CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS

Regional Groundwater Monitoring Networks

Review of Networks and Integration of Data for Future Network Development

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PROJECT 307074-01303 - REGIONAL GROUNDWATER MONITORING NETWORKS

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Disclaimer

Any questions concerning the information or its interpretation should be directed to Andrew Hinnell or Francisco Castrillon-Munoz.

EXECUTIVE SUMMARY

The Canadian Association of Petroleum Producers (CAPP) and its member companies are committed to protecting fresh groundwater resources and support the recently released “Baseline Groundwater Monitoring Practice” for tight gas development. Under this practice, companies will participate with local governments in establishing, where appropriate, science-based regional groundwater monitoring programs. This phased program has been developed to inform CAPP members and to facilitate their interaction with federal and/or provincial governments with respect to developing regional groundwater monitoring programs. The purpose of this program is to provide information to develop a framework, in cooperation with provincial regulators, for the design and implementation of scientifically based regional groundwater monitoring networks in areas of current and future tight gas and oil development.

In support of these objectives a review of existing regional groundwater monitoring networks was completed. From this review, key themes, best practices and relevant sources of existing data that can be used to inform the design, implementation, and operation of energy industry specific regional monitoring networks were identified.

This report presents a review of a selection of groundwater monitoring networks that were specifically designed for, or have been adapted to monitor the energy industry. A few generic and more broadly based monitoring networks were included in the review to provide context to some of the key themes and best practices discussed in the report.

Based on the review of monitoring networks, it is important to have a clear definition of monitoring objectives. As noted in some of the examples these objectives should be expected to evolve over time as industry and hydrogeologic understanding matures.

To support these objectives the network should be:

- hydrogeologically and technically sound, backed by a scientifically based design methodology;
- structured so monitoring is completed at a frequency and with analysis of appropriate parameters, to meet the network objectives (e.g. sentinel observations for water quality changes);
- supported by stakeholders: landowners are especially important for access to well; and
- transparent in the data collection and analysis.

The goal should be the design, implementation and operation of a credible network.

The second part of this work focused on mapping existing information to inform CAPP member companies of the data available on which to base future discussion of monitoring network design. The scope for the development of the GIS included identifying and integrating data from existing databases and maps into a single product that would add value for PTAC uses. Information and data that were gathered and integrated within the GIS included: locations of known tight gas plays, watershed boundaries, fresh water aquifers, provincial and municipal groundwater monitoring wells, existing or suspended non-saline source wells or monitoring wells used for oil and gas development, domestic wells, and existing oil and gas wells.

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1. INTRODUCTION

Exploration and production of tight oil and gas has increased significantly in the past several years due to the success of combining horizontal drilling and hydraulic fracturing technologies in a manner that allows natural gas and oil to be released from relatively impermeable formations (Leatherbury and Denson 2012). Hydraulic fracturing is a controlled operation that pumps a fluid and a propping agent to a target geologic formation to create fractures in the formation thus releasing the oil and gas. Hydraulic fracturing has been safely used throughout the oil and gas industry for about 60 years (CAPP 2012d). However, popular public opinion generally views tight oil and gas development and hydraulic fracturing in particular as an environmentally unfriendly practice. (Leatherbury and Denson 2012).

In response to these concerns the Canadian Association of Petroleum Producers (CAPP 2012a) has developed “Guiding Principles for Hydraulic Fracturing” to inform CAPP member companies and reassure the public. The guiding principles are as follows:

a) “We will safeguard the quality and quantity of regional surface and groundwater resources, through sound wellbore construction practices, sourcing fresh water alternatives where appropriate, and recycling water for reuse as much as practical.

b) We will measure and disclose our water use with the goal of continuing to reduce our effect on the environment.

c) We will support the development of fracturing fluid additives with the least environmental risks.

d) We will support the disclosure of fracturing fluid additives.

e) We will continue to advance, collaborate and communicate technologies and best practices that reduce the potential environmental risks of hydraulic fracturing.” (CAPP 2012a).

To support the guiding principles, CAPP has prepared seven operating practices which are intended to strengthen industry’s commitment to continuous performance improvement in tight oil and gas development. The operating practices cover:

- fracture fluid additive disclosure (CAPP 2012b);
- fracturing fluid additive risk assessment and management (CAPP 2012c);
- baseline groundwater testing (CAPP 2012d);
- wellbore construction and quality assurance (CAPP 2012e);
- water sourcing, measurement, and reuse (CAPP 2012f);
- fluid transport, handling, storage, and disposal (CAPP 2012g); and
- anomalous induced seismicity (CAPP 2012h).

The baseline groundwater testing operating practice states:

> "CAPP and its member companies are committed to protecting fresh groundwater sources. This practice outlines the requirements for companies … to participate in longer term regional groundwater monitoring programs. The purpose of the programs is to establish baseline characteristics of the groundwater pre-development and to analyze whether there have been changes over time. The testing process includes … regional groundwater monitoring where industry will work with government and regulators to design and implement regional groundwater monitoring programs." (CAPP 2012d).

The purpose of this report is to inform CAPP and its member companies on regional groundwater monitoring practices to facilitate working with government and regulators. It includes a literature review of existing regional ground water monitoring networks in North America (Section 3) from which key themes for design, implementation and operation are drawn (Section 5), and gathers existing information for western Canada pertaining to designing regional ground water monitoring networks (e.g. existing oil and gas wells and water well records) into an integrated mapping product (Sections 6 and 7).

2. SCOPE OF LITERATURE REVIEW

The scope of the literature review comprised identifying and summarizing existing groundwater monitoring networks, with a focus on identifying regional networks in North America that were purposely designed for the energy industry. This report presents a review of a selection of groundwater monitoring networks that were specifically designed for, or have been adapted to monitor the energy industry. A few generic and more broadly based monitoring networks were included in the review to provide context to some of the key themes and best practices derived from this review.

The provincial agencies who maintain groundwater monitoring networks are listed in Table A. The United States Geological Survey (USGS) also operates a monitoring network which covers much of the United States of America. The monitoring programs in Alberta (AB) and British Columbia (BC) are reviewed in detail in Section 3. Other provincial programs are either similar to these programs (e.g. Saskatchewan) or are located in provinces which do not have a large oil and gas industry presence. Energy industry specific groundwater monitoring networks are not as extensive as originally anticipated, yet these examples (Table B – Section 3) aided in shaping a contextual understanding of groundwater monitoring activities in North America.

Table A Groundwater Monitoring Networks or Legislation in North America

Geographic Location	Monitoring Network or Legislation
Alberta	Groundwater Observation Well Network
British Columbia	Groundwater Observation Well Network
Manitoba	Ground Water and Water Well Act
New Brunswick	Surface and Ground Water Monitoring Network
Newfoundland	Policy for Drinking Water Quality Monitoring and Reporting
Nova Scotia	Groundwater Observation Well Network
Nunavut and Northwest Territories	Department of Aboriginal Affairs and Northern Development Canada has a mandate to collect, analyze, and distribute information about the water resources of the Northwest Territories and Nunavut Territory
Ontario	Provincial Groundwater Monitoring Network
Prince Edward Island	Groundwater Pesticide Monitoring Program; Monitoring the Groundwater Table on PEI
Quebec	Réseau du Suivi des Eaux Souterraines du Québec (Network of Groundwater Monitoring Quebec)

Geographic Location	Monitoring Network or Legislation
Saskatchewan	Groundwater Observation Well Network
United States of America	Active Groundwater Level Network

The summary of monitoring networks included a literature review of publicly available documents, internet searches (e.g. Google Scholar, United States Environment Protection Agency [USEPA], and energy-related web sites) and discussions with academia, industry and government sources (e.g. Alberta Environment and Sustainable Resources Development [ESRD], Alberta Energy Resources Conservation Board [ERCB], and Geoscience BC). For each of the identified monitoring networks, a two page summary is provided in section 3. Information related to the design, installation, monitoring, and maintenance of the regional network, as well as data collection, storage and dissemination of information and data among stakeholders are reviewed. Based on these summaries, key themes and best practices were identified (Section 5) and the primary elements of an effective regional monitoring program identified.

3. IDENTIFIED GROUNDWATER MONITORING NETWORKS AND SUMMARIES

A synopsis of the monitoring networks identified and summarized in this report is provided in Table B. The location of each network is presented in Figure 1. Also summarized in Table B are the purpose and monitoring objectives for each network (where applicable and/or available). The purpose and objective of the monitoring programs varied, but it is important to highlight the objectives that can drive the development of a regional network. The purpose of the literature review was to identify monitoring networks across a wide geographic range, primarily in North America.

Table B Summary of Groundwater Monitoring Networks

Geographic Location	Name	Purpose/Description	Monitoring Objectives
Alberta	Alberta Groundwater Observation Well Network (AB GOWN)	Manage groundwater effectively for domestic, municipal, agricultural and industry activities, as well as maintaining river flows and lake levels.	Baseline information.
Alberta	Alberta Regional Groundwater Network (North Athabasca Oil Sands, South Athabasca Oil Sands, and Cold Lake Beaver River)	Improve the understanding of groundwater conditions and develop context for variable groundwater quality and level fluctuations occurring in the various aquifers in the region. Identify and address groundwater data and knowledge gaps.	Baseline information; better understanding of natural variability and aquifer interactions; assess potential cumulative effects.
Alberta	IOL Cold Lake Operations Monitoring Network	Part of key conditions for regulatory approvals, and to understand groundwater network in region of operations.	Assess groundwater supplies; understand the regional groundwater network and groundwater-surface water interactions.
Australia	Groundwater Monitoring for the Australia Pacific LNG Project	Respond to community concern to the potential for coal seam gas production to impact groundwater in the Great Artesian Basin (GAB).	Respond to stakeholder concern and to support regional groundwater management decisions.

Geographic Location	Name	Purpose/Description	Monitoring Objectives
British Columbia	British Columbia Groundwater Observation Well Network (BC GOWN)	Collect, analyze and interpret groundwater hydrographs and groundwater quality data from important aquifers in British Columbia.	Understand local and regional hydrogeological processes and characteristics and provide data and information for decision support.
British Columbia	Northeast British Columbia Aquifer Project	Use traditional and geophysical techniques to explore groundwater resources as they pertain to gas plays in Northeast British Columbia.	Expand existing provincial monitoring network, and provide data and information for decision support.
California	PXP Inglewood Oil Field Groundwater Monitoring Program	To ensure the protection of groundwater resources that may be adversely affected by increased oil field operations.	Baseline information and compliance.
Colorado	Colorado Oil & Gas Association Voluntary Baseline Groundwater Quality Sampling Program	An industry-led voluntary groundwater testing program to establish baseline groundwater quality conditions around new oil and gas well locations and to monitor water quality in the vicinity of the oil and gas wells before and after drilling and completion activities have concluded.	Baseline information.
Kentucky	Kentucky Groundwater Monitoring Network	A coordinated effort of monitoring organizations to reduce redundancies and expedite the use of data from multiple sources.	Baseline information and monitor groundwater resources for multiple users.
Louisiana	Louisiana State Groundwater Monitoring Program	Monitor both quantity and quality of water to manage aquifer resources.	Baseline information and monitor groundwater resources for multiple users.

