Regional groundwater monitoring initiatives related to the development of Alberta's oil sand resources

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ABSTRACT
Industrial activities related to Alberta's oil sand resources have increased dramatically in recent years and cumulative effects on provincial groundwater resources have become an increasing concern for stakeholders and regulatory agencies. In response, Alberta Environment has initiated studies in key areas to provide: an improved understanding of regional aquifers; the design and implementation of regional groundwater monitoring networks; and the development of regional groundwater management strategies.

This presentation focuses on recent progress made establishing regional groundwater monitoring networks in areas where concentrated industrial activities related to Alberta's oil sand resources are planned or already exist. Although specific to local areas, these groundwater monitoring initiatives form an important part of the overall groundwater management strategy for the province.

RÉSUMÉ
Les activités industrielles liées aux ressources de sables bitumineux d'Alberta ont augmentées considérablement au cours des dernières années et les effets cumulatifs sur les ressources de nappes phréatiques de la province sont devenus une inquiétude croissante pour les parties prenantes et les agences de contrôle. En réponse, Alberta Environment a lancé des études dans les régions clés pour fournir: une compréhension améliorée d'aquifères régionaux; la conception et implémentation des réseaux de surveillance des nappes phréatiques régionales; et le développement de stratégies d'administration des nappes phréatiques régionales.

Cette présentation se concentre sur le progrès récent, fait en établissant des réseaux de surveillance des nappes phréatiques régionales dans les régions où les activités industrielles concentrés liées aux ressources de sables bitumineux d'Alberta sont planifiées ou existent déjà. Bien que spécifique aux régions locales, ces initiatives de surveillance des nappes phréatiques fait une partie importante de la stratégie générale de l'administration des nappes phréatiques pour la province.

1 INTRODUCTION

Protection of the environment has become increasingly important to Albertans in recent years. At the same time, pressures on the environment have increased dramatically due to a booming economy and a rapidly growing population. Presently, in the Northern Region of Alberta the greatest pressures exist in the oil sand resource areas and current projections indicate that these pressures will continue into the future.

Alberta Environment currently operates a provincial Groundwater Observation Well Network (GOWN) and requires site-specific groundwater monitoring for facilities approved through the Alberta Environmental Protection and Enhancement Act (EPEA). The GOWN presently contains too few groundwater monitoring wells (e.g., approximately 12 in the Fort McMurray area) in areas where a high risk for groundwater impact exists. Additionally, the site-specific groundwater monitoring required through the EPEA approval process does not effectively address potential cumulative effects on provincial groundwater resources, as not all activities with the potential to impact the environment can be easily regulated.

In order to more effectively manage regional groundwater resources, Alberta Environment has initiated studies in the oil sand resource areas to provide: an improved understanding of regional aquifers; the design and implementation of regional groundwater monitoring networks; and the development of regional groundwater management strategies.

Extensive groundwater related work has been conducted in the Cold Lake-Beaver River Basin through the redevelopment of the Water Management Plan. This plan was revised and re-released in 2006. A key revision included the recognition of groundwater as an important component of regional water resources. As such, the Cold Lake-Beaver River regional study commenced in 2003. Technical committees for groundwater quality and quantity were formed with Alberta Environment and Industry representatives to develop the groundwater component of the plan. Subsequently, two State of the Basin Reports for groundwater quality and quantity were issued in 2006. These reports built upon related work done by the Alberta Geological Survey, Alberta Research Council, Alberta Public Health and Wellness, Alberta Environment, and industry dating back to the early 1970s.

In addition, as part of the management plan, the Beaver River Watershed Alliance (BRWA) was formed in 2007 and the technical committees were dissolved. Current Water Management Plan initiatives in the Cold Lake-Beaver River area are carried out by the BRWA with assistance from Alberta Environment and the Lakeland Industry and Community Association (LICA). Current initiatives include the development of a groundwater database and the expansion of GOWN to form an improved regional groundwater monitoring network.

