGS study was to:

- Summarize existing information available on groundwater quality in the basin.
- Compile the locations of potential point and non-point sources of contamination.
- Assess the sensitivity of aquifers in the area to contamination.

The groundwater quality component of the study was carried out in conjunction with a groundwater quantity study, which is described in a separate State of the Basin report.

3.4.1 Database Development

Data Sources

AGS compiled information from existing databases and studies that are, for the most part, in the public domain. No field sampling was conducted as part of the current investigation. Data were supplied to AGS from provincial and local governments and industrial operators in the basin.

Database Development

The data were used by AGS to develop a 3-D geological model of the quaternary deposits in the basin. Groundwater chemistry information was assigned to the formations based on the screened interval of each well's location in the model. In total, 1600 wells and over 200 different chemical parameters were included in the database.

The database was developed to allow queries for specific parameters for specific aquifers, and contains more information than can be summarized or detailed in this report. It is important the database be maintained to enable queries to be made and maps of parameters of concern easily constructed as needed.

Data Limitations

Numerous limitations were noted in the data. The database contains historical data, which means not all the wells have been tested for the same parameters and, in some cases, the names of the analyses have changed over time. Also, the data available for the eastern portion of the basin have more testing parameters and a greater density of wells monitored owing to a higher level of development in this area. AGS did not screen the data submitted by industrial operators for wells containing known contamination. These locations are generally under active remediation and are known to AENV.

3.5 Results and Discussion

Based on the groundwater model developed for the study area, the basin was divided into five flow regions, as follow:

1. Wiau — flow from north side of Moostoos Upland to the Wiau aquifer (located in northern quarter of basin).
2. Southeast — flow from the Cold Lake Hills to Beaver River (located south of Beaver River to the south basin boundary).
3. Southwest — flow from Whitefish Upland into the Amisk River, with some flow to Whitefish Lake (located in southwest corner of basin, south of Beaver River).
4. Northeast — flow from Moostoos Upland to the Sand River, Cold Lake and Beaver River (located east of Sand River and north of Beaver River).
5. Northwest — flow to Amisk and upper Beaver rivers; some flow exits the basin to the northwest toward Lac La Biche (located to the north of Beaver River and west of Sand River).

In the Cold Lake–Beaver River area, domestic-use groundwater is found in the geologically recent formations located above the bedrock. Such formations are referred to as Tertiary or Quaternary Aquifers. (Geological units consisting of sediment deposited after the bedrock, but before glaciation, are referred to as Tertiary; units consisting of sediment deposited during glaciation are referred to as Quaternary.)

Dividing the regional aquifers into groups based on their flow characteristics and interconnections was useful in mapping groundwater quality parameters in the basin. The identified aquifer groupings are:

- Empress 1 Formation.
- Channel Aquifers — Empress 2 and 3, Bronson Lake, Muriel Lake formations.
- Intermediate Aquifers — Bonnyville and Ethel Lake formations.
- Shallow Aquifers — Grand Centre, Sand River and Marie Creek formations.

Surficial sediments located along rivers and creeks are the uppermost unconfined aquifer. In some locations, wells were found to be completed in units that had traditionally been classified as aquitards (formations not expected to provide usable quantities of groundwater). Examples of these include the Grand Centre, Marie Creek, Bonnyville and Bronson Lake formations. This result suggests that locally these formations may contain sand and gravel deposits suitable for groundwater production for domestic purposes.

3.5.1 Contaminant Sources in CLBR Study Area

AGS mapped the locations of potential point sources of contamination in the study area, which included:

- urban areas
- wastewater treatment sites
- landfills

- confined feeding operations
- agricultural land use
- transportation infrastructure
- oil and gas wells
- oil and gas infrastructure
- documented oil and gas related spills
- storage tanks.

These are only sources that are regulated by various government agencies. In addition to this list, there are other potential sources of contamination not covered by government regulations, such as septic tanks and improperly abandoned domestic wells.

3.5.2 Groundwater Quality Indicator Parameters

A variety of potential contaminants may be present in groundwater. Many of the potential contaminants in groundwater (listed below) have both natural and anthropogenic sources.

Chemicals of concern identified in samples taken in the study area included the following:

chloride
fluoride
nitrogen compounds
sodium
sulphur
total phenols
hydrocarbons
petroleum distillates
aluminum
antimony
arsenic
barium
boron
cadmium
chromium
cobalt
copper
iron
lead
manganese
mercury
molybdenum
nickel
selenium
silver
thallium
uranium
vanadium
zinc

In addition to these identified chemicals, pathogenic contaminants may also be present in groundwater, such as bacteria and viruses. These were not considered in the study because few wells in the database had information on such contaminants.

For the purposes of the study, parameters were selected that would provide a simple, yet representative indication of groundwater quality in the basin. One of the purposes of the groundwater quality evaluation was to determine if development is impacting groundwater quality. Therefore, parameters were selected based on their usefulness in determining groundwater quality changes resulting from human activities. The selected parameters were total dissolved solids, geochemical composition or major ions, chloride, arsenic and phenols.

Concentrations of the various parameters were compared to guidelines developed by the Canadian Council of Ministers of the Environment (CCME) and Alberta Environment. The relevant guidelines considered are:

- Community use (drinking water).
- Freshwater aquatic.
- Agricultural use (irrigation and livestock watering).

Table 3-1 provides a summary of the guideline values for the parameters considered in this study.

Table 3-1. Summary of guideline values.

Parameter	Drinking Water (mg/L)	Freshwater Aquatic Life (mg/L)	Agricultural – Irrigation (mg/L)	Agricultural – Livestock (mg/L)
TDS	≤500*	NG	500-3500	3000
Chloride	≤250*	NG	100-700	NG
Arsenic	0.025**	0.005	0.1	0.025
Phenols	NG	0.004	NG	0.002

* *Aesthetic objectives*
** *Interim maximum acceptable criteria*
NG = No Guideline

A statistical method called box plots was used to determine if groundwater quality had been changing over time. Data from the 1990s and from 2000-2003 was considered separately to determine if there has been a statistically significant change in groundwater quality between the two decades.

Total Dissolved Solids

Total dissolved solids are the amount of dissolved constituents in water. The TDS concentration of groundwater determines whether it is considered fresh, brackish or saline. In this study, the AGS defined fresh water as having TDS less than 1000 mg/L, and brackish water having TDS between 1000 mg/L and 20,000 mg/L. However, the *Water (Ministerial) Regulation* under the *Water Act* defines saline (brackish) groundwater as water with more than 4,000 mg/L TDS.

According to the *Guidelines for Canadian Drinking Water Quality*, water for human consumption should have a TDS of 500 mg/L or lower. Above this level, there may be a taste or odour issue, but not necessarily a health concern. CCME guidelines for TDS for water used in irrigation and livestock consumption were also compared by the AGS. The irrigation and livestock guideline values are based on levels that cause crop growth impairment, damage to the soil, and inability of livestock to consume the water.

Concentrations of TDS are plotted on Figure 3-1 by aquifer group. Figure 3-2 presents box plots of TDS in the different aquifer groups. Table 3-2 summarizes groundwater quality guideline exceedances noted in the AGS database using the most recent data from a given well.

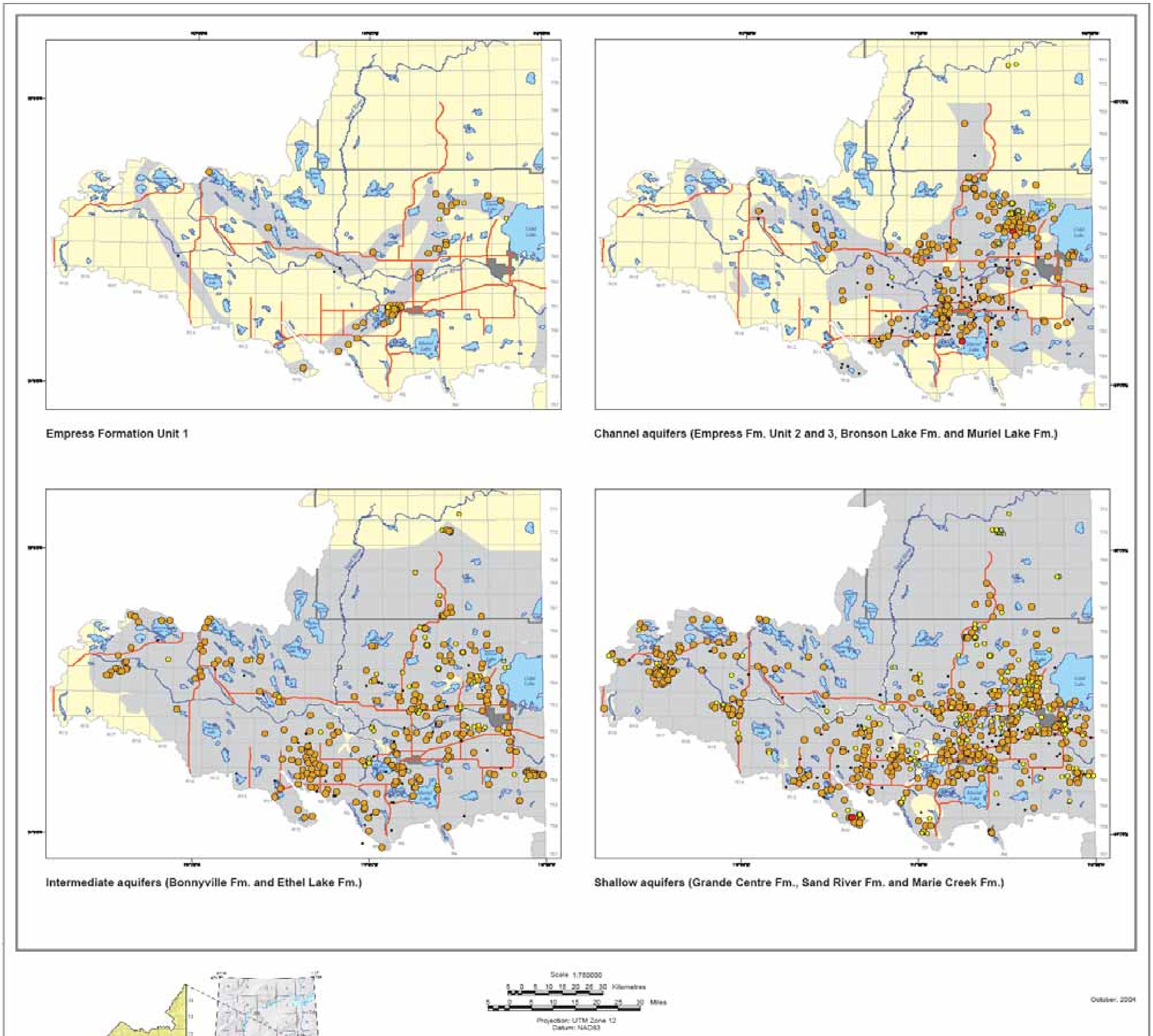
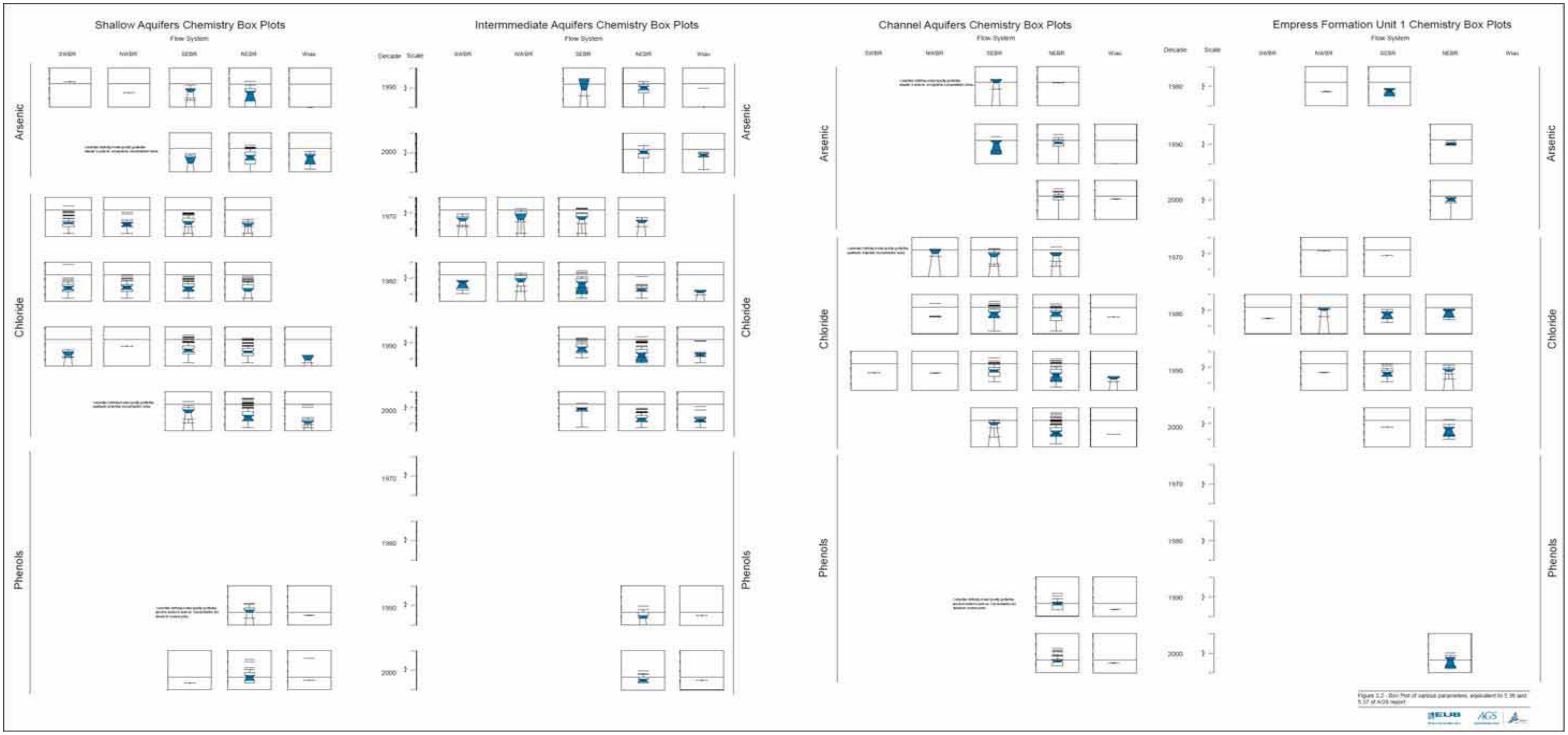


Figure 3.1 TDS concentrations by Aquifer Group


Shallow Aquifers Chemistry Box Plots
Intermediate Aquifers Chemistry Box Plots
Channel Aquifers Chemistry Box Plots
Empress Formation Unit 1 Chemistry Box Plots
Arsenic
Chloride
Phenols

Total dissolved solids in quaternary groundwater in the basin range from 29 mg/L to 10,529 mg/L. In 79% of the samples, the TDS concentrations in the groundwater exceeded the *Guidelines for Canadian Drinking Water Quality* aesthetic objective of 500 mg/L. For comparison purposes, in a survey of farm water wells across Alberta, 85% of the wells sampled exceeded the aesthetic objective for TDS. The result is considered to be in line with values for groundwater in glacial deposits, such as the till and aquifer units in the study area. Only 0.5% of the samples exceeded the upper irrigation guideline and 0.8% exceeded the livestock water guideline.

TDS concentrations in groundwater were found to increase from recharge to discharge areas in the basin. This result is consistent with expected trends, as more dissolved constituents are introduced into groundwater as it flows from recharge to discharge areas.

Table 3-2. Total Dissolved Solids exceedances summary—most recent values.

Formation	Range of Values (mg/L)		Number of Samples	Drinking Water	Agricultural – Irrigation		Agricultural – Livestock
	Min.	Max.			Lower Limit	Upper Limit	
Grand Centre	39	3960	273	189 (69%)	189 (69%)	2 (1%)	4 (1%)
Sand River	0	10529	252	179 (71%)	179 (71%)	1 (1%)	1 (1%)
Marie Creek	133	3092	166	125 (75%)	125 (75%)	0	3 (2%)
Ethel Lake	0	3967	205	173 (84%)	173 (84%)	1 (1%)	1 (1%)
Bonnyville	152	3776	143	107 (75%)	107 (75%)	1 (1%)	3 (2%)
Muriel Lake	293	6846	238	220 (92%)	220 (92%)	1 (1%)	1 (1%)
Bronson Lake	218	3182	14	13 (93%)	13 (93%)	0	1 (1%)
Empress	29	4690	139	119 (86%)	119 (86%)	1 (1%)	1 (1%)
All Aquifers			**1430**	**1125 (79%)**	**1125 (79%)**	**7 (0%)**	**15 (1%)**

Major Ions

In classifying and determining the origin of groundwater, hydrogeologists use the geochemical composition made up of major anions and cations types dissolved in the groundwater. It is also a useful indicator of the age of the water. For example, groundwater with a dominant sodium-chloride type is associated with marine deposits, which are geological material laid down when a shallow sea covered the Beaver River Basin. The ionic composition of groundwater changes as it flows from the ground surface to depth, and different constituents are dissolved out of the soil and rock.

The major anions considered in the study were chloride, sulphate and bicarbonate. The major cations were sodium, potassium, magnesium and calcium. The major ions in the groundwater are plotted as pie charts representing the proportion of each constituent in the overall sum of ions in the groundwater. Figure 3-3 presents the major ions for the three main aquifer groups.

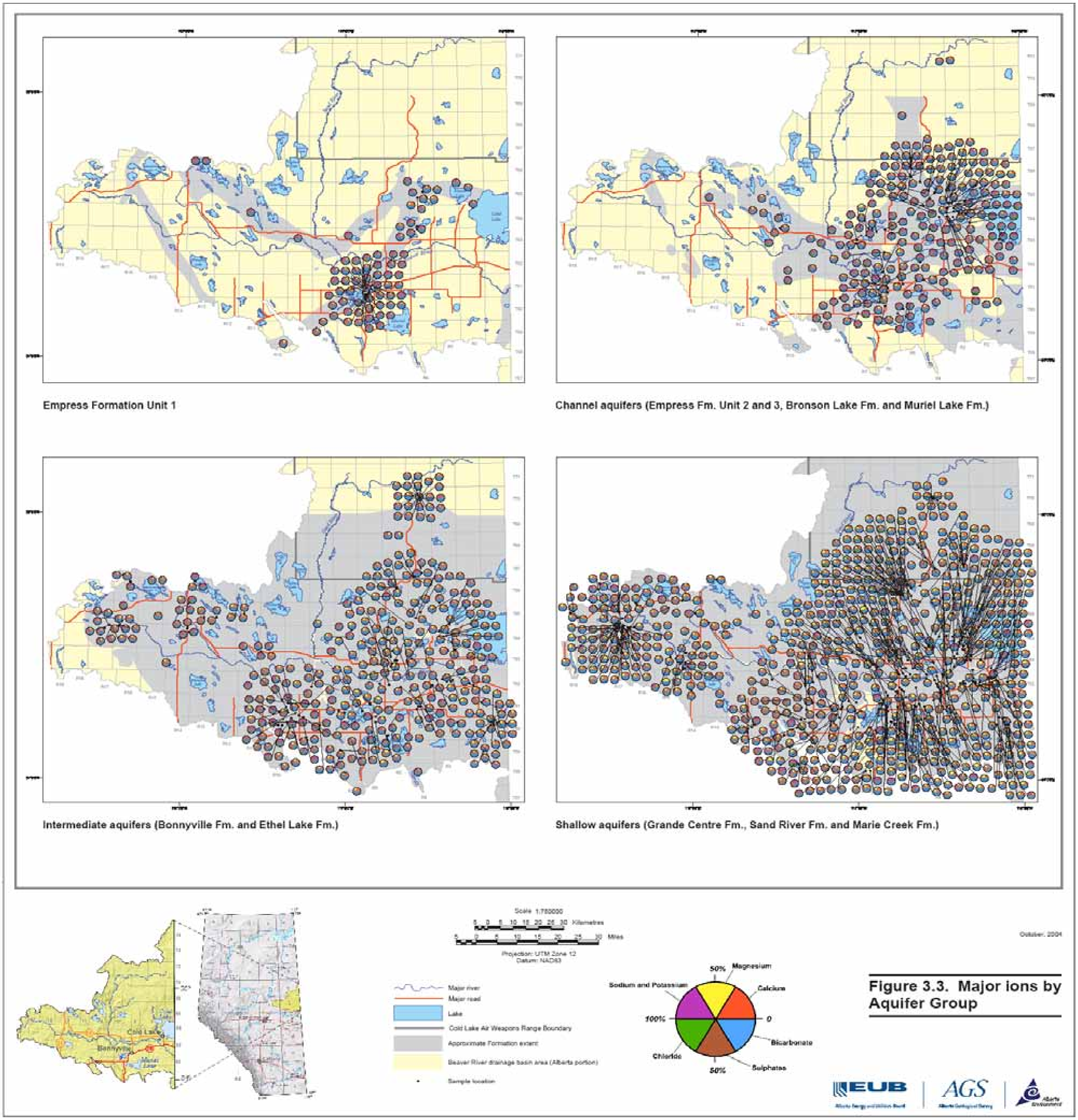


Figure 3.3. Major ions by Aquifer Group

Groundwater geochemistry in the CLBR Basin generally follows the pattern found in other flow systems. Recharge areas in the basin are characterized as being calcium, magnesium, bicarbonate type water. Discharge areas are characterized as being sodium and bicarbonate or sulphate type water. An exception to the general pattern is chloride in some areas of the basin. Although chloride is generally not expected to be a major ion in the water in this area, natural diffusion of chloride from underlying bedrock or from contamination sources may result in it being a dominant anion in some groundwater.

