GROUNDWATER MANAGEMENT IN CANADA

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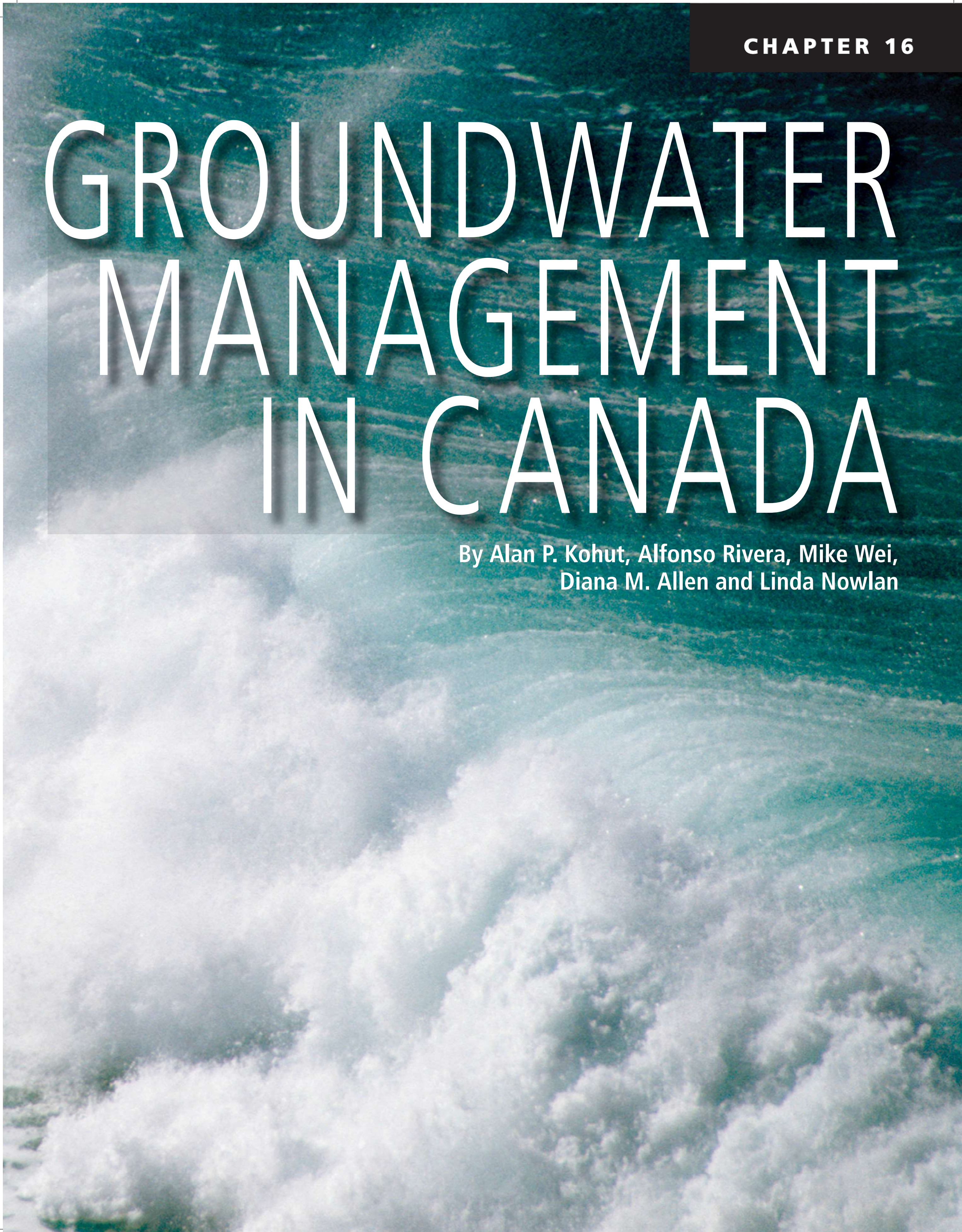

16.1 INTRODUCTION

This chapter provides an overview of the current and diverse state of groundwater management in Canada, the roles of the management agencies, and the scope of their activities.

Canada is a large federation of ten provinces (British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador), three territories (Yukon, Northwest Territories, and Nunavut). Each province and territory has its own government. Additionally there is a federal government. As such, there is a variety of legislative framework under which groundwater resources are governed and managed. It is not surprising, then, that there are significant differences across the nation.

In recent years, several publications (Rivera et al., 2003; Nowlan, 2005; Côté, 2006; Council of Canadian Academies, 2009) have noted the diverse groundwater management approaches which have evolved in various parts of the country. Several of these publications speak to the need for a more collaborative, coordinated and integrated approach among all levels of government, and with the public, to ensure groundwater sustainability. Although coordinated and integrated assessments are being undertaken, some persistent and emerging issues still need to be addressed.

16.2 GROUNDWATER USE IN CANADA

In order to manage our groundwater resources properly, it is important to have information on how much groundwater is available and how much groundwater is used. To date, there is no recent comprehensive compilation of groundwater use data in Canada. This is because it is very difficult to obtain information on groundwater use within individual provinces and territories, all of which regulate the resource differently. The picture is also incomplete because water use is not always measured and reported (e.g., lack of compliance with measurement and reporting requirements, groundwater extraction not regulated in British Columbia, and domestic use exempt from permitting). Groundwater is also vital for sustaining ecosystems, but no information is available on how much groundwater is "used" for this purpose.

Based on 1996 statistics data, Environment Canada (2011a) reports that 30.3% of Canada's population relies on groundwater for municipal, domestic and rural use. Based on the 2010 population of 33.7 million, this means 10.2 million Canadians depend on groundwater. Approximately two thirds of these users live in rural areas, wherein wells may produce a more reliable and less expensive water supply than that obtained from nearby lakes, rivers and streams. The remaining users (or 33%) are located primarily in smaller municipalities and/or communities, where groundwater is the primary source for their water supply systems. The percentage of population dependent on groundwater ranges from 23.1% in Alberta to 100% in Prince Edward Island (Figure 16.1).

Groundwater use in Canada has increased by 500% in recent decades, with the total volume pumped increasing from 200 Mm^3/year (million cubic metres per year) in the 1970s to more than 1,000 Mm^3/year in the late 1990s (Statistics Canada, 2003). The amount of groundwater used for domestic purposes has risen right along with the increase in population (Figure 16.2), from 10% in the late 1960s to 30% in the late 1990s.

Groundwater also sustains economic activity by providing significant water supplies to industries involved in manufacturing, mining and petroleum.

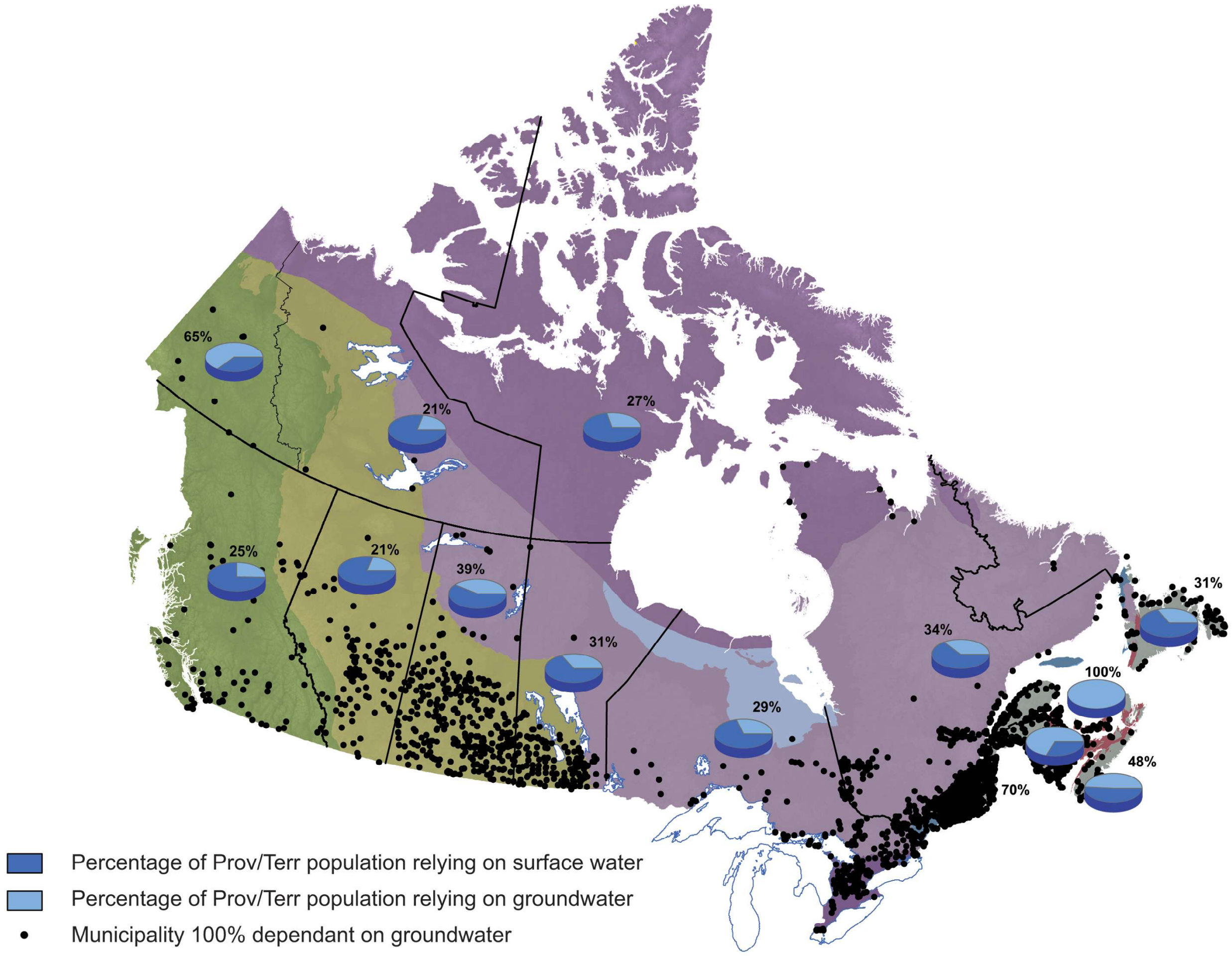

Figure 16.1 Groundwater use in each province and territory. Also shown are the hydrogeological regions in Canada.

Information on groundwater use in Canada for various sectors has been compiled by Rutherford (2004) from several data sources spanning a number of years. Table 16.1 provides a representative indication of sector use based on allocation permits and estimates. The following descriptions of water use for various sectors are adapted from Rutherford (2004).

The groundwater use data by Rutherford (2004) in Table 16.1 has been pooled and organized into five categories. Although logical, these categories have been created on a somewhat arbitrary basis, representing a compromise between managing the unevenness within the data and finding some common basis for comparison. Establishing five categories for BC was challenging, because data for BC is usually presented in four groundwater use categories. Saskatchewan's data is usually presented in 14 groundwater use categories. In some cases domestic wells are included in the "municipal" category. The "other" category includes a variety of uses, ranging from fish management, to recreation, irrigation of parks, space heating/cooling, firefighting, etc.