An initiative to implement a regional groundwater monitoring network in the Athabasca Oil Sands area north of Fort McMurray was commenced in 2005, with a study conducted by the Alberta Geological Survey, in partnership with Alberta Environment, to improve knowledge of surficial buried valley aquifers in the region (Alberta Geological Survey, 2007). In 2007, Alberta Environment initiated a study through the Cumulative Environmental Management Association (CEMA) to build upon the Alberta Geological Survey mapping and carry out a detailed regional hydrogeological assessment. Alberta Environment then formed a technical groundwater group to manage the project with representatives invited industry and First Nations communities. The implementation of a regional groundwater monitoring network is underway and completion is expected by September, 2009.

Establishing regional groundwater monitoring networks in the Athabasca Oil Sands area south of Fort McMurray and the Peace River Oil Sands area are planned as future initiatives.

2 METHODS

Resources were focussed in high priority areas to begin establishing regional groundwater monitoring networks within the Northern Region of Alberta Environment. The process undertaken was a phased approach generally involving: regional aquifer mapping, regional hydrogeological assessment, regional groundwater monitoring network design, and ongoing management of the regional groundwater monitoring network.

2.1 Regional Aquifer Mapping

Regional aquifer mapping was conducted to define the extent of groundwater resources in three-dimensional space. A series of hydrogeology reports and associated maps were produced by the Alberta Research Council, commencing in 1971. The hydrogeology reports were continued for over a decade until coverage of the entire province was completed and they remain an important resource today. Although they provide important information, the reports are based on limited information at a larger, regional scale. Therefore, additional local, detailed mapping, based on current information is required to address the pressures applied by current industrial and population demands on groundwater in the oil sand resource areas.

The Alberta Geological Survey has conducted extensive mapping in many areas of the province, improving knowledge of surficial deposits, including the spatial extents of buried valley and glacial channel aquifers. Unmapped portions exist in the northwest corner of Alberta, creating a need for improved knowledge of regional surficial aquifers in these areas. In areas designated as a high-priority to address cumulative effects, some updated regional aquifer mapping was conducted as an initial phase to better understand the spatial extents of provincial groundwater resources and provide a conceptual geological framework for the region.

2.2 Regional Hydrogeological Assessment and Groundwater Monitoring Network Design

Once the spatial extents of regional aquifers have been mapped, a significant amount of hydrogeological assessment is required to produce an effective regional groundwater monitoring network. In Alberta, a significant amount of hydrogeological data has been collected throughout the province largely due to oil and gas exploration. However, limited regional groundwater resource assessments using recent database management technologies exist in the public domain.

A variety of hydrogeological data were compiled, ranging from paper reports to digital databases. Regional aquifers were identified and characterized based on various physical, chemical, and biological parameters. An aquifer vulnerability assessment was carried out to identify areas with a higher sensitivity for impacts to groundwater from the surface. Additionally, a conceptual regional hydrogeological flow model was developed for the region to understand the flow dynamics of regional aquifers. A detailed regional hydrogeological assessment is very important, as each layer of knowledge was incorporated into the design of the regional groundwater monitoring network.

The main purpose of the regional groundwater monitoring networks is to establish the present state of groundwater and assess future long-term trends in groundwater quality and quantity. The intent is to monitor potential cumulative effects on a region as a whole from all regulated and non-regulated activities, rather than monitoring focussed on potential impacts to groundwater from site-specific sources. New groundwater monitoring well locations were chosen strategically in high-priority areas to improve the knowledge of regional aquifers and in areas where regional aquifers are most vulnerable to potential impacts form the surface. Current high-quality groundwater monitoring wells were considered during the design in order to enhance coverage and lower the implementation cost of the regional groundwater monitoring network.

2.3 Regional Groundwater Monitoring Network Ongoing Management

Regular sampling and maintenance of groundwater monitoring networks is required to obtain long-term trends, which are necessary to understand complex

hydrological systems. A shared governance model has been adopted to assist in the management of these regional groundwater monitoring networks and Watershed Planning and Advisory Councils (WPACs), formerly established through Alberta Environment's Water For Life Strategy, have proven to be a practical group to achieve this.