Chloride

Chloride may be a naturally occurring element or an indication of groundwater contamination by human activities. Chloride may occur naturally in the quaternary aquifers owing to diffusion from the marine shale bedrock beneath the quaternary deposits. Anthropogenic sources of chloride in groundwater include shallow groundwater contamination from sources such as road salt along roadways and in highway maintenance yards, produced oil field water, leachate from landfills, septic fields, and agricultural and livestock operations.

Owing to its properties in groundwater flow, chloride is a useful indicator contaminant. Chloride does not degrade or become adsorbed to soil particles as it travels in groundwater. As a result, in a plume containing chloride along with other parameters, the chloride will be at the leading edge of the plume making it valuable for determining the extent of groundwater contamination.

The distribution of chloride in the four aquifer groups is plotted in Figure 3-4. Figure 3-2 presents box plots of chloride concentrations in the flow systems for the 1990s and 2000s. Table 3-3 summarizes the number of chloride guideline exceedances recorded in the AGS database using the most recent data from a given well.

The *Guidelines for Canadian Drinking Water Quality* state an aesthetic objective for chloride of 250 mg/L. Of the samples on record in the basin, 6% exceed the aesthetic objective. This compares with 6% of the samples that were found to exceed the objective in the study of farm wells across Alberta. The median chloride concentrations in the different aquifers in the basin remain below the aesthetic objective for drinking water and do not appear to be changing over time. The one exception is chloride concentrations in the deep formations in the NEBR flow system. This may be a result of increased well completion in the area recording natural diffusion of chloride from the bedrock. Additional study is needed to determine if this is occurring.

Chloride concentrations exceeded the irrigation upper guideline in 1% of the samples in the database for the most recent sampling for a given well. Chloride concentrations in the basin range from below laboratory detection limits up to 5,500 mg/L.

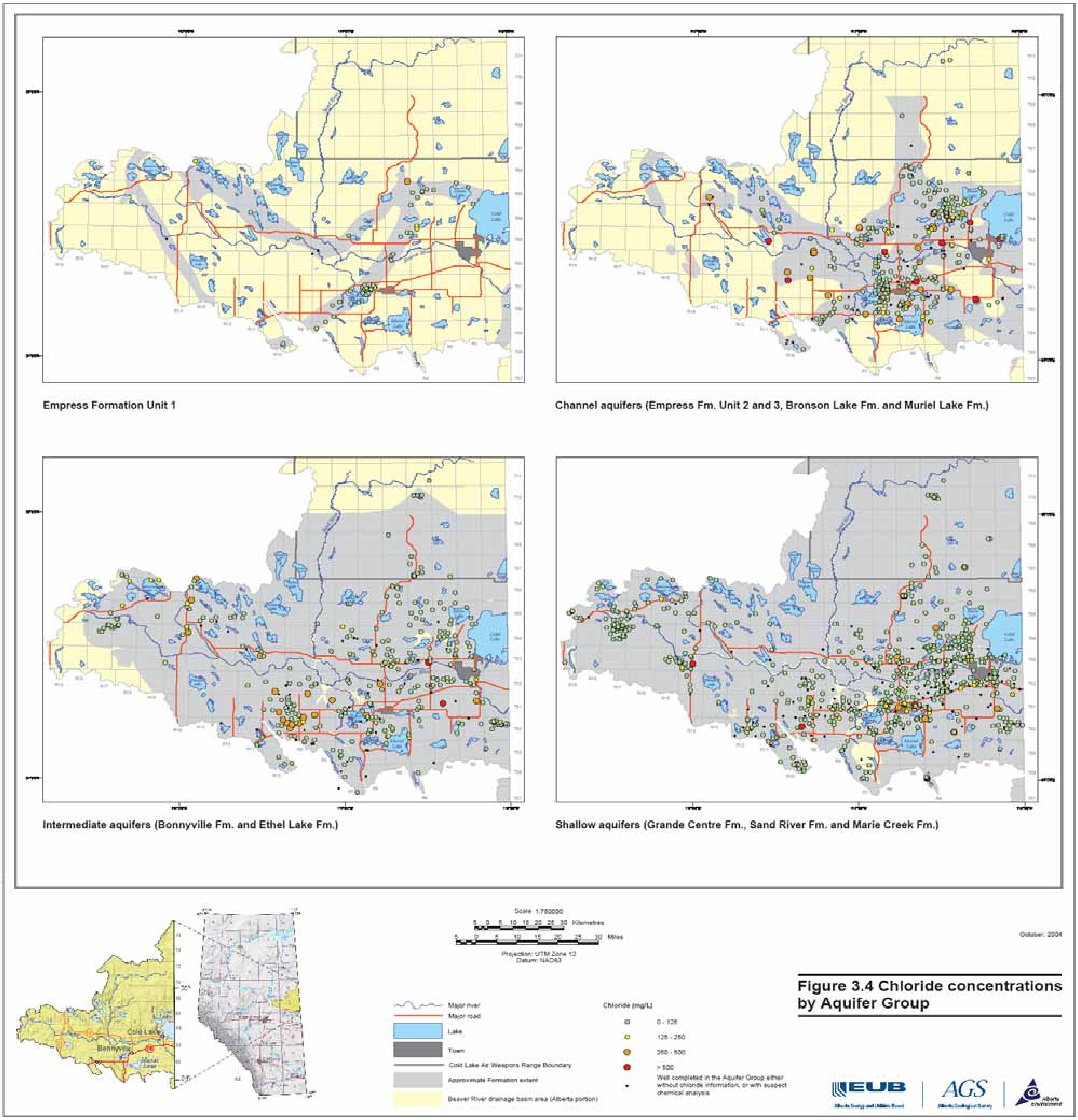


Figure 3.4 Chloride concentrations by Aquifer Group

Table 3-3. Chloride exceedances summary—most recent values.

Formation	Range of Values (mg/L)		Number of Samples	Number of Non-detect Samples[1]	Drinking Water	Agricultural – Irrigation	
	Min.	Max.				Lower Limit	Upper Limit
Grand Centre	<0.5	1350	276	24	16 (6%)	29 (11%)	5 (2%)
Sand River	<0.5	5500	269	23	5 (2%)	16 (6%)	1 (1%)
Marie Creek	<0.5	550	167	15	5 (3%)	17 (10%)	0
Ethel Lake	<0.5	545	207	17	9 (4%)	22 (11%)	0
Bonnyville	<0.5	825	144	5	12 (8%)	25 (17%)	1 (1%)
Muriel Lake	<0.5	1475	241	5	22 (9%)	47 (20%)	3 (1%)
Bronson Lake	<0.5	1430	14	1	1 (7%)	1 (7%)	1 (7%)
Empress	1	2520	141	0	15 (11%)	32 (23%)	3 (2%)
All Aquifers					**85 (6%)**	**189 (13%)**	**14 (1%)**

[1]*Concentration of chloride in groundwater sample was below the laboratory method detection limit*

Arsenic

Arsenic is naturally present in the rocks and soil through which groundwater flows, and elevated levels in groundwater are common in areas underlain by marine shales. In the past, elevated arsenic concentrations within the study area have been identified in separate studies conducted by Alberta Environment and Alberta Health and Wellness.

Sediments in the CLBR area frequently contain large concentrations of arsenic-bearing minerals. The environment in which the sediments were deposited resulted in high variability in the concentration of arsenic-containing minerals in the basin. A variety of mechanisms allow arsenic to be released from the aquifer material to the groundwater. The mechanisms that cause a release of arsenic may potentially be enhanced through oil sands production methods used in the area.

The distribution of arsenic in the four aquifer groups is plotted in Figure 3-5. Figure 3-2 presents box plots of arsenic concentrations in the flow systems for the 1990s and 2000s. Table 3-4 summarizes the number of exceedances for drinking water, freshwater aquatic and agricultural guidelines recorded in the AGS database based on the most recent monitoring event at a given well.

In total, 20% of the samples in the database exceeded the Interim Maximum Acceptable Concentration (IMAC) for arsenic, and 63% of the samples exceeded the Freshwater Aquatic Life guideline as clarified in the *Guidelines for Canadian Drinking Water Quality*. In a provincial-wide study, 2.5% of the samples exceeded IMAC for arsenic. Arsenic concentrations in groundwater in the basin ranged from below the laboratory detection limit up to 0.145 mg/L.

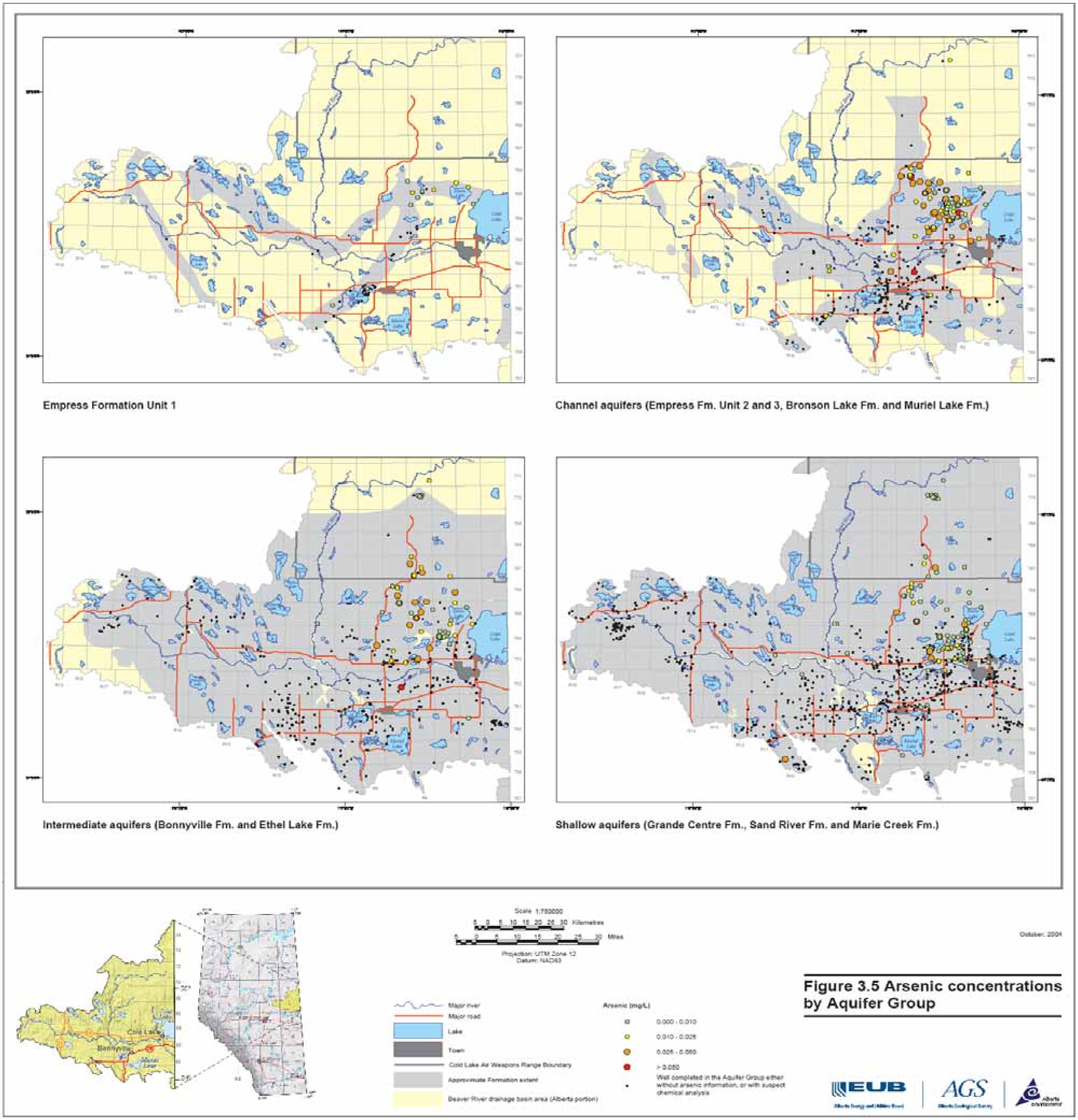


Figure 3.5 Arsenic concentrations by Aquifer Group

Table 3-4. Arsenic exceedances summary—most recent values.

Formation	Range of Values (mg/L)		Number of Samples	Number of Non-Detect Samples[1]	Drinking Water	Freshwater Aquatic Life	Agricultural – Irrigation	Agricultural – Livestock
	Min.	**Max.**						
Grand Centre	<0.0001	0.04	68	16	2 (3%)	20 (29%)	0	2 (3%)
Sand River	0.0002	0.0452	36	0	4 (11%)	21 (58%)	0	4 (11%)
Marie Creek	0.0001	0.055	27	0	4 (15%)	17 (63%)	0	4 (15%)
Ethel Lake	<0.001	0.0805	27	1	7 (26%)	22 (82%)	0	7 (26%)
Bonnyville	<0.0001	0.055	55	1	9 (16%)	36 (66%)	0	9 (16%)
Muriel Lake	0.0009	0.129	57	0	23 (40%)	45 (79%)	1 (2%)	23 (40%)
Bronson Lake	0.0002	0.053	4	0	3 (75%)	3 (75%)	0	3 (75%)
Empress	<0.0001	0.078	55	2	12 (22%)	42 (76%)	0	12 (22%)
All Aquifers			**329**		**64 (20%)**	**206 (63%)**	**1 (0%)**	**64 (20%)**

[1]*Concentration of arsenic in groundwater sample was below the laboratory method detection limit.*

Phenols

Phenols are produced naturally through the decay of organic matter. Anthropogenic sources of phenols are associated with oil production and produced water. Phenols are a useful contaminant indicator since they biodegrade with time. Small concentrations of phenols can provide a good indicator of groundwater contamination.

The distribution of phenols in the four aquifer groups is plotted in Figure 3-6. Figure 3-2 presents box plots of phenols concentrations in the flow systems for the 1990s and 2000s. Table 3-5 summarizes the number of exceedances for freshwater aquatic life and livestock guidelines recorded in the AGS database based on the most recent monitoring event at a given well.

Phenol concentrations exceeded the CCME guideline for freshwater aquatic life in 16% of the samples. Forty-four percent of the samples exceeded the livestock water criteria. Phenol concentrations in groundwater in the basin range from below the laboratory detection limit to 1.45 mg/L.

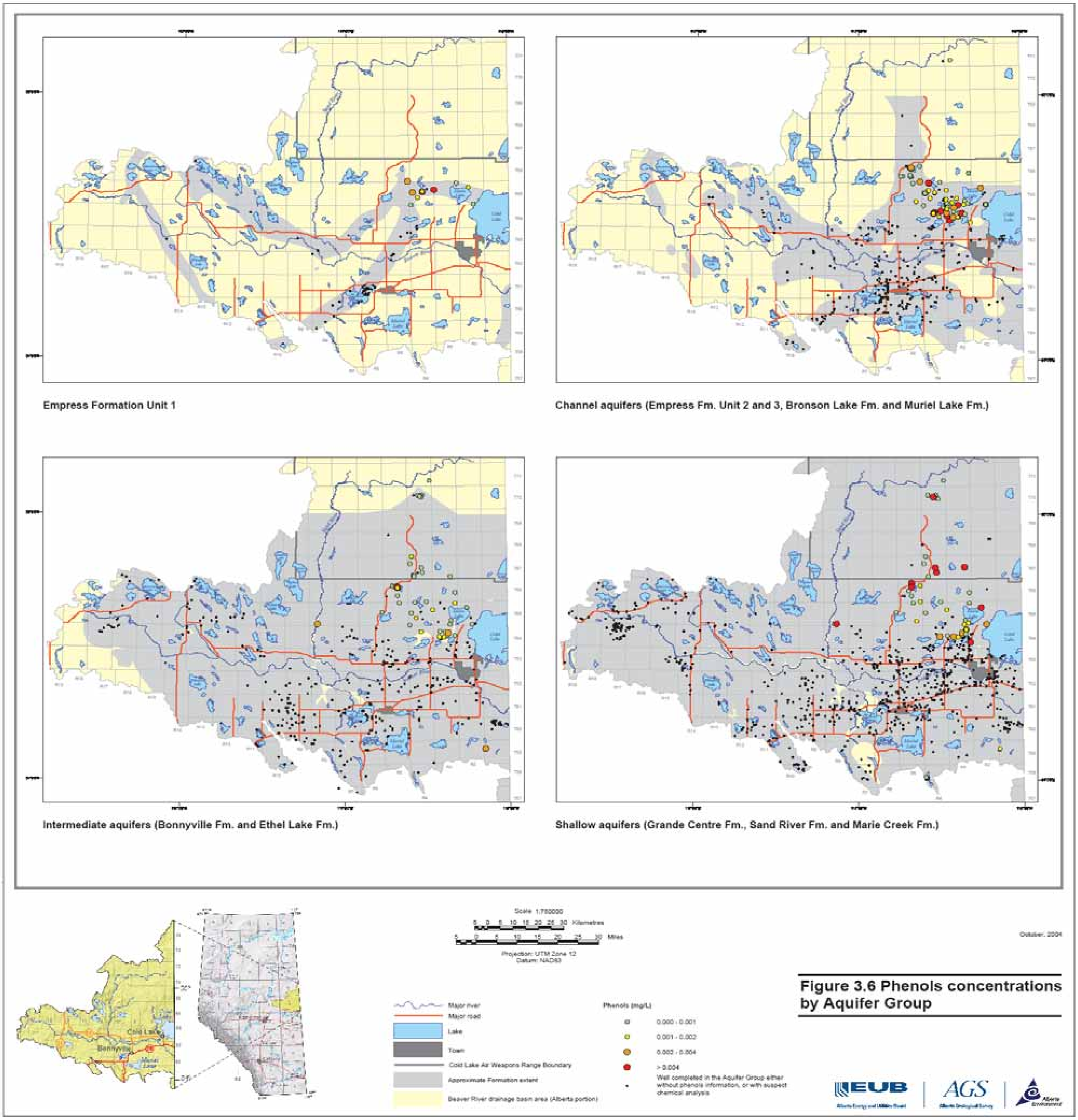


Figure 3.6 Phenols concentrations by Aquifer Group

Table 3-5. Phenols exceedances summary—most recent values.

Formation	Range of Values (mg/L)		Number of Samples	Number of Non-Detect Samples[1]	Freshwater Aquatic Life	Agricultural – Livestock
	Min.	Max.				
Grand Centre	<0.001	0.175	53	24	16 (30%)	27 (51%)
Sand River	<0.001	0.01	5	1	1 (20%)	3 (60%)
Marie Creek	<0.001	0.012	24	13	2 (8%)	10 (41%)
Ethel Lake	<0.001	0.003	21	15	0	4 (19%)
Bonnyville	<0.001	0.009	48	27	3 (6%)	15 (31%)
Muriel Lake	<0.001	0.016	42	18	4 (10%)	19 (45%)
Bronson Lake	<0.001	<0.001	2	2	0	0
Empress	<0.001	0.031	48	14	13 (27%)	29 (60%)
All Aquifers			**243**		**39 (16%)**	**107 (44%)**

[1]*Concentration of phenol in groundwater sample was below the laboratory method detection limit*

3.5.3 Aquifer Sensitivity Maps

Aquifer sensitivity maps were developed for the study area. The purpose of these maps was to identify areas where potential exists for contaminants to be released into surficial aquifers or deeper aquifers with connections to the surface. These maps will help regulators, municipalities and industry site future facilities to reduce the likelihood of groundwater impacts related to operations.

