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FRESHWATER MANAGEMENT IN CANADA: IV. GROUNDWATER

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INTRODUCTION

For most Canadians, "freshwater" means expanses of surface water such as lakes and rivers. But groundwater is just as essential a link in the hydrological cycle as surface water. The two cannot in fact be dissociated. Groundwater is just as essential to life. For almost 9 million Canadians, it is the main source of drinking water, and according to UNESCO more than half the world's population depends on this source of supply. This paper, the fourth of a series on freshwater management in Canada, focuses on groundwater.(1)

Despite being hidden away, groundwater is vulnerable to a number of threats, including climate change and pollution. Protecting it from these threats is vital. But the challenge is complicated by inadequate data about our groundwater. Canadians take access to groundwater resources for granted but this attitude is misguided, largely because of our imperfect knowledge in a number of areas.(2)

DEFINITIONS AND CONCEPTS

Contrary to popular belief, groundwater rarely takes the form of subterranean lakes or rivers. Instead, it is present in the form of aquifers – rocky or sedimentary layers capable of holding a reserve of water. An aquifer generally consists of unconsolidated deposits (sand and gravel), sandstone, limestone or granite. It is either confined (artesian) or unconfined

(1) The other papers, by the same author, are: *Freshwater Management in Canada: I. Jurisdiction*, PRB 04-48E; *Freshwater Management in Canada: II. Resources, Use and Treatment*, PRB 04-47E; and *Freshwater Management in Canada: III. Issues and Challenges*, PRB 04-51E, Parliamentary Information and Research Service, Library of Parliament, Ottawa, 2004.

(2) Linda Nowlan, *Buried Treasure: Groundwater Permitting and Pricing in Canada*, prepared for the Walter and Duncan Gordon Foundation, with case studies by the Geological Survey of Canada, West Coast Environmental Law and the Sierra Legal Defence Fund, Walter and Duncan Gordon Foundation, Toronto, 2005 p. x, http://www.buriedtreasurecanada.ca/Buried_Treasure.pdf.

(phreatic, i.e., the water table). In the case of unconfined groundwater, the upper surface is directly subject to atmospheric pressure, while in the case of confined groundwater, the upper surface is covered by a semi-permeable or impermeable formation. Water in an artesian aquifer is under pressure, which explains how the water level in a well can be higher than the water level in the aquifer itself.

Like surface water, groundwater is constantly in motion as part of the hydrological cycle. Its circulation is dictated by the recharge (or intake) and discharge processes. Recharging is the process whereby aquifers are resupplied from surface water, mainly by the infiltration of precipitation (rain, snow) in the soil. Environment Canada's Freshwater Website explains that "some of the precipitation and snow melt moves downwards, percolates or infiltrates through cracks, joints and pores in soil and rocks until it reaches the water table where it becomes groundwater."(3) An aquifer's recharge rate is influenced by various factors, including type of soil, vegetation cover, slope, soil moisture content, precipitation intensity, and the presence and depth of confining layers. Aquifers are also fed by expanses of surface water, especially in arid regions.

It is gravity that makes groundwater circulate in the water table. Under normal conditions groundwater sinks, but it can return to the surface via watertable springs or small springs on the shore or bed of an expanse of water. The process by which groundwater leaves the aquifer is called discharge. A number of rivers, lakes and wetlands depend to a great extent on groundwater, without which they would be dry during periods of low precipitation. It should be noted that, because of the discharge process, contaminants present in groundwater may be found in surface water expanses. Groundwater can also be extracted from an aquifer by pumping.

The discharge process for an artesian aquifer is not very different, with the exception that it is pressure and not gravity that forces the water toward the surface. The word "spring" is used when an aquifer discharges its water naturally. If groundwater emerges via an artificial outlet, the term used is "flowing artesian well."

Water may stay in the ground for as little as a few days or weeks or for more than 10,000 years. "Residence times" measured in tens, hundreds or thousands of years are not exceptional. By comparison, the average turnover (complete replacement) time of river water is estimated at two weeks.

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(3) Environment Canada, *Freshwater Website*, http://www.ec.gc.ca/water/.