Alberta Environment intends to make use of relevant and current technologies to provide groundwater information to the public through web-based data management systems.

3 RESULTS

Work is currently underway for the Athabasca Oil Sands area north of Fort McMurray and the Cold Lake-Beaver River Basin. This discussion focuses on results from the Cold Lake-Beaver River Basin initiative, as much more progress has been made in this region.

Results from the Cold Lake-Beaver River State of the Basin Reports include resource appraisals for groundwater quantity and quality. The appraisals included:

- an assessment of the hydrogeological framework;
- the development of a regional numerical flow model;
- an overview of groundwater flows and interactions with surface water;
- an assessment of brackish water supply;
- a retrospective analysis of groundwater quality data;
- an overview of existing data on deep well disposal;
- recommendations for a program to monitor and assess future groundwater quality; and
- targeting new objectives and locations for groundwater monitoring.

3.1 Regional Groundwater Quantity Appraisal

For the groundwater quantity appraisal, the hydrogeological framework was reassessed with updated information from new developments. The focus of the update was on fresh and extensive Quaternary aquifers, as shown in Figure 1.

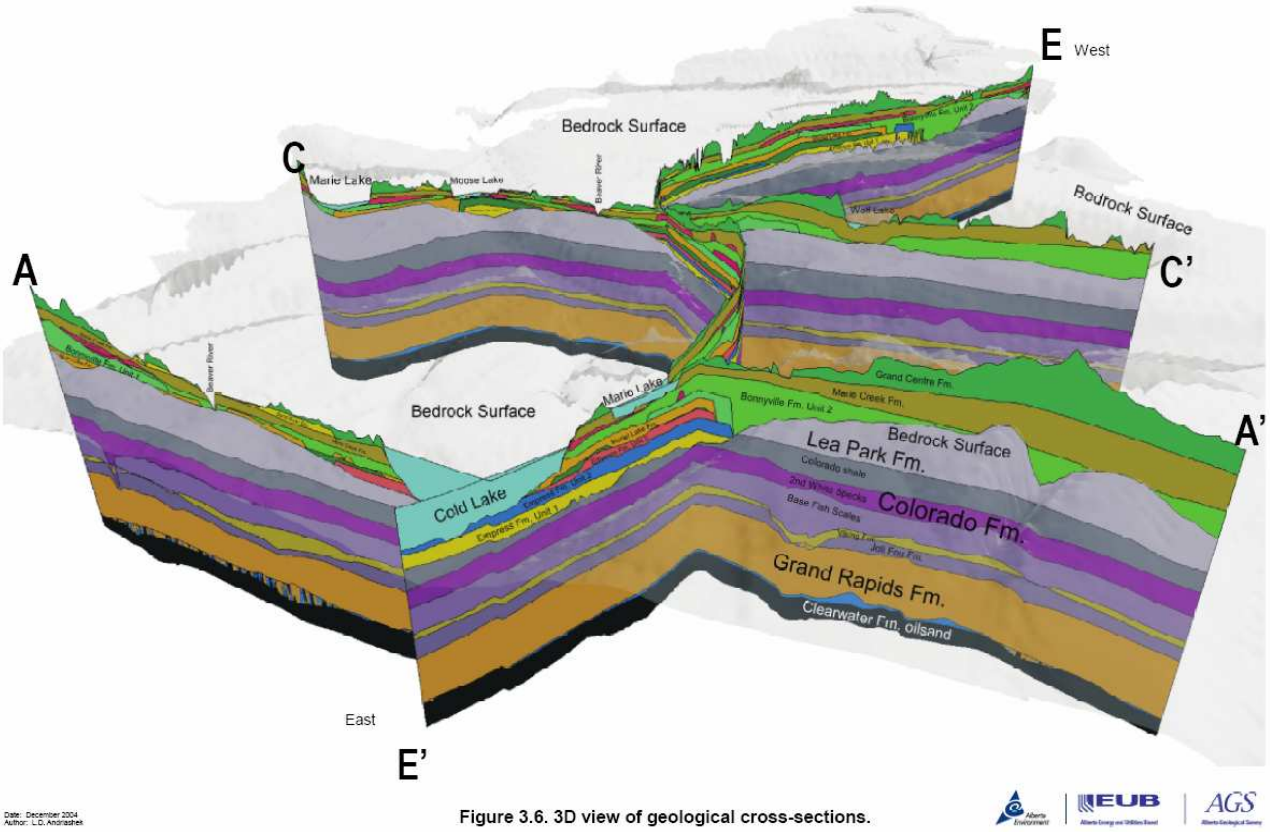