Geographic Location	Name	Purpose/Description	Monitoring Objectives
Montana	Montana Bureau of Mines and Geology: Groundwater Assessment Program	Produce and maintain long-term water level and water quality records and a groundwater characterization program to systematically assess and document the hydrogeology and quality of the state's major aquifers.	Baseline information and compliance.
Montana	Montana CBM Groundwater Monitoring	Document baseline hydrogeologic conditions in current and prospective Coal Bed Methane (CBM) areas in southeastern Montana, to determine actual groundwater impacts and recovery, and to provide data and interpretations for permitting and exploration decisions.	Baseline information and provide data and information for decision support.
North America	Groundwater Monitoring of Landfills	Monitor for potential impacts associated with a land fill.	Baseline information and compliance.
North Dakota	North Dakota State Water Commission Groundwater Monitoring Program	Collect, organize, store, and evaluate water resources for current and future needs.	Provide data and information for decision support.
Pennsylvania	Shale Network	Assist stakeholders (e.g. citizens, scientists, industry) to collect, store, and interpret data for water resources which may be affected by tight gas production.	Not in this scope.
Pennsylvania	Marcellus Shale Coalition: Water Quality Data Repository	Provide an electronic storage network for pre-drill water quality data for oil and gas companies and the Pennsylvania Department of Environmental Protection (DEP).	Not in this scope.

Geographic Location	Name	Purpose/Description	Monitoring Objectives
Texas	TWDB Groundwater Monitoring Network (tentative name)	Track water level changes over time; characterize ambient, or background, water quality, track any changes that may be occurring over time; and assess naturally occurring constituents of concern.	Understand natural variability and aquifer interactions and provide data and information for decision support.

The groundwater monitoring networks summarized in the following sections are based on the completed data collection tables (Appendix 1). These tables provide additional information, references, and sources, including contact information for personal communications.

3.1 Alberta Groundwater Observation Well Network

Information for this section was collected through personal communication with Carole Oduro from ESRD, as well as other sources cited in the summary.

3.1.1 Background, Purpose, and Design

In 1957, the Alberta Research Council (ARC) initiated the Alberta Groundwater Observation Well Network (AB GOWN). Alberta Environment (AENV) assumed ownership of the AB GOWN in 1982, which included 55 provincial wells and 90 wells within area of oil sands development (ESRD 2012a). By 2012, the AB GOWN had grown to include 215 water level monitoring wells of which 177 were used for water quality monitoring.

The primary purpose of the AB GOWN is to obtain continuous water level data in order to monitor natural and human-induced fluctuations of groundwater levels at sites identified as representative of the various hydrogeological environments found in Alberta. The AB GOWN has grown in phases over the past 55 years, and thus multiple drivers have influenced the design of the network as a whole. The various phases would have each had distinct design methodologies. The network was cut back by over 50% in 1997 with relatively minor expansion since. A few new wells were added between 2003 and 2007 in response to development of coal bed methane and in situ coal gasification projects. A similar expansion was planned for 2012-2013 in areas of tight gas and oil development in western Alberta.

AB GOWN wells have been installed in areas with significant groundwater use for a variety of reasons. Three examples of drivers for monitoring include:

- areas with strong groundwater/surface water interaction;
- areas of predicted increased diversion of groundwater or surface water; and

- areas that showed significant groundwater yield based on the ARC hydrogeological maps and Alberta Water Well Information Database.

The general criteria for locating AB GOWN wells have been:

- locations not affected by human development activities;
- aquifers with good yield potential; and
- spatial coverage throughout the province, especially considering a balance of different land use zones.

The wells, that form the AB GOWN, are a combination of purpose drilled wells and existing wells that were redeveloped and incorporated in the network.

3.1.2 Monitoring

Water level data are measured and recorded at the well using a pressure transducer and a datalogger, providing detailed time series of water levels. These automated monitoring networks are subject to electronic drift. Most wells are visited bi-annually by ESRD technologists to manually measure the water level and download stored water level data. The manual measurements are used to correct the electronic drift in the automated water level records.

Water quality in each well is monitored once every three years. Chemical analysis to characterize water quality included an analytical suite similar to one used for domestic water wells in Alberta (routine, major ion, and nutrient analytical suites). Additionally, analysis are completed for metals, benzene, toluene, ethylbenzene, and xylenes (BTEX), polyaromatic hydrocarbons (PAH), other organic compounds, pesticides, and pharmaceuticals. Dissolved and free state gas samples are also collected for analysis to define the gas composition. ESRD is also undertaking isotopic finger printing of water and/or gas samples on an as needed basis. Analysis of samples is completed at an accredited laboratory.

3.1.3 Data Collection, Storage, and Dissemination

Water level and water quality data generated as a result of the monitoring activities are stored on the AB GOWN Data Management System. Data are uploaded after completion of ESRD quality control reviews. If during this review an anomalous measurement is identified the ESRD technologist would work with the analytical laboratory and responsible hydrogeologist to confirm the analysis is representative. The laboratory may re-run the analysis and re-sampling may be required. If the value is confirmed further site investigation may be undertaken.

Data available for dissemination are presented on the AB GOWN website. Water level data are available by contacting Data Management staff who will compile and email the data needed to answer specific requests. Enhancements to the current AB GOWN website are currently underway and when complete the actual water level data will be available from the AB GOWN website.

Municipal, provincial, and federal governments, consultants, academia, research councils, industry, and private citizens have used the data. Examples of how the data have been used include:

- mapping potentiometric surfaces and spatial variations in chemical constituents of groundwater within the province;
- assessing industrial and agricultural impacts on groundwater;
- observing long term changes in water levels to examine the impacts of drought; and
- assessing groundwater/surface water interactions.

ESRD primarily uses the data for State of the Environment reporting. The data are also used for developing inputs for the Provincial Groundwater Mapping Program.

3.1.4 Funding

The AB GOWN is funded by the Alberta Government. A core budget is allocated for monitoring activities on an annual basis as monitoring has been identified as a top priority by ESRD.

3.2 Alberta Groundwater Management Areas-North Athabasca Oil Sands, South Athabasca Oil Sands, and Cold Lake Beaver River

Information for this section was collected through personal communication with Margaret Klebek and Steve Wallace from ESRD, as well as other sources as cited in the summary.

3.2.1 General Overview

The Lower Athabasca Regional Plan Groundwater Management Framework (LARP GWMF) subdivides the Lower Athabasca Region (LAR) into three distinct groundwater management areas, each with a supporting groundwater monitoring network (AENV 2011). The current status of monitoring and modelling efforts conducted within the LAR is summarized in Table C. The networks are at different stages of development which is reflected in the amount of information available about each network. The general approach is outlined below with network specific information provided in the following sections. The SAOS is in the early stages of development and thus not discussed further.

Table C Summary of Groundwater Management Areas from LARP (AENV 2011)

Groundwater Monitoring Networks	Monitoring Network	Model	Risk Mapping
North Athabasca Oil Sands (NAOS)	Existing with Expansion Underway	Proposed	Complete
South Athabasca Oil Sands (SAOS)	Conceptual Design Stage	Complete	Complete

Groundwater Monitoring Networks	Monitoring Network	Model	Risk Mapping
Cold Lake Beaver River (CLBR)	Existing with Expansion Proposed	Existing – with Update Proposed	Complete

Much of the LAR groundwater monitoring over the last 30 years has been associated with site-specific programs at oil sands operations (mining and in situ). Individual oil sands operators have designed and implemented groundwater monitoring programs on their leases pursuant to the terms and conditions of their *Water Act* and *Environmental Protection and Enhancement Act* approvals. Some regional groundwater monitoring was conducted through the AB GOWN from the early 1970s until the mid-1990s as part of a provincial government initiative. Considering the limited scale of the oil sands developments during this period, and the location of the AB GOWN wells, the information obtained from this monitoring may be considered pre-development. A hiatus of regional monitoring occurred between the mid-1990s until the regional monitoring network in the NAOS area was established in 2009 (CEMA 2010). During this interruption, site-specific monitoring continued.

The objectives of the Regional Groundwater Monitoring Networks (RGMN) are to:

- gain a better understanding of natural variability of groundwater conditions in the region;
- provide good baseline coverage (in areas of no anthropogenic effects) in each of the key regional aquifers;
- gain further understanding of aquifer interactions, and how/where the groundwater system is connected to surface environments; and
- assess long-term water quality and water level trends, and assess potential cumulative effects from current and future development activities in the three groundwater management areas (Klebek n.d.).

Each RGMN will be used to assess whether changes in groundwater quantity and/or quality have occurred, or are occurring, that fall outside of the range of natural variability, or the natural ability of the region to attenuate related effects. Each RGMN will be used to establish regional triggers and limits for the regional aquifers in each of the three groundwater management areas using historical data and ranges at established monitoring locations. It must be recognized that knowledge of the region's groundwater resources is incomplete and continues to develop. Once regional triggers and limits have been established, the data from the RGMN will be compared and evaluated against those triggers and limits. If a trigger or limit is reached, a regional management response will be initiated as defined in the groundwater management frameworks.

In summary, the objectives of the LARP GWMF are as follows:

- developing GWMF for NAOS Region, SAOS Region, and CLBR Region;

- provide context to groundwater resources (both quality and quantity) so development activities may be assessed in relation to natural conditions and ranges of variability;
- provide a network to manage groundwater resources in a sustainable manner and protect groundwater from contamination or over-use;
- develop a consistent approach that manages cumulative effects of groundwater recognizing potential effects from site-specific industrial activities; and
- establish groundwater quality targets and thresholds, guidance for the development of groundwater quality target values, and area specific management action.

Design and implementation of the monitoring networks for the three GWMF's is following the same process:

- establish local monitoring objectives;
- inventory existing monitoring resources; and
- construct monitoring network by selecting existing wells and/or installing new wells.