GROUNDWATER USE IN CANADA

According to statistics for 1996, 30.3% of Canadians depend on groundwater for their drinking water. The percentage varies from region to region. All inhabitants of Prince Edward Island depend on groundwater, while only 23% of Albertans do; the growth rate of demand, however, is probably higher in Alberta. Relying on groundwater as a source of drinking water is primarily a rural reality: two-thirds of the Canadians who use groundwater for domestic purposes live in rural areas.(4) In Quebec, the province's Ministry of Sustainable Development, Environment and Parks estimates that groundwater from private wells constitutes the main source of drinking water for almost half the province's population spread out over 90% of the province's inhabited territory. The Ministry says that, outside urban centres, groundwater is by far the commonest way for Quebeckers to meet their water needs.(5)

Groundwater is normally fit for human consumption, especially where the catchment area is protected from both diffuse ("non-point") and specific ("point") sources of pollution.(6) Statistics Canada data indicate, however, that about 40% of rural wells are contaminated by nitrates and bacteria in concentrations that exceed recommended drinking-water quality levels.(7) According to an Agriculture and Agri-Food Canada document, "Nitrate contamination is agriculture's chief environmental effect on groundwater quality."(8) In 1977, for example, 44% of the wells in Prince Edward Island contained concentrations of nitrogen that exceeded recommended levels. A number of regions also show contamination related to

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(4) Statistics Canada, Environment Accounts and Statistics Division, "Freshwater Resources in Canada," feature article in *Human Activity and the Environment: Annual Statistics 2003*, Cat. No. 16-201-XPE, Ottawa, 2003.

(5) Government of Quebec, *Le puits*, Ministry of Sustainable Development, Environment and Parks, Québec, 2003, http://www.mddep.gouv.qc.ca/eau/ souterraines/puits/le_puits.pdf.

(6) One example of point contamination of groundwater can be found in Shannon, Quebec, where trichloroethylene has leached into the ground. The federal government has a major role to play here, because of the presence of CFB Valcartier: the contamination is thought to be related to industrial activity carried on first by Canadian Arsenals Ltd. and subsequently by the private firm that replaced it.

(7) Statistics Canada (2003), pp. 4 and 27. In southern Canada, groundwater is usually found no more than 20 metres down. The surface aquifers usually contain freshwater while the deeper aquifers tend to contain higher concentrations of dissolved solids that make the water less drinkable. At depths below 500 metres, groundwater may be as salty as seawater, or even saltier. Surface aquifers are more exposed to contamination by pollutants, which partly explains the poor quality of water in many shallow wells in Canada.

(8) G. L. Fairchild *et al*., "Groundwater Quality," Chapter 6 in D. R. Coote and L. J. Gregorich, eds., *The Health of Our Water: Toward Sustainable Agriculture in Canada*, Agriculture and Agri-Food Canada, Research Branch, Ottawa, 2000, p. 76, http://res2.agr.gc.ca/publications/hw/PDF/water.pdf.

pesticide use, although concentrations of this type of contaminant are considered to be low and well within recommended maximums.[9] Statistics Canada finds that consumers are generally more exposed to contaminants when they are served by private rather than municipal wells. In addition, users of private wells often neglect the regular testing of their water. For instance, in 2001, 64% of Canadian farmers with their own wells did not have their water tested regularly, and only 16% had it tested once a year.[10]

According to a recent statistical compilation of profiles of groundwater use by province, it is the industrial sectors – primarily manufacturing, mining, thermal power generation and aquaculture – that are the biggest consumers. Next come the municipal and agricultural sectors (for example, crop irrigation, cleaning, livestock watering). The beverage industry, which depends on potable water, obtains it mainly from municipalities, which in turn are likely to use groundwater.[11]

It is interesting to note that an increasingly common use of groundwater in this country is for bottling. This use is characterized by the fact that the extracted water is used entirely for human consumption, and often exported beyond the limits of the region where the extraction took place. According to the International Council of Bottled Water Associations, 1.49 billion litres of water were bottled in Canada in 2003, an increase of 183% in less than 10 years.[12] In Quebec, the Association des embouteilleurs d'eau du Québec estimates that 19% of bottled groundwater is intended for export, and thus permanently removed from the aquifer from which it was extracted.[13]

The situation is even more serious in other countries than it is in Canada. For example, in 2003 the United States bottled 24.5 billion litres, or 16 times more than Canada, even though American groundwater resources are comparable to Canada's in quantity but more heavily drawn on and more vulnerable. There are thus good reasons for concern about the pattern of use both in Canada and elsewhere.