Figure 1. 3-D cross-sections through the Cold-Lake Beaver River Basin (Source: AGS Special Report 74)

The groundwater mapping, historical groundwater level and hydrology monitoring components of the regional study were considered to be complete enough to estimate a regional water balance with a groundwater component. Figure 2 shows results from the average annual water balance for the basin. It was estimated that groundwater within the basin is recharged by approximately 2% of annual precipitation, or 166 million cubic metres of water. It was also estimated that the same amount of groundwater discharge occurs at lakes,

streams, and wetlands, with a small portion leaving the basin through consumptive use.

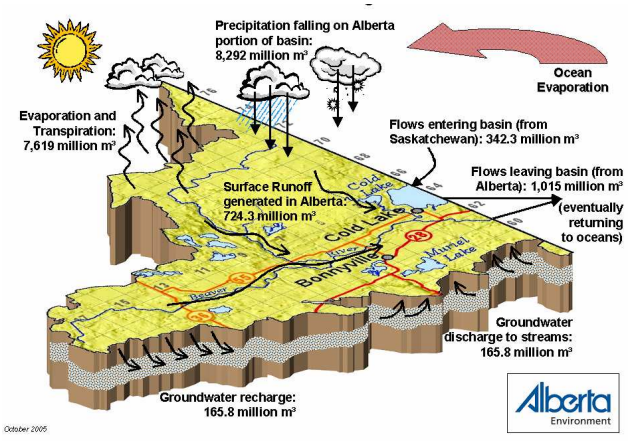

Figure 2. Annual Water Balance

An inventory of fresh groundwater allocations (licensed under the *Water Act* or *Water Resources Act*) and users was completed in conjunction with an inventory of reported use. There are several groundwater users within the Cold Lake Oil Sands deposit area, including domestic, agricultural, municipal and industrial users. When compared with the Athabasca Oil Sand deposit, there are several domestic and agricultural groundwater users in close proximity to past, current and projected resource development activities. Figure 3 shows a map of reported water wells within the Cold Lake-Beaver River Basin.