The maps were based on the surficial geology and presence of near-surface aquifers that had been mapped by AGS in the CLBR Basin.

- Areas with clay till identified as the surficial material type were classified as having low sensitivity to contamination.
- Areas designated as having high sensitivity to inter-aquifer contamination were located primarily along river valleys, where there is potential for surficial aquifers to be in direct contact with deeper aquifers.
- Areas of high sensitivity to surficial aquifer contamination are areas where surface aquifers or outcrops of buried aquifers were identified by AGS.
- Areas of high sensitivity also include locations with organic surface deposits such as peat.

The maps were overlain with the potential contaminant sources identified in the study, and locations were plotted of these possible sources relative to the sensitivity of the underlying aquifers to contamination.

Figures 3-7 to 3-14 present a series of aquifer sensitivity maps prepared by AGS for the study area.

Note: Aquifer sensitivity maps are only a tool for use in planning type assessments. Detailed site-specific investigations are needed for facilities that may pose a threat to groundwater quality.

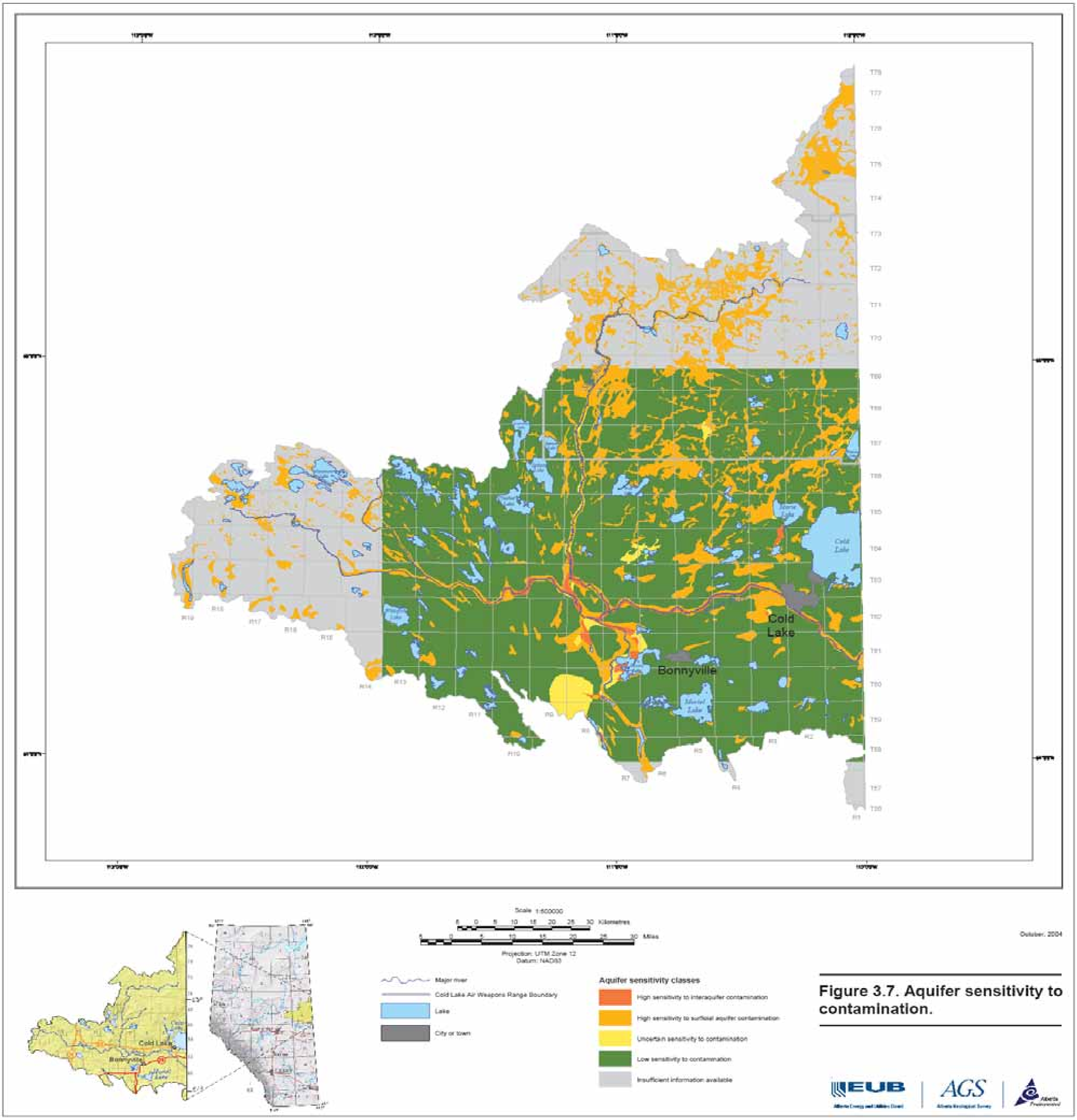


Figure 3.7. Aquifer sensitivity to contamination.

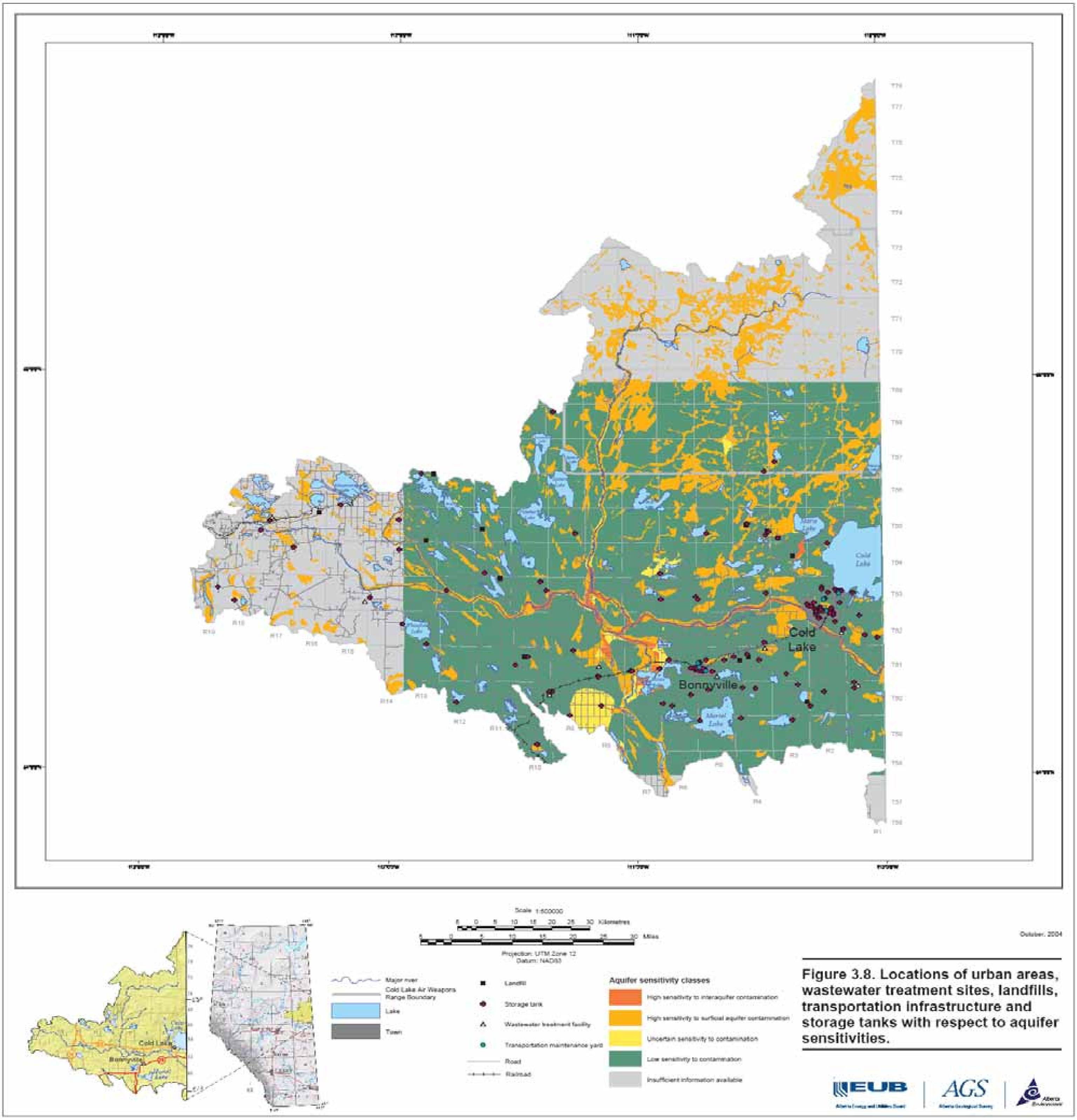


Figure 3.8. Locations of urban areas, wastewater treatment sites, landfills, transportation infrastructure and storage tanks with respect to aquifer sensitivities.

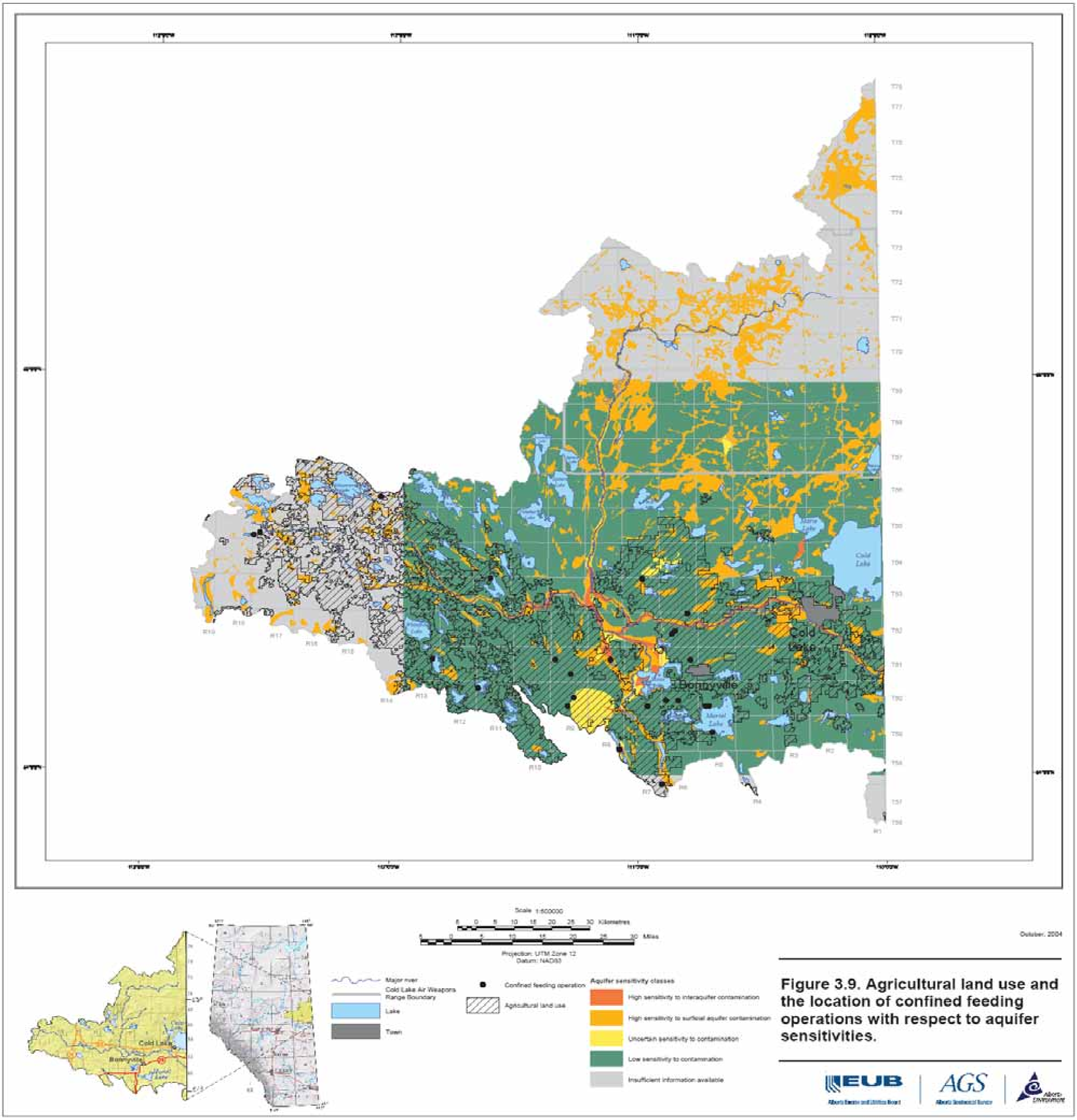


Figure 3.9. Agricultural land use and the location of confined feeding operations with respect to aquifer sensitivities.

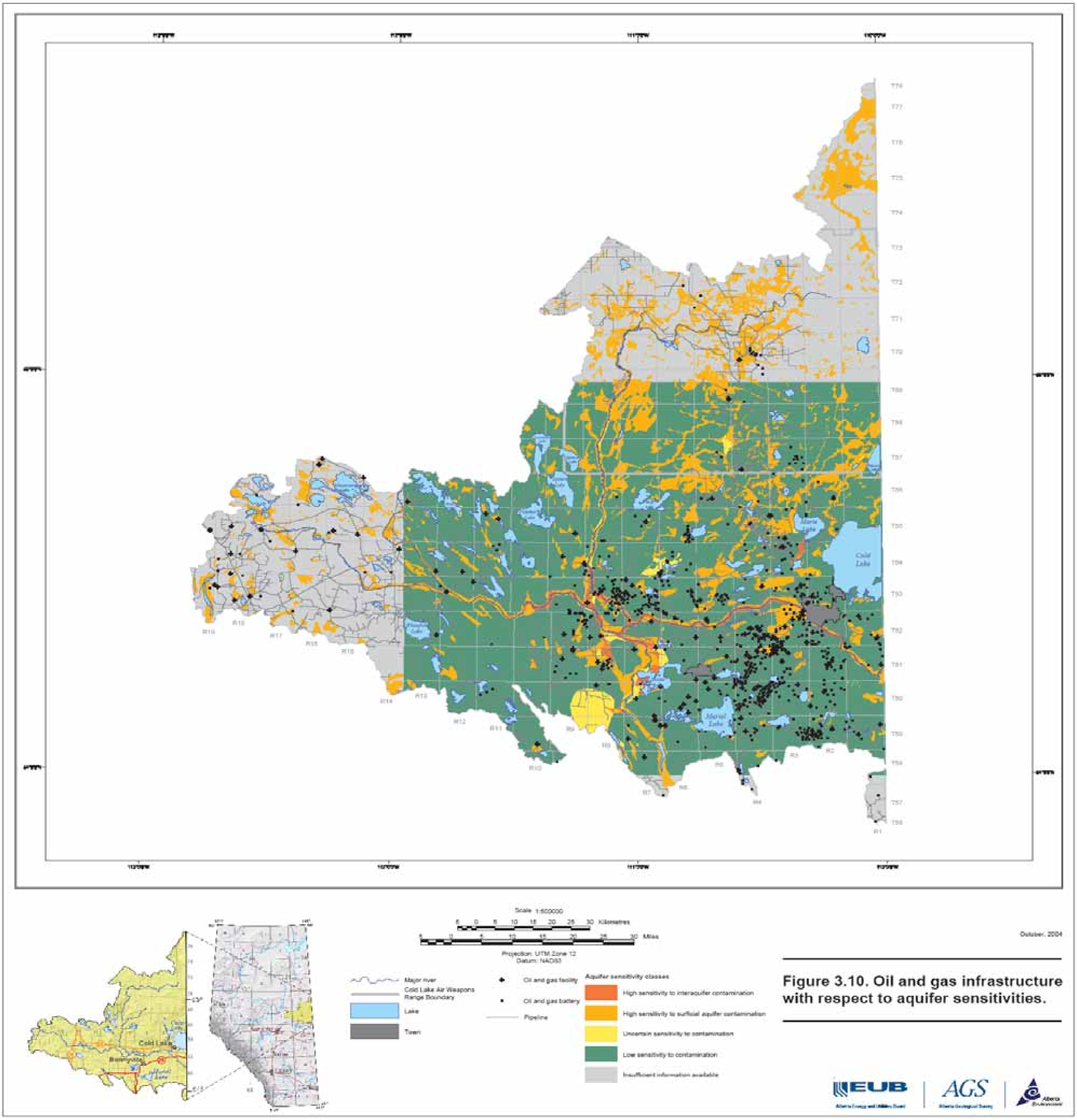


Figure 3.10. Oil and gas infrastructure with respect to aquifer sensitivities.

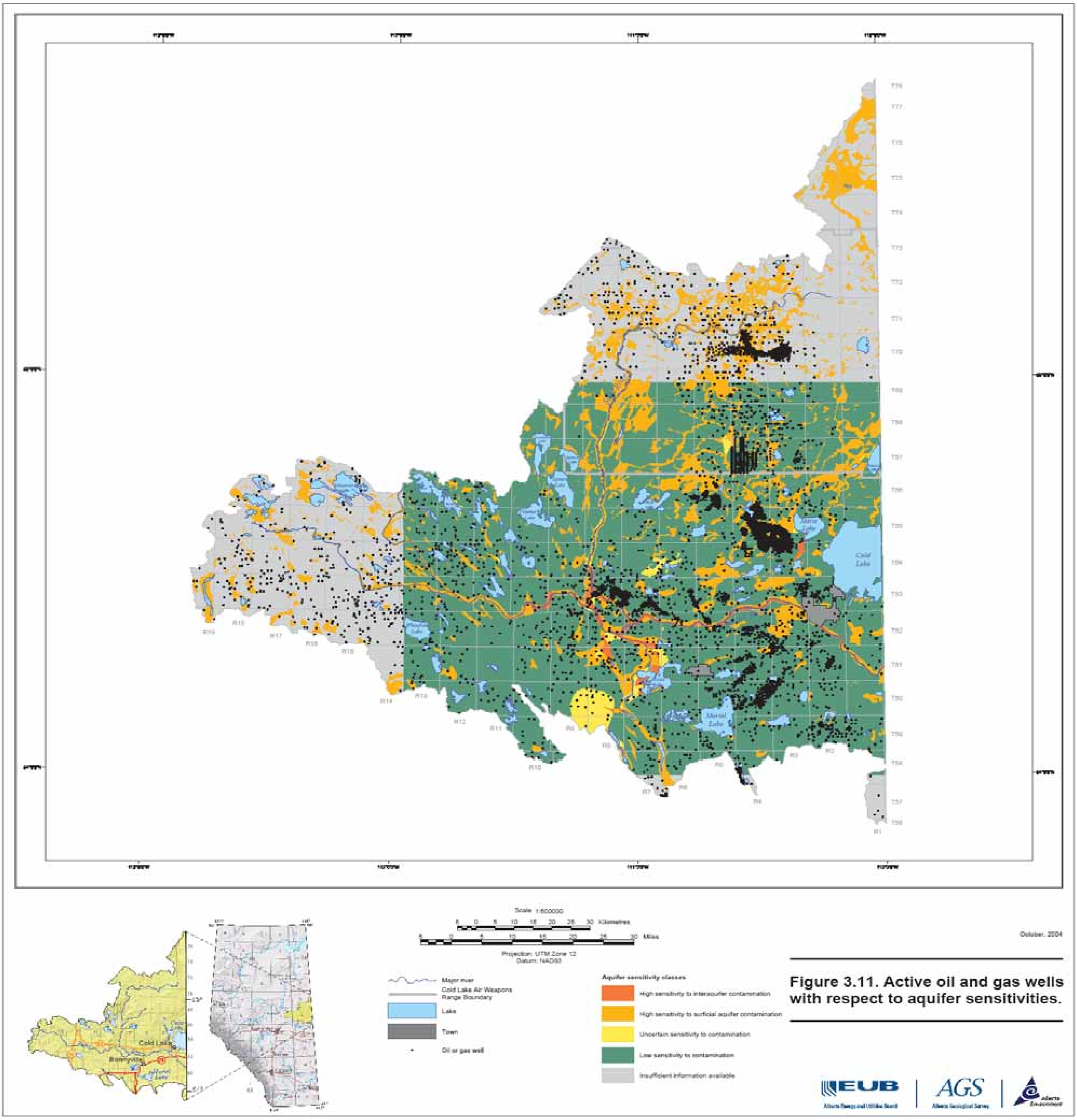


Figure 3.11. Active oil and gas wells with respect to aquifer sensitivities.