Establishing local monitoring objects is completed by a working group of government and local stakeholders. ESRD has found mapping of aquifer vulnerability to be a helpful tool in this process. Developing an inventory of existing monitoring resources requires pulling together information from multiple government, and industry databases to form a complete list of monitoring wells and which aquifers they monitor. The final step of constructing the network is a process of selecting a subset of wells from the inventory that best meet the monitoring objectives. Further details are provided for the NAOS which is the network that is most developed.

3.2.2 North Athabasca Oil Sands

Information for this section was collected through personal communication with Margaret Klebek and Steve Wallace from ESRD, as well as other sources as cited in the summary.

Background, Purpose, and Design

The objectives of the NAOS are to improve the understanding of groundwater conditions in the region, develop context for variable groundwater quality and level fluctuations observed in the regional aquifers, and identify and address groundwater data and knowledge gaps. The network is composed of 40 monitoring wells. The locations for regional monitoring wells were chosen based on vulnerability mapping results and the location of current and future oil sands development. The initial network development plan proposed the installation of new monitoring wells, however, upon review of existing groundwater monitoring wells owned by ESRD and operators within the area, it was determined that the NAOS would utilize existing infrastructure for initial implementation where possible.

The selection of the existing wells to include in the network was completed in two stages reflecting the relative importance of the different criteria.

a) Initial prioritization criteria:

   i) level of potential risk to groundwater resources considering vulnerability and future development (higher risk areas being targeted);

   ii) importance of an aquifer relative to development activity (level of use);

   iii) level of knowledge regarding quality and quantity (higher priority for areas with limited data); and

   iv) spatial distribution of wells (up-gradient of development [baseline], down-gradient of development [sentinel], proximity to sensitive areas [sentinel]).

b) Secondary prioritization criteria:

   i) well construction;

   ii) accessibility of well location;

   iii) current condition of well; and

   iv) quality of the water produced from the well (priority given to wells where water quality met surface water discharge criteria) (Klebek n.d.).

Monitoring

The monitoring network is managed by the Monitoring Evaluation and Reporting (MER) Group, which includes representatives from government, industry and academia. Any decisions made towards adding wells to the network are made by the MER Group.

The existing wells that were incorporated into the network were redeveloped prior to the start of monitoring. The wells in the NAOS are instrumented with pressure transducers and dataloggers. Water levels are recorded every 12 hours.

Water quality samples are collected to measure: routine portability (including total dissolved solids [TDS]), dissolved metals (and trace elements), total phenols, BTEX, petroleum hydrocarbon fraction, ammonia, naphthenic acids, sulphide, and stable isotopes of oxygen and deuterium. Selected wells are also tested for stable and radiogenic carbon isotopes.

Data Collection, Storage, and Dissemination

All data collected are compared to the local baseline criteria. If data deviate from these criteria, a follow-up investigation is initiated. This five step investigation will include Verification; Investigation (phase 1); Investigation (phase 2); Evaluation; and Modification of activities (through risk-based management).

Water level and water quality data are currently stored in ESRD's internal database. In the future the data will be transferred to ESRD's Monitoring and Science division and will eventually become available to the general public. The data are used to inform the LARP GWMF. Data are currently available to government and industry upon request.

Funding

The NAOS network is currently funded by ESRD for the purposes of getting the project underway. Plans for future funding will include drawing on funding from all involved parties.

3.2.3 Cold Lake and Beaver River

Water resources in the Cold Lake Beaver River basin are managed based on the basin management plan which was originally adopted in 1985 and updated in 2006 (AENV 2006). The plan provides a framework for decision making by the Alberta government and was developed in consultation with stakeholders and the public. In support of the plan update the Alberta Geological Survey (AGS) compiled existing information into a central database. In total, 1600 wells and over 200 different chemical parameters were included in the database (AENV 2006).

Following the introduction of the LARP GWMF, a groundwater monitoring network was established with in the CLBR management area. This new network is composed of approximately 40 monitoring locations that were selected from existing wells. Well selection considered hydrogeological and logistical factors similar to those considered in the development of the NAOS network.

Development of regional targets for groundwater quality and quantity in the CLBR region is based on the current level of knowledge and data obtained from existing monitoring infrastructure. As more data become available, statistical control charting will be utilized for each selected indicator at a regional monitoring well. Regional groundwater quantity and quality targets established in this GWMF are associated with investigative and management actions. Implementation of this GWMF will include the establishment of a Groundwater Working Group (GWG) that will maintain and manage the regional groundwater monitoring network (LICA 2010).

Development of the CLBR groundwater monitoring network is ongoing and details related to monitoring, data dissemination, and funding are sparse, although it is expected to follow a similar model to the NAOS region.

3.3 Imperial Oil Limited Cold Lake Operations Groundwater Monitoring Network

Information for this section was collected through an interview and personal communication with Stuart Lunn from Imperial Oil Limited (IOL), as well as other sources as cited in the summary.

3.3.1 Background, Purpose, and Design

The groundwater monitoring network for the IOL Cold Lake Operations (CLO) in the Cold Lake region was primarily set up to assess resource availability for development, sustainability, protect domestic and livestock groundwater supplies, understand the regional groundwater network, and understand groundwater-surface water interactions. Other motivations that helped to drive the monitoring network in place today include monitoring for thermally liberated arsenic, specifically around well pads, providing information and knowledge for Environmental Impact Assessments (EIAs) and other regulatory approvals, and verification of hydraulic containment of the shale unit between the reservoir and non-saline groundwater aquifers.

There are two groundwater monitoring networks: shallow and deep. The shallow network monitors groundwater (less than 20 m) localized around plants and facilities (approximately 350 wells). The deep network consists of approximately 400 wells to monitor deeper aquifers including regional wells and groundwater evaluation wells (localized around wells pads). Regional wells consist of nested locations with wells completed in different aquifers, allowing for a more complete picture of the groundwater system.

The monitoring network has increased with the expansion of the footprint of in situ oil production. During expansion phases, regional monitoring wells are constructed prior to development to monitor baseline conditions. The local network is then expanded during the development phase of a new production area. Regional monitoring wells include up gradient, onsite, and down gradient wells. There is also a regional domestic and livestock water well monitoring network where IOL collected samples from local landowners for analysis.

3.3.2 Monitoring

Groundwater wells are consistently monitored and maintained with the longest continuous records starting in 1992. Given the significant baseline chemistry variability observed, ambient conditions are established using both trends from individual wells and statistics from regional monitoring data.

The groundwater monitoring networks are monitored regularly by IOL staff and third party contractors. Frequency of measurements depends on the parameter being monitored (e.g. three times a week for manual water levels near steam injection well pads). The frequency of water chemistry sampling varies from weekly to semi-annually depending on the well. For regional wells, initial water quality sampling is quarterly for two years followed by a reduction to semi-annually. Water samples are analysed for salts, dissolved hydrocarbons, and dissolved metals. Detailed analytical schedules were not available.

3.3.3 Data Collection, Storage, and Dissemination

A dedicated team of people are tasked with data processing/quality control, and database development and maintenance. Water pressure (quantity) and water quality data collected as part of the groundwater monitoring program at CLO are collected manually, processed, and stored and maintained on a third party database. Water levels are also stored and managed locally at CLO for rapid analysis.

Data are used to improve the understanding of the local and regional groundwater networks and to monitor for changes in water level or quality that could either impact operations or indicate change due to the operation. IOL has, and will continue to, investigate all anomalous results from the monitoring at CLO. Should an anomalous result be confirmed, an investigation will be undertaken to determine the possible source and necessary mitigation actions (IOL 2009).

Monitoring requirements are determined by the ERCB and ESRD (e.g. Water Act, and Alberta Environmental Protection and Enhancement Act) as well as other research requirements. CLO has designed and implemented an online database to facilitate monitoring and tracking the terms and conditions specified in ERCB and ESRD approvals (IOL 2003). Detailed monitoring information is provided to ESRD every two years. Annual reviews are conducted with ESRD and ERCB and bimonthly results are provided to land owners in the region. Annual reviews are conducted with Marie Lake Air and Watershed (MLAWS). IOL also participates at the Beaver River Watershed Alliance which is the regional Watershed Planning and Advisory Council (WPAC). An annual open house (Neighbour Night) is held as a forum for discussion of any concerns including groundwater.

3.3.4 Funding

The network is funded by IOL. As operations expand, capital expenses for monitoring well installation are included in the cost of new projects and project expansions. Operational expenses (maintenance, data collection) are built into the operating costs. Building in expenses to capital and operational expenses provides a sustainable funding plan for the monitoring. This funding model works and is logical for long term success of the network.

3.4 Groundwater Monitoring for the Australia Pacific Liquefied Natural Gas Project

Information for this section was collected through personal communication with Ryan Morris from Origin Energy, as well as from other sources cited in the summary.

3.4.1 Background, Purpose, and Design

Coal Seam Gas (CSG) production relies on the extraction of water from coal seams to depressurise the coal measures to allow natural gas to flow. Responsible management of CSG water and the impacts of CSG production on groundwater levels and water quality are critical to Australia Pacific Liquefied Natural Gas's (APLNG) business (APLNG n.d.). Some groups in the community have expressed concern that the depressurisation of the coal seams will lead to impacts on groundwater levels or water quality in GAB aquifers that are used for water supply. An extensive groundwater monitoring program has been designed that will operate throughout the entire duration of production operations. The information collected from ongoing monitoring will be compared with computer modelling to examine whether observed variability is in line with predictions. Decisions about groundwater management will be guided by modelling, but any action taken will be based on actual monitoring results. APLNG is working with government, landholders and other CSG operators in the region to develop a consistent approach to regional and cumulative effects groundwater monitoring. APLNG proposes to continuously adapt and improve the monitoring network in response to better understanding of the hydrogeological regime that may result from analysis of collected data.

The network was designed as an "early warning system" such that aquifers in vertical proximity to the CSG reservoir are more intensively monitored, and monitoring locations close to existing or early development areas are highest priority. If depressurisation effects are observed in the early warning wells, the monitoring network will be expanded. Additional monitoring wells specifically target aquifers used for water supply by local stakeholders.

The monitoring network is also designed to screen for potential effects of regional scale depressurisation during CSG production (APLNG n.d.). Locations were selected on the basis of a multi-criteria analysis which utilised a source-pathway-receptor risk model (similar to a vulnerability mapping exercise).

In designing the monitoring network, multiple zone monitoring systems were considered to allow monitoring water pressure in multiple aquifers from one borehole. However, these systems were not considered reliable for deep installations and each observation location was installed from an individual borehole.