The largest quantities of groundwater are most often allocated for industrial purposes. Specific industrial applications vary significantly from province to province, with some overlaps. One

TABLE 16.1 GROUNDWATER ALLOCATION BY SECTOR USE. DATA FROM RUTHERFORD (2004) ARE BASED IN PART ON PERMIT ALLOCATIONS AND VARIOUS ESTIMATES. NOTE THAT VALUES HAVE BEEN ROUNDED OFF TO THE NEAREST PERCENT.

PROVINCE / TERRITORY	INDUSTRIAL	AGRICULTURAL	MUNICIPAL	COMMERCIAL / INSTITUTIONAL	OTHER
British Columbia (estimated)	55 %	20 %	25 %	No	No
Alberta	35 %	17 %	26 %	14 %	8 %
Saskatchewan	52 %	3 %	43 %	1 %	1 %
Manitoba	22 %	44 %	17 %	?	17 %
Ontario	35 %	27 %	24 %	6 %	8 %
Quebec	30 %	16 %	54 %	?	?
New Brunswick (estimated)	27 %	No	73 %	No	No
Nova Scotia	n/a[1]	n/a	n/a	n/a	n/a
Prince Edward Island (estimated)	Some	Some	#1 use	No	No
Newfoundland and Labrador (estimated)	No	No	#1 GW use	#2 GW use	No
Yukon (estimated)	No	No	#1 and only real use	No	No
Northwest Territories	n/a	n/a	n/a	n/a	n/a
Nunavut	n/a	n/a	n/a	n/a	n/a

1. n/a: data not available.

common industrial set of customers, and a heavy user of groundwater, is the manufacturing sector. Paper and allied products, food, and primary metals manufacturing are among the largest consumers of fresh groundwater in this sector, with each withdrawing 65.8 Mm^3/year, 44.6 Mm^3/year and 22.9 Mm^3/year, respectively. Nonmetallic mineral products (9.9 Mm^3/year), wood products (9.5 Mm^3/year), and beverage manufacturing (8.1 Mm^3/year) follow. The thermal power generation industry in Canada utilizes 137.6 Mm^3/year of self-supplied fresh water from groundwater sources. Of this, 129.7 Mm^3/year is used by the electrical power industry and 7.9 Mm^3/year is used by paper and allied industries.

It is estimated that 97.9% of the Canadian mining sector's total water needs of 518.2 Mm^3/year are self-supplied; of this, groundwater sources comprise 40.4 Mm^3/year or 7.8% of mining's freshwater needs, and 4.0 Mm^3/year or 0.8% of the sector's brackish water needs. The metal mining sector is the largest user of fresh, self-supplied groundwater, at 23.5 Mm^3/year; coal mines follow at 10.3 Mm^3/year; then nonmetal mines at 6.5 Mm^3/year. It is also common practice in mining for large quantities of groundwater to be withdrawn in place because mines are dewatered in preparation for mining. Dewatering of mine pits and adits reduces groundwater pressures, stabilizes the site by reducing risk of landslides and rockslides, and improves mine safety.

Aquaculture is another common industrial use

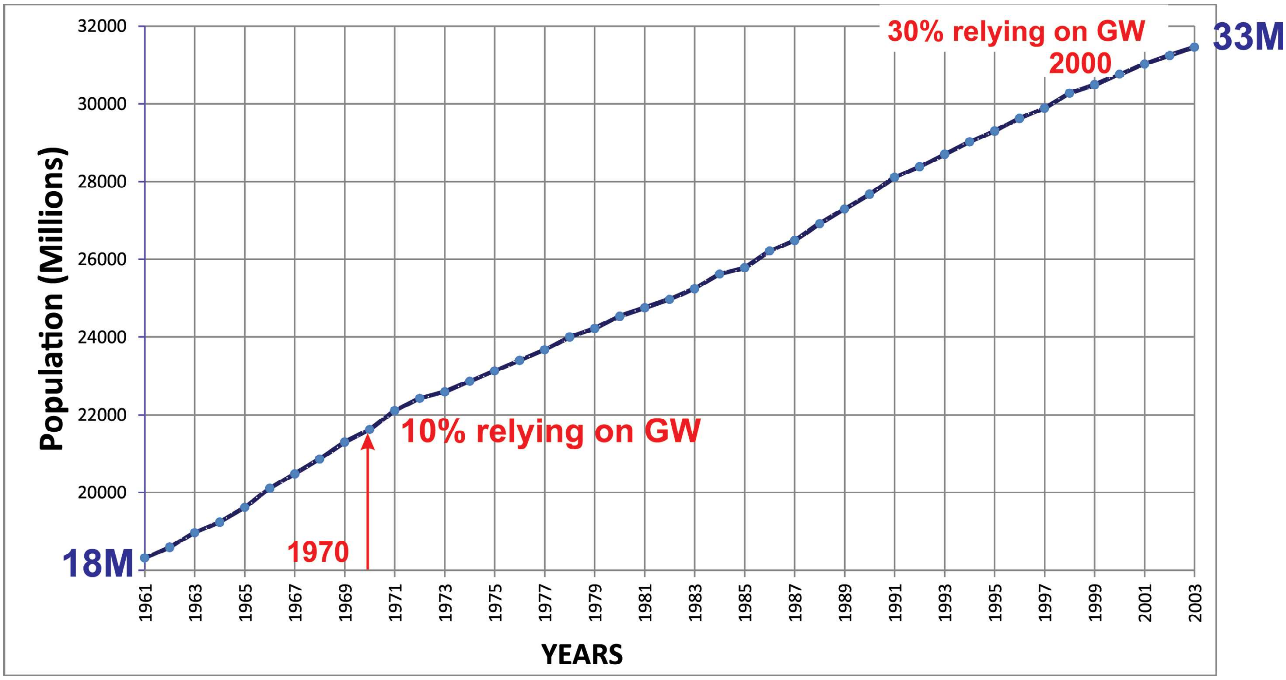

Figure 16.2 Groundwater use in Canada since the 1960s.

of groundwater across Canada. The aquaculture industry's use of groundwater is tracked in at least six provinces. Groundwater is often used in fish-rearing ponds, which are gravity-fed; its constant water temperature and quality make it a valuable supply source for hatcheries as well. Groundwater used in aquaculture operations is typically recycled because of high water demand.

Public waterworks and/or municipal systems are other regular groundwater users. Municipal systems service not only residential consumers, but also many city-dwelling commercial and industrial operations. It has been estimated that only 1% of the municipally-supplied treated water in Canada is used for human consumption (Rutherford, 2004). Some of the many uses of water in municipal systems for industrial, commercial and institutional use include pulp and paper production, industrial processing, heating, ventilation and air conditioning for buildings, restaurants (for cooking and washing), hotels (for washing bedding, flushing toilets, etc.), schools, universities and hospitals (for cooking, washing and bathroom uses).

Groundwater is commonly used in agriculture, especially for crop irrigation and watering of livestock. Brook et al. (2004) report that "Groundwater provides nearly all of the water used to produce livestock in Canada."

Water bottling is another common use of groundwater in Canada. Saskatchewan, Manitoba, Quebec, New Brunswick, and Newfoundland and Labrador all specifically track allocations for bottled water operations. Compared to some other uses, water bottling is not a currently high-volume use, but unlike some other uses, it is 100% consumptive (consumptive water use is water removed from available supplies without being returned to a water resources system, e.g., water used in manufacturing, agriculture, and food preparation that is not returned to a stream, river, or aquifer).

Finally, groundwater baseflow provides a critical ecological function. Rivera et al. (2003) report that

TABLE 16.2 FEDERAL JURISDICTION OVER SURFACE WATER AND GROUNDWATER RESOURCES

FEDERAL GOVERNMENT	COMMENTS
Water on federal lands (e.g., National Parks), federal facilities (e.g., military bases), in the Northwest Territories and Nunavut and on First Nations reserves	"Federal waters" means, other than in Yukon, waters under the exclusive legislative jurisdiction of Parliament and, in Yukon, waters in a federal conservation area within the meaning of section 2 of the *Yukon Act* (*Canada Water Act*).
Federal works and undertakings (including international or interprovincial)	Water is taken for use by federal works, for instance, in federal lands, transboundary aquifers, or the north.
Interprovincial and international boundary waters	"International waters" means water that flows in rivers that cross the international boundary between the United States and Canada (*Canada Water Act*). "Boundary waters" are defined as the waters in lakes that straddle the international boundary between the United States and Canada and rivers that cross the international boundary between the United States and Canada (*International Boundary Waters Treaty Act*). Formally, the *Boundary Water Treaty Act* does not include groundwater. "Inter-jurisdictional waters" means any waters, whether international, boundary or otherwise, that, whether wholly situated in a province or not, significantly affect the quantity or quality of waters outside the province (*Canada Water Act*).
Environmental assessment for any project involving a "facility for the extraction of 200,000 m^3/year or more of groundwater"	Covered under the *Canadian Environmental Assessment Act*, and triggered in cases where there is direct federal interest, such as federal funding or extraction on federal land.
Fisheries (groundwater sustains streams, lakes and wetlands particularly during the dry season)	Prohibits damage to fish habitat and the deposit of deleterious substances in fish-bearing waters and which may be useful to protect groundwater essential to fish habitat (*Fisheries Act*).
Drinking water quality	Sets guidelines for water quality (*Canadian Drinking Water Guidelines*). Binding only if incorporated into provincial/territorial laws.
Water management planning and water quality management plans	Enables the preparation of plans where water quality management of any inter-jurisdictional waters has become a matter of urgent national concern (*Canada Water Act*). *The Great Lakes Charter Annex*, signed by eight states in the U.S. and two provinces, (Ontario and Quebec) requires both countries to better understand and conserve groundwater as well as surface-water resources. In 2010, the International Joint Commission (IJC) released its report, *Groundwater in the Great Lakes Basin*, calling for greater effort to protect groundwater in the basin.
Research, data collection and inventory	Enables establishing and maintaining an inventory of water resources and conducting research (*Canada Water Act*).

Note: This listing is for illustrative purposes and not necessarily comprehensive.

"all Canadians rely indirectly on groundwater because it is the primary source of water for livestock watering and crop irrigation. As groundwater is an integral component of the hydrological cycle, the health of our streams, lakes, wetlands, and associated ecosystems depends upon groundwater." Groundwater also maintains baseflows in rivers and streams during periods of drought, and is critical for sustaining wildlife habitat and fish spawning areas.