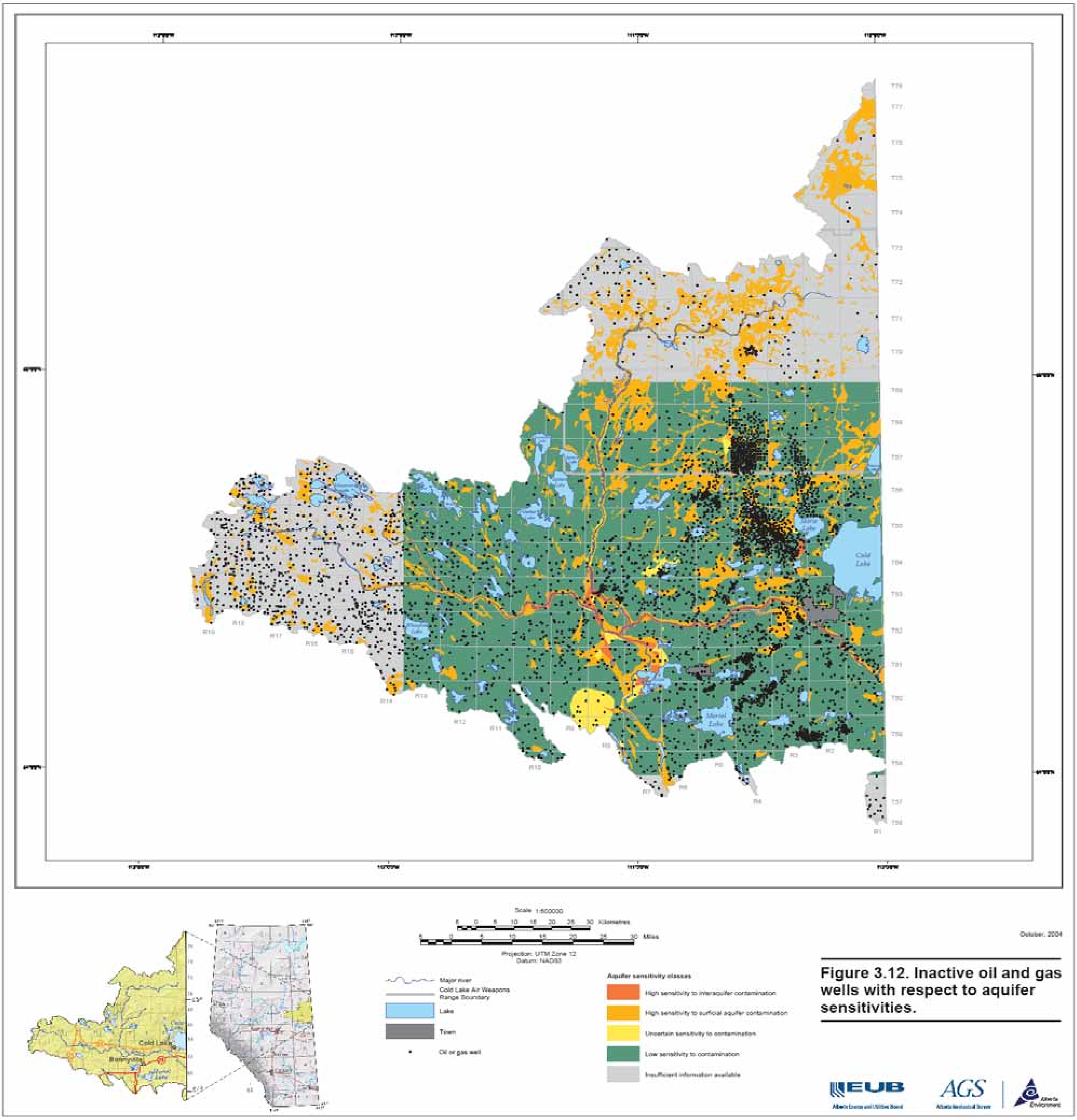


Figure 3.12. Inactive oil and gas wells with respect to aquifer sensitivities.

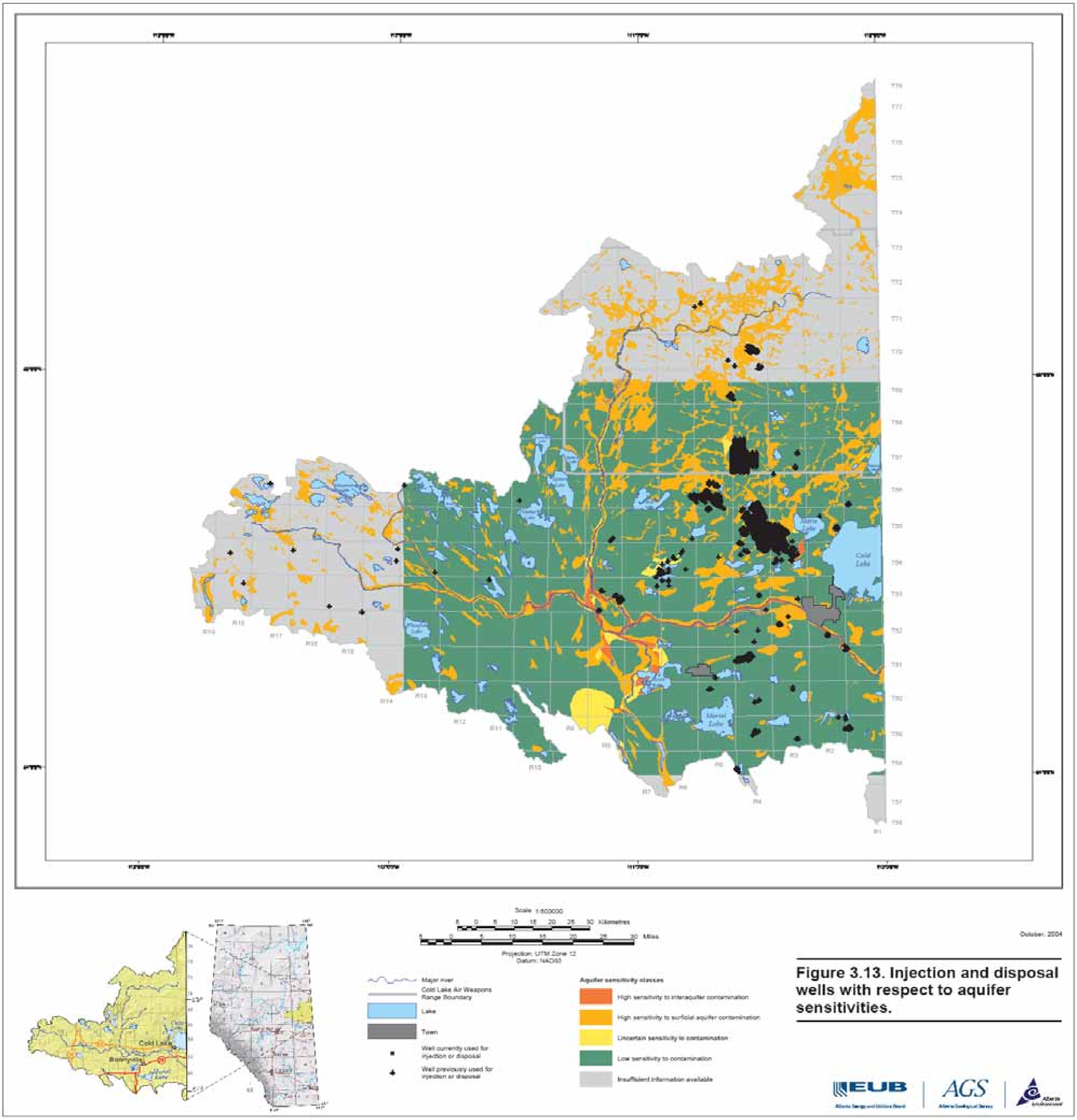


Figure 3.13. Injection and disposal wells with respect to aquifer sensitivities.

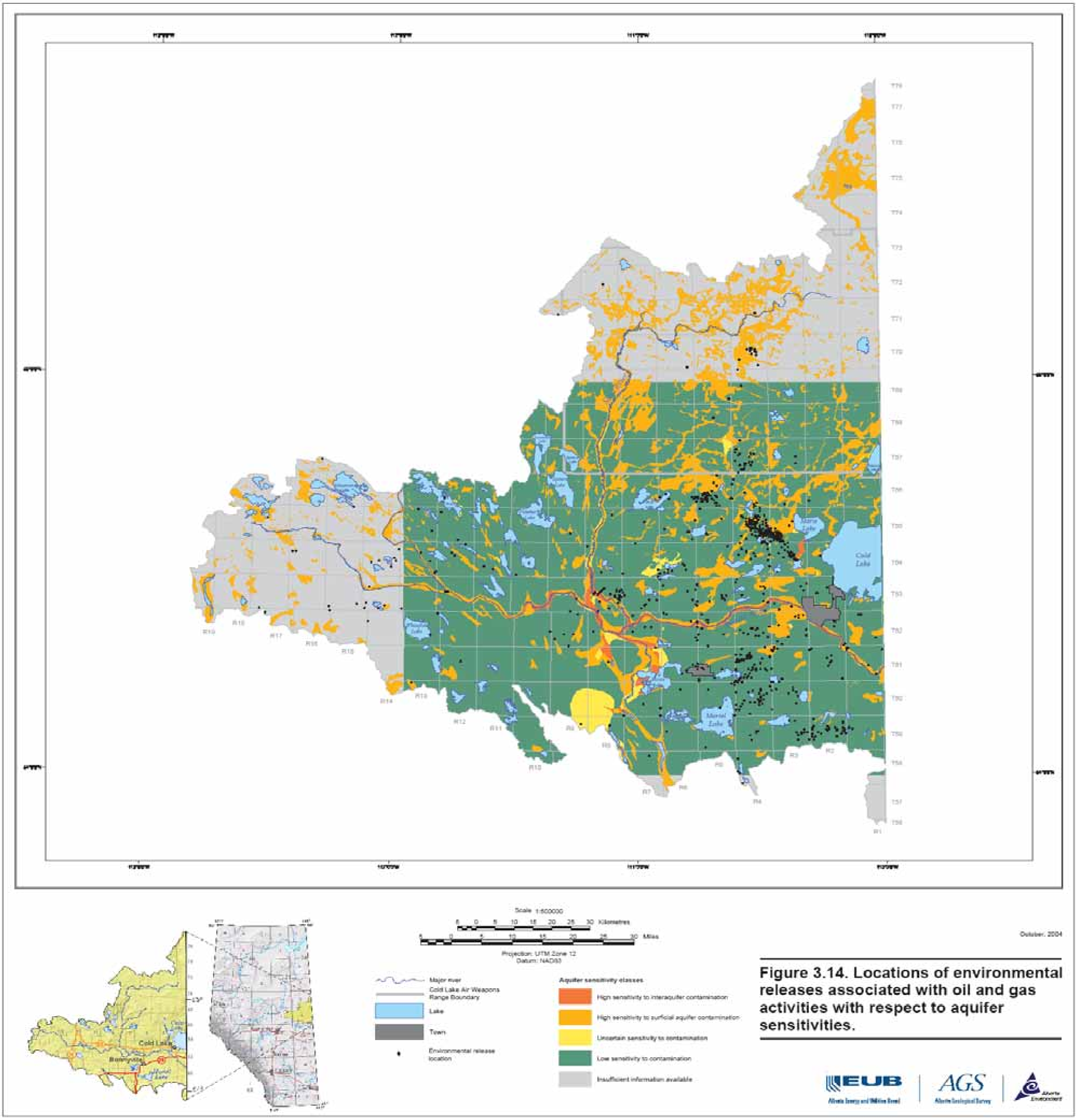


Figure 3.14. Locations of environmental releases associated with oil and gas activities with respect to aquifer sensitivities.

3.6 KEY POINTS

The key points (findings) are based on a regional scale assessment.

1. The regional groundwater chemical quality is generally within Canadian drinking water quality guidelines, and has not changed detectably over time.
   - Groundwater quality at a particular location may not meet the Canadian Drinking Water Quality Guidelines due to natural or anthropogenic causes. Individual well owners should test their wells to determine what treatment is needed before using the water. Maintenance and proper abandonment of wells are necessary to prevent contamination of groundwater resources.
   - The original Cold Lake–Beaver River management plan did not include an assessment of groundwater quality. The finding that groundwater quality is not changing is based only on two decades of data for the region. Additional data over time is needed to further evaluate if there is any change in regional groundwater quality.
2. A number of areas within the basin were determined to be potentially sensitive to contamination.
3. A number of potential point and non-point sources of contamination are located within these sensitive areas.
4. The study as conducted could not identify all potential contaminant sources, and only sources regulated by various government departments were included. Unregulated sources may be locally impacting groundwater quality. These sources include improperly abandoned water wells acting as conduits for surface runoff, septic fields and agricultural operations.
5. Based on the study, potential risks to groundwater from industrial operations in the eastern portion of the basin are well known and studied. The industrial facilities operate with the requirement for groundwater monitoring and submission to regulatory agencies of annual groundwater monitoring reports. Areas in the western portion of the basin do not have extensive groundwater monitoring networks associated with industrial operations, and therefore the quality of groundwater in these areas is less certain.
6. Development of aquifer sensitivity maps is an important aspect of protecting groundwater quality for the future in the basin. Planning agencies and proponents can use these maps to aid in selecting site locations to avoid areas where groundwater is at risk due to geological conditions.
7. The study identified the need for a regional groundwater-monitoring program in order to provide additional information on groundwater quality in the basin, and to help assess the impact of development on groundwater quality over time.

SECTION 4. DEEP WELL DISPOSAL

4.1 INTRODUCTION

Production of hydrocarbons is generally accompanied by some amount of formation water, referred to as "produced water". In the CLBR Basin, bitumen is produced from the Grand Rapids, Clearwater and McMurray Formations by primary and thermal methods. The oil sands deposits in this basin fall within the Cold Lake Oils Sands Area, and are developed only through the use of wells, as the depth at which the deposits are located precludes mining. Gas production, primarily from the Grand Rapids Formation, also occurs on a relatively small scale.

None of the hydrocarbon-producing formations are above the base of groundwater protection; therefore, all produced water in this basin is saline. The base of groundwater protection is the depth to which groundwater is considered useable with total dissolved solids concentrations less than 4,000 mg/L. This water must be managed to prevent impacts to the environment, non-saline aquifers and hydrocarbon resources. Deep well disposal is the primary method for the final disposal of these fluids.

The Alberta Energy and Utilities Board (EUB) regulates the management of all produced water as per the *Oil and Gas Conservation Act*. The EUB does not permit surface disposal of produced water:

> *In accordance with the Oil and Gas Conservation Act, Section 26(1)(c), EUB approval of a scheme is required for the gathering, storage, and disposal of water produced in conjunction with oil and gas. Section 26(1)(d) requires EUB approval of a scheme for the storage or disposal of any fluid or other substance to an underground formation through a well.*

This complements the 1985 Cold Lake–Beaver River Water Management Plan statement that industrial wastewater from thermal oil sands operations will not be discharged to the surface environment. As a result, produced water that is not suitable for recycling at thermal operations is disposed of in deep, secure formations under stringent requirements.

This section presents information on current provincial deep well disposal requirements used to manage produced water, and provides specific information on disposal locations, zones and volumes in the CLBR Basin.

4.2 REGULATORY REQUIREMENTS

Deep well disposal is an important component of industrial water management in the basin. Managing this water is a significant part of the water budget for every large-scale industrial project, particularly for the in situ thermal enhanced oil recovery projects that are now in place and also those under development. The EUB requires operators of thermal oil sands projects to minimize disposal volumes of produced water by maximizing recycle rates and volumes, thereby reducing reliance on non-saline water sources and conserving energy (heat) in the produced water stream. EUB recycle requirements are outlined in Informational Letter (IL) 89-5: *Water Recycle Guidelines and Water Use Information Reporting for In Situ Oil Sands Facilities in Alberta.*

Disposal wells are reviewed and approved in accordance with EUB Guide 51: *Disposal and Injection Wells*, and Guide 65: *Resource Applications for Conventional Oil and Gas Reservoirs*. These guides include requirements for appropriate formation selection, wellbore design and completion, and hydraulic isolation monitoring. EUB Guide 55: *Storage Requirements for the Upstream Petroleum Industry*, Guide 56: *Energy Development Applications and Schedules*, and Guide 58: *Oilfield Waste Management Requirements for the Upstream Petroleum Industry* may also apply to the surface facilities associated with these wells.

The following sections explain in more detail the EUB requirements associated with drilling, completing and operating a disposal well.

4.3 Guide 51: Disposal and Injection Wells

4.3.1 Deep Well Disposal Introduction

The philosophy behind deep well injection is contained in Sections 2.1 and 2.2 of Guide 51.

> *2.1 Background*
>
> *A system of classifying injection and disposal wells has been developed on the basis of injected or disposed fluid such that design, operating, and monitoring requirements are consistent with the type of fluid injected.*
>
> *2.2 Deepwell Disposal Philosophy*
>
> *Deepwell disposal of oilfield and industrial wastewaters is a safe and viable disposal options where wells are properly constructed, operated and monitored. Deepwell disposal should remain as an option, but should be guided by the following principles:*
>
> - *Waste minimization shall be implemented prior to using the deepwell disposal option;*
> - *Resource conservation, including surface water and the waste streams themselves, shall be pursued whenever possible;*
> - *Disposal wells will be classified and designed, on the basis of the fluid being injected, so as to provide for increased monitoring and surveillance of operations of wells injecting sensitive waste fluids;*
> - *Waste fluids shall not be diluted solely for the purpose of avoiding waste fluid classification; and*
> - *Operators of surface facilities that generate or process water material that is disposed through Class Ia or Class Ib wells are expected to design and operate*

those facilities using sound waste management practices and principles of waste minimization.

Regulatory activities will focus on issues related to:

- *Wellbore integrity to ensure initial and ongoing containment of the disposal fluid in the interests of both hydrocarbon conservation and groundwater protection;*
- *Formation suitability to ensure initial and ongoing confinement of the disposal fluid in the interests of both hydrocarbon conservation and groundwater protection;*
- *Suitability of the waste stream for deepwell disposal having regard for the nature of the fluid, the integrity of the well, and alternative waste management options;*
- *Reporting and manifesting of disposed wastes; and*
- *Where appropriate ensuring the aforementioned principles have been followed.*

Matters of fluid-fluid, fluid-equipment, and fluid-formation compatibility will be left primarily to the disposal well operator, with regulators relying on operating and monitoring requirements to provide for early detection and mitigation of potential problems. The waste generator has the primary responsibility to ensure the aforementioned waste minimization and resource conservation principles are followed. In all cases, it is the responsibility of the waste generator to ensure that each waste stream had been properly identified, characterized, and is handled, treated, and disposed of in an acceptable manner.

4.3.2 Deep Well Disposal Well Classification

Disposal wells are classified from IV to I to identify those that require increasing levels of monitoring and surveillance based on the injected or disposed fluids. Each classification is associated with specific completion, logging, testing and monitoring requirements. A brief overview of the classes is as follows:

- Class IV — Well used for injection into the reservoir matrix of potable water with no anticipated future conversion to produced water or steam from potable water or recycled water.
- Class III — Well used for the injection of hydrocarbons, or inert or other gases, for the purpose of storage in or enhanced hydrocarbon recovery from a reservoir matrix.
- Class II — Well used for the injection or disposal of produced water (brine).
- Class Ib — Well used for the disposal of produced water, specific common oilfield waste streams, and waste stream meeting specific criteria.
- Class Ia — Well used for the disposal of oilfield or industrial waste fluids.