Details on the number of wells in the network were not provided.

3.4.2 Monitoring

APLNG conducts water quality and water level monitoring in the major aquifers in the vicinity of its project as well as in other geological units not generally accessed for groundwater development. Monitoring is conducted in both existing landowner wells and APLNG monitoring wells. As part of initial sampling of monitoring wells and including collection of baseline samples from landowner wells, samples are analysed for carbon isotopes present in methane and carbon dioxide dissolved in the groundwater. The Queensland Government requires bi-weekly pressure monitoring in a subset of the monitoring network. The water quality requirements are bi-weekly monitoring of electrical conductivity and temperature, and then annual collection of samples for laboratory analysis. Water quality monitoring includes field parameters (electrical conductivity, temperature, pH, and reduction-oxidation potential), major and minor ions, trace metals and a limited number of organic parameters.

Dedicated monitoring wells have automated level sensors, which are in the process of being connected by telemetry to provide internet based access to remote wells. Wells will be visited a minimum of twice yearly to manually measure water levels/pressures and to check instrumentation. It is intended that field data are collected using handheld computing devices that automatically upload data into the database. This is currently being implemented.

If monitoring data suggests an unacceptable trend, additional monitoring wells may be installed, and an investigation response framework is followed. If the detection is found to be due to APLNG activities, appropriate management/mitigation measures are put in place.

3.4.3 Data Collection, Storage, and Dissemination

Where APLNG installs water level logging devices into landowner wells the data are provided directly to the landowner. Data are also disseminated to government through annual reporting. These reports are publically available online. Only data that relates explicitly to an approved regulatory plan will be made public initially. Any additional data may be made public at a later date. APLNG is in the process of customising a commercially available database. The database will have the ability to export directly to the government database.

3.4.4 Funding

The network is privately funded through the APLNG project. The monitoring is a requirement of state and federal environmental approvals for the APLNG project and is therefore the responsibility of the organisation to fund and implement.

3.5 British Columbia Groundwater Observation Well Network

Information for this section was collected through personal communication with Jillian Kelly from the British Columbia Ministry of Environment, as well as other sources as cited in the summary.

3.5.1 Background, Purpose, and Design

The primary purpose of the BC GOWN is to collect, analyze and interpret groundwater hydrographs and groundwater quality data from various developed aquifers in British Columbia.

There are two primary monitoring objectives. The first is to understand local and regional hydrogeological processes and characteristics including:

- groundwater/surface water relationships;
- recharge and discharge mechanisms/rates/timing in lowland and upland areas;
- the impact of drought and flooding on groundwater;
- fundamental aquifer or basin characteristics (e.g. water table and potentiometric levels, gradients and trends, transmissivity, hydraulic conductivity and storativity values, water chemistry, etc.); and
- the impact of short and long term climate fluctuations on groundwater levels.

The second monitoring objective is to support the effective use of water resources and minimize groundwater conflicts between users (BC MoE 2009). The BC GOWN achieves this by assessing the impact of groundwater withdrawals in specific areas to determine if further groundwater development is possible without adversely affecting the sustainability of the resource. Information from BC GOWN also helps to resolve water use conflicts (e.g. groundwater withdrawal near fully allocated lakes and streams). The BC GOWN also assesses the long term and short term effects of human-induced activities such as pumping and construction of drainage works on groundwater levels, both locally and regionally.

Historically the provincial network was a combination of wells drilled by the Province and private water wells donated to the Province, typically located in higher groundwater use areas. Today, the aquifer classification method is used to guide the priority of the well locations.

The network is evolving with the establishment of new monitoring locations and the abandonment of redundant monitoring locations. The network is designed to allow for continual improvement, updating or changing well locations as new information becomes available. For a well to be part of the provincial network, it must be a dedicated monitoring well and must not be actively used (i.e. pumped) for other purposes.

An evolving monitoring network provides flexibility and cost savings, however administering an evolving network creates its own challenge to ensure all subsequent areas related to the network monitoring (i.e. the databases, IT systems, etc.) reflect the current information and state of wells in the network.

Expansion of the network into new areas has been most successful when local qualitative information is incorporated into planning rather than relying solely on existing quantitative data.

3.5.2 Monitoring

Automatic water level recorders have been installed in all wells. Some of the recorders have been connected to a telemetry system removing the necessity of a site visit to download data. Frequency of water level measurements was not provided.

The frequency of water quality sampling ranges from twice a year to once every two or five years based on physical characteristics of the aquifer, well construction, and water quality trends. The wells are sampled for a standard "Provincial Observation well analytical suite" (not further defined). Additional site specific parameters can be added to the suite to monitor local concerns (nitrates, pesticides, hydrocarbons etc.) based on local area needs.

3.5.3 Data Collection, Storage, and Dissemination

The water quality analytical data are stored in the Ministry of Environment's (MoE) Environmental Monitoring System (EMS). The water level data are stored in a MoE Database and displayed on the publically available groundwater levels website (http://www.env.gov.bc.ca/wsd/data_searches/obswell/). Other information about the monitoring network available to the public on this website includes the network objectives summarizing the goals/objectives for monitoring water levels and water quality, and an Observation Well Network Interactive Map tool showing the general location of all active observation wells. Clicking on a well provides a link to access information on the well including hydrographs, data downloads, detailed well reports and observation well photos.

Other users of the monitoring data are consultants, industry, university researchers. In the future, when groundwater use is regulated in British Columbia, the data may be used in water allocation decisions.

3.5.4 Funding

The MoE receives an annual operating budget for the Provincial Observation Well Network.

3.6 Northeast British Columbia Aquifer Project

Information for this section was collected through personal communication with Jillian Kelly from the British Columbia MoE, as well as other sources as cited in the summary.

3.6.1 Background, Purpose, and Design

Tight gas development in BC has been increasing, including growing activity in the Horn River Basin, the Liard Basin, the Cordova Embayment and the Montney gas play area. Hydraulic fracturing requires substantial quantities of water, and therefore, secure water supplies could be a limiting factor in development. Two collaborative projects have been initiated to begin addressing ground- and surface-water sustainability: the Northeast British Columbia Aquifer Project and the Streamflow Modelling Decision Support Tool (Wilford et al. 2012).

The Aquifer project is in the process of exploring groundwater aquifers in the Montney gas play area. The project includes four components:

- private well water survey;
- expansion of the BC GOWN;
- the geological framework of the Groundbirch paleovalley; and
- a groundwater level (GWL) interface data update.

Six observation well locations were selected using the following criteria and incorporated into the MoE observation network:

- within the Montney play trend and in proximity to recent tight gas activity;
- within a vulnerable aquifer(s), as identified by the MoE;
- access along a British Columbia Ministry of Transportation and Infrastructure road rights-of-way;
- south of the Peace River within a MoE priority area for new observation wells;
- a good chance of water production based on nearby water well records;
- reasonable depth to bedrock so that no individual well would be overly expensive; and
- establishment of three wells within each of two aquifers so groundwater flow direction and gradient can be determined.

3.6.2 Monitoring

Monitoring activities include both automated water level monitoring and water quality sampling. Field measurements of pH, electrical conductivity, dissolved oxygen and reduction-oxidation potential are collected during water sampling. The analytical schedule included major ions, isotopes, trace metals, alkalinity, total dissolved solids and nutrients. Detailed information of which isotopes are analysed was not provided. Water samples were not analysed for volatile organic compounds. Frequency of monitoring was not available.

3.6.3 Data Collection, Storage, and Dissemination

Data are included in the MoE observation well network database and data storage and dissemination are thus the same as for the BC GOWN (Section 3.5).

3.6.4 Funding

The project received funding from Geoscience BC, the British Columbia Ministry of Forests, Lands and Natural Resource Operations, the British Columbia Ministry of Energy and Mines, the British Columbia Ministry of Environment, and the Oil and Gas Commission. Additional funding has been provided by the Climate Action, Clean Energy (CACE) Fund.

3.7 California Plains Exploration and Production Inglewood Oil Field Groundwater Monitoring Program

Information for this section was collected through personal communication with Joanna Pankey from Plains Exploration & Production Co. (PXP), as well as other sources as cited in the summary.

3.7.1 Background, Purpose, and Design

The monitoring program was developed to evaluate groundwater flow and quality and to ensure the preservation and protection of groundwater resources that may be adversely affected by oil field operations. The monitoring network is composed of five monitoring wells.

The monitoring program was prepared in accordance with the requirements of the Baldwin Hills Community Standards District and the Final Environmental Impact Report. The ordinances require that the operator develops, implements, and carries out a groundwater quality monitoring program for the oil fields that is acceptable to the Director and consistent with all requirements of the Regional Water Quality Control Board (RWQCB). The operator will install and maintain groundwater monitoring wells in the vicinity of each surface water retention basin, which is permitted by the RWQCB (ENTRIX 2009).

All of the proposed monitoring wells will be installed within the shallow, uppermost groundwater zones since this zone is the most susceptible to impacts associated with the operation. If groundwater monitoring data indicate the potential for impacts to deeper groundwater zones, then additional wells would be installed to monitor groundwater quality in those zones.

3.7.2 Monitoring

Groundwater monitoring is conducted on a quarterly basis and involves manual measurement of depth-to-water within each well and collection of groundwater samples for submission to a State of California certified laboratory. The groundwater samples will be analyzed for pH, EC, temperature, and turbidity (field and laboratory measurements), total dissolved solids, total petroleum hydrocarbons, volatile organic compounds; and total recoverable petroleum hydrocarbons.

Water quality samples from each monitoring well are collected using dedicated, disposable polyethylene bailers equipped with a bottom-emptying device, which allows emptying the bailer from the bottom at a slow, controlled rate (ENTRIX 2009).

Monitoring results are submitted to the Director of the County of Los Angeles, Department of Public Health as directed by the county (ENTRIX 2009).

3.7.3 Data Collection, Storage, and Dissemination

The groundwater monitoring data will be used to establish baseline conditions and evaluate potential impacts associated with oil field operations. Groundwater level data will be used to determine groundwater elevations across the site and the direction of groundwater flow. Water quality data will be compared with regulatory water quality criteria and existing local water quality information to identify potential impacts to groundwater. If changes in groundwater quality linked to oil field operations are identified then PXP, in consultation with the RWQCB, will evaluate options to address the issue (ENTRIX 2009).

No information with regard to how or if the data are disseminated was provided.

3.7.4 Funding

No information was available regarding the funding of this monitoring network.