16.3 EXISTING LEGISLATIVE FRAMEWORK

Although Canada's Constitution is silent on the specific issue of groundwater, specific elements of groundwater governance are embedded within other jurisdictional responsibilities (Côté, 2006). As set out in the Constitution, however, provinces and territories have primary legal jurisdiction over water and groundwater through their powers of ownership over public land, and jurisdiction over natural resources and public land. The federal

TABLE 16.3 PROVINCIAL AND TERRITORIAL JURISDICTION OVER WATER AND GROUNDWATER RESOURCES

PROVINCIAL GOVERNMENTS	COMMENTS
Allocation of water within their respective land areas	Includes regulation of water use and administration of water rights through water-use licences or water-taking permits (e.g., *BC Water Act, Alberta Water Act, Ontario Water Resources Act*).
Inter-basin water transfers and bulk water removal	Prohibits large-scale diversions and water removal from province or territory (e.g., *BC Water Protection Act, Saskatchewan Watershed Authority Act, and Manitoba Water Resources Conservation and Preservation Act*).
Environmental assessments	Provides for systematic evaluation of the environmental, socioeconomic and cultural aspects of proposed major developments (e.g., *BC Environmental Assessment Act, Saskatchewan Environmental Assessment Act, Ontario Environmental Assessment Act*).
Water quality protection	Includes the regulation of waste discharges into the environment including water and groundwater (e.g., *BC Environmental Management Act, Yukon Environment Act, Quebec Environmental Quality Act*).
Water management planning	Allows for the designation of water management planning areas and preparation of water management plans (e.g., *BC Water Act, Ontario Water Resources Act, New Brunswick Community Planning Act*).
Drinking water quality	Sets standards and guidelines for drinking water quality, treatment and water quality monitoring requirements and requirements for source water protection (e.g., *BC Drinking Water Protection Act, Manitoba Drinking Water Safety Act, Ontario Safe Drinking Water Act*).

Note: This listing is for illustrative purposes and not necessarily comprehensive.

government, on the other hand, has legislative and proprietary powers to manage groundwater on federal lands, including national parks and military bases (Council of Canadian Academies, 2009). Federal jurisdiction over surface water and groundwater also extends to interprovincial and international waters and fisheries (Table 16.2).

Provincial/territorial jurisdiction in Canada includes the prime responsibility for allocation of water and administration of water rights, or water use authorizations, and other related management activities (Table 16.3). Both federal and provincial/territorial levels of government are also involved in various water management activities such as planning, environmental assessments, water quality standards and protection, water monitoring, water research, dissemination of groundwater information and the promotion of water stewardship.

Hill et al. (2007) provide a comprehensive overview of water legislation and policies in Canada's provinces and territories, in addition to listing the most relevant federal water legislation and/or programs and policies enacted by federal government agencies with direct roles in water management. Nowlan (2007) provides an overview of groundwater- permitting processes in provincial and territorial jurisdictions. The Guelph Water Management Group (2007) has compiled a detailed and comprehensive summary of the various water allocation systems within each province and territory.

16.4 MANAGEMENT VERSUS GOVERNANCE

Although this chapter focuses primarily on groundwater management, we think some mention of water (and groundwater) governance is appropriate for setting the groundwater management context. Many Canadian scholars have defined the difference between management and governance as the difference between operational, on-the-ground activity (management), and the range of political, organizational, and administrative processes through which interests are articulated, input is received, decisions are made and implemented, and decision makers are held accountable (governance) (Council of Canadian Academies, 2009, University of British Columbia, 2010).

Table 16.4 compares various water management activities and governance principles.

Despite efforts to clarify terminology, terms are used differently by various agencies.

The *Canada Water Act* (Government of Canada, 2010), for example, takes a broad view defining water resource management as the conservation, development and utilization of water resources including activities such as research, data collection, maintaining of inventories, planning, implementation of plans, and control and regulation of water quantity and quality.

Environment Canada (2011b) reported that "governments in Canada are moving to integrated ecosystem and watershed management approaches that draw on sustainable development principles." These are designed to ensure that decision making reflects the interests of many stakeholders and balance a range of goals, including sustainable water and aquatic resource management, protection from water quality–linked health threats, protection of aquatic ecosystems and species, and reduction of the health, economic and safety impacts from floods and droughts.

The Expert Panel on Groundwater (henceforth referred to as the Panel) , which prepared the report of The Sustainable Management of Groundwater in Canada, states that "good water governance" includes elements such as inclusiveness, participation, transparency, predictability, accountability, and the rule of law (Council of Canadian Academies, 2009). Providing relevant information to the decision maker and the public in a form that is accessible (e.g., maps, reports, databases) is regarded as a prerequisite for any fair and transparent decision-making process. The Panel views the "application of good governance" as a key goal for a sustainable groundwater management strategy. According to the Panel, the concept of groundwater sustainability should encompass five interrelated goals: three that involve primarily the physical sciences and engineering domain, and two that are largely socioeconomic in nature. The Panel's five sustainability goals are characterized in Figure 16.3.

No matter what the terminology, the current trend is toward more holistic and inclusive forms of governance and management—forms that include many of the elements which shape how groundwater (and, indeed, water) is allocated and used, and on what bases those use and allocation decisions are taken.

TABLE 16.4 COMPARISON OF MANAGEMENT ACTIVITIES AND GOVERNANCE PRINCIPLES

MANAGEMENT ACTIVITIES	GOVERNANCE PRINCIPLES
• Water allocation • Regulation of drillers, pump installers and well construction and closure • Protection of environment or water quality • Water and land use planning • Data collection, including monitoring of regional groundwater conditions • Acquisition of science (e.g., hydrogeological mapping and characterization)	• Facilitates decision making through inclusiveness, shared responsibility and accountability • Assures the quality, consistency and transparency of decision making • Improves the efficiency of water management and water use • Improves government responsiveness

16.5 GROUNDWATER MANAGEMENT ACTIVITIES

Groundwater management in any jurisdiction often includes some or all of the main activities shown in Table 16.5. Readers should note that the activities in the upper portion of this table are regulatory, while the activities in the lower portion are generally non-regulatory (acquisition of science, provision of information, stewardship). There are major differences between the various jurisdictions in how they manage their groundwater resources and the scope of their activities (e.g., style of governance, priorities and agency capacity). Activities that promote good governance and involve public participation include water management planning, wellhead and aquifer protection plans, environmental impact assessments, and undertakings that consider the impacts to groundwater by decision makers of other activities (e.g., land use) not directly related to groundwater but with potential to impact it. Data management activities that make well record data, information and reports readily available to the public through electronic format via the internet also enhance good governance. A summary of some of these activities is presented here—water allocation, environmental and groundwater quality protection, groundwater monitoring networks, and inter-agency cooperation; however, a comprehensive discussion of every activity is beyond the scope of this chapter.

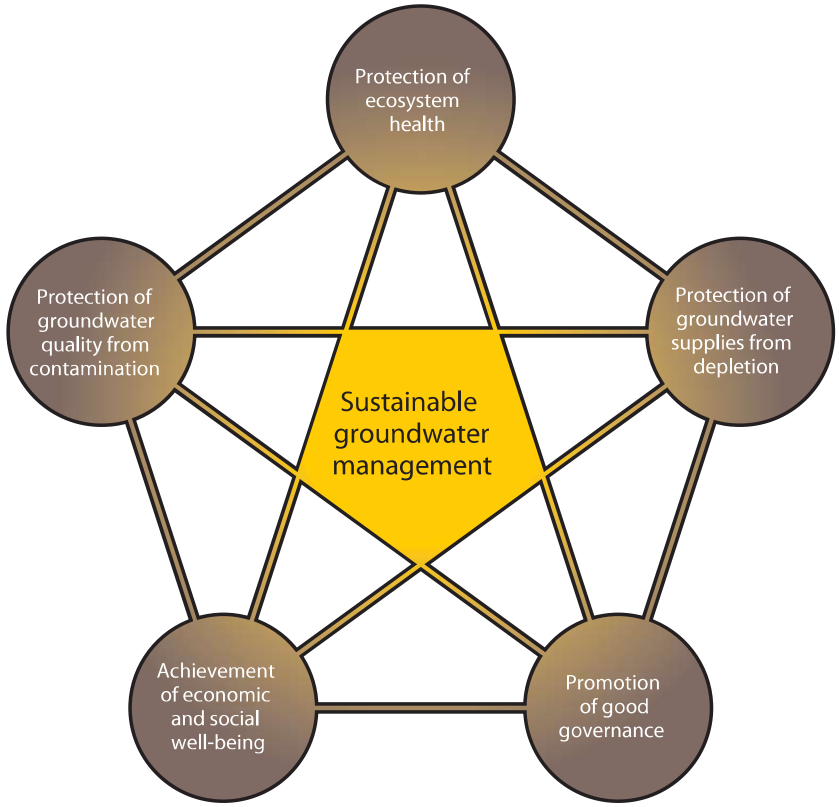

Figure 16.3 Groundwater sustainability pentagons from "The Sustainable Management of Groundwater in Canada" (Council of Canadian Academies, 2009).

16.5.1 Groundwater supply allocation in the provinces and territories

Allocating groundwater as a water supply is a prime regulatory activity, and includes the regulation of water use and administration of water rights through water-use licences, or water-taking permits. In Canada, the provinces and territories have primary jurisdiction for regulating and allocating quantities of groundwater to various users and for various purposes. All three territories and all provinces, except Ontario and PEI, assert ownership of water to grant water rights or authorizations to others, and to charge royalties or rent for the use of water (Nowlan, 2005). All provinces and territories, with the exception of British Columbia, have developed a groundwater allocation system, although the licensing and permitting processes vary widely between the jurisdictions

TABLE 16.5 GROUNDWATER MANAGEMENT ACTIVITIES

ACTIVITIES	COMMENTS
REGULATORY	
Groundwater supply allocation • Different systems of provincial and territorial approaches within Canada • Water pricing • Water management planning	• Includes regulation of water use and administration of water rights (e.g., water-use licences, water-taking permits) • Fees, water rentals
Regulation of well drilling • Regulating drillers and pump installers • Standards and guidelines for well drilling and testing • Regulating deep wells for oil and gas	• Certification and licensing of water-well drillers and pump installers • Drilling, well construction and testing procedures and materials
Environmental and groundwater quality protection	• Waste permitting, quality standards and objectives • Environmental impact assessments • Source protection, wellhead protection • Land use planning
Enforcement of regulations	• Compliance checking • Fines and other measures
NON-REGULATORY	
Data collection, databases and information systems	• Well record collection and processing, groundwater reports, water quality analyses, geophysical logs, inventories, water level and water quality monitoring networks • Public access to data and reports
Aquifer characterization and modelling	• Aquifer delineation and characterization • Vulnerability to potential contamination at surface from land use activities • Groundwater flow modelling
Public and stakeholder consultation	Policy planning, environmental assessments and water management planning
Water stewardship and public awareness	Workshops, publications, fact sheets, websites, signage

Note: This listing is for illustrative purposes and is not necessarily comprehensive.

(Nowlan, 2007). British Columbia is currently considering regulating groundwater use in all areas of the province (British Columbia Ministry of Environment, 2010).