Additional detail on well classification, and appropriate waste streams is contained in Guide 51. Class IV and III wells are related to conventional enhanced recovery schemes and some thermal oil sands recovery schemes, and are referred to as injection wells. Classes II, Ib and 1a wells are for permanent disposal of waste fluids. Most disposal wells are Class II. *Note: For the purpose of this document, all further discussion relates only to disposal wells.*

4.3.3 Cementing and Casing Requirements

All well completions must provide hydraulic isolation of the disposal zone and usable groundwater. The EUB requirement for cemented casing across usable (non-saline) groundwater came into effect in the early 1990s. As a result, some disposal wells in operation prior to that time may not have cemented casings across non-saline groundwater. These wells have been assigned additional monitoring requirement to ensure wellbore integrity and containment of the disposal fluid. All new Class Ia wells must have cemented surface casing extending to below the base of groundwater protection surface casing.

A cement top-locating log must be performed on wells where cement returns were not maintained at surface during cementing operations. In addition, a temperature survey log, and one of a radioactive tracer survey, oxygen activation log, or cement integrity log must be performed on Class II, Ia and Ib wells to ensure hydraulic isolation of the disposal zone. None of these logs have the ability to impact non-saline aquifers. Allowable wellhead injection pressures are routinely limited to the pressures at which these logs were performed.

A casing inspection log is a type of log designed to evaluate the condition of the steel casing, and must be run on all existing wells converted to disposal. As well, a baseline casing inspection log is recommended for all Class Ia wells. All wells must pass an initial pressure test of the tubing/casing annulus to a minimum pressure of 7 mPa for 15 minutes.

4.3.4 Monitoring Requirements

Class Ib and II wells require a minimum of an annual packer isolation test to a minimum surface pressure of 1.4 mPa for 15 minutes. Additional monitoring requirements may be assigned on a specific well basis as necessary. Class Ia wells require:

- Monitoring of injectivity and annular pressure on a minimum daily basis.
- Hydraulic isolation logging every five years subsequent to the initial log.
- Annual formation pressure survey.
- Annual packer isolation test to the greater of 7 mPa (at surface) or 1.3 times the wellhead injection pressure.

4.3.5 Maximum Allowable Wellhead Injection Pressure

The maximum wellhead injection pressure is limited to 90% of the formation fracture pressure, which can be determined from a step-rate injectivity test, or from fracture data from that well or offset wells. The maximum injection pressure may also be limited to the pressure at which the hydraulic isolation logging was conducted, if it is less than the formation fracture pressure.

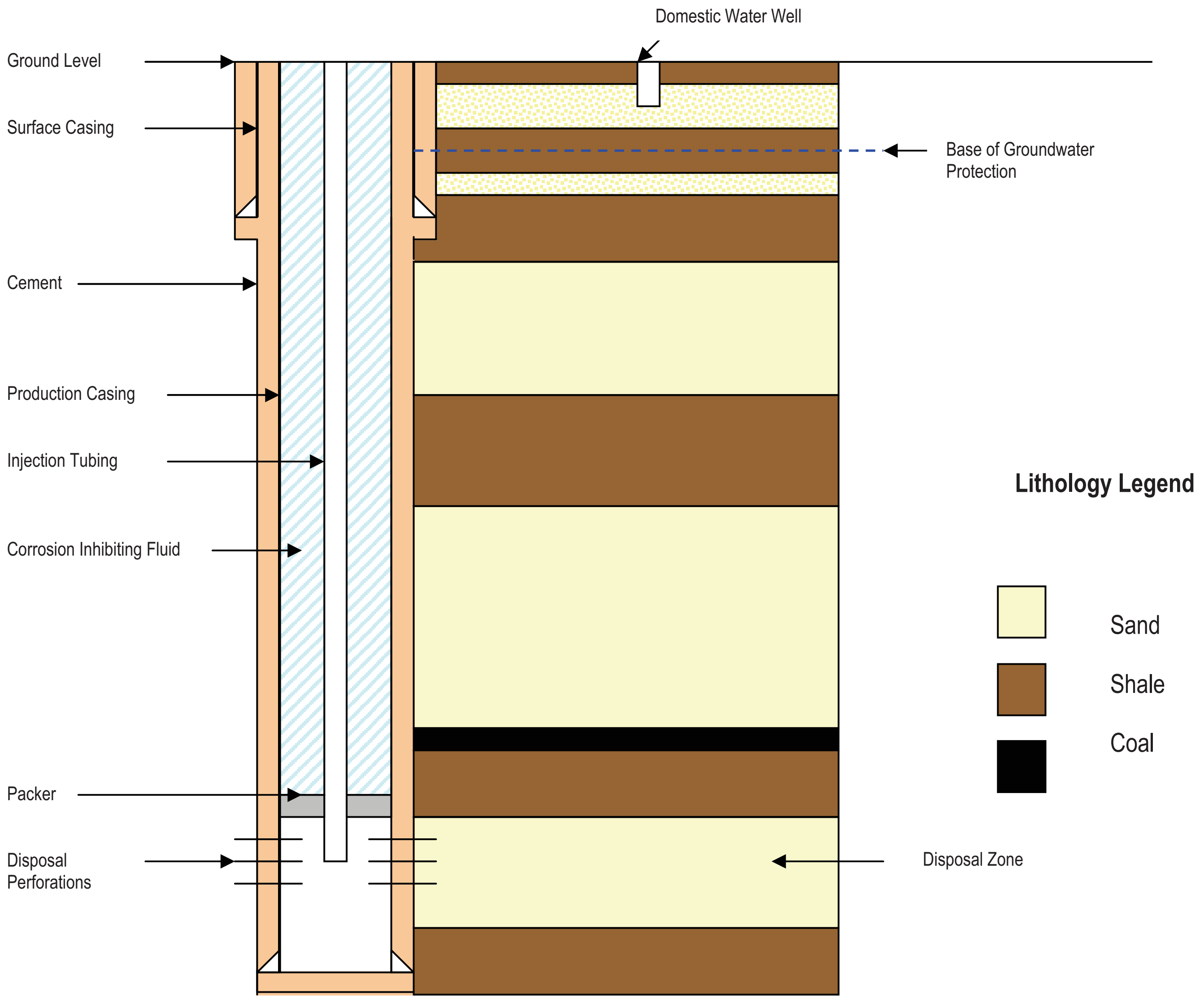


Figure 4-1. Typical disposal well.

4.4 Regulatory Guidelines

4.4.1 Guide 56: Energy Development Applications and Schedules

All wells drilled for hydrocarbon recovery or other purposes, but deeper than 150 m, require an EUB well license. The requirements for each type of well are described in Guide 56. The applicant is required to identify the location, purpose, depth of well, mineral disposition and potentially affected parties. As well, the applicant is required to confirm the company has met the public consultation requirements, and that it will comply with all other EUB regulations and requirements which apply to the drilling completion and operation of the specific well. An applicant may also require an application under Guide 56 for the surface facilities associated with the disposal well.

4.4.2 Guide 65: Resource Applications for Conventional Oil and Gas Reservoirs

In addition to meeting the requirements for a well license, an application under Unit 4 of Guide 65 is required for disposal wells. An application for disposal may be approved if:

- Disposal is not above the base of groundwater protection as per *General Bulletin (GB) 2000-8,*
- Disposal will not impact hydrocarbon recovery,
- The disposal fluid will be confined to the injection formation,
- Offset mineral owners within 1.6 km of the disposal well(s) have been consulted and have no objections or concerns to the disposal scheme,
- The applicant has the right to dispose into the requested formation.

The applicant is also required to provide information regarding the need for the well, the suitability of the disposal formation and wellbore, type and volume of fluids injected, and the status of application for surface facilities under Guides 56 or 58.

4.5 Cold Lake–Beaver River Basin

In the CLBR Basin, several deep geological formations are present that are suitable for disposal. Table 4-1 shows the active disposal well in the study area. Note that all disposal horizons are significantly below the base of groundwater protection. Disposal of produced water is the predominant purpose of disposal wells in the area. Several 1B wells are present in the basin in the Cold Lake Oil Sands area. These wells are used to dispose mainly produced water, but are also designed to handle 1B waste associated with thermal oil sands extraction, as designated in EUB Guide 51. The EUB does not have a record of any casing failures or releases associated with disposal wells.

Table 4.1. Active disposal wells in the Cold Lake–Beaver River Basin.

Well ID	2002 Vol (m^3)	Cum. Volume (m^3)	Date on Injection	Approval Number	G 51 Class	Disposal Zone	Base of GW Protection
02/02-28-061-04W4/0	0	2,431,727	Apr-83	6432	II	Clearwater	Quaternary
00/10-04-061-05W4/0	0	321,219	Jan-98	8416	IB	Cambrian	Quaternary
00/13-03-062-04W4/2	13,094	103,345	Dec-97	8168	II	Clearwater	Quaternary
00/11-18-062-04W4/0	8,73877	8,738	May-02	8987	II	Clearwater	Quaternary
00/12-36-062-15W4/0	8,293	58,479	Jul-98	7971		McMurray	Wapiti
00/04-01-063-04W4/0	54,281	397,882	Feb-93	7126	II	McMurray	Quaternary
02/06-04-063-08W4/0	5,276	46,497	Nov-80			LGR *	Quaternary
00/13-13-063-08W4/2	162,011	596,755	Sep-97	8760		McMurray	Quaternary
00/15-14-063-08W4/0	15,460	21,987	Jun-01	8760	IB	McMurray	Quaternary
03/10-21-063-08W4/0	95,801	95,801	Jan-02			Cambrian	Quaternary
00/10-06-063-15W4/2	3,579	39,843	Aug-93	7315	II	LGR	Quaternary
00/07-26-063-18W4/2	10,436	404,351	Mar-79	7848 (2785)		Nisku	Wapiti
02/16-17-064-03W4/0	186,571	794,151	Sep-87	8175		Cambrian	Quaternary
03/16-17-064-03W4/0	39,790	169,668	Sep-97	8175		McMurray	Quaternary
00/07-18-064-03W4/0	165,306	3,982,253		4510		Cambrian	Quaternary
00/01-19-064-03W4/0	97,177	1,967,726	Dec-85	4510		Cambrian	Quaternary
00/12-06-064-06W4/0	51,469	570,321	Nov-85	9275 (1755)	II	Cambrian	Quaternary
00/10-01-064-13W4/2	10,061	131,073	Dec-81	8381	II	LGR	Quaternary
00/10-25-064-14W4/0	11,527	398,949	Jul-80	7971	II	Grosmont	Quaternary
00/02-30-064-16W4/0	3,237	45,462	Nov-86	8496 (4480)		Nisku	Quaternary
00/11-21-064-18W4/0	3,483	30,392	Nov-95	7848 (2785)		Nisku	Wapiti
02/02-03-065-03W4/0	296,095	4,631,842	May-84	4510		Cambrian	Quaternary
00/15-35-065-05W4/2	1,490	5,033	Mar-00	8617	II	McMurray	Quaternary
00/15-07-066-05W4/0	286,735	5,015,555	Aug-87	8672 (5808)		Cambrian	Quaternary
00/10-08-066-05W4/0	120,731	4,353,231	Jan-85	8672 (5808)		Cambrian	Quaternary
00/11-19-066-13W4/0	23,013	266,476	Oct-84	4222	II	McMurray	Quaternary
F1/11-02-067-03W4/0	142,889	1,159,102	May-97	8186		McMurray	Quaternary
00/03-11-067-03W4/0	199,038	1,253,079	May-97	8186 (6804)		McMurray	Quaternary
02/10-05-067-04W4/0	0	443,778	Apr-84	3929		Cambrian	Quaternary
03/10-05-067-04W4/0	5,258	150,649	May-83	4128		McMurray	Quaternary
07/08-12-069-05W4/0	2	132,174	Apr-91	6462	II	McMurray	Quaternary
00/09-12-069-05W4/0	19,686	38,434	Oct-91	6462	II	McMurray	Quaternary
00/02-02-070-04W4/0	114,027	229,357	Oct-01		II	McMurray	Quaternary
02/02-02-070-04W4/0	368,532	453,275	Oct-01	9011	1B	McMurray	Quaternary
00/03-02-070-04W4/0	199,485	303,281	Sep-02	9011	II	McMurray	Quaternary
00/08-02-070-04W4/0	451,322	530,941	Sep-01	9011	II	McMurray	Quaternary

Well ID	2002 Vol (m^3)	Cum. Volume (m^3)	Date on Injection	Approval Number	G 51 Class	Disposal Zone	Base of GW Protection
03/11-02-070-04W4/0	231,009	231,009	Mar-02	9319 (9164)	II	McMurray	Quaternary
04/11-02-070-04W4/0	116,084	116,084	May-03		II	McMurray	Quaternary
05/11-02-070-04W4/0	445,167	445,167	Mar-03		II	McMurray	Quaternary
03/01-21-070-04W4/0	166,877	845,316	Jul-97	9319 (9164)	II	LGR	Quaternary
03/15-21-070-04W4/2	9,239	66,076		9319 (9164)	II	LGR	Quaternary
00/04-22-070-04W4/0	36,047	156,251	Jul-97	9319 (9164)	II	LGR	Quaternary
04/05-22-070-04W4/2	12,224	298,977	Jul-97	9319 (9164)	II	LGR	Quaternary
Totals	***4,190,537***	**33,741,703**					

**LGR = Lower Grand Rapids*

4.6 KEY POINTS

1. Although there is some variation in the minor chemical components of the produced water, these waters are classified as sodium chloride-type waters (saline). This water must be managed to prevent impacts to the environment, non-saline aquifers and hydrocarbon resources. Deep well disposal is the primary method for the final disposal of these fluids.
2. Where produced waters are returned to the formation of origin, compatibility issues are minimized and are the responsibility of the operating company.
3. Several deep geological formations in the basin are suitable for disposal The Cambrian, where present, is the deepest zone available for disposal in the area. Other suitable disposal zones include the McMurray, Clearwater and Lower Grand Rapids.
4. Several companies target the McMurray as a source of saline groundwater for use in steam generation. There are hundreds of metres between the shallowest disposal zone and the base of groundwater protection.
5. Several 1B wells are present in the basin in the Cold Lake Oil Sands area. These wells are used to dispose mainly produced water, but are also designed to handle 1B waste associated with thermal oil sands extraction.
6. The EUB requirement for cemented casing across usable (non-saline) groundwater came into effect in the early 1990s. Some disposal wells in operation before that time may not have cemented casings across non-saline groundwater. These wells have been assigned additional monitoring requirement.

APPENDIX A. LEGISLATION, POLICIES AND GUIDELINES

This appendix highlights and summarizes some of the current legislative statutes, policies and guidelines that influence water management in the Cold Lake-Beaver River Basin. In addition, information is provided on the inter-provincial agreement between Alberta and Saskatchewan and the *Cold Lake Subregional Integrated Resource Plan*.

Provincial and Federal Legislation

Managing water resources in the Cold Lake–Beaver River Basin is guided by both provincial and federal laws. The Government of Alberta holds the property rights for water resources, and has the authority to legislate on all aspects of water resources management. The *Water Act* is the main legal tool used to govern water resources management in the province. Specific parts of the *Environmental Protection and Enhancement Act (EPEA)* also regulate aspects of water and water resources activities. Both Acts are administered by Alberta Environment.

The Alberta Energy and Utilities Board (EUB) administers legislation that covers certain aspects of surface water/groundwater through the *Oil and Gas Conservation Act* and *Regulations* (e.g., *Part 2 [Regulations] Licensing of Wells*—Siting facilities with respect to waterbodies and the existing water table).

The Government of Canada has jurisdiction over international water management and inter-provincial water-sharing agreements, as well as migratory birds. Some of the legislation administered by the federal government includes the following:

- *Fisheries Act* (R.S. 1985, c. F-14)
- *Navigable Waters Protection Act* (R.S. 1985, c. N-22)
- *Canada Water Act* (R.S. 1985, c. C-11)
- *Canadian Environmental Protection Act, 1999* (1999 c. 33)
- *Migratory Birds Convention Act, 1994* (1994d, c. 22)
- *Species at Risk Act* (proclaimed 2003).

Several provincial and federal policies also provide direction for water resources management and water-related activities. Provincial water-related policies (www3.gov.ab.ca/env/WATER/Legislation/Index.cfm) include the following:

- Codes of Practice
- Albert Water Strategy
- Framework for Water Management Planning
- Groundwater Evaluation Guidelines.

Other provincial guidelines include:

- A Fish Conservation Strategy for Alberta 2000 –2005.
- Strategic Plan and Industrial Guidelines for Boreal Caribou Ranges in Northern Alberta.

Federal policies include:

- Federal Water Policy (1987)
- Habitat Conservation and Protection Guidelines (1998)
- Policy for the Management of Fish Habitat (1986)
- Federal Policy on Wetland Conservation (1991).

Alberta Water Act

The *Water Act* (W-3 RSA 2000) replaced the *Water Resources Act* (1980 cW-5), and represented a shift from water allocation to a strong focus on water conservation, protection and management guided by the concepts and objectives of sustainable development. The *Water Act* is based on the following principles:

- Water must be managed in a sustainable way.
- Water is a vital component of the environment.
- Water plays an essential role in a prosperous economy and balanced economic development.
- Water must be managed using an integrated approach with other natural resources.
- Water must be managed in consultation with the public.
- Water must be managed and conserved in a fair and efficient manner.

The *Water Act* addresses all actions that may affect water use or the management of water use. In addition, it provides a more streamlined licensing and approval process for water-related activities and diversions. The *Water Act* includes the following actions:

- protects the rights of existing water licenses that are in good standing;
- protects existing traditional agriculture uses of water through a streamlined, voluntary registration process;
- protects the statutory rights for household uses of water and grants priority over all other uses;
- prohibits the export of water to United States;
- prohibits any inter-basin transfers of water between Alberta's major river basins;
- allows for flexible water management by allowing transfer of water licenses; and
- offers opportunities for Albertans to provide input and advice for water-related activities.

The Act also contains comprehensive tools to protect aquatic resources and riparian areas. These include:

- Strategy for protecting aquatic resources, which is to be developed as part of the provincial water management planning.
- Water conservation objectives (water quality and quantity necessary for a healthy aquatic environment).
- Transfer of water allocations and water conservation holdbacks (up to 10% of the water being transferred may be withheld to protect the aquatic environment).
- Framework for water management planning, which provides guidelines for water management planning.

The *Water Act* encourages cooperation and proactive measures to resolve management issues, and provides a wide range of enforcement tools where necessary. The Act also contains also tools for supervising water licenses and approvals, which are issued by Alberta Environment.

Environmental Protection and Enhancement Act (EPEA)

The *Environmental Protection and Enhancement Act* (E-12 RSA 2000) provides a strong regulatory framework for environmental protection in Alberta. As part of its objective, the Act addresses specific aspects of water resources and water-related activities, as follows:

- **Environmental Impact Assessment** — *EPEA* establishes a legislative process for reviewing the potential environment impact of proposed development. The review process evaluates impacts of proposed development on water quality, protecting surface and groundwater, deposition of harmful substance into waterbodies, and land and water-based activities.
- **Potable water** — *EPEA* regulates the treatment and supply of water for human consumption.
- **Groundwater and related drilling** — *EPEA* regulates the drilling of water wells and provides protection for groundwater quality.
- **Wastewater and Storm Drainage** — *EPEA* regulates the operation of wastewater collection and treatment systems, as well as disposal of wastewater sludge and storm drainage.

As shown in the *Water Act*, *EPEA* also contains strong enforcement measures to ensure the compliance of environmental regulations. Penalties under *EPEA* range from fines to imprisonment, or both depending on the infraction.

Fisheries Act (Government of Canada)

The federal *Fisheries Act* was established to manage and protect Canada's fisheries and their supporting habitats. It applies to all Canadian waters and the exclusive economic zone and continental shelf of Canada. The Act also applies in all provinces and territories, and affects provincial, territorial and federal governments.

The *Fisheries Act* is a powerful regulatory tool and provides strong penalties for contraventions. The penalties for harmful destruction, alteration or disruption or deposition of deleterious substance in fish-bearing water ranges up to $300,000 depending on the severity of the offence, with penalties up $1M for more severe offences.

The Department of Fisheries and Oceans Canada (DFO) is responsible to Parliament for administering the provisions of the *Fisheries Act*, which are designed to protect fish habitat. The provisions described below are particularly relevant for protecting and conserving fish and fish habitat.

Fish Habitat Protection

Section 35(1) of the *Fisheries Act* frequently applies to projects undertaken in or near water. This section prohibits the unauthorized "harmful alteration, disruption or destruction of fish habitat" (HADD). DFO defines HADD as "... any change in fish habitat that reduces its capacity to support one or more life processes of fish."