3.8 Colorado Oil & Gas Association Voluntary Baseline Groundwater Quality Sampling Program

Information for this section was collected through personal communication with Andrew Casper from the Colorado Oil & Gas Association (COGA), as well as other sources as cited in the summary.

3.8.1 Background, Purpose, and Design

The COGA has developed an industry-led voluntary groundwater testing program to establish baseline groundwater quality conditions around new oil and gas well locations and to monitor water quality in the vicinity of the oil and gas wells before and after drilling and completion activities have concluded. The Baseline Groundwater Quality Sampling Program is meant to demonstrate that drilling operations are safe and does not compromise the quality of Colorado’s important water resources (COGA 2011a). This program is the first statewide voluntary groundwater quality monitoring program for oil and gas operations in the USA and was developed to proactively address groundwater quality concerns across the state associated with the drilling and hydraulic fracturing of oil and gas wells. The oil and gas industry recognized that stakeholders desire assurance that their groundwater is not being impacted by drilling operations.

The Colorado Oil and Gas Conservation Commission (COGCC) and COGA plan to review the program annually, and COGA will prepare a written summary report on the program that will be presented to the Commission. Participating operators confirm annually with COGA that they are following the program guidelines (COGA 2011a). This program does not exempt operators from mandatory federal and state groundwater monitoring requirements.

The program is new, with data collection starting in 2012. The Colorado Water and Energy Research Center (CWERC) at University of Colorado-Boulder completed a review of COGA's voluntary groundwater monitoring program and found the following shortcomings:

a) Water samples will be collected only in areas where new gas wells are being drilled. With over 46,000 oil and gas wells already active in Colorado, there are many places that will not be sampled, including sites where "old" gas wells are hydraulically fractured for a fourth, fifth, or sixth time.

b) Private water well owners have no say in whether their well will be tested or not. Gas operators will sample two "groundwater features" (e.g. a well or a spring) within one-half mile of a new gas well. If there are more than two groundwater features within that radius, the operator will choose which ones to sample.

c) Operators will collect only one baseline sample. By collecting only one baseline sample, it is not possible to capture seasonal changes in water quality.

d) After drilling, operators will only collect one water sample from the two chosen groundwater features within one year of completing the gas well. One post-drilling sample is not sufficient to track water quality over the long term. Contaminants might not turn up in a well for years after a gas well has been drilled.

e) Operators do not have to measure depth-to-water in water wells. The height of standing water in a well provides critical information. For example, if a well's water chemistry changes and its water level drops by 100 ft. at the same time, it would be clear that the aquifer experienced an acute disturbance (Williams et al. 2012).

3.8.2 Monitoring

Under the program, oil and gas operators who drill wells on new pads will collect groundwater samples before and after drilling. Water samples will be collected from the two water wells or groundwater seeps located within a half mile of the oil and gas well pad. These baseline samples will be collected prior to the setting of the well conductor casing.

A second sample will be collected within one year of well completion, unless prior notification is filed with the COGCC (COGA 2011a). When multiple wells are constructed on a single pad or as part of an expansion of an existing pad, baseline samples will be collected prior to installing the conductor casing of the first well. These samples will serve as a baseline for the initial well plus all future wells. Post-completion samples must be collected every two years while wells are actively being drilled and completed on a pad, and within one year following completion of the final well on the pad.

The procedures for groundwater sampling are coded in the Sampling and Analysis Plan (SAP). The primary objective of the SAP is to identify proper field data collection and data management procedures to provide consistency in data collection, allow uniform and efficient data handling and transfer, and provide clear documentation of sample locations, field procedures, and analytical methods. Samples will be analyzed for the following constituents: major cations and anions, total dissolved solids, iron, manganese, and selenium; nutrients (nitrate, nitrite, and phosphate); dissolved methane; pH; specific conductance; and BTEX. Water samples will be analyzed at an accredited laboratory. Field observations at the time of sampling such as temperature, odor, water color, sediment, bubbles, and effervescence will also be recorded (COGA 2011b).

3.8.3 Data Collection, Storage, and Dissemination

The COGCC database will be used to assist operators in conducting the baseline groundwater sampling program and to characterize and evaluate trends in groundwater quality within different basins in Colorado. Laboratory results will be provided to each landowner within three months of collecting the sample(s), and will be provided with a letter explaining the testing and analyses completed and a copy of the laboratory analytical report. At the same time, the results will be provided to the COGCC, with landowner consent, for inclusion in their electronic database. The data will be posted and made available to the public through the COGCC's website (COGA 2011a). Annually, COGA and COGCC will prepare a joint report to the Commission summarizing participation and findings.

3.8.4 Funding

The design process was funded in part by the state, but also through industry dues paid to COGA (i.e. equivalent to royalties). The testing program is funded by industry.

3.9 Kentucky Groundwater Monitoring Network

Information for this section was collected through personal communication with Bart Davidson from the Kentucky Geological Survey, Water Resources Section, as well as other sources as cited in the summary.

3.9.1 Background, Purpose, and Design

A significant portion of the population of the state of Kentucky relies on groundwater for potable water and industrial and agricultural supply (Sendlein 1996). To support these activities multiple state agencies collaboratively established the network. The network is an amalgamation of the multiple networks developed by the individual state agencies.

The Kentucky Groundwater Monitoring Network (KGMN) incorporated both digital and non-digital data collection from multiple organizations. The Kentucky Groundwater Data Repository has collected 39,000 water well records from various sources, including the data from the Kentucky Division of Water which includes 32,000 water well records based on well completion forms from the Certified Well Driller Program. The network also collects data from the Kentucky Division of Conservation which consists of rural water testing data for approximately 5,000 wells across Kentucky.

The Kentucky Department of Surface Mining and Reclamation Enforcement retains water quality data from 4,000 pre-mining wells from 1983-1990. Other data collection organizations include: the Kentucky

Division of Waste Management, Kentucky Division of Pesticides, Kentucky Cabinet for Human Resources, the USGS, and the Kentucky Division of Oil and Gas (Sendlein 1996).

Wells included in the network were selected to ensure adequate coverage informed by physiographic regions, major watersheds, and major aquifers. This also results in wells in areas where stakeholder interests are prevalent, and where there is a risk to the resource. The design of the groundwater monitoring network had to account for the large amount of existing data available through the various organizations already conducting groundwater monitoring within the state. Protocols were established to ensure consistency in selection of monitoring of wells.

3.9.2 Monitoring

The primary objective of the network is to determine the condition of groundwater used in each major area of Kentucky and to document long term changes in quality and quantity. The network is monitored at a regular frequency to ensure samples at multiple times of year, although details of the temporal sampling were not provided.

3.9.3 Data Collection, Storage, and Dissemination

Geographic Information Systems (GIS) are used to convert the data collected into useful and accessible information. This information includes ranges and trends in water quality for regions, sub-regions, major watersheds, aquifers, well-depth ranges, age of wells, major land uses, types of flow systems in the area and other subsets of data (Sendlein 1996). The KGMN also makes use of outside expertise and training. As the needs of KGMN change, so too must the expertise of the people involved.

The network managers have emphasised collection of digital data as a means of reducing errors and costs associated with transferring paper monitoring records to electronic database. A digital approach also facilitates rapid distribution of data.

The groundwater monitoring data are kept in the Kentucky Groundwater Data Repository and with the USGS. The information is used to improve the strategy for development of groundwater resources in the state. The information is available to the public and other stakeholders through the internet, paper publications, and other appropriate avenues of distribution. Much of the information is interpreted into user-friendly maps and tables which are designed for non-scientists to access.

3.9.4 Funding

No information was available regarding the funding of this monitoring network.

3.10 Louisiana State Groundwater Monitoring Program

Information for this section was collected entirely through personal communication with Dave Walters and John Lovelace from the USGS Louisiana, and Chris Stellmore, Louisiana Office of Conservation, Groundwater Resource Program.

3.10.1 Background, Purpose, and Design

The Louisiana State Groundwater Monitoring Program (LSGMP) is an integration of a number of monitoring networks found throughout the state that are used for different purposes. The networks monitor both quantity (ensuring withdrawals are not degrading the aquifer) and quality (primarily handling changing regulatory parameters and saltwater encroachment). The networks were created based on local need, and service a diverse group of stakeholders. These stakeholders now benefit from having access to regional data. The majority of the monitoring wells are located in major producing aquifers to monitor change and static response to withdrawals.

The networks that form the LSGMP are generally underfunded resulting in poor spatial coverage of monitoring locations. Wells are often repurposed from other functions to be included in the network, resulting in suboptimal locations and relying on cooperation of land owners for access.

The development of the contributing local networks spans decades and was generally not documented resulting in a loss of institutional memory about the original drivers for design.

The LSGMP depends extensively on existing groundwater wells on private lands and requires landowner permission to access these wells for monitoring and thus the success of the network relies on maintaining positive relationships with land owners and stakeholders to ensure continued cooperation. The one exception to the use of existing wells is for monitoring saline encroachment. A custom network of monitoring wells was installed specifically for this purpose.

3.10.2 Monitoring

Most measurements are collected onsite by the USGS, a small number of wells are remotely monitored, but these sites are still field checked on a regular basis. Frequency of monitoring can change based on the need but generally water levels are measured on quarterly. Water quality samples are collected and analyzed either annually or semi-annually based on local conditions and requirements.

3.10.3 Data Collection, Storage, and Dissemination

All of the data are stored in the USGS database following quality control. The data are published for stakeholders and the general public on an annual basis. Prior to 2005 data were provided in hard-copy and since 2005 data are published electronically on the USGS website.

3.10.4 Funding

Funding is provided primarily through state funds administered by both the Department of Environmental Quality and the Department of Transportation and Public Works and cooperation with local and federal agencies.

3.11 Montana Bureau of Mines and Geology: Groundwater Assessment Program

Information for this section was collected entirely through personal communication with John LaFave from the Montana Bureau of Mines and Geology (MBMG).

3.11.1 Background, Purpose, and Design

The Montana Legislature established the Groundwater Assessment Program in 1993 after considering the recommendations of a Groundwater Task Force organized by the Environmental Quality Council in 1989. The statute specifically requires a groundwater monitoring program to produce and maintain long-term water level and water quality records and a groundwater characterization program to systematically assess and document the hydrogeology and quality of the state's major aquifers. As part of its mandate to make groundwater information widely available, the assessment program includes the Groundwater Information Center (GWIC) database. The Legislature also created an interagency Steering Committee that selects study areas, addresses the need for better coordination among state, federal, and local government units, and oversees assessment program progress.