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(9) *Ibid.*

(10) Statistics Canada (2003). In Canada, 41.2% of municipal water systems rely on groundwater as their source of supply.

(11) Susan Rutherford, "Groundwater Use in Canada – Case Study Summary," in Nowlan (2005), p. 32.

(12) Canada produced 527 million litres of bottled water in 1995. International Council of Bottled Water Associations, *Global Bottled Water Statistics 2000-2003*, http://www.icbwa.org/2000-2003_Zenith_ and_Beverage_Marketing_Stats.pdf.

(13) Association des embouteilleurs d'eau du Québec, *Information générale : Saviez-vous que?*, http://www.aeeq.org/saviez-vous_fr.html.

The federal government has a special role to play in this sector, since it regulates bottled water under the *Food and Drugs Act*. The regulations made under the Act define springwater, for example, as "potable water obtained from an underground source but not obtained from a public community water supply."(14) The federal government has, however, no jurisdiction or control over the tapping of groundwater for bottling.

JURISDICTION OVER WATER MANAGEMENT AND THE ROLE OF THE FEDERAL GOVERNMENT(15)

While it is true that the *Constitution Act, 1867* does not expressly attribute responsibility for drinking water to either order of government, the matter falls largely under provincial jurisdiction. The provinces have authority over the supply of drinking water within their territory. They thus play a predominant role in regulating such supply.

It is, however, accepted that the federal and provincial governments share responsibility for agriculture, health, interprovincial waters and important national water-related issues. The federal government has sole jurisdiction in such areas as boundary and transboundary waters, fisheries, navigation, and water on federal lands, in the territories and on First Nations reserves.

According to a document published by the Walter and Duncan Gordon Foundation, the federal government's role in water management derives from its legislative powers and its ownership of Crown land. The federal government has jurisdiction over groundwater when aquifers cross interprovincial or international boundaries. Moreover, the importance of water both environmentally and strategically justifies a federal presence in this area,(16) given the Parliament of Canada's broad powers over the environment and its power to legislate for "peace, order and good government."

Groundwater management where aquifers cross international borders – between Canada and the United States – poses a special problem. In Canada, the federal government is

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(14) Canada, *Food and Drug Regulations*, C.R.C., ch. 870, http://laws.justice.gc.ca/en/F-27/C.R.C.-c.870/123984.html#rid-124102.

(15) See also F. Côté, *Freshwater Management in Canada: I. Jurisdiction*, PRB 04-48E, Parliamentary Information and Research Service, Library of Parliament, Ottawa, 2004.

(16) Nowlan (2005).

clearly the competent authority in such cases, but in the 1909 *Boundary Waters Treaty* there is no mention of groundwater,[17] and the mandate of the International Joint Commission (IJC) does not explicitly include the prevention or resolution of conflicts over the use or quality of boundary groundwater. The IJC has, however, looked into groundwater-related issues in the past. For example, it has on a number of occasions (most recently in 2004) urged the Canadian and American governments to do more to increase knowledge of their groundwater resources.

FEDERAL GOVERNMENT INITIATIVES

Federal involvement in the management of freshwater resources has taken the form of a number of initiatives, including collaboration in work done by various Canadian Council of Ministers of the Environment (CCME) groups on water quality and conservation. The federal government is also active on a number of tripartite (federal-provincial-territorial) committees, including one on drinking water. Among the results of this involvement was the development of the multi-barrier approach, which has received the support of Canadian authorities responsible for a safe drinking water supply.[18] The multi-barrier approach is an integrated system of procedures, processes and instruments that collectively prevent or reduce contamination of drinking water from source to tap, thus reducing risks to public health. It has three elements:

- source water protection;
- drinking water treatment; and
- drinking water distribution systems.