Any HADD that occurs as a result of a work or undertaking is a violation of s. 35(1) of the *Fisheries Act*, unless authorized by the Minister of Fisheries and Oceans (under s. 35[2]) or by regulation. The planning, design, construction and operation phases of a project should include measures to avoid adverse effects on fish habitat. Such measures may include relocating or redesigning the project.

In keeping with the no net loss guiding principle outlined in DFO's *Policy for the Management of Fish Habitat* (1986), an authorization may be issued if HADD cannot be avoided. An authorization is generally issued when the HADD can be compensated. Where adequate compensation is not possible, the habitat losses are unacceptable, or for other reasons (e.g., habitats that are essential or critical for the survival of a fish species), an authorization may be denied.

Other Sections of the *Fisheries Act*

Within the *Fisheries Act* are other sections that also protect fish and fish habitat from the effects of human activities. These include the following:

- *s.20(1)* Requirement for safe passage of fish around an obstruction using fish-ways or canals.
- *s.21(4)* Provision of fish stops or diverters at obstructions.
- *s.22(1)* Provision of sufficient flow over obstructions.
- *s.22(2)* Provision for free upstream and downstream movement of fish during construction of an obstruction.
- *s.22(3)* Provision of sufficient water downstream of an obstruction for the safety of fish and flooding of spawning grounds.
- *s.26* Main channel not to be obstructed.
- *s.29* Nets, weirs, etc., not to obstruct passage.
- *s.30(1)* Requirement for fish guards and screens at water intakes, ditches, channels or canals.
- *s.32* Prohibition of the unauthorized destruction of fish by means other than fishing.
- *s.36(1)* Prohibition of throwing overboard certain substances.
- *s.36(3)* Prohibition of the discharge of deleterious substances in waters frequented by fish, unless otherwise authorized by regulation.
- *s. 36(5)* Governor in Council may make regulations for authorizing certain deposits.
- *s.37(1)* Requirement to provide plans specifications or undertake studies at the request of the Minister of Fisheries and Oceans.
- *s.37(2)* Requirement to implement modification or mitigation measures if ordered by the Minister of Fisheries and Oceans.

Navigable Waters Protection Act (Government of Canada)

The *Navigable Waters Protection Act* (R.S. 1985, c. N-22) (*NWPA*)) applies to many different types of projects undertaken on any of the navigable waterways and coastal zones of Canada. It is implemented to protect the public right to marine navigation, ensure the safety of mariners, and protect the marine environment by enforcing the *Navigable Waters Protection Act* and the *Environmental Assessment Act* with respect to major projects.

The principle objective of the Act is to protect the public right of navigation by prohibiting the building or placement of any "work" in, upon, over, under, through, or across a navigable water without authorization from the Minister of Transport. All structures that are between low and high water marks require federal approval under *NWPA*. Works subject to approval under *NWPA* are listed in Part 1 of the Act.

The authority to determine the navigability of a waterway and consequently the requirement for an application under the *NWPA* rests with the Minister of Transport or designate (see Appendix B for definition of navigable waterway).

Note: An approval granted by the Minister of Transport is not a general approval of construction or an authorization under any law, aside from the *Navigable Waters Protection Act*. An authorization may also be required from the Minister of Fisheries and Oceans under the *Fisheries Act*. DFO should be contacted to obtain information on requirements under the *Fisheries Act.* In addition, local, municipal, provincial and other government offices should be contacted to determine if other approvals are required for the proposed project.

Provincial Initiatives

Water for Life: Alberta's Strategy for Sustainability

Water for Life: Alberta's Strategy for Sustainability is the Government of Alberta's new approach to water management. Released in November 2003, the strategy identifies short-, medium- and long-term goals to ensure safe, secure drinking water, healthy aquatic systems, and reliable quality water supplies for a sustainable economy. It provides a road map to improved water management for years to come.

This strategy was developed following extensive consultation with Albertans. During the public consultations concern was expressed regarding the use of fresh water for oilfield injection purpose, specifically the "permanent loss" of water for oilfield injection. Albertans were also concerned that fresh-water uses for injection purpose could reduce the amount of water available to other water users. (Summaries of all the consultations as well as background and process information on the strategy are available from the following website: www.waterforlife.gov.ab.ca/.)

In response to these concerns, the Minister of Albert Environment established the Advisory Committee on Water Use Practice and Policy in September 2003, to provide advice and recommendations on fresh-water uses for oilfield injection purposes. The work of the Advisory Committee is currently in progress.

The water strategy focuses on three core areas, including water conservation and attaining the knowledge needed to make wise water management decisions. One of the most significant initiatives reflected in the strategy is the partnership approach, which provides opportunities for Albertans to work collaboratively on watershed management. In support of this, a long-term goal of the strategy is the development of Water Management Plans for all major watersheds in Alberta.

Water Management Planning

Water management planning is a process that addresses multiple issues, involves stakeholders, and produces recommendations for water management. These recommendations are then used in forming the basis for a water management plan. The plan is used to provide guidance for water management decision makers when their decisions may affect water quantity, quality, habitat or species within a particular watershed. All activities within a watershed can impact the water sources within it.

The *Framework for Water Management Planning* outlines the process for water management planning and the components for water management plans in the province (http://www3.gov.ab.ca/env/water/Legislation/Framework.pdf). The Framework applies to all types of waterbodies including streams, rivers, lakes, aquifers and wetlands. Staff within Alberta Environment will work with stakeholders and watershed organizations to develop water management plans for Alberta's major watersheds. Using the Framework, individuals or organizations may initiate a water management plan by following the direction and process provided, to ensure appropriate input is obtained from stakeholders and the necessary steps are followed to obtain support from Alberta Environment.

Groundwater Allocation Policy for Oilfield Injection Purposes

In 1990, Alberta Environment implemented the Groundwater Allocation Policy for Oilfield Injection Purposes. The purpose of this policy is to manage groundwater resources in the White Area (settled area of the province) in a manner that provides continued protection of the existing and future domestic, municipal, agricultural and industrial water users while maintaining the principle of multi-purpose use of water. Under this policy, oil and gas industries are required to investigate alternative recovery methods and alternative sources of water before applying to use potable groundwater. The policy also outlines quantity limitations and time limit restrictions on water diversions. The main principles of the policy are described below.

Principles of Policy

- **Quantity Limitation —** Applicants proposing to use potable groundwater for oilfield injection will be restricted to a maximum of one half of the long-term yield of a given aquifer in the immediate vicinity of the water source well.
- **Time Limit Restriction —** All initial approvals will be limited to a one year time period. The first five-year extension will be issued only if the aquifer is performing in accordance with the terms and conditions of the approval, and without unreasonable negative impact on other wells in the community. Future annual extensions will automatically be granted for five-year time periods if the required conditions are met, and no applications that exceed the remaining available aquifer capacity have been received from the surrounding community.
- **Surface Water, Non-Potable Groundwater and Non-Water Alternatives —** It is understood that an appropriate level of investigation into the use of surface water, non-potable water and non-alternatives water will be carried out by the applicant prior to the

submission of an application to develop a potable groundwater source for oilfield injection purposes.

- **Monitoring Stations —** Groundwater monitoring stations must be established and available for inspection by designated officials and affected parties.

Cold Lake Subregional Integrated Resource Plan

The Cold Lake Sub-Regional Integrated Resource Plan (IRP) was prepared by government agencies and public consultants in recognition of the need for improved management of Alberta's lands and resources. It was approved by Cabinet in 1996, and applies only to public lands within the Cold Lake planning area, not to Métis Settlements or private or federal lands. The plan is intended to be a guide for resource managers, industry and the public in the Cold Lake area, rather than a regulatory mechanism.

The Cold Lake IRP focuses on land allocation and management. It also addresses water management as a necessary means to reduce impacts on water resources, and to maintain habitat as well as opportunities for recreational use. However, the IRP is based on the 1985 Cold Lake–Beaver River Long-Term Water Management Plan, which is being updated by the Cold Lake–Beaver River Water Management Plan (2004) to more accurately reflect changing use of the area.

Prairie Provinces Master Agreement on Apportionment

Alberta shares borders with British Columbia, Northwest Territories, Saskatchewan and Montana. Currently, apportionment agreements only exist with Saskatchewan and Montana. In the North and South Saskatchewan and Cold Lake-Beaver River watersheds, the water originates in Alberta and flows into Saskatchewan. The Prairie Provinces Master Agreement on Apportionment (1969) between Alberta and Saskatchewan governs how this water is shared.

The agreement is managed by the Prairie Provinces Water Board (PPWB). It provides for "reasonable and equitable" apportionment of river waters by allotting provinces 50% of the natural flow arising in or flowing through an upstream province, thereby balancing the concepts of territorial sovereignty and territorial integrity. All water diversions and consumptive uses come under the agreement. Natural flow is an important part of the Master Agreement's formula. Broadly defined, it is the volume of flow that would occur in a particular river if that river had never been affected by human activity.

However, it was also recognized that there are downstream surface water quality impacts on some jurisdictions. The Agreement on Water Quality was signed, and became Schedule E to the Master Agreement on Apportionment in 1992. The Agreement defines the water quality mandate of the Board in interprovincial watercourses. It states the PPWB shall "foster and facilitate interprovincial water quality management among the parties that encourages the protection and restoration of the aquatic environment".

APPENDIX B. RELATED TERMINOLOGY AND ACRONYMS

AC	Asbestos cement (pipe)
ALMS	Alberta Lake Management Society
AMWWP	Alberta Municipal Water/Wastewater Partnership
APF	Agriculture Policy Framework
ATV	All-terrain vehicle
BMP	Best management practices
CAFWP	Canada-Alberta Farm Water Program
CAWSEP	Canadian–Alberta Water Supply Expansion Program
CCME	Canadian Council of Ministers of the Environment
CFB	Canadian Forces Base
CLAWR	Cold Lake Air Weapons Range
CLBR	Cold Lake–Beaver River
CLRUC	Cold Lake Regional Utilities Commission
CNRL	Canadian Natural Resources Limited
CSS	Cyclic Steam Stimulation
DFO	Department of Fisheries and Oceans (Canada)
DND	Department of National Defence
EPEA	*Environmental Protection and Enhancement Act* (Alberta)
GIS	Geographic Information System
HADD	Harmful alteration, disruption or destruction (of fish habitat) (Federal *Fisheries Act*)
IMAC	Interim maximum acceptable concentration
LICA	Lakeland Industry and Community Association
MASL	metres above sea level
MD	Municipal District
NWPA	*Navigable Waters Protection Act*
NWSEP	National Water Supply Expansion Program
PFRA	Prairie Farm Rehabilitation Association
PPWB	Prairie Provinces Water Board
PRA	Provincial Recreation Area
SAGD	Steam Assisted Gravity Drainage

SSARR	Streamflow Synthesis and Reservoir Regulation (model)
TDL	Temporary Diversion Licenses
TDS	Total Dissolved Solids
USEPA	United States Environmental Protection Agency

Alberta Water Council	A multi-stakeholder group formed in 2004 to provide direction and advice to the Alberta government, stakeholders and the public on improving water management, provide guidance on the implementation of the water strategy, and investigate and report on existing and emerging water issues in Alberta (www.waterforlife.gov.ab.ca).
Allocation	Water redirected for a use other than for domestic purposes. Agricultural, industrial and municipal water users apply to Alberta Environment for a license to use a set allocation of water. This water license outlines the volume, rate and timing of diversion of water.
Approval	Provides authority for constructing works or for undertaking an activity within a waterbody. The approval includes conditions under which the activity can take place.
Aquatic ecosystem	An aquatic area where living and non-living elements of the environment interact. These include rivers, lakes and wetlands, and the variety of plants and animals associated with them.
Aquiclude	An impermeable body of rock that may absorb water slowly but does not transmit it.
Aquifer	An underground water-bearing formation that is capable of yielding water. Aquifers have specific rates of discharge and recharge. As a result, if groundwater is withdrawn faster than it can be recharged, the aquifer cannot sustain itself.
Aquitard	A layer of rock having low permeability that stores groundwater but delays its flow.
Brackish water	Salty or briny water.
Consumptive use	The balance of water taken from a source that is not entirely or directly returned to that source. For example, if water is taken from a lake for cattle to drink, it is considered a consumptive use of water.
cubic dam (dam^3)	1,000 cubic metres of water

Discharge	Water exiting groundwater systems in an upward-oriented, exiting flow into surface waterbodies, marshes, wetlands, springs, etc.
Diversion of water	The impoundment, storage, consumption, taking or removal of water for any purpose. This does not include the taking or removal for the sole purpose of removing an ice jam, drainage, flood control, erosion control or channel realignment.
Domestic water use	Water used for drinking, cooking, washing and yard use. A very small percentage of the water used in this province is used for domestic purposes.
Drinking water	Water that has been treated to provincial standards and is fit for human consumption.
Evapotranspiration	Process where moisture is returned to the air by evaporation from the soil and transpiration by plants.
Groundwater	All water under the surface of the ground whether in liquid or solid state. It originates from rainfall or snowmelt that penetrates the layer of soil just below the surface. For groundwater to be a recoverable resource, it must exist in an aquifer. Groundwater can be found in practically every area of the province, but aquifer depths, yields and water quality vary.
Habitat	The term used to describe the natural home of a living organism. The three components of wildlife habitat are food, shelter and water.
HADD	Any change in fish habitat that reduces its capacity to support one or more life processes of fish. (DFO)
Household purposes	Water used for human consumption, sanitation, fire prevention and watering animals, gardens, lawns and trees.
Hydrologic cycle	The process by which water evaporates from oceans and other bodies of water, accumulates as water vapor in clouds, and returns to oceans and other bodies of water as rain and snow, or as run-off from this precipitation or as groundwater. (Also called water cycle.)
Instream needs	The scientifically determined amount of water, flow rate or water level that is required in a river or other body of water to sustain a healthy aquatic environment or to meet human needs such as recreation, navigation, waste assimilation, or aesthetics. An instream need is not necessarily the same as the natural flow.
Irrigation district	A water delivery system for a given region.

Littoral zone	The shallow shoreline area of a lake.
Micro-organisms	Tiny living organisms that can be seen only with the aid of a microscope. Some micro-organisms can cause acute health problems when consumed in drinking water.
Natural flow	The volume of flow that would occur in a particular river if that river had never been affected by human activity Natural flow is the flow in rivers that would have occurred in the absence of any man-made effects.
Navigable water	Designates any body of water capable, in its natural state, of being navigated by any type of floating vessel for the purpose of transportation, recreation or commerce and includes a canal and any other body of water created or altered for the benefit of the public, as a result of the waterway assigned for public use. (NWPA)
Non-consumptive use	A use of water in which all of the water used is directly returned to the source from which it came. For example, water used in the production of hydroelectricity is a non-consumptive water use.
Non-point source pollution	Contamination that cannot be identified as originating from one site. This type of pollution comes from a larger area of land and is carried by run-off and groundwater.
Organic contaminants	Carbon-based chemicals, such as solvents and pesticides, which can enter water through run-off from cropland or discharge from industrial operations.
Point source pollution	Pollution that originates from an identifiable cause or location, such as a sewage treatment plant or feedlot.
Potable water	Water that is fit for human consumption, but has not been treated.
Produced water	Water that comes from an oil or gas well during production is called produced water. Some of this water exists naturally within the formation. In the case of steam injection processes, however, the term generally refers to water recovered from an oil reservoir following steam injection. This recovered water can be recycled and used over again, and is an important factor in minimizing the volumes of freshwater that could otherwise be required.
Raw water	Water in its natural state, prior to any treatment for drinking.
Recharge	Water entering groundwater flow systems through the downward-directed percolation of infiltrating precipitation or directly from surface waterbodies.

Reservoir	Man-made lake that collects and stores water for future uses. During periods of low river flow, reservoirs can release additional flow if water is available.
Riparian area	The area along streams, lakes and wetlands where water and land interact. These areas support plants and animals, and protect aquatic ecosystems by filtering out sediments and nutrients originating from upland areas.
River basin	An area of land drained by a river and its associated streams or tributaries. Alberta's *Water Act* identifies seven major river basins within the province: Peace/Slave River Basin, Athabasca River Basin, North Saskatchewan River Basin, South Saskatchewan River Basin, Milk River Basin, Beaver River Basin, Hay River Basin.
River reach	A group of river segments with similar biophysical characteristics. Most river reaches represent simple streams and rivers, while some river reaches represent the shorelines of wide rivers, lakes and coastlines.
Run-off	Refers to water that moves over the surface of the ground. Run-off collects sediments and contaminants as it moves from higher elevations to lower elevations.
Surface water	Water sources such as lakes and rivers, from which most Albertans get their water. The run-off from rain and snow renews surface water sources each year. If the demand for surface water is higher than the supply, there will not be enough available to balance the needs of Albertans, the economy and the environment.
Water allocation transfer	A water allocation transfer occurs after the holder of an existing water withdrawal license agrees to provide all or part of the amount they are allocated to another person or organization, Alberta Environment next approve any transfer of this kind. When this occurs, the allocation is separated from the original land, and a new license, with the seniority of the transferred allocation, is issued and attached to the new location. Under the *Water Act*, Alberta Environment can place conditions on the new license. Water allocation transfers can occur only if authorized under an approved water management plan, or by the Lieutenant Governor in Council.
Waterbody	Any location where water flows or is present, whether or not the flow or the presence of water is continuous, intermittent or occurs only during a flood. This includes, but is not limited to, wetlands and aquifers.

Water conservation	The planned protection, improvement and wise use of natural resources. It includes controlling, protecting and managing water.
Water conservation objective	As outlined in Alberta's *Water Act*, a water conservation objective is the amount and quality of water necessary for the protection of a natural waterbody or its aquatic environment. It may also include water necessary to maintain a rate of flow or water level requirements.
Watercourse	A creek, ditch or other permanent or intermittent stream that has a well-defined channel with a streambed or banks.
Water license	Provides the authority for diverting and using surface water or groundwater. The license identifies the water source; the location of the diversion site; an amount of water to be diverted and used from that source; the priority of the "water right" established by the license; and the condition under which the diversion and use must take place.
Watershed	The area of land that catches precipitation and drains it into a larger body of water such as a marsh, stream, river or lake.
Watershed approach	Focuses efforts within watersheds, taking into consideration both ground and surface water flow. This approach recognizes and plans for the interaction of land, waters, plants, animals and people. Focusing efforts at the watershed level gives the local watershed community a comprehensive understanding of local management needs, and encourages locally led management decisions.
Water well	An opening in the ground, whether drilled or altered from its natural state, that is used for the production of groundwater, obtaining data on groundwater, or recharging an underground formation from which groundwater can be recovered. By definition in the provincial *Water Act*, a water well also includes any related equipment, buildings, and structures.
Wetland	Wetlands are formed in depressions or low areas where the ground is saturated with water or is flooded. Alberta has five types of wetlands: bogs, fens, swamps, marshes and ponds.
Xeriscape	The conservation of water and energy through creative landscaping (from the Greek word "Xeros" meaning dry).

APPENDIX C. BIBLIOGRAPHY

Berry, D.K. 1995. Alberta's Walleye Management and Recovery Plan. Alberta Environmental Protection, Natural Resources Service, Fisheries Management Division.

Berry, D.K. 1999. Alberta's Northern Pike Management and Recovery Plan. Alberta Environment, Natural Resources Service, Fish and Wildlife Management Division.

Boreal Caribou Committee. September 2001. Strategic Plan and Industrial Guidelines for Boreal Caribou Ranges in Northern Alberta. Sustainable Resource Development. Government of Alberta. (http://www3.gov.ab.ca/srd/land/pdf/Strategic_Plan_rwoods.pdf).

Environment Canada. 1994. National Action Plan to Encourage Municipal Water Use Efficiency. Canadian Council of Ministers of the Environment (CCME) Water Use Efficiency Task Group. (http://www.ec.gc.ca/water/en/info/pubs/action/e_action.htm).

Environment Canada. 1999b. Municipal water use database (MUD). Ottawa, Ontario.

Fetter, C.W. 1999. Contaminant Hydrogeology. Prentice-Hall Inc., Upper Saddle River, New Jersey. 500 pp.

Fisheries and Oceans Canada. 1986. Policy for the Management of Fish Habitat. (http://www.dfo-mpo.gc.ca/canwaters-eauxcan/infocentre/legislation-lois/policies/fhm-policy/index_e.asp).

Freeze, R.A. and Cherry, J.A. (1979): Groundwater; Prentice Hall Inc., Englewood Cliffs, NJ, 604 p.