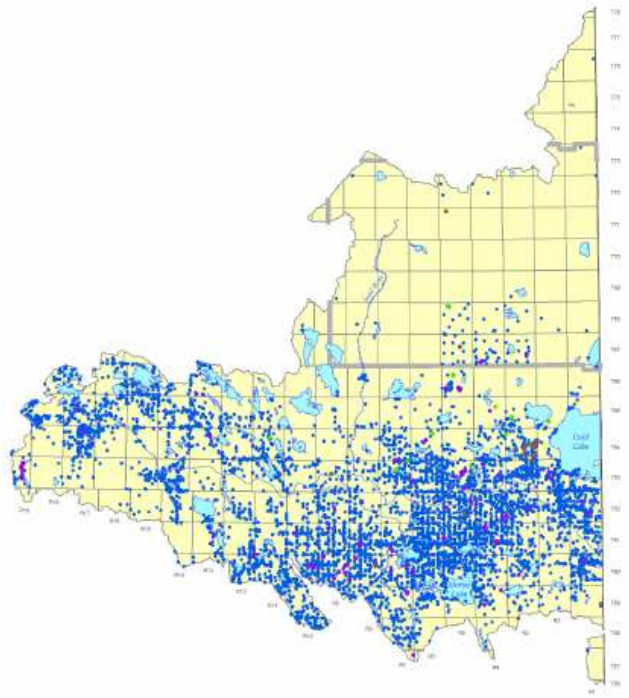

Figure 3. Locations of groundwater wells in the Cold Lake–Beaver River Basin

Through the licence inventory, it was found that groundwater allocations within the basin represent 38% of fresh water allocations (surface water allocations represent the remaining 62%). On a provincial scale, groundwater allocations represent less than 3% of fresh water allocated. Annual groundwater allocations and estimates for unregulated users within the basin totalled approximately 28 million cubic metres (approximately 17 million cubic metres is licensed). The total allocation, when compared to groundwater recharge, was considered to be regionally sustainable. In addition, the inventory of reported groundwater use in the basin was found to represent approximately 33% of the total allocation. Consequently, the need for a pipeline from the North Saskatchewan River was withdrawn from the Water Management Plan.

Alberta Environment retained the Alberta Geological Survey to develop a regional numerical groundwater model to investigate a wide variety of hydrogeological conditions such as estimate groundwater and surface water interaction, and predict impacts due to groundwater pumping as well as estimate groundwater balances and availability. The model was also used to design a regional groundwater monitoring network.

Theoretical transition curves were developed from the regional model for simulated pumping events in various formations at various locations. This type of modelling could allow management of groundwater and surface water as one resource, which is one of the objectives of the Water Management Plan. Figure 4 shows a theoretical transition curve where water produced from a well changes from water released from aquifer storage to reduced discharge to lakes or streams plus induced recharge. In most cases, the model showed that groundwater flowing to a source well would result in a strong interaction with surface water within three years.

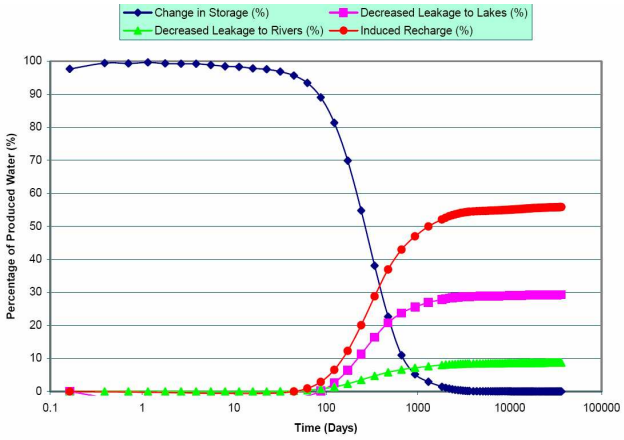

Figure 4. Theoretical transition curve

To address public concern regarding groundwater-surface water interactions around declining lakes within the region, the numerical model was used to calculate fluxes of the groundwater system under steady state and pumping conditions to identify recharge and discharge lakes. Modelled results did not show large groundwater contributions or losses to lakes and the difference between pumping and non-pumping scenarios was assessed as minor. However, there was uncertainty in the modelled fluxes and more work is required to better understand groundwater-surface water interactions around lakes within the basin. Nevertheless, results from this task added confidence in the hypothesis that groundwater plays a relatively minor role in the water balance for declining lakes within the area and that evaporative losses are the main reason why lake levels continue to decline.

Brackish water with Total Dissolved Solids (TDS) concentrations greater than 4000 mg/L is not regulated by Alberta Environment under the *Water Act*. As such, it is important for industry to manage the brackish water resource to ensure sustainability. The *in situ* oil sands operators have conducted numerical groundwater flow modelling studies to assess the availability of brackish water. Thus far, results indicate that there is a sustainable supply of suitable water from the McMurray Formation. The Grand Rapids Formation was identified as a secondary brackish water supply that may be limited by hydraulic conductivity. In addition, it has been determined that a large amount of separation exists between the fresh Quaternary aquifers and brackish water supplies within the area as is displayed in Figure 5.