Water allocation is the process used to decide how water should be shared between industrial, agricultural, municipal, and domestic and conservation uses, including how conflicts between users and uses are to be addressed (Nowlan, 2005). This procedure is normally carried out by issuing a water licence, approval or water-taking permit, all of which allow the holder specific water rights or privileges while setting out certain limiting conditions and responsibilities which need to be met. Water-use licences and permits may specify the rate, quantity, duration, and time of use and purpose for which the specific water supply will be used (Nowlan, 2005). Conditions on licences are routine. In Saskatchewan, for example, licences have a standard requirement wherein the applicant must mitigate any problem that arises between existing users; in Manitoba, each licence includes a reporting requirement on water usage (Nowlan, 2005).

16.5.1.1 Approaches to groundwater allocation

Christensen and Linter (2007), based on Percy (1988), recognize five approaches to water rights in Canada:

(a) Prior allocation
(b) Riparian
(c) Civil code
(d) Public authority management
(e) Aboriginal rights

Prior allocation rights are dominant in the west: British Columbia, Alberta, Saskatchewan and Manitoba. Prior allocation is based on seniority where licence or permit holders acquire the exclusive right to use the water from the date in the licence or permit. Prior allocation is generally referred to as "first in time, first in right" or FITFIR. In BC (with surface water), Alberta, and Manitoba, water licences can be transferred, while in Saskatchewan they cannot. Transfer requires an approval to ensure that the public's interest in water use continues to be protected.

Riparian rights are common in eastern Canada and subject to regulation (i.e., regulated riparian). They entitle landowners whose land borders on water sources to have certain non-transferable water rights. These rights also give landowners the right to extract groundwater from wells on their property.

In Quebec, water is designated in the Civil Code as a resource "common to all"; the province has responsibility for allocation, regulation, and the establishment of priority use in the public interest.

Public authority management is practiced in the territories: local water boards decide on the allocation and transfer of licences.

Aboriginal rights are guaranteed as existing rights in the 1982 version of the Constitution Act; these rights have priority over other uses in the legislation of Nunavut.

16.5.1.2 Exemptions and terms of licences and permits

Many jurisdictions usually limit licences and permits to terms of <25 years depending upon purpose of use or source of water. The majority of these jurisdictions do not require licences or permits for domestic household and agricultural use under 50,000 L/day (0.58 L/sec). Thresholds for exemption, however, range over several orders of magnitude across the nation, from as low as 3.4 m^3/day in Alberta to 345 m^3/day in PEI. In fact, about a third of jurisdictions do not require any form of reporting of actual water use and only about a half charge fees for groundwater use (Nowlan, 2005).

16.5.1.3 Changing values and water use

Historically, allocation and protection laws in Canada have prioritized settlement, economic development and maximizing resource extraction (Nowlan, 2007). Water allocation has been primarily an administrative function focused on technical and legal concerns (de Loë et al., 2007). Over the years, however, there has been a growing desire to recognize changing values related to water use, the interconnectedness of surface water–groundwater quantity and/or quality, and the role of planning as a guide to allocation. British Columbia developed Water Allocation Plans for Vancouver Island to examine the water budget or water availability in watersheds, so as to establish guidelines for future surface water allocation. Today, integrating and incorporating environmental, social and economic factors are becoming an increasingly important consideration in the decision-making process, e.g., *BC Water Act Modernization* (British Columbia Ministry of Environment, 2010), *Alberta's Water for Life Action Plan* (Government of Alberta, 2009) and Nova Scotia's *Water Resource Management Strategy*, *Water for Life* (Province of Nova Scotia, 2010).

Historically the allocation of groundwater use in Canada has not involved an integrated ecosystem and watershed management approach, which draws on sustainable development principles. This includes regulating groundwater and surface water use in a conjunctive manner.

In principle, because all jurisdictions have a single Act that speaks to water, groundwater and surface water should not be managed separately. Nevertheless, this has commonly been the case across Canada. Thus, the challenge faced is to manage surface water and groundwater conjunctively.

Today, we have greater expectations regarding ecological flow needs in streams, as compared to a hundred years ago. There is a recognized need to protect groundwater-dependent ecosystems in the water allocation decision making, including decisions related to groundwater allocation, and, in some jurisdictions (e.g., BC), there is also the requirement to consult with First Nations before making these decisions. The result is there are more considerations and a greater complexity in the decision-making process because interests have broadened over the years.

16.5.2 Environmental and groundwater quality protection

Groundwater quality may be degraded by human activities on or below the land surface. These include industrial and municipal waste discharges, mining, chemical spills, and runoff from agricultural activities. Canadian provinces manage groundwater quality, in part, through

- Regulation of waste discharges to the ground
- Remediation of contaminated sites
- Protection of drinking water sources
- Land use and watershed planning
- Establishment of water quality standards and guidelines

A brief discussion of some of these measures is provided below.

16.5.2.1 Waste discharges and contaminated sites

Waste discharges are commonly regulated through permitting and approval processes which consider the nature of the potential contaminants and the environment's ability to assimilate these pollutants (e.g., *BC Environmental Management Act, Quebec Environmental Quality Act, Yukon Environment Act*). Land sites that may contain hazardous chemicals are mandated to remove or contain contaminants that threaten groundwater quality (e.g., *BC Contaminated Sites Regulation, Ontario Environmental Protection Act, Nova Scotia Environment Act*). Management of contaminated sites in Canada is risk-based and standards and practices vary from province to province (Council of Canadian Academies, 2009). A key feature of this risk-based approach is the fact that remediation or treatment is triggered only when there is an identifiable on-site or off-site risk, where risk refers to the likelihood of exposure of a hypothetical human or ecological receptor to specific contaminants present at levels exceeding maximum acceptable concentrations (Council of Canadian Academies, 2009).

16.5.2.2 Protection of drinking water sources

Canada's provinces and territories regulate the quality of groundwater used by most water supply systems across the country, with the exception of individual domestic wells. Hill et al. (2007) have outlined some key aspects of drinking water protection (e.g., water treatment requirements and monitoring) currently being implemented. The federal government works with the provinces and territories through the Federal-Provincial-Territorial Committee on Drinking Water (CDW) to establish *Guidelines for Canadian Drinking Water Quality.* These guidelines set out levels of microbiological, chemical and radiological parameters that every water system should strive to achieve in order to provide the cleanest, safest and most reliable drinking water possible (Federal-Provincial-Territorial Committee on Drinking Water, 2013), although use of these guidelines varies by jurisdiction. Ontario, for example, has adopted drinking water quality standards for 161 parameters and requires monitoring for 57 organics, 13 inorganics, and three microbiological contaminants. British Columbia requires the monitoring of bacteriological contaminants only and leaves additional contaminants to the discretion of the Drinking Water Officer (Hill et al., 2007).

All jurisdictions support the multi-barrier approach, which prevents or reduces contamination of drinking water supplies from source to tap (CCME, 2002). This method evaluates and implements measures for ensuring high-quality drinking water in every component of the water-supply system, from broad environment to supply aquifer or reservoir, to water treatment facility and finally to the distribution system (Council of Canadian Academies, 2009). One key aspect of this multi-barrier approach is source or watershed planning and source water protection.

Source protection, more specifically called wellhead protection, involves identifying capture zones and time-of-travel zones around water supply systems or community wells, assessing potential sources of contaminants in these zones, and developing measures that reduce or eliminate contamination risks from these sources. New Brunswick, for example, has implemented a wellfield protection program for all municipal wellfields (covering 20% of the population) under the *Wellfield Protected Area Designation Order* (Crowe et al., 2003).

In 2000, British Columbia developed a guidance document entitled *The Well Protection Toolkit* to assist water purveyors and communities throughout the province in their development of well protection plans. The toolkit outlines a six-step process for preparing and implementing a wellhead protection plan. While these plans are voluntary in British Columbia, some local health authorities require their preparation for large, new well water supply sources. Ontario requires the preparation of source protection plans under the *Clean Water Act* to ensure activities carried out near municipal wells do not threaten the quality and quantity of the drinking water supply.

16.5.2.3 Land use and watershed planning

Local governments make land use decisions, which can impact on both groundwater quantity and quality. Accordingly, this level of government has an important role in groundwater management. Quantity is affected by local governments' supply of water to local users on a central system (e.g., industrial or domestic users within a municipality), which usually requires that local government obtain a permit from the province to supply their own systems. Land development may be restricted by the availability of groundwater (Nowlan, 2007). Quality is affected by many things (local government's decisions on polluting industries, control of urban runoff, and pavement limits, to name a few), which can impair groundwater recharge.

Although most jurisdictions do not have

comprehensive watershed regulations, important examples for watershed planning and protection do exist (Hill et al., 2007). Nova Scotia and New Brunswick, for example, regulate specific activities in entire watersheds, while Newfoundland and Labrador, and Prince Edward Island have designated buffer zones around wells (Hill et al., 2007). In Ontario, communities are required to develop source protection plans in order to protect municipal sources of drinking water. These plans aim to identify risks to local drinking water sources and to develop strategies to reduce or eliminate these risks. British Columbia's *Water Act* and *Drinking Water Protection Act* enable the designation of water management planning areas and drinking water protection plans, respectively. Such plans will address risks to water quality, or prevent threats to drinking water. In 2007, the Regional District of Nanaimo on Vancouver Island was one of the first local governments in British Columbia to develop a *Drinking Water and Watershed Protection Action Plan*. Although not strictly prepared under the above legislative processes, the plan was developed through the participation of a number of provincial ministries, water districts, municipal, private, public and industry organizations (Lanarc Consultants Ltd., 2007).

16.5.3 Best management practices and standards

Best management practices, codes of practice, standards, and guidelines are important management tools for sustaining and protecting both water quality and quantity. Agriculture and Agri-Food Canada (2000), for example, have developed *Agricultural Best Management Practices* to address the potential negative impacts agriculture can have on soil and water quality, by stressing those farming practices which minimize such impacts.

One particularly challenging groundwater quality issue is contamination derived from diffuse or non-point sources. Nitrate contamination from septic systems, or from agricultural activities, is a particular example of this problem. Sources of contamination tend to be small and localized, but in number can exert a measurable impact on groundwater quality. The challenge with non-point source contamination is that effective solutions to the problem require remedial actions which affect and involve many landowners (e.g., provide septic servicing or adopt best management practices for fertilizer application).

16.5.4 Groundwater monitoring networks

All Canadian provinces maintain active regional groundwater monitoring networks (commonly referred to as observation well networks), to monitor long-term (seasonal and annual) fluctuations in groundwater levels and, in many cases, water quality. Maathuis (2005) compiled a comprehensive survey of groundwater level networks (Figure 16.4). The number of wells in these networks range from 25 in Prince Edward Island, to over 500 in Manitoba (Council of Canadian Academies, 2009). Many of these wells are located in important aquifers where they monitor stresses caused by aquifer withdrawals and/or climatic variations (see for instance Figures 9.1, 10.27, 10.32, 10.34, 12.26 and 13.20).