Komex International Ltd. January 2003. Lakeland Region Watershed Study, Volume 1. Prepared for Lakeland Industry Community Association (LICA).

Lemay, T.G. (2004). Regional Groundwater Quality Appraisal, Cold Lake-Beaver River Drainage Basin, Alberta (Draft). Alberta Energy and Utilities Board, EUB/AGS Client Report. Alberta.

Lovey, H.A. 2004. The Fish and Fisheries of the Cold Lake–Beaver River Basin. An update of their status and utilization. Alberta Environment, Alberta Sustainable Resource Development, Fisheries and Oceans Canada, Edmonton, and Lakeland Industry and Community Association, Bonnyville, Alberta.

Marshall Macklin Monaghan Western Limited. 1983. Beaver River Basin Water-Based Recreation. *In* Cold Lake-Beaver River water management study, Vol. 6: Recreation. Alberta Environment, Edmonton.

Rippon, (sic), B. 1983. Water related wildlife resources. Appendix I, Volume 5, Fisheries and Wildlife. Cold Lake–Beaver River Water Management Study. Alberta Environment Planning Division, Edmonton, Alberta.

Rippin, B. 2004. An assessment of change in habitat and associated wildlife on 28 lakes in the Cold Lake–Beaver River Watershed from 1980 to 2003. Report to Alberta Environment, Edmonton. 148 pp.

Welch, E.B. 1980. Ecological effects of wastewater and applied limnology and pollution effects. Cambridge University Press. Cambridge.

APPENDIX D. INTRODUCTION TO HYDROGEOLOGY

Groundwater in the Subsurface

Groundwater is an integral part of the hydrologic cycle. Some precipitation falling to the earth's surface eventually infiltrates through the unsaturated subsurface where it recharges aquifers and becomes incorporated into the subsurface groundwater flow regime. Figure D-1 presents a conceptual diagram of the hydrologic cycle.

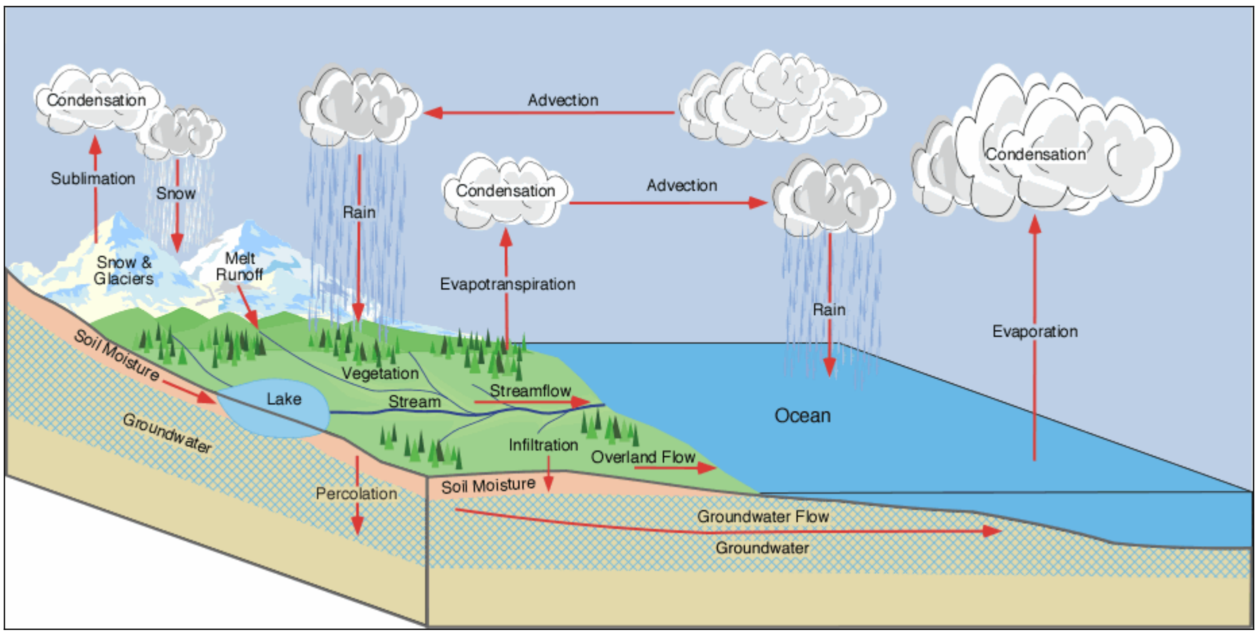


Figure D-1. Hydrologic cycle.

It should also be noted that humans are also a part of the hydrologic cycle, as human use or diversions of water for municipal, agricultural, industrial and other purposes can have a direct influence on the system.

In general, the subsurface can be broken into two distinct zones—the unsaturated zone and the saturated zone. The unsaturated zone (also termed the vadose zone) refers to the portion of the subsurface that lies above the groundwater table. In this region, the void space of the geologic medium is not completely saturated with water. Figure D-2 presents a conceptual diagram of the various subsurface zones.

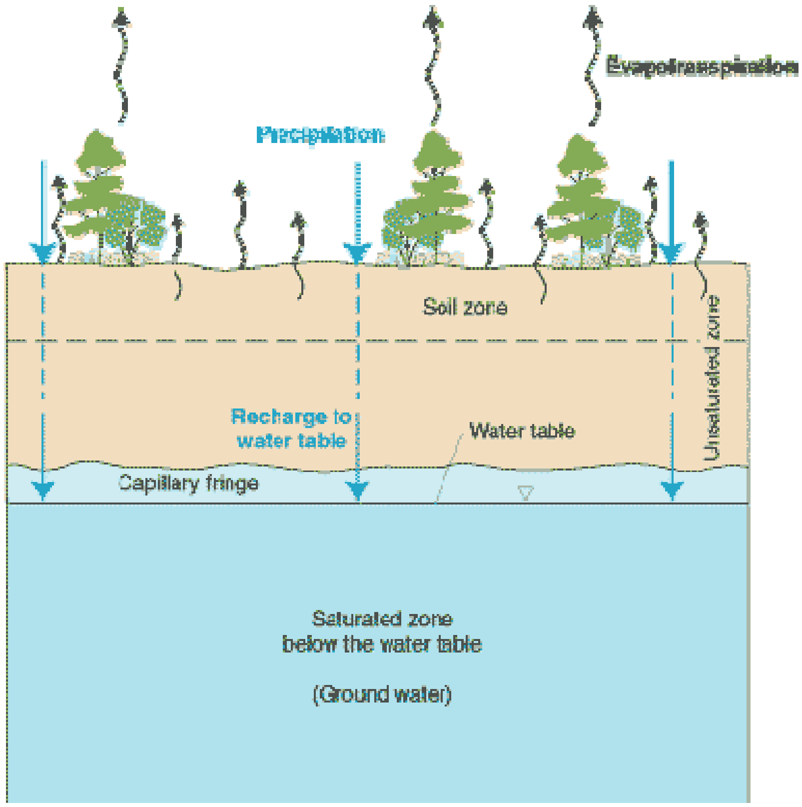


Figure D-2. Unsaturated and saturated zones.

Once atmospheric water infiltrates through the unsaturated zone, it becomes part of the saturated zone. The saturated zone refers to the portion of the subsurface that is situated below the groundwater table. Here the available pore spaces within the geologic medium are filled with groundwater, which in turn becomes available for water supply by drilling and pumping a well. Groundwater below the water table is generally in constant motion (albeit at times very slowly), and moves under the influence of changes in piezometric head.

Piezometric Head and the Piezometric Surface

The movement of groundwater in the subsurface is in response to a driving mechanism or change in potential energy of the subsurface system. Like surface water, which moves from high ground elevations to lower elevations, groundwater will move from areas of high potential energy (generally upland areas) towards areas of lower potential energy (for example, lowland areas which often contain surface water bodies). Piezometric head (also termed hydraulic head) is the term used to describe the fluid potential at a given point within a subsurface system. The piezometric head is a measure of the elevation to which the water level in a well will rise above an arbitrary datum (most commonly mean sea level). Figure D-3 presents a typical series of maps that hydrogeologists construct to determine groundwater flow directions and gradients.

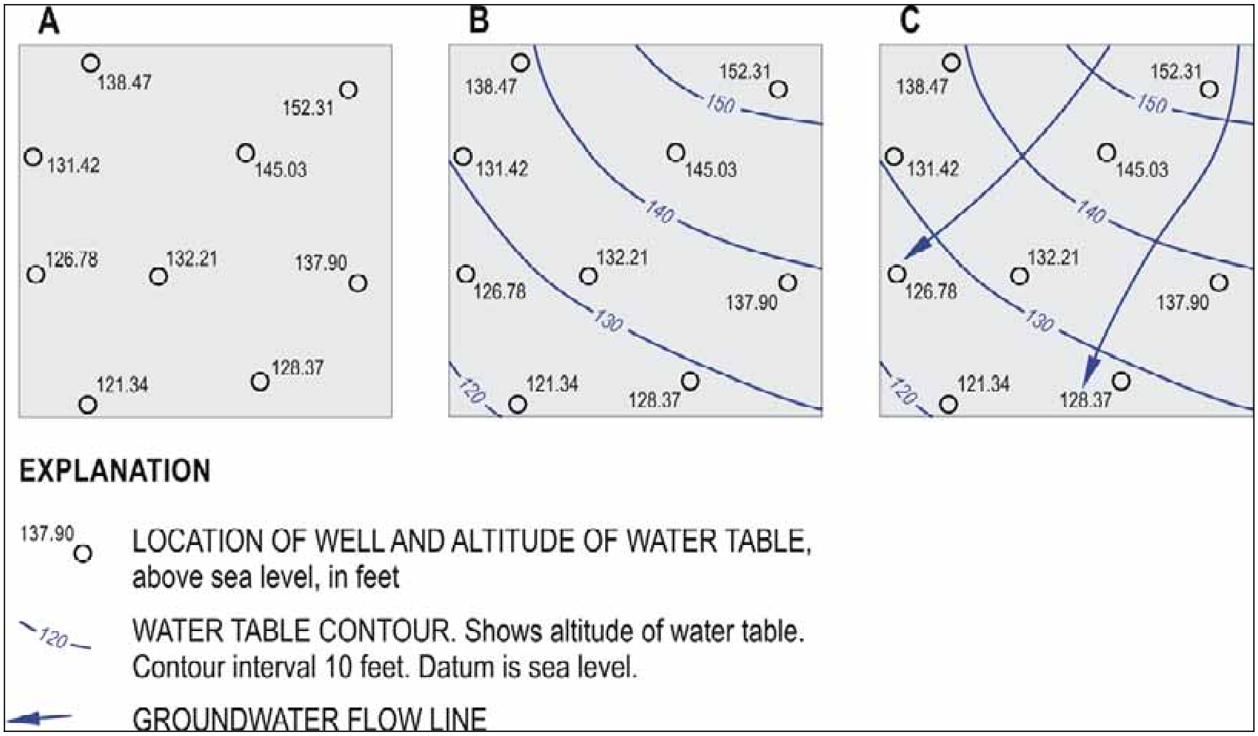


Figure D-3. Piezometric surface and horizontal hydraulic gradients.

Once the hydraulic head has been defined for several points within a subsurface system ("A" in Figure D-3), a three-dimensional piezometric surface (also termed potentiometric surface) can be established for that system. By drawing equipotential lines (contours) through points in the system of equal hydraulic head ("B" in Figure D-3), a two-dimensional representation of the three dimensional surface can be drawn. The piezometric surface represents the areal distribution of hydraulic head in a subsurface system. It can be thought of as an imaginary surface that coincides with the water levels in an aquifer.

The piezometric surface can be used to estimate the movement of groundwater in the subsurface. Groundwater will move perpendicular to the equipotential lines on a piezometric surface from points of higher hydraulic head to points of lower hydraulic head ("C" in Figure D-3).

This information can be used to determine the direction of groundwater movement and the rate of movement. The piezometric surface can also be used to interpret changes in hydraulic gradient. In places where the equipotential lines are tightly spaced, the hydraulic gradient is greater than in places where the equipotential lines are spaced far apart from each other.

A hydraulic gradient can also be measured in a vertical direction between two points at the same location, but at varying depths. Figure D-4 presents a conceptual diagram of three wells completed at different depths but at the same location.

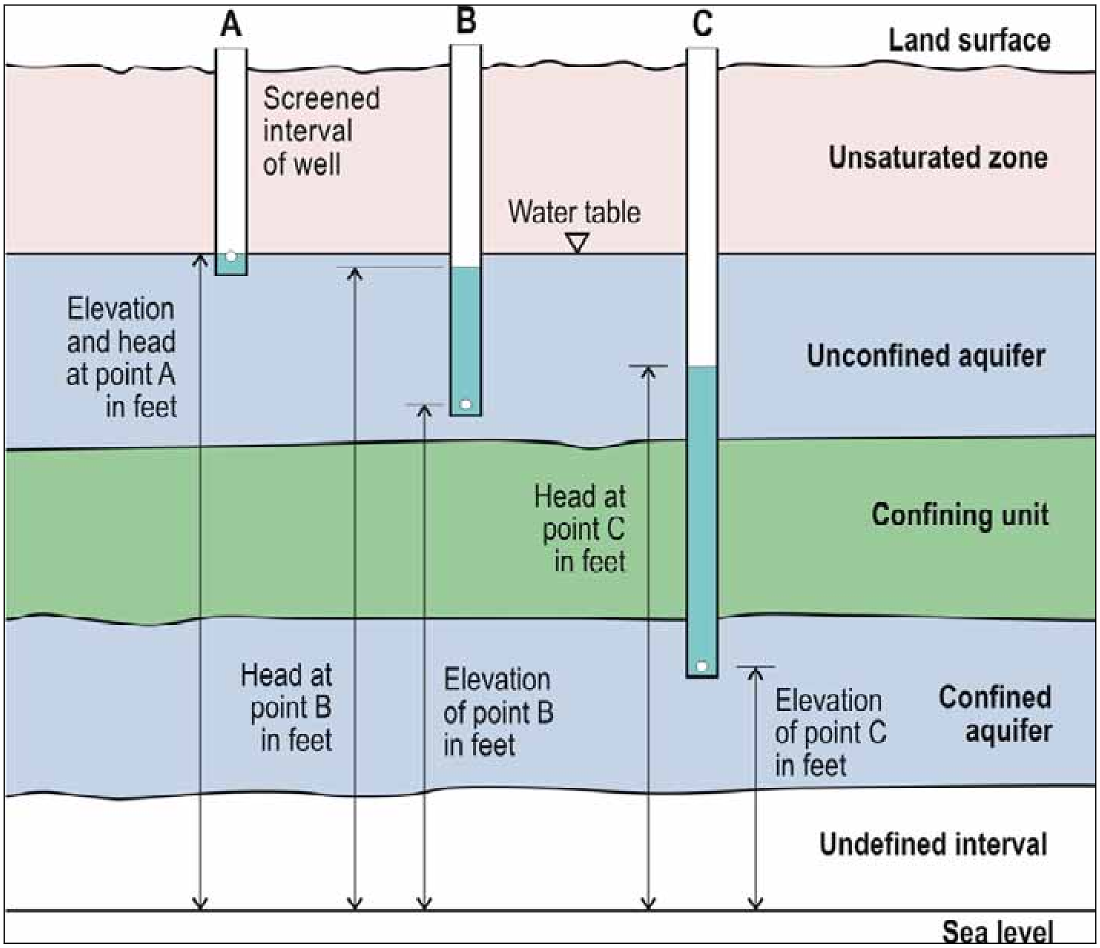


Figure D-4. Vertical hydraulic gradient.

As the hydraulic head in Well A is higher than the hydraulic head in Well B, which in turn, is higher than the hydraulic head in Well C, the vertical movement of groundwater is downward. Groundwater will always move from points of higher hydraulic head to points of lower hydraulic head, either horizontally or vertically.

Classification of Geological Units

Geologic units can be classified based on their ability to transmit water across their boundaries. The terms aquifer, aquitard and aquiclude are all used to describe geologic units with different physical properties that allow or preclude the movement of groundwater both horizontally and vertically.

An aquifer is defined as an underground water-bearing formation that is capable of yielding water. This broad definition is subjective, as the availability of groundwater may mean that a given geologic unit would be considered an aquifer in a region with scarce groundwater resources, whereas the same geologic unit in a region with abundant groundwater resources may not be considered an aquifer. As such, the term aquifer must be used within the context of a given geographic region.

Aquifers can further be classified into either confined or unconfined aquifers, based on the position of the water table relative to the boundaries of the aquifers, as shown in Figure D-5.

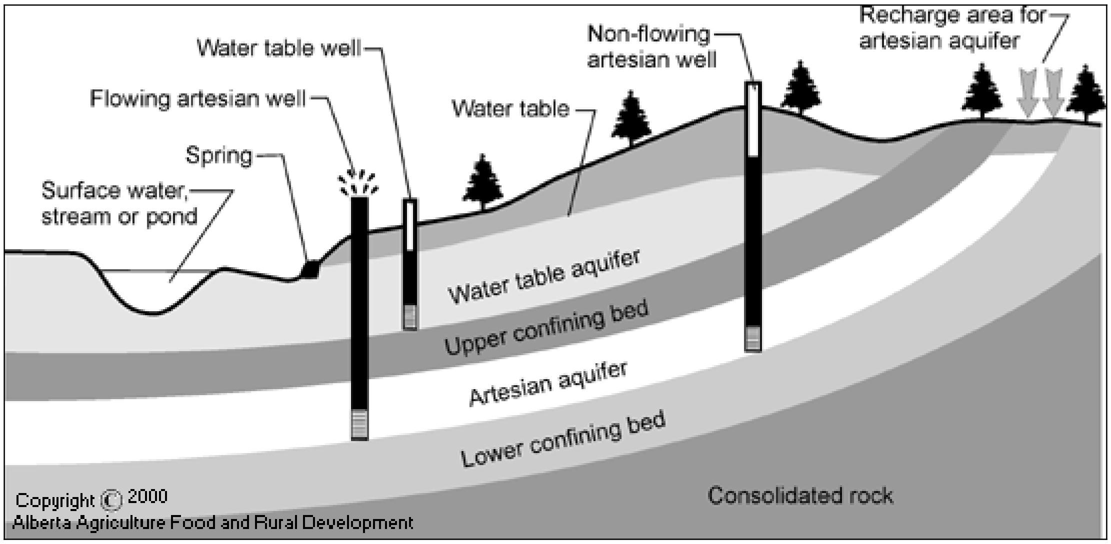


Figure D-5. Unconfined and confined aquifers.

An *unconfined aquifer* is an aquifer whose upper boundary is defined by the groundwater table. Water table aquifers are a type of unconfined aquifer, and as such the saturated thickness of the aquifer may vary with time as the groundwater table rises and falls in response to changes in the hydrologic cycle.

A *confined aquifer* (also termed an *artesian aquifer*) is bound both above and below by a lower permeability geologic unit (upper and lower confining bed). As noted previously, the piezometric surface is an imaginary line to which water would rise if a well were drilled into the confined aquifer. A confined aquifer may also possess an artesian pressure if the height to which water rises in a well is above the land surface. An artesian well will flow without the aid of any pumps. It is important to maintain the confined pressure such that the aquifer remains fully saturated. The potential exists for a confined aquifer to become unconfined if the piezometric surface falls below the top of the aquifer in response to groundwater withdrawals from that aquifer.

An *aquitard* is broadly defined as a geologic unit possessing a lower permeability than the other units in a stratigraphic sequence. Aquitards may be permeable enough to transmit water in quantities that are significant on a regional scale, but their permeability is not sufficient to allow for the completion of production wells within them.

An *aquiclude* is defined as a geologic unit incapable of transmitting water across its boundaries. By strict definition, such geologic units are relatively rare. However, in human time scales versus geologic time scales, and in localized areas, it may be appropriate to consider a given geologic unit an aquiclude.

Geological Parameters Affecting Groundwater Movement

The physical properties of geologic materials greatly affect the movement of groundwater through the subsurface. The porosity, permeability, and hydraulic conductivity of a given geological unit can vary widely over the geographical extent of the unit. The variation of these parameters must be understood before the characterization of the groundwater flow regime can be defined.

Most rocks and soils naturally contain a certain percentage of empty spaces, which may be occupied by water or other fluids. These empty spaces are called the *porosity* of the geological medium. Porosity can vary from near zero to roughly 50%; however, the degree of interconnection of the void spaces will govern movement of fluids through the medium. Although clay has a high porosity, the rate of movement is much less than for sand which can have lower porosity yet higher effective (interconnected) porosity.