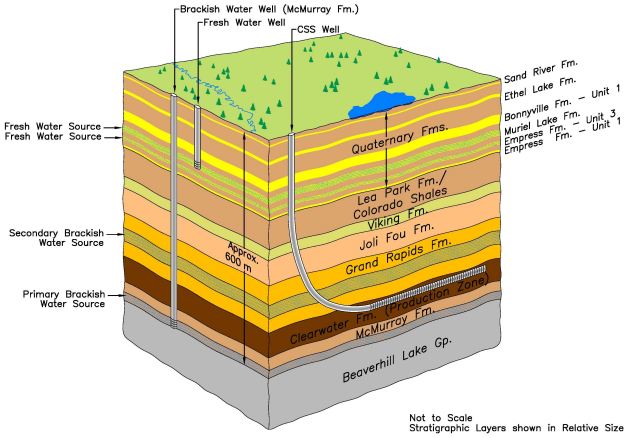

Figure 5. Schematic diagram of subsurface oil sands activities in the Cold Lake-Beaver River Basin

3.2 Regional Groundwater Quantity Appraisal

For the groundwater quality appraisal, the intent was to address public concern for the protection of groundwater quality given the level of oil and gas development occurring in the area. Since oil sands operators in the northeast part of the basin collect and report groundwater data pursuant to EPEA approvals, extensive data around *in situ* facilities indicates that groundwater quality in usable aquifers naturally contains high levels of arsenic and other concentrations of concern (above Guidelines for Canadian Drinking Water Quality). Currently, other parts of the basin have limited dissolved metals data to use for comparative purposes.

To identify and better understand the data gaps, the Alberta Geological Survey compiled a database of groundwater quality within the basin, develop concentration maps, sensitivity maps, and maps of potential contaminant sources. Figure 6 shows a map of arsenic concentrations for various Quaternary hydrostratigraphic units. Similar maps were compiled for TDS, chloride, major ion pie charts, and phenols. Figure 7 shows results of aquifer sensitivity mapping, where areas with high sensitivity to inter-aquifer contamination have been identified. Potential groundwater contaminant sources such as landfills, oil and gas activities, petroleum storage tanks, waste disposal wells, and reported releases were also plotted on the aquifer sensitivity map to further assess regional groundwater quality and to identify areas where further investigation might be required. In spite of the fact that the database was developed after the basin became settled and somewhat industrialized, the database can also be used as a tool to better understand baseline groundwater quality for the area.