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(17) The Preliminary Article of the 1909 *Boundary Waters Treaty* (http://laws.justice.gc.ca/en/I-17/ 245665.html) defines boundary waters as "the waters from main shore to main shore of the lakes and rivers and connecting waterways, or the portions thereof, along which the international boundary between the United States and the Dominion of Canada passes, including all bays, arms, and inlets thereof, but not including tributary waters which in their natural channels would flow into such lakes, rivers, and waterways, or waters flowing from such lakes, rivers, and waterways, or the waters of rivers flowing across the boundary." The 1978 *Great Lakes Water Quality Agreement*, which also comes under the IJC's authority, does refer to groundwater.

(18) Federal-Provincial-Territorial Committee on Drinking Water of the Federal-Provincial-Territorial Committee on Environmental and Occupational Health, and the Water Quality Task Group of the Canadian Council of Ministers of the Environment, *From Source to Tap: The multi-barrier approach to safe drinking water*, Ottawa, 2002, http://www.ccme.ca/assets/pdf/mba_eng.pdf.

According to a CCME document, the federal government is supporting the multi-barrier approach by undertaking research to determine, understand and reduce the impact of microbiological and chemical substances that contaminate drinking water sources and aquatic ecosystems. This commitment is in line with the Federal Water Policy of 1987. At that time, the federal government established two goals in this regard:

- to protect and enhance the quality of Canada's water resources; and
- to promote the wise and efficient management and use of water.

According to the Walter and Duncan Gordon Foundation, the Federal Water Policy recognizes the federal government's role in groundwater management. When it developed the Policy, the federal government made a commitment to take concrete action to improve the management of this resource. But, again according to the Foundation, Ottawa has not in fact done very much.(19) The Commissioner for the Environment and Sustainable Development (CESD) noted in 2001 with reference to the Great Lakes and St. Lawrence Basin how little progress the federal government had achieved despite its 1987 commitments,(20) which were to:

> - develop, with provincial governments and other interested parties, appropriate strategies, national guidelines and activities for ground water assessment and protection;
> - conduct research and undertake technological development and demonstration projects in response to ground water problems;
> - develop exemplary ground water management practices involving federal lands, responsibilities, facilities, and federally funded projects;
> - develop measures to achieve appropriate ground water quality in transboundary waters; and
> - provide information and advice on ground water issues of federal and national interest.(21)

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(19) Nowlan (2005), pp. xi and 18.

(20) Commissioner of the Environment and Sustainable Development, *2001 Report*, Chapter 1, Section 3, "Water," Ottawa, 2001, para. 3.5.14-3.5.19.

(21) Canada, *Federal Water Policy*, Environment Canada, Ottawa, 1987, p. 14, http://www.ec.gc.ca/Water/en/info/pubs/fedpol/e_fedpol.pdf.

Two departments share the essential core of the federal government's responsibility for groundwater-related scientific activities: Environment Canada and Natural Resources Canada. With respect to the Great Lakes and St. Lawrence Basin, the CESD said in her 2001 report that "Natural Resources Canada, together with Environment Canada, should develop enough knowledge of groundwater in the basin to understand its contribution to the availability of surface water – in particular, knowledge of key aquifers, their geology, potential yields, and current withdrawals."(22) The government said that it agreed with this recommendation. There is in fact a groundwater cooperation agreement (signed in 1991, renewed in 2002) between Environment Canada's National Water Research Institute (NWRI) and the Geological Survey of Canada (GSC), which is part of Natural Resources Canada's Earth Sciences Sector (the main geoscience information and research body in Canada).

The research for which Natural Resources Canada is responsible is conducted by the GSC and focuses on groundwater quantity. One of the GSC's roles is to describe the country's groundwater resources.(23) It administers a groundwater program that will be receiving $4.4 million a year over the next three fiscal years (2005-2006 to 2007-2008), and under which the GSC will map Canada's main aquifers and study their dynamics. The aims of the program are to:

- ensure clean and sustainable groundwater;
- fill gaps in the knowledge of Canada's groundwater resources;
- provide governments with a groundwater resources inventory;
- assess regional aquifer dynamics (recharge and discharge, sustainable yield, vulnerability); and
- facilitate best groundwater management practices.

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(22) Commissioner of the Environment and Sustainable Development (2001), para. 3.1.33.