These monitoring networks also provide an important indication of the magnitude of groundwater recharge taking place, as well as when aquifers are being depleted. These monitoring networks play a key role in gauging aquifer sustainability, especially as limited data is available on actual water use in many areas. The BC Ministry

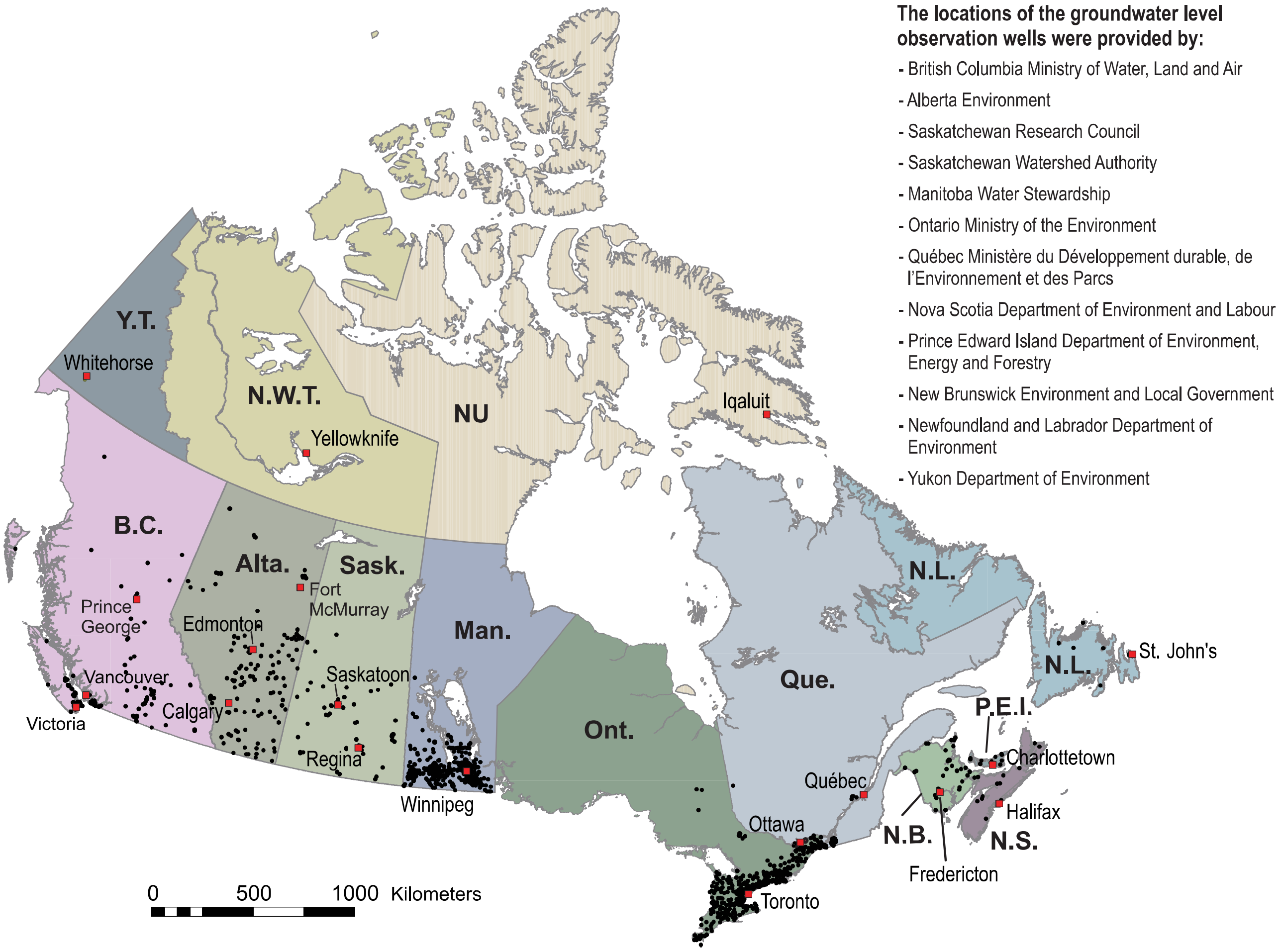

Figure 16.4 Observation wells in Canada in 2005 (after Maathuis, 2005).

of Environment (2007), for example, reported an increase in the percentage of observation wells showing declining water levels due to human activities during the period 2000–2005.

Water quality is also monitored. Environment Canada and the BC Ministry of Environment have tracked groundwater quality in the Abbotsford-Sumas aquifer, British Columbia, since the early 1970s (see Box 9-2).

16.5.5 Inter-agency cooperation

Although much is made of jurisdictional fragmentation, in practice there exists a high level of inter-jurisdictional coordination, particularly on issues of data collection and database maintenance, yet even here, significant gaps and overlaps exist (Dunn and Baker, 2011). A good example of a groundwater study involving inter-agency partnerships, which brought funding sources to the table, focused on the Okanagan Basin in British Columbia. Here, local governments, provincial officials, federal and academic researchers, water districts, groundwater associations, and the Okanagan Basin Water Board participated in the Groundwater Assessment of the Okanagan Basin (GAOB). This large-scale research effort was initiated in 2004 by the Geological Survey of Canada (GSC) and the BC Ministry of Environment to bring together and guide groundwater studies in the Okanagan, as part of the Okanagan Water Supply & Demand Study. The goal was to give local governments the information they need to balance water needs and availability into the future. A comprehensive overview covering the scope of the project has been prepared by Carmichael (2006). Other similar examples of groundwater studies and aquifer assessments with inter-agency cooperation exist across Canada; descriptions of some of these projects can be found at: http://www.nrcan.gc.ca/earth-sciences/about/current-program/groundwater-geoscience/4106.

In 2003, a National Ad Hoc Committee on Groundwater comprised of stakeholders from a number of federal and provincial agencies, along with academic researchers and individuals from the groundwater industry, developed the *Canadian Framework for Collaboration on Groundwater* (Rivera et al., 2003). Their document recognizes and emphasizes the need to address the groundwater issues of Canada through close co-operation between federal, provincial, territorial, municipal, and First Nations governments.

Most jurisdictions in Canada currently regulate groundwater and surface water without much consideration as to the type of source. This may be because surface water–groundwater interactions are not well understood. (For a discussion of surface water and groundwater interaction, see Chapter 5). In some provinces (e.g., Alberta, Ontario) surface water and groundwater are managed conjunctively. Groundwater, however, is not always considered in many land and other resource use decision-making processes. New water management strategies under development are aimed at providing a more holistic and integrated approach for natural resource management, by involving groundwater–surface water interactions, protecting in-stream flows and ecosystems (ecological flows), requiring more efficient use of water, and using economic instruments and incentives.

There is also an increasing trend for provinces to involve local governments, watershed agencies (such as Ontario's Conservation Authorities) and multi-stakeholder bodies in managing and protecting groundwater (Council of Canadian Academies, 2009). Examples of such activities include groundwater monitoring, conducting joint studies, protecting sensitive recharge areas in land use planning, considering groundwater availability in planning growth, and helping raise local awareness. In many jurisdictions, local governments such as municipalities, regional districts, counties and conservation authorities are playing an increased and more proactive role in groundwater management activities. They are often involved in groundwater management where groundwater is the source of municipal water supply, and/or indirectly, through land use decisions that have groundwater contamination potential (Council of Canadian Academies, 2009). Local government has a broad mandate, which includes authority over land use that might impact groundwater, planning growth, water demand, and the servicing of water supply and sewerage.

In Quebec, the Municipality of Chelsea collaborated with the University of Ottawa's Institute of Environment, and with Action Chelsea for the Respect of the Environment (ACRE), a local non-government organization, in developing a policy that requires land developers to conduct pumping tests to demonstrate that there is sufficient available water to support the number of homes planned for the development (Nowlan, 2007). Elsewhere in Quebec, several municipalities recently collaborated with the provincial government and academic researchers to examine groundwater resources of the Abitibi-Temiskaming region (Société de l'eau souterraine Abitibi-Témiscamingue, 2010).

In Ontario, the Grand River Basin Water Management Study provides a solid example of collaborative work between the local conservation authority, several municipalities, residents of the area, and several provincial ministries in the investigation of water resources within the basin (Grand River Implementation Committee, 1982).

In British Columbia, the Township of Langley developed its *Water Management Plan (Part 4 of the Water Act*) in collaboration with the province (Township of Langley, 2009). The plan proposes policies and regulations to protect local groundwater resources for community use, in addition to promoting healthy aquatic habitats. Proposed new regulatory tools include expanded water conservation initiatives and water quality protective measures, including stopping and controlling artesian flow, well sitting requirements and the initiation of a nutrient management plan. These procedures have yet to be approved by the provincial government.

B.C's Smart Growth on the Ground (SGOG) initiative involved development of a team where elected officials and staff from local government, community members, experts and representatives of key agencies worked together to create plans for land use, transportation and other designs. The team in Oliver, BC, a community in the southern Okanagan Basin dependent upon community wells, coordinated research in a number of areas, including climate change and water resources (Smart Growth on the Ground, 2006). Other water stewardship initiatives have also been implemented, including the Royal Bank of Canada (RBC) Blue Water Project aimed at fostering a culture of water stewardship across Canada.

16.6 ISSUES IN GROUNDWATER MANAGEMENT IN CANADA

During the last decade, a number of authors including Rivera et al. (2003), Nowlan (2005, 2007), Council of Canadian Academies (2009), and CCME (2010), identified several existing and emerging issues for groundwater management in Canada. A listing of the main issues, which can be categorized as being concerns about quantity, quality and other, is provided in Table 16.6. Aquifers with both quantity and quality issues are common. Many of the concerns in the other column of Table 16.6 may simply reflect poor governance due to a lack of appreciation for, and understanding of, groundwater resources and their importance in sustaining aquatic ecosystems; such oversights resulted in a lack of priority, investment, and insufficient legal authority for the jurisdiction to act.

Some of the issues in Table 16.6 may merely reflect symptoms of other problems: the real issue may be that funding allocation for groundwater study has not kept pace with current demands, as has been reported by the Council of Canadian Academies (2009). There is a strong need for fundamental groundwater assessments and characterization to be undertaken now, before specific problems develop.