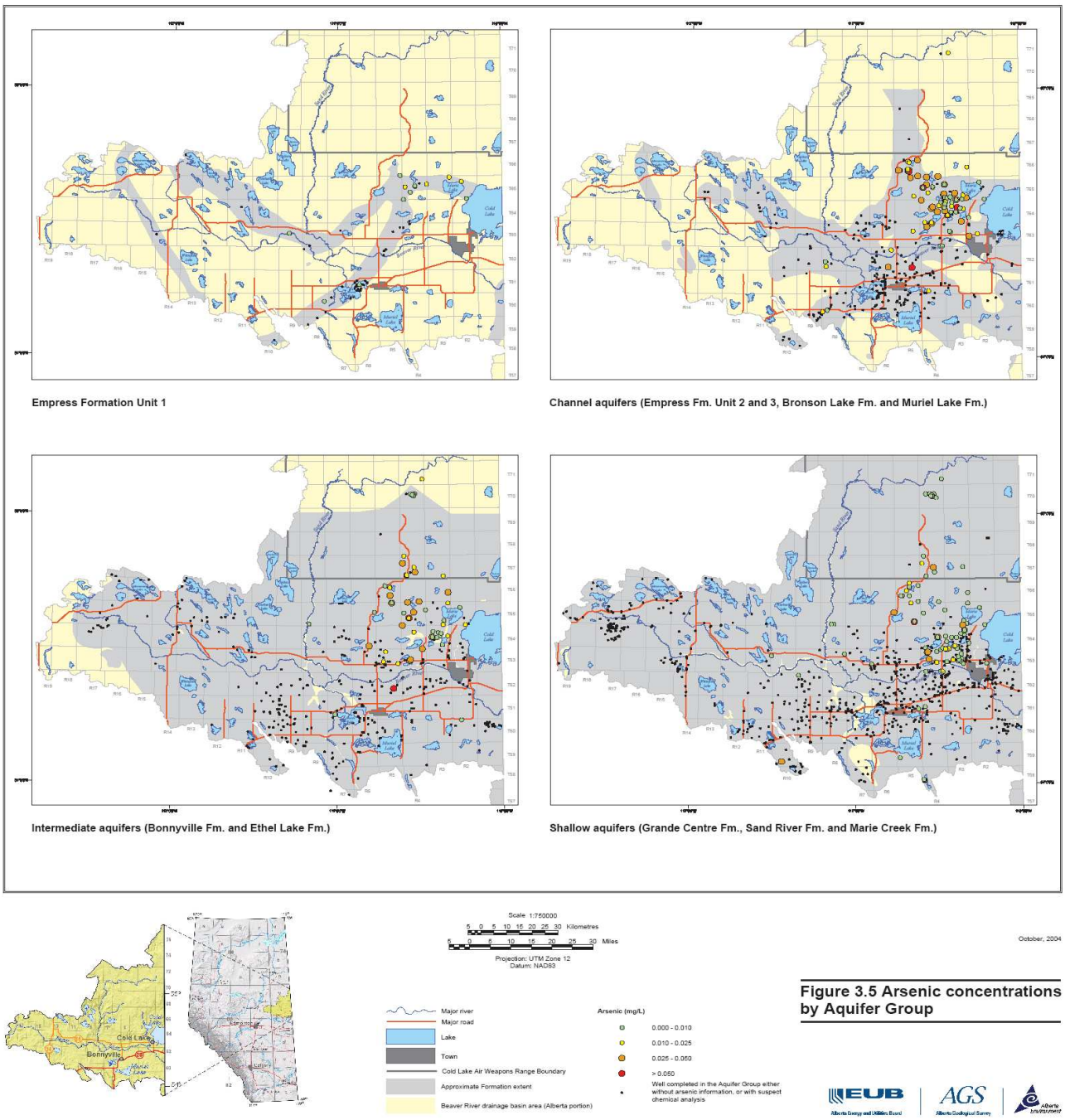

Figure 6. Arsenic Concentrations by Aquifer in the Cold Lake-Beaver River Basin

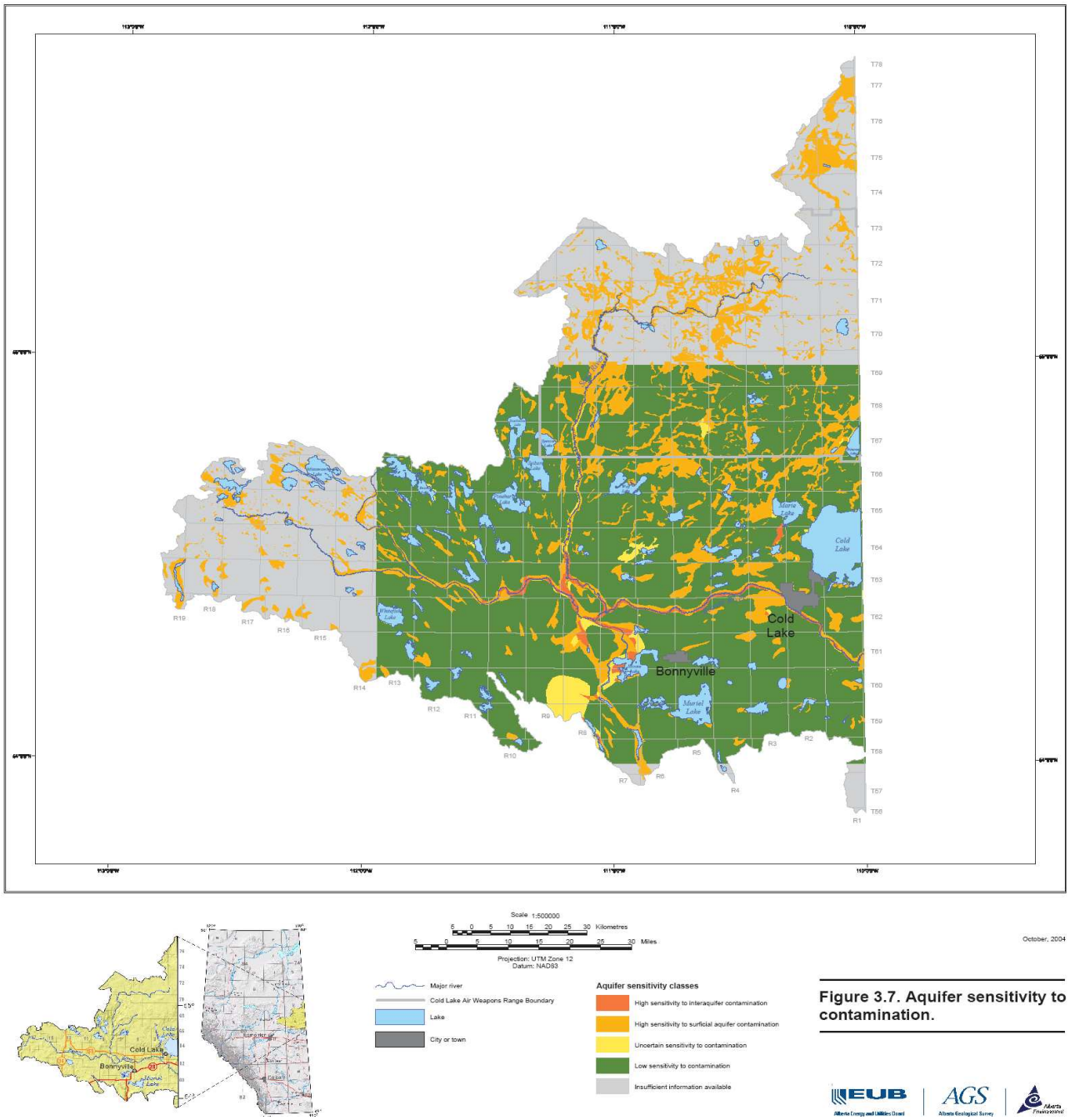

Figure 7. Aquifer Sensitivity to Contamination in the Cold Lake-Beaver River Basin

An inventory of deep well disposal was conducted as part of the study. The study included a review of regulatory requirements and guidelines and formations used for injection purposes. It was found that the regulatory requirement for cemented casing across usable aquifers did not come into effect until the early 1990s. Wells without cemented casings were identified and assigned additional monitoring requirements.

3.3 Regional Groundwater Monitoring Strategy

Information gathered from both groundwater quantity and quality studies will be used to develop a comprehensive, long term groundwater monitoring strategy that will also address data gaps. Increased groundwater monitoring will include installing groundwater monitoring wells and monitoring water levels at buried channel entry and exit points, improving monitoring for groundwater recharge, monitoring groundwater levels in formations that might be hydraulically connected to sensitive lakes, and extending groundwater quality monitoring to target sensitive areas. It was also

recommended that a publicly available groundwater database be constructed to educate the general public and to monitor long term quality trends within the basin. Currently, these initiatives are being carried out by the BRWA with assistance from Alberta Environment and LICA.

4 CONCLUSIONS

Cumulative effects on provincial groundwater resources have become an increasing concern for stakeholders. In response, Alberta Environment instigated initiatives to develop regional groundwater monitoring networks in the Cold Lake-Beaver River Basin and the Athabasca Oil Sands area north of Fort McMurray. The Cold Lake-Beaver River Basin initiative has progressed to the implementation of an operating regional groundwater monitoring network. The Athabasca Oil Sands initiative north of Fort McMurray has completed a number of studies and will have a plan developed for the design of a regional groundwater monitoring network in the summer of 2008. In the future, Alberta Environment intends to establish regional groundwater monitoring networks in the Athabasca Oil Sands area south of Fort McMurray and the Peace River Oil Sands area.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the valuable contributions of Margaret Klebek, Laurence Andriashek and Heather vonHauff.

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