(23) Natural Resources Canada, *2005-2006 Estimates, Part III – Report on Plans and Priorities*, Public Works and Government Services Canada, Ottawa, 2005, http://www.tbs-sct.gc.ca/est-pre/20052006/NRCan-RNCan/NRCan-RNCanr56_e.pdf. On p. 9, this report states that the GSC "works with the provinces and territories to provide the geological information that ensures a competitive investment climate for mineral and petroleum exploration, elucidates groundwater resources, maps the geology of the seafloor, [and] helps reduce the risk posed by natural hazards such as earthquakes, magnetic storms, landslides and naturally-occurring toxic substances."

The anticipated results are a national database on aquifer and groundwater characteristics and the mapping of 20% of key aquifers by 2006. This information will, for example, help municipalities make decisions about their water and waste management, especially in areas near aquifers with proven vulnerability levels.

In 2003, the federal government published a document entitled *Canadian Framework for Collaboration on Groundwater*.(24) The recommended framework was developed by a special national committee as part of a GSC initiative. The National Ad Hoc Committee on Groundwater is made up of representatives of all levels of government, universities and the private sector. According to the supporting document, collaboration among the various public bodies that manage groundwater resources suffers from an absence of shared vision as to how the water should be managed and how access to it can be guaranteed to everyone. The Canadian Framework was designed to solve this problem, and will serve among other things to support the effort needed to fill the gaps in our knowledge of groundwater in Canada. The document also inventories, for each province and territory, issues that must be addressed, involving both the quality and quantity of groundwater as well as current and future activities. The inventory emerged from the first National Groundwater Workshop, held in Quebec City in 2000. One of the workshop's main recommendations was to prepare a national groundwater inventory. Implementation of the Canadian Framework has yet to be completed.(25)

More recently, the federal government created an interdepartmental committee on water made up of assistant deputy ministers from 19 departments. A water framework was developed in 2004 and a water research network was set up to integrate and coordinate federal research activities.(26) These initiatives refer specifically to groundwater.(27)

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(24) Alfonso Rivera *et al.*, *Canadian Framework for Collaboration on Groundwater*, Ottawa, 2003, http://gwp.nrcan.gc.ca/pdf/cadre_canadien_collaboration_eau_souterraine_e.pdf.

(25) Alfonso Rivera, *How Well Do We Understand Groundwater in Canada? A Science Case Study*, with the collaboration of the Walter and Duncan Gordon Foundation, Natural Resources Canada, Ottawa, April 2005, p. 5. A summary of the study appears in Nowlan (2005).

(26) John Carey, Director General, National Water Research Institute, Environment Canada, *The Federal Water Framework: Where Federal Initiatives in Water are Headed*, presentation to the Canadian Water Network annual symposium, Ottawa, 22 June 2004, http://cwn-rce.ca/pdfs/CWN2004_JC.pdf.

(27) Rivera (2005), p. 29.

LEGISLATION AND OTHER PARLIAMENTARY ACTION

Unlike the provincial legislative assemblies, the Parliament of Canada has passed few acts dealing with groundwater, largely because of the federal government's limited role in this domain. Provincial laws and regulations address quantitative and qualitative aspects of groundwater extraction, environmental assessments, and land use and development. At the federal level, only a small number of regulations in the mining, oil and fisheries sectors refer to groundwater. Groundwater is also mentioned in certain laws implementing international agreements, mainly to withdraw it from their application.

All the provinces and territories, as well as the federal government, have passed laws regulating environmental assessments. Some of the projects and activities targeted by these laws have the potential to affect groundwater and must be evaluated from this perspective. For example, federal regulations on the extraction of groundwater – the *Comprehensive Study List Regulations*, made under the *Canadian Environmental Assessment Act* – provide that a comprehensive environmental assessment is required for any project involving a "facility for the extraction of 200 000 m^3/a or more of ground water."(28)

Among non-legislative parliamentary action on groundwater is the report tabled in 2005 by the Standing Senate Committee on Energy, the Environment and Natural Resources, entitled *Water in the West: Under Pressure*.(29) The Committee was motivated to undertake this study in part by the special situation of the Prairies: the aridity of their climate, amplified by climate change; the rapidity of their demographic growth and economic development; and their dependence on water for agriculture and oil production. With respect to groundwater, the Committee recommended that the federal government "take the necessary steps to ensure that all of Canada's major aquifers are mapped by 2010. This data should be made available in the national groundwater database and supported by a summary document assessing the risks to groundwater quality and quantity." The recommendation is similar to ones put forward by a large number of stakeholders, including the CESD, in recent years. The government has said that it agrees in principle with the recommendation's objective.