The monitoring network relies mostly on existing wells. While it would have been preferable to install dedicated monitoring wells, this would be cost prohibitive. Individual wells within locally administered networks were selected by the groundwater steering committee.

Network operators report some of the greatest challenges of the design of the network include cooperation from well owners to provide access to wells, managing the logistics of monitoring a large network, and managing the data flow so that the data are made readily available.

3.11.2 Monitoring

The Groundwater Monitoring Program measures water levels each calendar quarter in 954 strategically located wells. Continuous water level recordings (hourly interval) are conducted in a small subset of the wells.

Water quality samples are collected on a frequency of about once every seven years. If a constituent is detected above the health standards the well owner is notified. Water samples are analysed for major ions, trace metals and other indicator parameters (not defined).

3.11.3 Data Collection, Storage, and Dissemination

All data gathered by the monitoring or characterization programs, other MBMG projects such as the Ground Water Investigations Program, and projects managed by other agencies are stored in the Ground Water Information Center database. The data, as well as maps and reports, are available online (http://mbmggwic.mtech.edu/).

About 20% of requests for information are related to drilling new wells. Another 17% of GWIC data requests are to support land sales and filing of water rights. About one-third of data users request a drilling log for a particular well. More than 16,700 registered GWIC customers include people from all parts of Montana and about 2,570 individuals from other states. Out-of-state users are either private citizens who are considering purchasing land in Montana or consultants who are employed in Montana. In 2005, GWIC staff began scanning well-log documents so that the images could be delivered through the website. Currently there are more than 205,000 images available.

3.11.4 Funding

The Program is funded by the state, and there is an effort to maintain the network with long term financial stability.

3.12 Montana Bureau of Mines and Geology Groundwater Monitoring around Coal and Coal Bed Methane Development in the Powder River Basin

Information for this section was collected through personal communication with Liddi Meredith from the MBMG, as well as other sources as cited in the summary.

3.12.1 Background, Purpose, and Design

This program was initiated:

- to document baseline hydrogeologic conditions in current and prospective CBM areas in southeastern Montana;
- to determine actual groundwater impacts and recovery; and
- to provide data and interpretations for permitting and exploration decisions.

Community concerns include impacts to groundwater levels and potential soil and surface water quality impacts associated with water withdrawal and disposal (Wheaton and Donato 2004).

The monitoring network was constructed primarily from existing wells. An inventory of existing wells revealed an extensive set of candidate wells associated with coal mine operation from which to select the wells to include for monitoring. The final network included an array of wells designed to provide geologic and hydrogeologic data about coal beds that may be developed for CBM production, and aquifers that underlie and overlie potential production zones. The wells in the network are located within active coal mine development areas, within future development areas and, outside areas of potential development. Because the network was developed from existing wells, the well distribution was also strongly controlled by landowner cooperation, and distribution of state and federally owned land.

Gaining landowner and industry cooperation was challenging on occasion. Through continued communication most stakeholders were convinced of the benefit of third party monitoring and participated in the network development. However, even with good stakeholder cooperation, there are areas with insufficient distribution of wells. New wells are installed as funding becomes available.

3.12.2 Monitoring

Water levels in most wells are measured monthly. Water level dataloggers are used at approximately 15 wells. These loggers measure and store water levels hourly.

Alluvial aquifers are sampled for complete chemistry analysis twice yearly and water quality samples from deep wells are collected from selected wells once a year. (Wheaton and Donato 2004). Water samples were measured for physical parameters (pH, EC, SAR, and TDS) during sample collection at the well. Major and minor constituent analysis is completed at the MBMG laboratory in Butte, Montana. Isotopic analyses are sent to commercial or academic laboratories. Detailed analytical schedules were not provided.

3.12.3 Data Collection, Storage, and Dissemination

Data are disseminated to well owners and other stakeholders through personal communication, an annual report, and public meetings.

All water level measurements and water quality analyses are stored in the GWIC database. This database is free and available to the public. Data from previous reports have been entered in GWIC to provide a longer period of record.

Reporting is completed at the end of each water year (12 months, starting October 1) and usually published in early spring (March) after internal and external reviews. All annual reports are available on the MBMG publications website. Non-technical interpretation and explanations are presented in Informational Pamphlets (IP5, IP6 and IP7 on the MBMG publications website). These are written for the general public and disseminated at public meetings and during field visits.

3.12.4 Funding

The majority of funds for the monitoring network are provided by the U.S. Bureau of Land Management through a grant that is renewed yearly. The Rosebud, Big Horn, and Powder River Conservation Districts have been long-term supporters of coal-hydrogeology work (Wheaton and Donato 2004). Project specific funding has come through the US EPA, US DoE, and Montana State. This is not an ideal funding structure for a long-term monitoring network (annual grants); however, long term funding has never been secured.

One of the major benefits from this monitoring program is the continuity of data; however, lapses in funding occasionally create data gaps.

3.13 Groundwater Monitoring Requirements for Municipal Solid Waste Landfills

Information for this section was collected through sources as cited in the summary as well as personal communication with 311 operators for the City of Calgary and the South Calgary BFI Landfill.

3.13.1 Background, Purpose, and Design

Nearly all municipal solid waste landfills (landfills) in North America are required to monitor the underlying groundwater for contamination during their active life and post-closure care period (BC MoE n.d.; Government of Alberta 2010; U.S. EPA 2012). Groundwater monitoring at landfills is meant to detect unacceptable groundwater contamination resulting from landfill operations. In most cases, owners of the landfill must develop the groundwater monitoring program to include, at a minimum, all of the following:

- background groundwater quality for each monitoring well;
- groundwater quality control limits for each naturally occurring parameter;
- a detailed program for groundwater sample collection frequency and analysis; and
- a groundwater management contingency plan.

Landfill owners/operators responsible for a new or laterally expanding landfill must construct groundwater monitoring wells that provide an accurate representation of up gradient and down gradient groundwater quality (BC MoE n.d.; Government of Alberta 2010; U.S. EPA 2012). Each groundwater monitoring location along the compliance boundary must include at least one well designed to allow for the collection of groundwater samples from the uppermost formation. Groundwater monitoring wells should be protected from damage and be locked, except when being sampled. Typically a groundwater monitoring network would consist of a series of wells placed up gradient (baseline wells) and down gradient (sentinel wells) of the landfill. The location and number of wells required to adequately describe hydrogeological conditions will depend upon the site-specific geology, soil and groundwater regime (BC MoE n.d.). A groundwater monitoring well network should consist of a sufficient number of wells, installed at appropriate locations and depths, to yield samples that represent the quality of both ambient groundwater and leachate which has passed under or through the disposal area of the landfill. Networks of wells can be developed in phases, with data reviewed at the end of each phase (BC MoE n.d.; Government of Alberta 2010).

3.13.2 Monitoring

Typically, there are three phases of the groundwater monitoring for landfills (Government of Alberta 2010; U.S. EPA 2012) including detection monitoring, assessment monitoring, and corrective action. These three phases are described below.

Detection Monitoring

During the detection monitoring phase, owner/operators monitor throughout the facility's active life and post-closure care period. The frequency of sampling is determined on a site-specific basis by the provincial or state regulatory agency.

If at any time during the detection monitoring phase, one of the monitored constituents (e.g. findings of Volatile Organic Compounds: BTEX, F1, F2, Phenols) is detected at a statistically significant level higher than the established background level, the owner/operators must notify the state/provincial regulatory agency. The facility must establish an assessment monitoring program unless the owner/operators can prove that the detection of the constituent(s) was the result of a sampling, analysis, or statistical evaluation error (i.e. a false positive result), a natural fluctuation in groundwater quality, or caused by another source.

Assessment Monitoring

After detecting a statistically significant increase in a monitored constituent, the landfill must begin an assessment monitoring program to characterize the nature of the release, determine if the contamination has migrated beyond the facility boundary, and begin assessing corrective measures.

Corrective Action

Landfill owners/operators must immediately notify the regulator and implement a groundwater contingency plan if at any time, including until the end of post-closure, the groundwater fails to meet the groundwater performance standards within the compliance boundary (locations where measurements of groundwater quality for regulatory purposes are taken to assess a landfill’s performance).

3.13.3 Data Collection, Storage, and Dissemination

In British Columbia, monitoring reports in electronic format containing suitably tabulated groundwater quality data, quantity measurements and other monitoring data for inspection are to be submitted to the Regional Waste Manager within 30 days of each sampling term (BC MoE n.d.). In a specific case of the BFI landfill in south Calgary, groundwater samples are taken several times per year and analyzed by an independent laboratory. The results are then submitted to ESRD for their review. In addition, the results are available to the public on the BFI website.

3.13.4 Funding

No information was found on funding for landfill monitoring. Funding is likely provided by operators/owners of the landfill, which include private companies, municipalities, and provincial and state governments.

3.14 North Dakota State Water Commission Groundwater Monitoring Program

Information for this section was collected through personal communication with Bob Shaver from the North Dakota State Water Commission, as well as other sources as cited in the summary.

3.14.1 Background, Purpose, and Design

The State Water Commission (SWC) maintains a groundwater monitoring network. The original purpose of the network was to monitor water appropriations and allocations, primarily for agricultural uses. With the increase in oil production and the associated increased pressure on water resources, the SWC expanded the existing network in coordination with the USGS cooperative water resources monitoring program.

The North Dakota SWC’s groundwater monitoring program has three main goals:

- collect water resource data;
- organize and store water resource data; and
- evaluate water resource data and future data needs (Sando 2011).

The focus of the network is to monitor allocated water use under state law. Monitoring of oil field operations only occurs when the operations overlap with the primary purpose of the network. The design of the network is augmented as required resulting in a flexible network that is expanded based on the demand on water resources in the state. Monitoring wells are installed in areas of increased demand for groundwater and in areas with little existing monitoring.

3.14.2 Monitoring

The network started out by looking at the valley gravel aquifers, and then evolved to mirror the broader use of groundwater within the state.

The SWC develops annual maintenance/action plans that are updated every two years. The current 2011-2013 Action Plan with task target dates includes (Sando 2011):

- install test holes and plug obsolete observation wells (April-Dec., annually);
- install 125 to 175 monitoring wells (April-Dec., annually);
- install 20 to 30 staff gauges, monitor water levels and flows (April-May, annually);
- measure 25,000 to 30,000 water levels in wells and surface water bodies (April-Dec., annually);
- collect data from 60 to 70 continuous water level recorders (Jan.-Dec., annually);
- collect 1,500 to 2,000 samples from wells and surface water bodies (April-Dec., annually);
- analyze samples for various chemical constituents (April-Jan., annually);
- repair and maintain 3,500 to 4,000 measurement and sampling locations (April-Dec., annually);
- enter data into the database (ongoing);
- coordinate the USGS cooperative water resource monitoring (March-Dec., annually); and
- conduct aquifer tests (as requested/needed).