16.6.1 Quantity issues

16.6.1.1 Aquifer depletion

While many of the quantity issues are significant on a local scale, there are a few examples of excessive groundwater depletion on a large scale

TABLE 16.6 CURRENT AND EMERGING GROUNDWATER ISSUES

CURRENT AND EMERGING ISSUES		
QUANTITY	**QUALITY**	**OTHER**
Growing water demand and limited water availability leading to conflicts and competing priorities among agriculture, municipal, recreation and natural habitats • Aquifer depletion in local areas (e.g., over-pumping, uncontrolled flowing artesian wells) • Local well interference • Groundwater–surface water interaction, wells affecting in-stream flows	Water quality concerns from human activities (diffuse) • Nitrate, bacteriological and pesticide contamination from various agricultural and septic disposal sources • Degradation due to road salts • Localized saltwater intrusion from seawater and saline aquifers (e.g., PEI, Gulf Islands, BC) • Improperly constructed or closed wells posing a risk of cross connection of aquifers with different water quality • Degradation from unidentified chemicals (e.g., synthetic organic compounds and volatile organic compounds)	Limited enforcement of laws and regulations
Increasing resource extraction • Increased demand from growing population and resource extraction (e.g., oil sands development in AB) • Aquifer depletion due to coal-bed methane extraction and dewatering • Demand for high water volumes for fracking of shale formations in northeast BC	Water quality concerns from human activities (point source) • Contamination from acid mine drainage from metal mining • Local contamination from chemical leaks and spills (e.g., hydrocarbons) • Contamination from petroleum activities (e.g., oil sands development) • Degradation at contaminated sites • Thermal degradation from geothermal activities Potential contamination due to hydrofracking	Limited resources for data collection, maintenance and management (both regional and place-based assessments) • Effectiveness of groundwater monitoring networks for quantity and quality • Few indicators of groundwater quality and quantity • Limited number of aquifer characterization studies (recharge rates, groundwater use, quality)
	Naturally occurring water quality concerns—elevated levels (e.g., metals, nonmetals —arsenic, chloride, radioactive elements)	Aboriginal and Treaty Rights to water
		Effects of climate variability and changes

(Council of Canadian Academies, 2009). One such case involves deep buried-valley aquifers located in southern Saskatchewan (see Box 10-2); heavy pumping from these aquifers has led to significant drawdowns, extending tens of kilometres from the pumping centre. Recovery of water levels to the aquifers' original static levels may take decades or even centuries (Maathuis and van der Kamp, 2003).

There is also a general shortage of data on actual use of groundwater in Canada. Most jurisdictions have some data available on groundwater volume allocations (under a permit or licensing regime), but few jurisdictions have available data to confirm the *actual* volume used (Rutherford, 2004). This severely restricts assessments of available water supply versus actual demand investigations and assessments of aquifer sustainability. Two emerging quantity issues of interest are oil sands development and transboundary aquifers.

16.6.1.2 Oil sands development

The long-term cumulative impact of oil sands development on groundwater is insufficiently understood (Council of Canadian Academies, 2009), given the magnitude of these projects over several decades. Oil sands, which are accessed through open-pit mining operations and *in situ* operations, involve extensive land areas, and the extraction of large volumes of both ground and surface water. *In situ* operations are projected to have the greatest impact, because of their much larger extraction areas and, because non-saline and saline groundwater is used, at the majority of sites, to provide steam for the oil extraction process.

Production of bitumen is expected to triple by 2020, resulting in more water withdrawals, declining wetlands and expanding tailings ponds. Most companies already recycle their water, so new policies and technologies are necessary to insure that water use does not grow at the same rate (Griffiths et al., 2006).

There are some 5,000 licenced wells in the Athabasca River, with groundwater allocations in the order of 120 Mm^3/year (Rosenberg International Forum, 2006). Allocations for the Peace River and the Cold Lake-Beaver River are 30 Mm^3/year and 20 Mm^3/year, respectively. Not all allocations, however, are for oil sands developments: it is estimated that some 79% of the allocations in the Athabasca River are for oil sands, 57% in the Peace River, and 86% in the Cold Lake-Beaver River.

16.6.1.3 Transboundary aquifers

When an aquifer extends beneath the border of two or more jurisdictions, there is shared interest in the quantity and quality of groundwater available. Canada's interest in transboundary groundwater issues (both between provinces and territories, and between Canada and the U.S.) has increased sharply over the recent past.

The most important cases of transboundary aquifers within this country are located in Alberta, Saskatchewan and Manitoba, but no disputes have been reported. The equitable and "reasonable" use of shared waters is the most essential principle considered when negotiating a groundwater apportionment method. Other factors considered are: the priority use, the sustainable yield of the aquifer, and the joint apportionment of surface water and groundwater. To ensure water resources are shared fairly in the Prairie Provinces, the provincial governments of Alberta, Saskatchewan, and Manitoba, working with the Government of Canada, created the Prairie Provinces Water Board in 1948 to manage inter-provincial transboundary waters. A Master Agreement on Apportionment shares water equitably between the Prairie provinces, in addition to protecting interprovincial surface water quality and groundwater aquifers (Prairie Provinces Water Board, 2011). The Mackenzie River Basin Master Agreement (British Columbia-Alberta-Saskatchewan, Yukon and Northwest Territories, in conjunction with the federal government) is another interprovincial coordinating agreement involving groundwater.

There are over 20 million Canadians living in watersheds that cross the Canada-US border (over 17 million people of them reside in the Great Lakes-St Lawrence watershed). Figure 16.5 is a map of Canada containing identified transboundary aquifers along the Canada-US border as per 2011.

16.6.2 Quality issues

16.6.2.1 Nitrate contamination

Contamination of groundwater and wells due to agricultural activities is common in all agricultural regions of Canada with elevated levels of nitrate the main concern. In fact, nitrate contamination is a major global contamination issue leading to

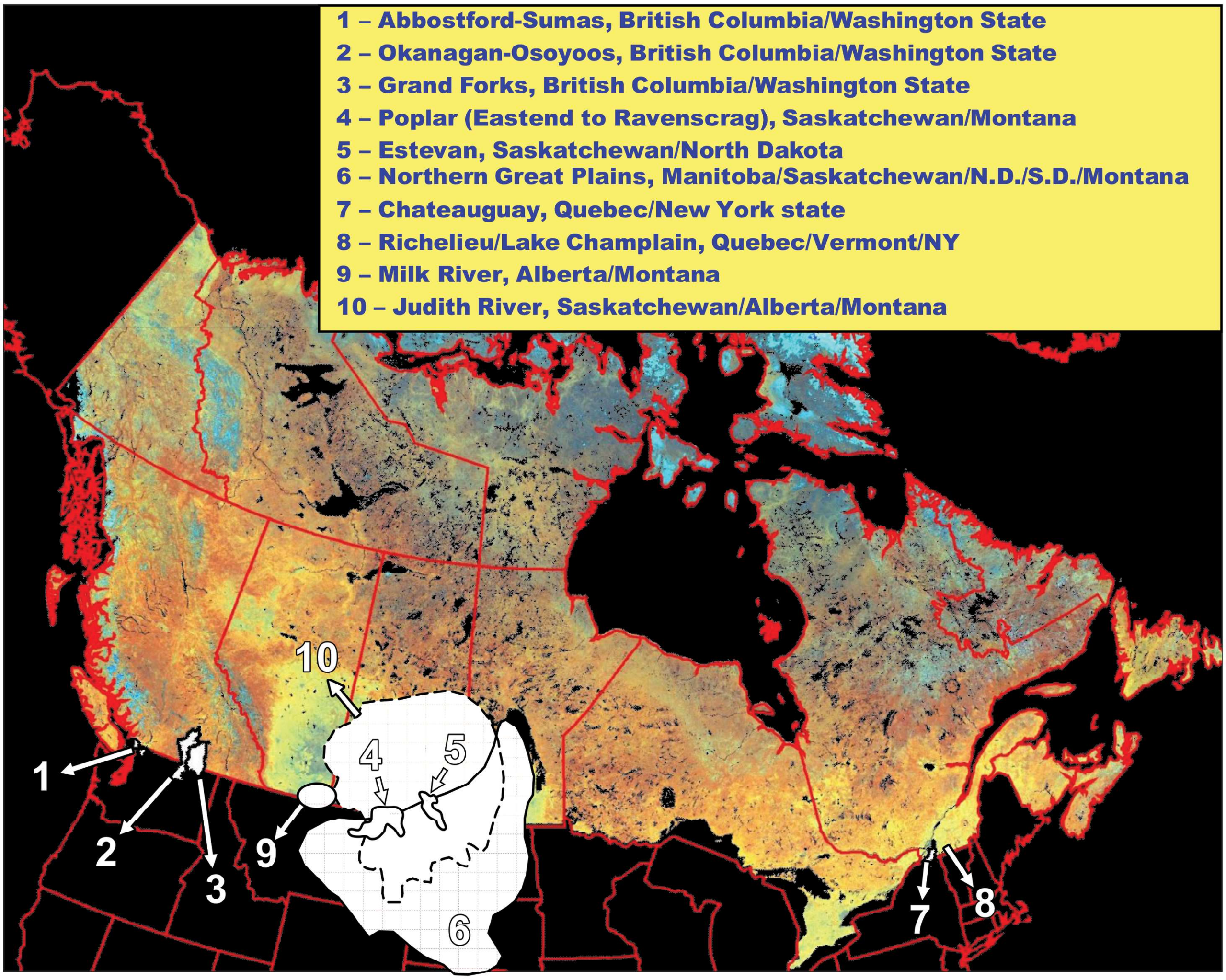

Figure 16.5 Some transboundary aquifers that have been identified along the Canada-US border (after Rivera, 2011).

water quality degradation in rivers, lakes, groundwater and coastal areas. Unconfined, shallow sand and gravel or sandstone aquifers with relatively high water tables are particularly susceptible (e.g., Abbotsford-Sumas Aquifer, BC; Environment Canada, 2004; and the Prince Edward Island sandstone aquifer; Savard and Somers, 2007). The behaviour of nitrates in groundwater is generally well understood, but information linking agriculture sources is inadequate. Nutrient applications related to agricultural land use raises particular challenges in balancing societal needs for both food and water; hence Canada needs to have more effective strategies for the containment and/or elimination of nitrates in agricultural areas (CCME, 2010). Part of the solution involves federal-provincial programs such as the National Farm Stewardship Program and Best Management Practices for minimizing contamination of groundwater; these procedures have not yet been widely adopted by agricultural producers (Council of Canadian Academies, 2009). In 2008, the Province of Prince Edward Island appointed an independent Commission on Nitrates in Groundwater to identify issues and find solutions to specific problems within their jurisdiction (Government of PEI, 2008). Other provincial guidelines have been enacted in BC (e.g., Guidelines and Best Management Practices; BC Ministry of Agriculture and Lands), Saskatchewan and Alberta.

16.6.3 Other issues

16.6.3.1 Aboriginal and treaty rights to water

Aboriginal peoples in Canada comprise First Nations, Inuit and Métis groups. Aboriginal rights are those that many of Canada's Aboriginal nations hold as a result of their ancestors' long-standing use and occupancy of the land: the right to hunt, trap and fish on ancestral lands are some examples. Aboriginal rights vary from society to society, depending on custom, practice and tradition (Indian and Northern Affairs Canada, 2011).