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(28) Canada, *Comprehensive Study List Regulations*, SOR/94-638, http://lois.justice.gc.ca/en/c-15.2/sor-94-638/66167.html.

(29) Standing Senate Committee on Energy, the Environment and Natural Resources, *Water in the West: Under Pressure*, 1st session, 38th Parliament, Ottawa, 2005, http://www.parl.gc.ca/38/1/parlbus/ commbus/senate/com-e/enrg-e/rep-e/rep13nov05-e.htm.

SIGNIFICANT AQUIFERS IN CANADA AND ELSEWHERE

It is not easy to determine just how many aquifers Canada contains. By their very nature, the limits of aquifers are diffuse and fluctuating. Surface water, on the other hand, can readily be defined, since watershed boundaries are dictated by quasi-immutable topographical characteristics.(30) Nonetheless, the GSC has been able to identify 30 aquifers which it has chosen at the regional level for assessment and inventory.(31) Its choice was made in consultation with the provinces and on the basis of varying criteria, ranging from the resource's importance as a source of drinking water to environmental characteristics. The assessment of 12 regional aquifers is being completed.(32) Among these are:

- *The Paskapoo Formation*, which covers over 10,000 km^2 of southwestern Alberta. More than one-sixth of the 600,000 groundwater wells drilled in the Prairie provinces are located in the Paskapoo Formation, and approximately 85% occur between Calgary and Red Deer; this region's demographic growth is among the strongest in Canada, entailing a significant increase in groundwater use. This aquifer is currently under study.

- *The Oak Ridges Moraine Aquifer System*, which is located in the Greater Toronto area and supports a booming urban region. The study of this aquifer was complicated by the nature of the subsurface glacial deposits. The study has been completed.

- *The Annapolis-Cornwallis Valley Aquifers* in Nova Scotia, which are important sources of freshwater for homes, farms, industries and aquatic habitats such as peat bogs and water courses in one of the province's main economic regions. The Valley runs parallel to the Bay of Fundy, between the North Mountain and the South Mountain. It covers 2,400 km^2. The characteristics of the groundwater resources in these aquifers are in the process of being defined.

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(30) It is therefore not surprising that we have a fairly precise idea of the number and characteristics of the country's watersheds, both nationally and locally. Canada contains 23 major river basins, the majority of which cross provincial and/or territorial boundaries and some of which cross our border with the United States. The Quebec government has estimated that Quebec includes 430 watersheds, 100 of which drain an area larger than 4,000 km^2. The Ontario government has identified 144 tertiary watersheds within 28 secondary watersheds.

(31) These regional aquifers are located in five of Canada's nine hydrogeological regions. The nine regions are: Cordillera, Western Canada Sedimentary Basin, Canadian Shield, Hudson Bay Lowlands, Southern Ontario Lowlands, St. Lawrence Platform, Magdalen Basin, Appalachians and Permafrost. See Rivera (2005), pp. 11 and 12.

(32) Rivera (2005), p. 12. Of these 12 aquifers, studies on 7 have been completed; studies are partially completed or ongoing on 5. It is anticipated that new studies will be undertaken and completed by 2010 on a further 10 aquifers (already part of the list of 30).

Globally, examples of notable aquifers include:

- *The Nubian Sandstone Aquifer System*, which stretches under the deserts of Libya, Egypt, Chad and Sudan. The system comprises four linked aquifers with a total capacity of some 120,000 cubic kilometres and a corresponding area of 2.5 million km^2 (almost one-quarter the size of Canada). Management of this aquifer is especially complex because four national governments are involved.

- *The Guarani Aquifer* in South America, which underlies a territory of 1.2 million km^2, divided between Brazil and Argentina.