Water resource data pertaining to water levels, water quality, and well information are collected on a continuous basis. Some of the data are measured using pressure transducers with dataloggers, other data are measured manually. The network design does not include telemetry, requiring that each well be visited to retrieve the data.

3.14.3 Data Collection, Storage, and Dissemination

The data are stored in an Internet-accessible state owned database. The database currently contains about 3.9 million water level measurements, over 34,000 site locations, nearly 65,000 water quality analyses, and 25,000 sites with lithological descriptions. Additional data acquisition sites are implemented as needed through time. Aquifer parameters and properties are evaluated through an aquifer-testing program.

Data are available online on the state water commission website. If problem areas are identified through sampling, the state water commission sets up a town hall meeting in the impacted communities to provide information and respond to community concerns.

3.14.4 Funding

The program was initially funded by state and federal governments in a cost share program to investigate water resources throughout the state. The network is now solely funded by the state, paid for in part from oil and gas revenues.

3.15 Pennsylvania Shale Network

Information for this section was collected through personal communication with Susan Brantley from the Pennsylvania Shale Network, and Andrew Paterson from the Marcellus Shale Coalition, as well as other sources as cited in the summary.

3.15.1 Background, Purpose, and Design

The Shale Network was established to assist stakeholders (citizens, scientists, industry, etc.) collect, store, and interpret data for water resources that may be affected by tight gas production. The Shale Network is a multidisciplinary data collection system gathering and storing water quality and water level data provided by watershed groups, government agencies, industry stakeholders, and universities. The network is designed to be an “honest broker” of information which facilitates data interpretation, and dissemination.

The Shale Network is not responsible for its own network of wells but rather relies on stakeholders to provide the data collected from stakeholder owned and operated networks. To assist in the establishment of the network, a steering committee connected with researchers, agencies, industry representatives, and community organizers to generate a system and database to collect, store and disseminate knowledge (Shale Network n.d.).

The most significant best practices of the network include collaboration with existing monitoring groups, the coordination of data, and the design and implementation of a database and interface that is complete and user friendly. Furthermore, the network focuses not only on monitoring and collecting water data, but adding value to the data to make it useful for the numerous stakeholders. This network is still under construction in some aspects, but makes use of existing ground and surface water monitoring capacities in Pennsylvania.

3.15.2 Monitoring

Community, industry, and government bodies collect water level and water chemistry data for the Shale Network. Common water quality indicators that are measured include: pH, Na, K, Mg, Ca, SO_4, Cl, Br, NH_4, NO_3, NO_2, total N, acidity, alkalinity, BOD, COD, hardness, TDS, specific conductance, and TSS. Trace elements include: Al, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Hg, Mo, Ni, Pb, Se, Ag, Sr, Th, U, and Zn. Organic constituents that are measured include acetophenone, benzene, bis (2-ethylhexyl) phthalate, ethyl benzene, ethylene glycol, methanol, methylene blue active substances, naphthalene, oil and grease, phenolic, toluene, and xylenes (Shale Network n.d.).

Much of the data collection is completed by volunteers (e.g. watershed groups). These volunteers are trained to measure water levels, collect water samples, and measure water physical parameters. Volunteers generally work with Alliance for Aquatic Resource Monitoring (ALLARM) to pass a split sample quality control test annually. Volunteers use TDS meters to test waters and then collect an extra set of water samples to send with their data to the ALLARM lab. The ALLARM laboratory double checks volunteer data. If precision is acceptable, volunteers have passed quality control and can continue monitoring to provide data. If precision is not acceptable (outside limits), ALLARM re-trains volunteers. All methods are documented. ALLARM is responsible for Quality Assurance/Quality Control (QA/QC) with volunteer groups as appropriate (Shale Network n.d.).

3.15.3 Data Collection, Storage, and Dissemination

Data are collected by 700 volunteer community-data collectors as well as county, state, and federal bodies, members of colleges, universities and gas industry. The Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. is going to build the Shale Network a Hydroserver to store and publish the monitoring data.

Data are currently stored in the Shale Network Object Data Manager (ODM) and made available to the public though a WaterOneFlow web service. An open source desktop application called Hydrodesktop allows users to search for data within the WaterOneFlow system.

The data are used for stakeholder information and decision-making (Shale Network n.d.).

3.15.4 Funding

The National Science Foundation funds the Shale Network. The steering committee consists of members from Dickinson College, Pitt University, Penn State University, and the Consortium of Universities for the Advancement of Hydrologic Sciences, Inc.

3.16 Pennsylvania Marcellus Shale Coalition: Water Quality Data Repository

Information for this section was collected entirely through personal communication with Andrew Paterson from the Marcellus Shale Coalition.

3.16.1 Background, Purpose, and Design

The Marcellus Shale Coalition does not operate a monitoring network, but rather provides a central data storage location for baseline water quality data collected by the Pennsylvania Department of Environmental Protection (DEP) and oil and gas companies. The Marcellus Shale Coalition (MSC) customized an existing software package (Earthsoft) to store the analytical data along with the associated well construction and completion information. The scope of the project was developed by industry representatives in consultation with the DEP.

Some of the major challenges that surrounded the implementation of the data repository included volunteer representation from industry (limited time) and training members to use the custom software.

3.16.2 Monitoring

The MSC is not responsible for monitoring activities. However, the central repository has influenced monitoring protocols resulting in a standardization of how data are collected by the contributing groups. No information was provided on the specific water quality data stored in the repository.

3.16.3 Data Collection, Storage, and Dissemination

Data are provided by the member entities to be stored in the repository.

Dissemination of information to stakeholders is not a priority of the repository. Individual landowners receive the laboratory data, and industry and the DEP can view the data as required. Data are not publicly available as the confidentiality of the landowner’s well information is requested by the DEP.

3.16.4 Funding

The MSC paid for the establishment of the database. Individual oil and gas companies pay for all the sampling and analysis. The repository is funded this way since the MSC did not anticipate that the DEP would have the required funds to pay for the database itself.

3.17 Texas Water Development Board Groundwater Monitoring Program

Information for this section was collected entirely through personal communication with Janie Hopkins from the Texas Water Resources Development Board (TWDB).

3.17.1 Background, Purpose, and Design

The TWDB groundwater monitoring program has its roots in local monitoring programs designed for special projects. In the past 25 years it has been expanded into a state wide network with the objective of monitoring major and minor aquifers within the state. Monitoring assists in understanding and managing the groundwater resource especially in times of drought.

The monitoring well network that supports the monitoring program is composed of existing wells. The goal in designing the network is to have 1 well per 25 sq. mi. per aquifer when greater than 100,000 ac-ft. of groundwater pumped annually from an aquifer or 1 well per 50 sq. mi. per aquifer when between 10,000 and 100,000 ac-ft. of groundwater pumped annually from an aquifer.

The monitoring program is managed at the state level, but is a collaborative effort with local groundwater conservation districts that are responsible completion of much of the monitoring activities.

3.17.2 Monitoring

Monitoring schedules vary across the network. For wells monitored by TWDB, water levels are measured annually in each of the monitoring wells. TWDB monitors water levels in nearly 2,000 wells and receives data from 50 groundwater conservation districts, the USGS, and several local operators/water districts.

A subset of the monitoring wells was selected for water quality analysis. In these wells water quality samples are collected once every four years. Water quality samples are analyzed for inorganic constituents, nitrate, and radionuclides.

Wells monitored by local groundwater conservation districts are monitored at a minimum following the TWDB protocol, but may be monitored more frequently based on local data needs.

3.17.3 Data Collection, Storage, and Dissemination

Water level data are collected by a combination of manual measurements and automatic water level measurements with data stored on dataloggers at remote well locations.

Well completion records, and water level and quality data are stored in a Microsoft Structured Query Language. The server is maintained by the TWDB. The Water Quality Program Specialist performs QA/QC on all data prior to uploading to the database. TWDB also maintains a repository of well records and water level and water quality field books.

Data collected during monitoring are available publically on the TWDB website (http://www.twdb.texas.gov/groundwater/data/).

3.17.4 Funding

The monitoring program is funded by the state general fund through TWDB and the local groundwater conservation districts. Additional funding has been supplemented in some years by federal funds bestowed by the EPA and channeled through the state's regulatory agency. Funding had been dependent on the status of State financial health and public perception of the value of the network. Significant increases in the program funding were realized following the drought in 1996-1997.

4. IMPEDIMENTS AND CHALLENGES TO THE LITERATURE REVIEW

This section is meant to briefly describe the impediments and challenges with collecting accurate and sufficient information for the literature review. The challenges described may put some of the information summarized in this document into context.

A significant portion of the information gathered for the literature review was not available through open source documents. Groundwater monitoring participants are sensitive to the political environment in which they operate. Respondents were often hesitant to provide information until they were assured that the information would be used for a literature review, and not as an assessment of their particular program or network.

Often identifying the appropriate contact person, who could provide the desired information for a groundwater monitoring network, proved difficult. There was often a high degree of interagency redundancy and confusion as to the appropriate person with authority to respond to the inquiry.

Further detailed information requested through follow-up communications was not always forthcoming. In several instances no response was received.

5. THEMES, BEST-PRACTICES, AND KEY FINDINGS

5.1 Key Themes

The key themes that developed from the literature review are centred on developing a groundwater monitoring network that meets the objectives of those driving the network development. Based on this review, a clear definition of network objectives is important especially for large networks with multiple objectives. As noted in some of the examples these objectives should be expected to evolve in time as the industry and the hydrogeologic understanding matures.

To support these objectives the network should be:

- hydrogeologically and technically sound, backed by a scientifically based methodology;
- structured so monitoring is completed at a frequency and with analysis of appropriate parameters, to meet the network objectives (e.g. sentinel observations for water quality impacts);
- supported by stakeholders: landowners are especially important for access to wells; and
- transparent in the data collection and analysis (government lead)

5.2 Best Practices

The best practices summarized from the individual networks follow from the key themes.

To ensure a hydrogeological sound network, network development should include input from technical experts, but should not discount local knowledge of the area as local water well drillers and landowners may have strong intuitive knowledge of the local hydrogeology.