Permeability may be described in qualitative terms as the ease with which fluid can move through a porous geologic medium. A material like sand will be sufficiently permeable to supply water to wells, whereas clay is not sufficiently permeable to yield adequate quantities of water for supply.

Hydraulic conductivity is the measure of the ability of the porous geological medium to transmit water. Hydraulic conductivity can range over many orders of magnitude, and best estimates of hydraulic conductivity are derived by conducting pumping tests. The hydraulic conductivity reflects the permeability of the porous media through which the water flows.

Hydraulic conductivity can have different values depending on the direction the water is flowing through the porous medium. In such a case, the medium is said to be *anisotropic*. If the hydraulic conductivity is the same in all directions, the medium is said to be *isotropic*.

Heterogeneity refers to the variation in a parameter with respect to spatial position within a given geological unit. A geological unit is homogeneous (with respect to permeability) if the permeability is the same from one point to another within the unit. Geological units whose permeability varies from one point to another are called *heterogeneous*.

The *storativity* relates to the volume of water that an aquifer releases or takes into storage in response to changes in pressure; for example, pumping. The storativity of confined aquifers is much less than that of unconfined aquifers, often by one or more orders of magnitude. Consequently, the effects of pumping are detected at much greater distances.

Transmissivity is the product of the saturated formation thickness and hydraulic conductivity. As such, it is a measure of the rate of flow of water through the entire saturated formation thickness.

Regional Groundwater Flow Concepts

The concept of regional groundwater flow is very important in undertaking the CLBR Basin study, and in understanding the application of the groundwater flow model. Figure D-6 illustrates the movement of groundwater in a theoretical groundwater flow system.

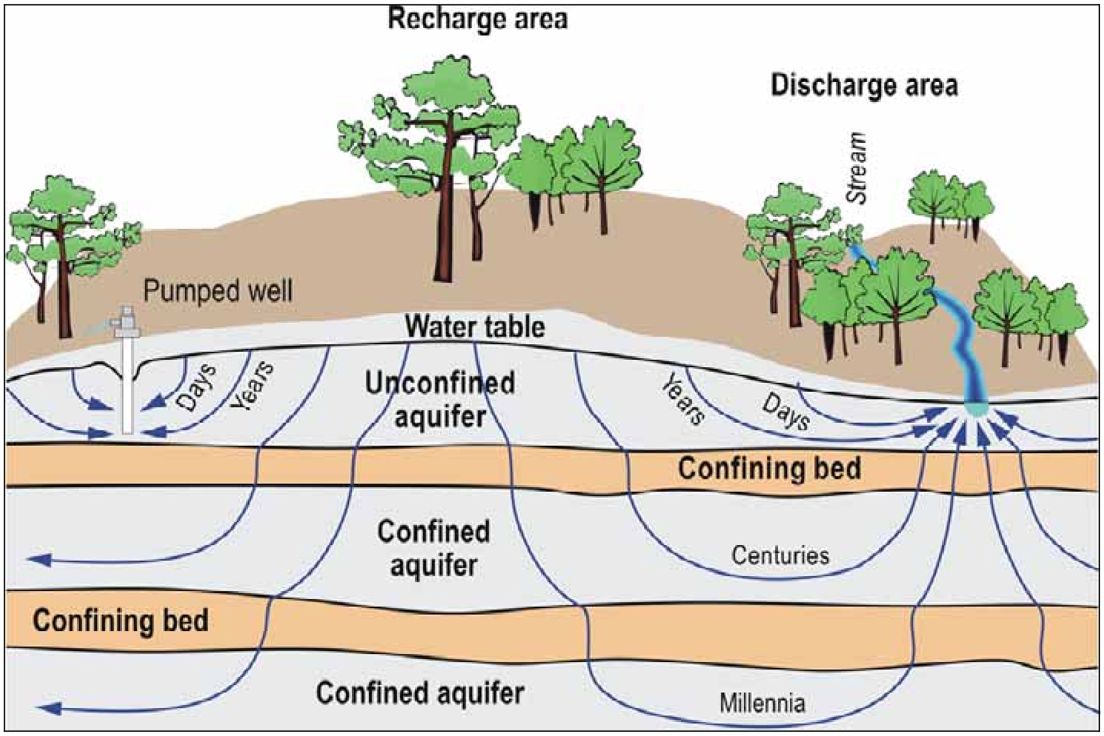


Figure D-6. Groundwater flow system.

Water enters groundwater flow systems via infiltration in recharge areas, or in some cases directly from surface water bodies. In shallow groundwater systems, groundwater moves from areas of high hydraulic head to areas of lower hydraulic head, which is generally controlled by surface topography. In the shallow groundwater system, travel times from recharge areas to discharge areas are typically measured in days or years. Water can exit shallow groundwater flow systems by upward flow into surface water bodies (rivers, lakes, etc.). This upward flow is called discharge, and the volumes of groundwater released to surface water will depend on the geological characteristics of the flow system.

Downward directed entering flow is called *recharge*. If the vertical hydraulic gradient is downward, groundwater migrates slowly through overlying confining beds to recharge underlying aquifers. This vertical migration is extremely slow, and consequently travel times for groundwater in deeper aquifers is typically measured in centuries or millennia.

Groundwater/Surface Water Interaction

Under natural conditions, groundwater moves from recharge areas to discharge areas, as shown schematically in “A” of Figure D-7. Pumping of a well intercepts groundwater that is slowly moving from recharge areas to discharge areas (“B” of Figure D-7). The initial effect is to reduce the quantity of discharge. With time, reversal of hydraulic gradients can occur such that the groundwater being pumped is derived partly from induced infiltration of surface water (“C” of Figure D-7).

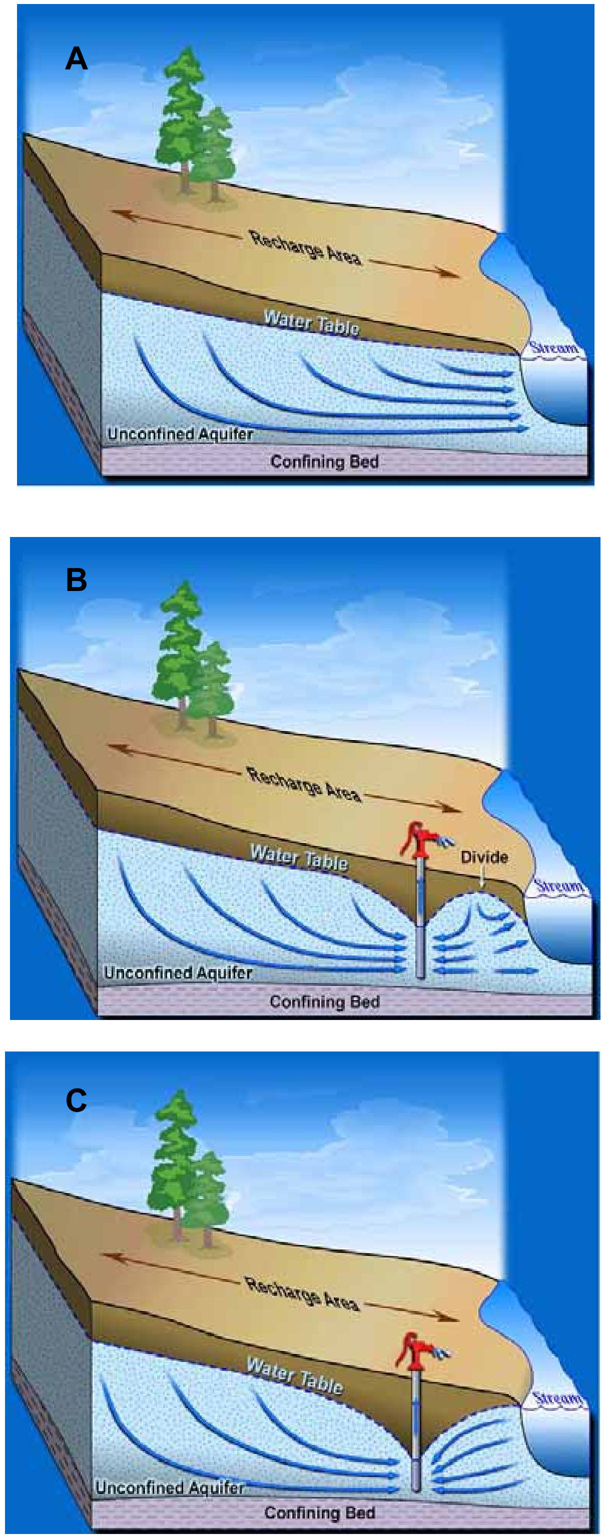


Figure D-7. Effects of groundwater pumping on surface water.

Depending on their position relative to the groundwater table, surface water bodies can gain or lose water to the subsurface system. Where the elevation of the groundwater table is above the elevation of the lake level, the lake will gain water from the groundwater system, as shown in "A" of Figure D-8. Conversely, where the elevation of the groundwater table is below the lake level, the lake will lose water to the groundwater system ("B" of Figure D-8). It is also possible for a lake to be neither gaining nor losing, but rather a flow-through lake where groundwater is entering upgradient of the lake and leaving downgradient of the lake ("C" of Figure D-8).

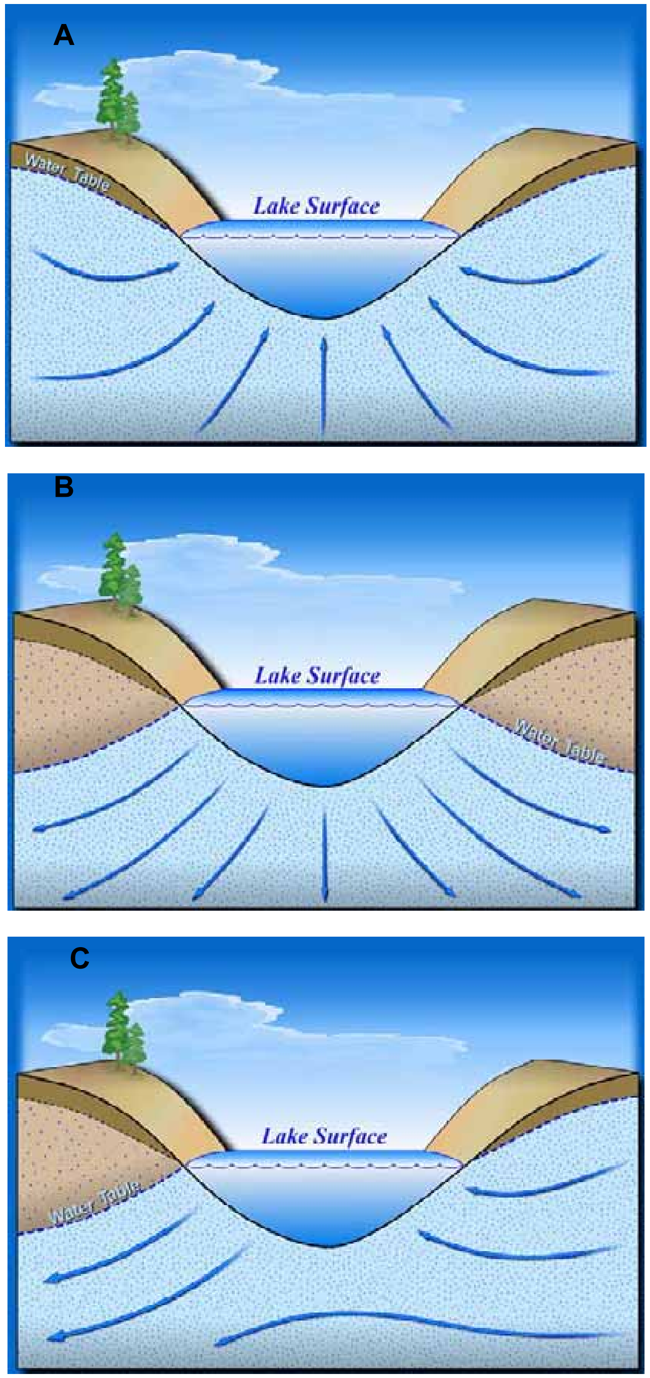


Figure D-8. Schematic diagram of groundwater/lake interaction.

In general, the interaction between groundwater and surface water is a reflection of the location of the surface water body relative to the groundwater flow system. Generally, lakes situated in topographic highs are more likely to be losing lakes, whereas lakes situated in topographic lows are more likely to be gaining lakes. It is possible for a gaining lake to become a losing lake owing to lower groundwater levels during a drought or from nearby groundwater pumping.

It is important to note that Figures D-7 and D-8 show simplified schematics of a very complex system. They depict unconfined aquifers that are directly connected to the lakes and therefore very predictable in their behavior. In the Beaver River basin, there are many low permeability confining beds as illustrated schematically in Figure D-7 which create confined aquifers. These aquifers do not communicate immediately with the surface as shown in Figure D-6, but can take a period of weeks to years (or longer) to draw water from the surface.

Some lakes in the area are quite shallow and are situated on low permeability strata. These lakes are still gaining or losing lakes but the amount of water gained or lost is much smaller than it would be for a lake sitting in close contact with permeable aquifer sands. By far the largest parameters controlling the levels of these lakes are fluctuations in climate that vary the amount of precipitation and evaporation that occur seasonally.

Factors Affecting Groundwater Quality

Several factors affect groundwater quality:

- Depth from surface.
- Permeability and chemical makeup of the sediments through which the groundwater moves.
- Climatic variations.
- Contamination from human activities.

Depth From Surface

Water is the world's greatest and most abundant solvent, and attempts to dissolve everything it contacts. As a result, the longer groundwater takes to move through the sediments, the more mineralized it becomes. Thus, shallow groundwater aquifers have a lower level of mineralization, or TDS, than deeper aquifers. Water from deeper groundwater aquifers typically has a much longer trip to its destination, thus it is usually more mineralized.

While shallow wells have lower TDS levels, they have higher levels of calcium, magnesium and iron than deeper wells. High levels of these minerals make the water "hard". Deeper wells have higher levels of sodium and lower levels of hardness, making the water "soft". The deeper sediments and rock formations contain higher levels of sodium, and as water moves downward through the sediment and rock formation, a natural ion exchange process occurs. Calcium, magnesium and iron in the groundwater are exchanged for sodium in the sediment and rock formations. The result is groundwater with higher levels of sodium and little or no hardness.

Permeability of Sediments

Groundwater moves very slowly through sediments with low permeability, such as clay. This allows more time for minerals to dissolve. In contrast, sediments with high permeability, such as sand, allow groundwater to move more quickly. As a result, there is less time for minerals to dissolve; thus, the groundwater usually contains lower levels of dissolved minerals.

There is also a difference in dissolved solids between groundwater in recharge zones and water in discharge zones. Recharge zones are uplands areas where precipitation enters the ground. Generally, water in recharge zones has a low level of mineralization. Discharge areas are low areas where groundwater flow eventually makes its way back to (or near) the ground surface. Groundwater found in such areas can be extremely high in minerals such as sodium, sulphates, and chlorides (e.g., saline seeps, sloughs and lakes).

Chemical Makeup of Sediments

Another factor affecting groundwater quality is the chemical makeup of minerals in the material through which it flows. Some chemicals are more soluble than others, making them more likely to become dissolved in the water. For example, groundwater in contact with sediments containing large concentrations of sodium, sulphate and chloride will become mineralized at a faster rate than when other chemicals are present.

Climatic Variations

Climatic variations such as annual rainfall and evaporation rates also play an important role in groundwater quality. In semi-arid regions, discharging groundwater often evaporates as it approaches the surface. The minerals from the water are deposited in the soil, creating a salt build-up. Precipitation infiltrating through the soil can re-dissolve the salts, carrying them back into the groundwater. For example, in east-central and southern Alberta where annual precipitation is from 25-40 cm and the evaporation rate is high, TDS are about 2500 mg/L.

In areas with higher precipitation and lower evaporation rates, precipitation that reaches groundwater is less mineralized. In western Alberta where annual precipitation is more than 45 cm, for example, groundwater in surficial deposits contains less than 800 mg/L of TDS.

Groundwater Contamination From Human Activities

Fetter (1999) lists a variety of potential sources of groundwater contamination. These include:

- Septic tanks and cesspools
- Injection wells
- Land application
- Landfills
- Illegal dumping
- Mine waste
- Material stockpiles
- Graveyards
- Animal burial sites
- Above-ground and underground storage tanks
- Containers
- Pipelines

- Material transport by truck or rail
- Irrigation
- Pesticide and fertilizer application
- Farm animal wastes
- Salt application for highway de-icing
- Urban runoff
- Percolation of atmospheric pollutants
- Production wells
- Natural leaching
- Saltwater intrusion.

Contaminant Transport Mechanisms

Contaminants spread in groundwater by three general mechanisms—advection, diffusion and dispersion.

Advection is transport of the contaminant with the general groundwater flow. The contaminants in solution in groundwater will move as the water flows through an aquifer or aquitard.

Diffusion is transport of contaminants from areas of high concentrations of contaminants to areas of low concentration. Contaminant transport by diffusion is not a major mechanism in the overall groundwater flow system, but can be an important mechanism for the movement of contaminants through or from a low-permeability unit to an aquifer (e.g., diffusion of contaminants through a compacted clay liner beneath a landfill).

Dispersion is the spreading out of contaminants as groundwater moves through an aquifer. Groundwater does not follow a straightforward path as it flows through soil or rock formations, thereby resulting in some flow paths moving faster than others. Contaminants contained in faster groundwater move along in front of other groundwater, which causes the contaminant to spread as it moves away from the source.

Contaminant Attenuation Mechanisms

Contaminant concentrations in groundwater can be attenuated or weakened by a variety of natural processes, which include adsorption, chemical reaction and biodegradation. However, not all processes work with all contaminants.

Adsorption is the process by which contaminants in the groundwater stick to the soil particles through which the groundwater flows. This reduces the concentration of the contaminant in the groundwater. Under certain conditions, the material that sticks to the soil particles may return to the groundwater.

Chemical reaction is the process by which a harmful contaminant in the groundwater undergoes a reaction that converts the substance to a non-harmful or less harmful form. These reactions are in the reduction and oxidation processes.

Biodegradation is the process by which organic contaminants in groundwater, such as gasoline, are consumed by microorganisms in the groundwater. The microorganisms convert the harmful contaminants into non-harmful by-products.

APPENDIX E. TECHNICAL ADVISORY COMMITTEE MEMBERS

Groundwater Quality Team

- Margaret Klebek, Contaminant Hydrogeologist Alberta Environment
- Jason Pentland, Contaminant Hydrogeologist, Alberta Environment
- Kate Rich, Groundwater Quality Specialist, Alberta Environment
- Tony Lemay, Hydrogeologist, Alberta Geological Survey
- Chrysta Lane, Environmental Team Leader, Imperial Oil Resources

Groundwater Quantity and Brackish Water Team

- Alan Hingston, Hydrogeologist, Alberta Environment
- Rob George, Hydrogeologist, Alberta Environment
- Brad Braun, CNRL
- Stuart Lunn, Imperial Oil Resources, Hydrogeologist
- Dave Edwards, CNRL, Hydrogeologist

Consultant to Groundwater Teams

- Dr. Kevin Parks, Section Lead, Energy, Alberta Geological Survey

Surface Water Quality

- Theo Charette , Limnologist, Alberta Environment
- Rasel Hossain, Municipal Approvals Engineer, Alberta Environment
- Randy Lewis, Source Of Protection Engineer, Alberta Environment
- Jamie Wuite, Water Quality Specialist, Alberta Agriculture, Food & Rural Development
- Candace Vanin, PFRA Ag-Can

Surface Water Quantity Team

- Pat Marriott, Water Team Leader, Alberta Environment
- Abdi Siad-Omar, Planner, Alberta Environment
- Carmen De La Chevrotiere, Hydrologist, Alberta Environment
- Brian Makowecki, Department Fisheries And Oceans Canada
- Wayne Nelson, Area Wildlife Biologist, Alberta Sustainable Resource Development
- George Walker, Fisheries Biologist, Alberta Sustainable Resource Development
- Paul MacMahon, Regional Head, Fisheries Management, Alberta Sustainable Resource Development
- Brian Ilnicki, Ducks Unlimited
- Chrysta Lane, Environmental Team Leader, Imperial Oil Resources, Cold Lake Operations
- Lori Neufeld, Imperial Oil Resources, Environmental Advisor, Cold Lake Operations