- *The Ogallala Aquifer*, which lies beneath eight states in the American heartland. Its groundwater is being rapidly depleted because of increasing use by municipalities and the agricultural sector. Its annual recharge is estimated at only 10% of what is being extracted.

- *The Great Artesian Basin* in Australia, one of the largest groundwater basins in the world. It underlies arid and semi-arid territory that makes up one-fifth of the country, or 1.7 million km^2.

FUTURE CHALLENGES

A. Expanding Our Knowledge of Groundwater

One of the issues that seems to come up in every forum is the need for a groundwater resource inventory. According to Rivera, "Despite our current scientific knowledge about groundwater, few would disagree that there are significant information gaps."(33) In Canada, the main gaps involve:

- the quantity of groundwater available and the use of being made of it;
- the dynamic of the interactions among groundwater, surface water and aquatic ecosystems;
- aquifer recharge rates;
- methods of evaluating groundwater flow in fractured aquifers;
- the vulnerability of regional aquifers;
- the characterization of fractured aquifers;

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(33) Rivera (2005), p. 6.

- recognition of groundwater's social and economic value; and
- long-term data and ongoing monitoring of groundwater levels and quality.

Insufficient knowledge and a failure on the part of managers to recognize the importance of the interaction between groundwater and surface water have serious consequences. In the United States, for example, excessive pumping of groundwater has caused inversion of the subterranean current under the Continental Divide along Lake Michigan in the state of Wisconsin. In some coastal regions, modifications in aquifer recharge rates caused by changes or variations in climate, or by pumping, can cause salt water to flow into an aquifer's freshwater zone(34) and contaminate it. Greater knowledge of the interactions among groundwater, surface water and aquatic ecosystems might make it possible to avoid this kind of problem. So far, governments have tended to approach the management of surface water and groundwater in isolation from each other. Recognition of the continuity of the water cycle should promote a shift to integrated management.

B. The Effects of Climate Change on Groundwater

Climate change is aggravating the existing threats to supplies of clean drinking water caused by population growth and economic activity. It is generally agreed that climate change adds to and even amplifies the effect of climate variability, and is having a significant impact on the water cycle. For groundwater, this means an alteration or disruption of the overall water balance. It should be noted, however, that, depending on their type and depth, aquifers react differently to surface stress factors.(35) As a general rule, the depth of groundwater resources and such characteristics as residence time have a buffering effect on these stresses.

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(34) The closer to the seacoast, the saltier the water table, producing a "salinity gradient." Pumping causes a siphon effect that draws salt water toward the location of the pumping ("saline intrusion").

(35) Alfonso Rivera, Diana M. Allen and Harm Maathuis, "Climate Variability and Change – Groundwater," Chapter 10 in Environment Canada, *Threats to the Availability of Water in Canada*, Report No. 3, National Water Research Institute, Burlington, Ontario, 2004, pp. 89-95, http://www.nwri.ca/ threats2full/ch10-1-f.html.

CONCLUSION

The federal government has a limited role in groundwater management. Nevertheless, as is the case in many areas linked to natural resources, a number of federal departments have been very active on the research front. Two examples are Environment Canada (via the NWRI) and Natural Resources Canada (via the GSC). Federal research responds in part to the commitments made in 1987 with the publication of the Federal Water Policy. It aims at filling various gaps in Canada's knowledge of groundwater, including those identified at the first and second National Groundwater Workshops held in Quebec City in 2000 and in Calgary in 2001, as well as in the 2003 *Canadian Framework for Collaboration on Groundwater*. Several observers, however, including the CESD, consider that progress has been slow. It should be borne in mind that the funding voted to support the research is limited: the GSC, for example, receives only $4.4 million annually for its groundwater program.

Groundwater management issues are important and will become even more urgent in the future, partly because of the anticipated effects of climate change. Those issues, as described in this paper, vary in nature and scope from one region of the country to another. For example, the situation could become especially difficult on the Prairies, where rate of use is approaching the critical threshold of aquifer recharge rates in certain areas. It is therefore essential that the federal government continue its research activities and its collaboration with other levels of government on adopting and coordinating effective conservation and management measures to protect this essential resource.