Aboriginal and Treaty Rights to water are a complex and unresolved issue in this country. The Supreme Court of Canada (SCC) has brought down rulings on the nature and extent of Aboriginal title and Aboriginal rights in a number of cases: some land claims and treaty settlements, in the Canadian North and other regions of the country (Nowlan, 2005), have partly addressed this issue as well. The Council of Canadian Academies (2009) reports that groundwater jurisdiction is complicated by unresolved Aboriginal water interests, which include legally recognized rights such as treaty rights, and unresolved claims of Aboriginal rights and title. In 2004, the SCC held that government had a duty to consult and accommodate Aboriginal interests before Aboriginal rights and title were finally determined. As reported by de Loë et al. (2007), some provinces and territories recognize and address Aboriginal rights in their legislation. Examples include

- The Northwest Territories' *Water Resources Agreement Act* which states in section 6 that "Nothing in this Act shall be interpreted so as to affect or diminish Aboriginal rights."
- In Nunavut, the *Nunavut Waters and Nunavut Surface Rights Tribunal Act* was formulated to be respectful of Aboriginal customary allocation boundaries and traditions.
- In Newfoundland, the *Water Resources Act* is to be applied in conjunction with the Labrador Inuit Land Claims Agreement, which includes provisions for Inuit water rights, allocation and management.

Water governance issues for First Nations communities were examined in 2010 at a workshop entitled *Sharing Water Challenges and Solutions: Experiences of First Nations Communities* (von der Porten and de Loë, 2010). Some of the outcomes included the following: the need for Aboriginal peoples taking the lead on water governance or other resource-related initiatives within their jurisdictions, incorporating Indigenous knowledge in decision making, asserting water rights, pooling common resources, and sharing among First Nations communities. Further aspects of this issue, including the quality of drinking water in First Nations communities, are examined by Phare (2009) and von der Porten and de Loë (2010).

16.6.3.2 Effects of climate change

Canada's climate is changing and projections show that it will continue to change in the future, with gradual shifts in average temperature and precipitation, changes in temperature and precipitation extremes, and changes in sea level (Lemmen et al., 2008).

Some of the most significant and pervasive impacts of climate change in this country will be related to water resources. Water-stressed areas will expand as runoff in many areas decreases as a result of precipitation changes and increased evapotranspiration. Reduced water quality and quantity will be experienced on a seasonal basis in every region of Canada. Observed water impacts include a trend toward earlier spring runoff and, in the Prairie Provinces, a decline in summer and fall runoff, leading to lower lake and river levels during those seasons. Increasing demands on water resources for agriculture, energy production, communities and recreation will need to be managed in conjunction with ecosystem needs. A number of processes suggest that spring recharge of groundwater regimes from snowmelt may decline, except in those regions where frozen soils thaw due to warmer winters (Council of Canadian Academies, 2009). Reduced groundwater recharge under climate change is anticipated in some areas of the country, while rising sea levels pose an increasing threat of saltwater intrusion into groundwater along coastal regions (Council of Canadian Academies, 2009). Groundwater withdrawals are expected to increase under warmer conditions, and during extended periods of drought, producing added pressures on both groundwater and surface water resources.

16.6.3.3 Limited place-based knowledge of the resource

Much of what is currently known about the groundwater resources of Canada is limited to those populated areas and corridors, such as along, and within, a few hundred kilometres of the Canada-United States border, or along major transportation routes. Vast areas of the country are unpopulated, as a result, little is known about the full extent, availability and quality of groundwater resources in these regions. Characterization of known aquifers remains very limited, even in settled areas of the country.

Dunn and Bakker (2011) suggest that managers and policy makers do not share common points of reference when using freshwater indicators of water quality and quantity to assess the state of water security. This, they suggest, impedes decision making on cross-cutting issues. They note that, while the challenges imposed by regional (climatic, topographical and hydrological) diversity are recognized, there remains a need for more standardized, integrated approaches to enable place-based assessments, which could then be compared at a broader scale.

As Canada's population continues to grow, and water demands for resource-based industries, such as oil and gas drilling, coal-bed methane production, oil sands development and mining activities continue to increase, there will be added pressures to improve the scientific knowledge of aquifers and their groundwater flow systems. Although Canada has a history of mapping aquifers (Betcher, 2011), there is growing consensus that this work needs to be emphasized and advanced in order to support informed decision making.

The Standing Senate Committee on Energy, the Environment and Natural Resources, acknowledged this issue in 2005 by recommending that the Government of Canada take necessary steps to ensure that all of Canada's major aquifers be mapped by 2010. It also recommended that the resultant data be made available in the national groundwater database, supported by a summary document assessing the risks to groundwater quality and quantity (Senate of Canada, 2005).

Previously in 2003, the *National Ad Hoc Committee on Groundwater* recommended the need to characterize and inventory, within 10 years, the groundwater resource in the settled areas of Canada, in

TABLE 16.7 LIST OF THE GEOLOGICAL SURVEY OF CANADA'S TOP 30 PRIORITY AQUIFERS ACROSS CANADA (FROM RIVERA, 2005)

NAME OF AQUIFER OR AQUIFER SYSTEM (LOCATION IN BRACKETS)	JURISDICTION(S)
Fraser Lowlands (east of Vancouver)	British Columbia
Nanaimo Lowland (east coast of Vancouver Island)	British Columbia
Okanagan Valley (southern interior of B.C.)	British Columbia
Fractured aquifers-Gulf Islands (Strait of Georgia)	British Columbia
Shuswap Highlands (Shuswap Lake)	British Columbia
Paskapoo (north of Calgary)	Alberta
Buried-valley/blanket aquifers (southern Manitoba)	Alberta, Saskatchewan, Manitoba
Upper Cretaceous sands (central east to northwest of Alberta)	Alberta, Saskatchewan
Milk River (southern Alberta)	Alberta
Judith River (southwestern Saskatchewan)	Saskatchewan, Alberta
Eastend-Ravenscrag (southeastern Saskatchewan)	Saskatchewan
Inter-till aquifers (southeast-northwest Saskatchewan	Alberta, Saskatchewan, Manitoba
Carbonate rock (south, east and northwest of Winnipeg)	Manitoba
Basal clastic unit (Winnipeg)	Manitoba
Odanah shale (southwestern Manitoba)	Manitoba
Sandilands (southeastern Manitoba)	Manitoba
Assiniboine delta (between east of Brandon and west of Lake Winnipegosis)	Manitoba
Oak Ridges Moraine (north of Toronto)	Ontario
Grand River Basin (south Hamilton)	Ontario
Credit River (between Brampton and Mississauga)	Ontario
Waterloo Moraine (Waterloo region)	Ontario
Upper Thames (centered in London, ON)	Ontario
Mirabel (north of Montreal)	Quebec
Chateauguay (south of Montreal)	Quebec
Richelieu (between east of Montreal and southwest Trois Rivières)	Quebec
Chaudière (south of Quebec City)	Quebec
Maurice (north of Trois Rivières)	Quebec
Portneuf (west of Quebec City)	Quebec
Annapolis-Cornwallis valleys (northeast-southwest line from Wolfville to Bridgetown)	Nova Scotia
Carboniferous basin (centered in Moncton)	Prince Edward Island, New Brunswick, Nova Scotia

terms of its quantity, quality, vulnerability, and sustainability, with areas selected depending upon jurisdictional priorities. *The Groundwater Mapping Program* managed by the Geological Survey of Canada has undertaken the task of assessing 30 key regional aquifers across the nation (Rivera, 2003, 2005; Table 16.7). It is evident that the ultimate task is a significant one that will likely require the combined resources and collaboration of governments at all levels, with assistance from all private and public sectors (academia, industry and organizations) that benefit from the use of groundwater resources.

16.7 CONCLUSIONS AND RECOMMENDATIONS

Canada's federation of provinces and territories occupies a large land mass. The country's groundwater has been managed more or less independently by the provinces and territories. The effectiveness of groundwater management within Canada may be more practically evaluated by examining how each of these jurisdictions manages its own groundwater resource. We will not do this here, because the scope of this chapter is limited to a national overview. Our recommendations in this chapter are necessarily broad, conceptual and overarching. They are also more or less common to all provincial and territorial jurisdictions:

1. Allocation of use of groundwater needs to be carried out using an integrated ecosystem and watershed management approach that draws on sustainable development principles. This includes regulating groundwater and surface water use in an integrated manner.
2. The science of groundwater hydrology is mature, yet the knowledge and understanding of groundwater in many basins in Canada is lacking.
3. Knowledge of groundwater is place-based. A systematic program to map and characterize aquifers or groundwater in a basin, beginning with the most important ones is necessary. Use of this information will be invaluable in mitigating the variety of groundwater issues that exist in any particular place: such work cannot be done when an issue is imminent.
4. A specific purpose for groundwater studies is to help jurisdictions establish goals for the aquifers. To achieve this, these studies must be done in partnership with provincial (allocation) and local (quality protection) agencies.
5. Stable and adequate base funding is required for provincial and territorial agencies to keep on top of collecting high-quality and spatially comprehensive groundwater data (e.g., collecting and processing well records, operating, groundwater monitoring networks). Such procedures would ensure that legacy groundwater data problems, which are costly to address later, are avoided.
6. There should be an integration of regulatory activities (allocation) with non-regulatory activities (groundwater science) to increase knowledge in support of decision making. Scientific knowledge and new research with groundwater management policies should be linked, and those agencies responsible for groundwater management should make groundwater information readily available to the public via the internet.
7. The role of local government in groundwater management and protection needs to be advanced. Strengthening and clarifying local government mandates in this area will improve groundwater governance by increasing local-scale government initiatives such as well protection planning by water suppliers, planning growth with consideration of basin water availability, and helping to address non-point source contamination problems through increased public awareness and smart land use.

8. Promoting water stewardship in the broadest sense.
9. Promote the sharing of data, which will increase transparency and relevancy of available groundwater information using modern tools.
10. The growing demand for groundwater, coupled with the greater complexity of problems related to its use, has compelled many different federal, provincial and territorial agencies, as well as universities and industry, to work together, collaborating their knowledge and expertise to address common groundwater issues and to achieve common goals for this valuable resource.
11. Despite the fact that management and protection of groundwater is a provincial or territorial responsibility, scientific leadership and dedicated coordination at the federal level is needed to promote meaningful dialogue and consistency in practice; collaboration on groundwater is more important than ever.