Monitoring should include baseline monitoring, if possible. Analytical schedules and frequency should be related to local hydrogeologic conditions and anthropogenic activities occurring within the area covered by the network. Flexibility in monitoring schedules should be included in the network to facilitate changing operations.

Support of the stakeholders is fundamental to the long-term sustainability of a network both from a funding perspective and with respect to the credibility of results published by the network managers. Maintenance of positive relations with land owners allows for access to existing wells and drilling new wells during expansion of networks.

Credibility of the data collected relies on a transparent process of consistent data collection practices, rigorous quality control and quality assurance. Credibility is also supported by housing data in centralized well maintained databases with the data accessible to the public.

Most of the networks identified are owned and operated by government agencies or third party organizations and not directly by the oil and gas industry.

5.3 Key Findings and Conclusions Pertaining to Groundwater Monitoring Networks

The monitoring networks identified as part of the literature review were primarily government operated networks that have evolved through time. Some of the networks are amalgamations of multiple local networks. The drivers behind the monitoring efforts have often changed through time as different types of industry have developed within the foot print of the monitoring network. These networks have a convoluted past that makes identifying design methodologies, and implementation and operation plans difficult.

In reviewing the experiences of the network operators the following conclusions can be drawn.

a) A clear understanding of monitoring objectives will assist in ensuring that monitoring network design and the data collected reflect the needs of stakeholders, decision-makers and others.

b) The intent of each monitoring network varies. Although groundwater quantity and quality issues may arise at various facilities, these tend to be quite localized and detectable by the established on-site compliance monitoring networks. To address the potential cumulative effects of regional development, an effective monitoring network with a baseline dataset is critical.

c) As a general observation, networks with the most information and documentation were the most comprehensive and well designed. They are ‘fit-for-purpose’ monitoring networks, with a related and specific design. Networks that are developed in pieces by different groups and for different purposes which are combined to form a monitoring network tend to have less available and interpreted information.

d) Water quality monitoring should include those compounds most likely to elucidate future changes to water chemistry, but should also include a wide array of analyses as it is not always possible to predetermine which chemical will indicate change.

e) QA/QC is often overlooked, possibly because it can be time-consuming and costly. Strong QA/QC programs provide legitimacy to data collected from the monitoring network. It can be critical to help resolve disputes between stakeholders by ensuring that questions around data quality don’t arise as a cause for dispute.

f) A sustainable funding model is vital to enable success of a long-term monitoring network. Building in monitoring expenses to capital and operational expenses of industrial development provides a sustainable funding plan for the monitoring.

Within the set of identified monitoring networks, the networks underdevelopment for the Alberta Groundwater Management Areas within the Lower Athabasca River Basin provided the best information about monitoring network design, implementation, and operation. In these cases, ESRD followed a design process that identifies the aquifers that are intrinsically vulnerable to potential impact and thus priorities for monitoring, and then assessed well placement based on a defined set of selection criteria. Implementation of these networks used existing wells for cost savings. The networks are operated by a management group that includes government, industry, groundwater experts and other stakeholders. The network is owned and maintained by the government. The data will become available to the general public. This combination of diverse management group and transparency of monitoring results should assist in the credibility of the monitoring results.

Fundamentally credibility of the monitoring should be a primary driver in design, implementation and operation of a monitoring network. Without a credible network, the value of the monitoring may be significantly reduced.

6. SCOPE OF MAPPING EXISTING INFORMATION

The mapping of existing information was completed using a GIS. This approach facilitates analysis of the spatial data. The GIS was developed using ArcGIS 10.0, although the data can be readily imported into other GIS software.

The scope for the development of a GIS included identifying and integrating data from existing databases and maps into a single mapping product that would help inform CAPP member companies and government of existing resources for building regional groundwater monitoring networks. The scope did not include developing new data or interpretation of data to develop new map products.

Information and data that were gathered and integrated within the GIS included:

- locations of known tight gas plays;
- watershed boundaries;
- fresh water aquifers;
- provincial and municipal groundwater monitoring wells;
- existing or suspended non-saline sources wells or monitoring wells used for oil and gas development;
- domestic wells; and
- distribution of existing oil and gas wells.

The study area for the GIS mapping was approximately the Alberta and Williston basins and covers parts of British Columbia, Alberta, Saskatchewan, and extends into southwestern Manitoba. The study area is outlined in orange on all figures.

7. GEOGRAPHIC INFORMATION SYSTEMS DATA

Data integrated in the GIS were collected from various governmental, private, and public sources. This section documents the sources of the data used to develop each GIS layer.

7.1 Tight Oil and Gas Plays

Several maps summarizing the locations of tight oil and/or gas plays were identified (e.g. Lewis 2010, NEB 2009, US EIA 2011). These have variable extents, varying in size from North America to western Canada. In consultation with the CAPP project management team, it was determined that the summary map of tight oil and gas resources plays in western Canada published by the Alberta Oil Magazine (Lewis 2010) was the most comprehensive and was thus adapted for this work (Figure 2).

7.2 Watershed Boundaries

The watershed boundaries for the major rivers and their tributaries in western Canada are presented in Figure 3. The watershed boundaries were developed from data accessed from the Water Survey of Canada (WSC). WSC have mapped sub-drainage areas across Canada. These drainage areas were linked to outline the drainage areas of the major tributary rivers using physiographic data from the Atlas of Canada. This mapping provides an intermediate level of detail compared to the primary and sub drainage areas outlined by WSC.

7.3 Subsurface Fresh Water Aquifers

The major fresh water aquifers presented in Figure 4 were accessed from the Geologic Survey of Canada (GSC). The map presents the major fresh water aquifers in the study area. Minor or local fresh water aquifers are not shown on the map. Deeper water bearing formations (not shown) generally contain water of poor quality for potable or agricultural use due to elevated salinity levels.

The GSC map is a compilation of maps originally developed by provincial entities and reflects the interpretation of the aquifers of primary importance within the respective provinces. This provincial focus results in discontinuous aquifer mapping along political boundaries that do not reflect the actual extent of the regional aquifers.

7.4 Provincial or Municipal Groundwater Monitoring Wells

The provincial governments of British Columbia, Alberta, Saskatchewan and Manitoba all own and operate GOWNs.

The BC GOWN includes 416 wells (Figure 5 light green), of which 163 wells are actively monitored for water levels and/or water quality. Most of the wells currently monitored are located in southern and in southwestern British Columbia. The British Columbia Ministry of Environment, Water Stewardship Department includes the BC GOWN wells within their water well record database[1].

The Alberta GOWN network is documented in Section 3.1. The AB GOWN includes 1212 wells (Figure 5, green circles), of which 257 are actively monitored for water levels and/or water quality.

The Saskatchewan GOWN network includes 67 wells actively monitored for water level and/or water quality (Figure 5, blue circles).

The Manitoba GOWN network contains 569 wells primarily located within the urban and agricultural southern part of the province (Figure 5, light blue circles). The data are available for request from the Manitoba Ministry of the Environment. The data include the locations of 569 monitoring wells (latitude and longitude) and text files with well information for a subset of 177 wells. The text files could be translated into a database format to facilitate searches of the data; however this was not part of the scope of this project.

7.5 Municipal and Domestic Wells

ESRD (ESRD 2012b), British Columbia Water Stewardship (BCWS) (GeoBC, 2012), and Saskatchewan Watershed Authority (SWA) (GeoSask 2012) maintain records of water wells drilled within their respective provinces . Each provincial entity has different reporting requirements. All information contained in the water well record databases has been included in GIS. These data include a descriptor for the use of the well.

The ESRD database contains 34 unique well use descriptors, the BCWS database contains 10 unique well use descriptors and the SWA database contains 12 unique well use descriptors. While there is some overlap in the well use descriptors, the three databases are not consistent. In an effort to provide a general level of consistency between the databases, seven higher level well use descriptors were defined: Abandoned, Domestic, Industrial/Commercial, Municipal, Observation, Other, and Unclassified. Table D provides the grouping for each provincial database in to the higher level descriptors. All of the water well records are plotted on Figure 6.

From these databases the municipal and domestic wells have been identified and plotted separately on Figures 7 and 8, respectively.

Water well records for the Province of Manitoba, other than the MB GOWN wells, were not accessible at the time of the preparation of this report.

[1] Within this database the well ID for BC GOWN wells is located in BSRVTNWLLN. All other wells have no entry in this field. The well status (e.g. active) is located in the MNSTRBSRVT field.

Table D Consolidated Water Well Record Descriptors

Consolidated Descriptors	ESRD Database	BCWA Database	SWA Database
Abandoned	Dry hole – Abandoned; Old well – Abandoned; and Test hole – Abandoned.	Abandoned	
Domestic	Co-ops (Colonies); Domestic; Domestic & Industrial; Domestic & Irrigation; and Domestic & Stock.	Private Domestic	Domestic
Industrial/ Commercial	Commercial; Dewatering; Geothermal; Golf courses; Heat transfer; Industrial; Industrial & Stock; Industrial camp; Injection; Intensive livestock Operation; Irrigation; Stock; and Water hauling.	Commercial and Industrial; Irrigation	Industrial; Irrigation; Mineral recovery; Mineral water; Multipurpose
Municipal	Municipal; Municipal & Industrial; Municipal & Observation; and Rural subdivision.	Water supply system	Municipal; Recreation
Observation	Observation.	Obs well	
Other	Contamination Invest.; Hydrostatic testing; Investigation; Monitoring; New well; Old well – Test; Other; and Standby.	Other; Test	Drainage; Other; Research

Consolidated Descriptors	ESRD Database	BCWA Database	SWA Database
Unclassified	Unknown	Unclassified; Unknown	Unclassified

7.6 Existing Oil and Gas Wells

A database of oil and gas wells in Canada is maintained by IHS Energy Canada Ltd. (IHS). This database is compiled from various government and industry sources. As of June 2012, the database contained 644,719 drilling records associated with oil and gas production and includes 218 different use descriptors. Broad classifications of the wells were defined by grouping the use descriptors into six categories (abandoned, producing, suspended, service, water, and, other) as shown in Table 1. The spatial distribution of the wells in the IHS database (IHS 2012) is presented in Figure 9.

7.7 Existing or Suspended Non-saline Water Source or Monitoring wells

Existing or suspended water source or monitoring wells used for oil and gas development are contained within the IHS database (Figure 9). Within the database there is a differentiation between brine and water source wells.

8. CLOSURE

We trust that this report satisfies your current requirements and provides suitable documentation for your records. If you have any questions or require further details, please contact the undersigned at any time.

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