CANADA'S GROUNDWATER RESOURCES

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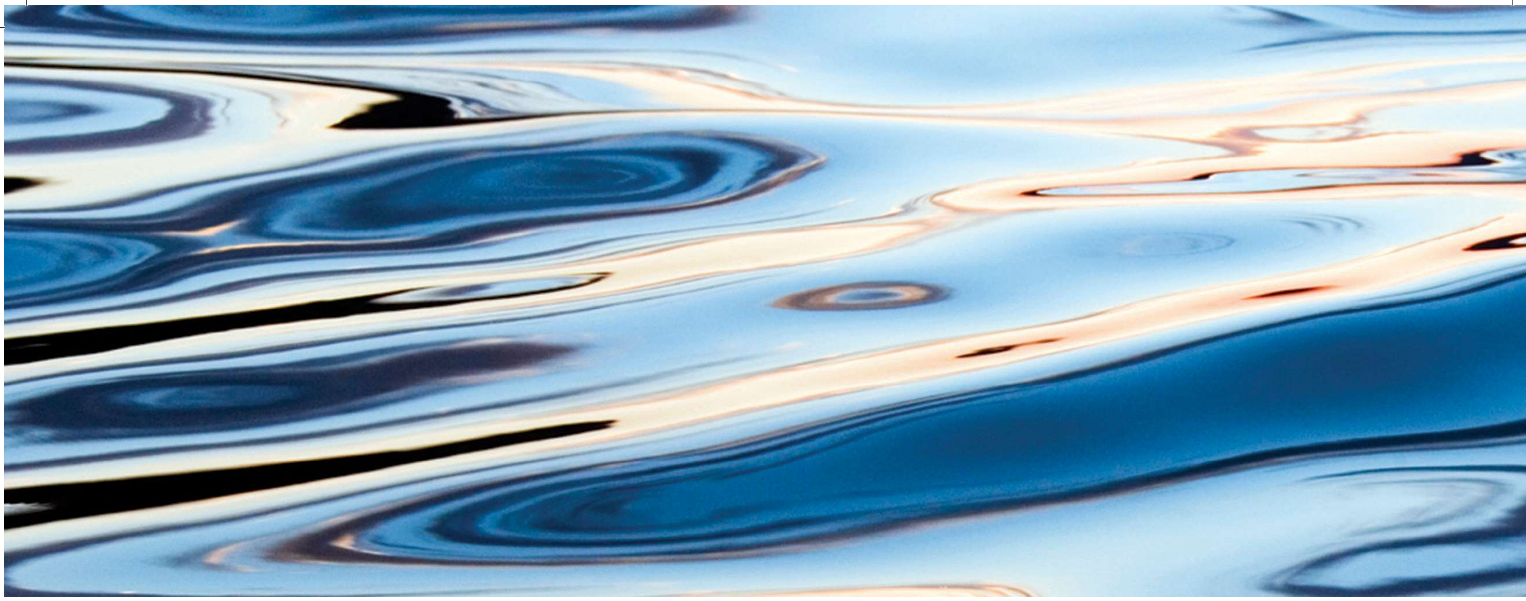

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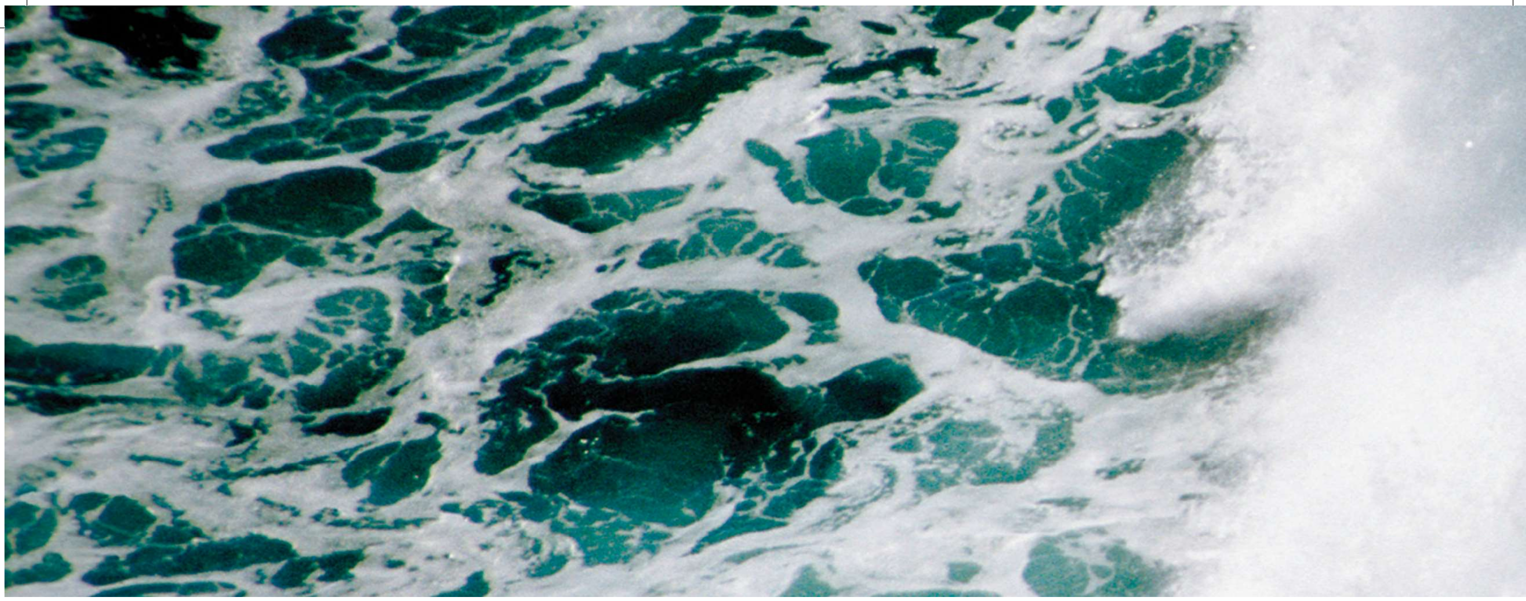

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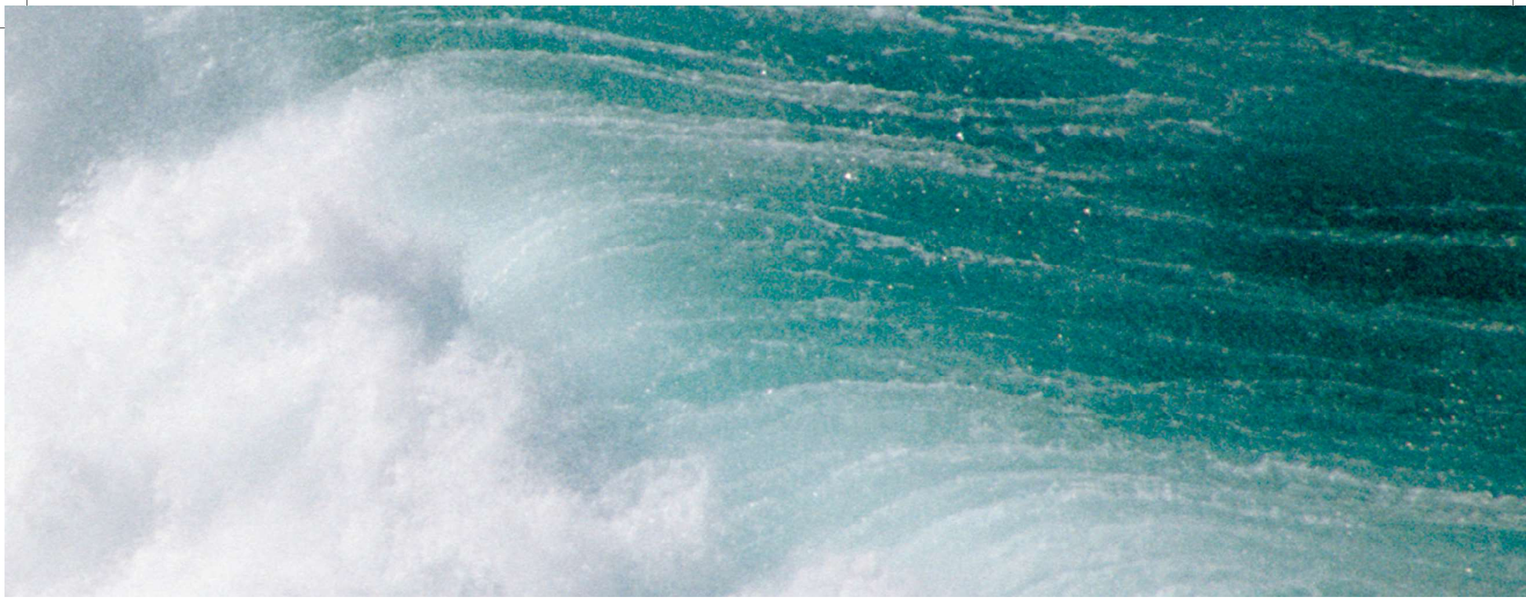

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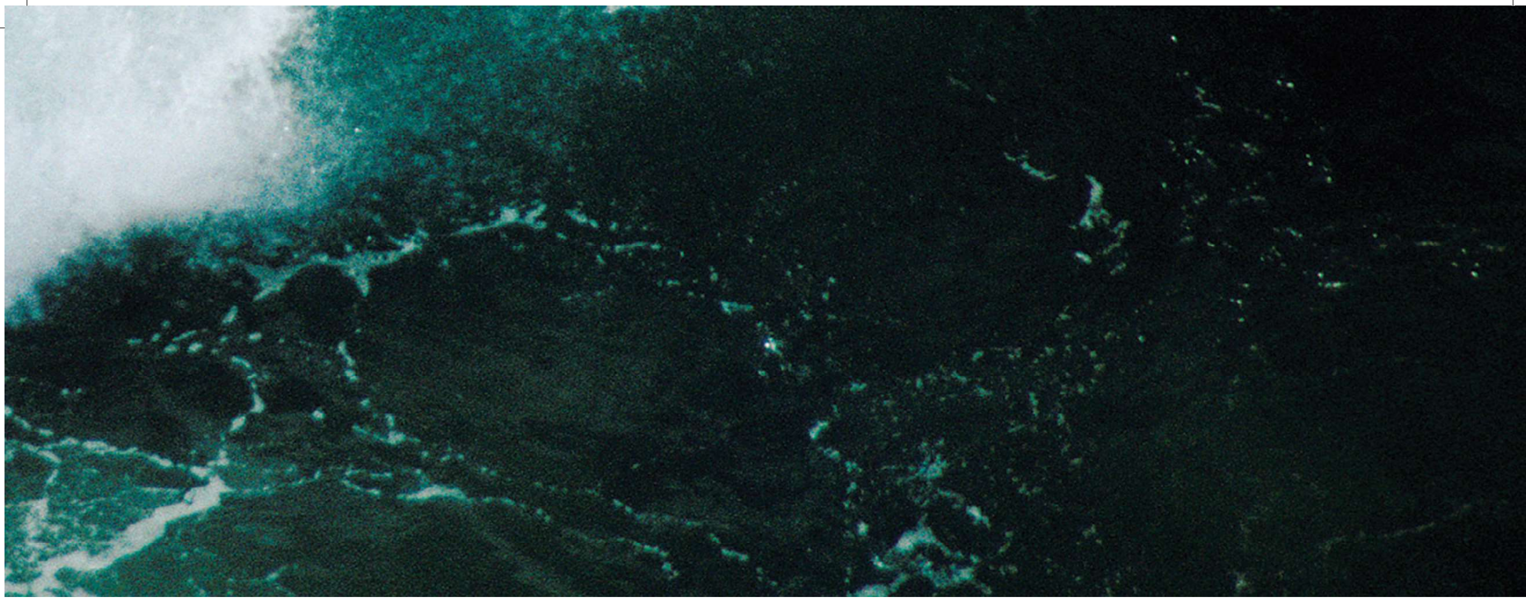

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