GROUNDWATER:
A NORTH AMERICAN RESOURCE

A DISCUSSION PAPER

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INTRODUCTION AND BACKGROUND

This document has been developed by the Commission for Environmental Cooperation (CEC) to spur discussion and focus debate on groundwater in the North American context. The CEC has previously examined the legal and policy framework that underlies transboundary freshwater management in North America and has identified a number of emerging freshwater issues. In June 2001, the Council of the CEC directed the Secretariat to analyze freshwater issues relating to local water pricing and watershed management, and promote accessible, affordable technologies for improving water management. The CEC will be including a special chapter on water in its next State of the Environment Report in 2003.

The CEC has chosen at this time to focus on groundwater because it is the least well understood component of North America's freshwater system. As described in this discussion paper, a number of agencies have called for governments to increase their understanding of the resource. We know very little about how much groundwater is available, how much is currently being consumed, how it flows underground, and other important facts. As a resource, groundwater has not been examined through a North American lens.

Groundwater is a vital (but under-appreciated) part of our freshwater system. Almost 200 million North American residents rely on groundwater for domestic use. It is also vital to the agricultural and industrial sectors of the North American economy and it plays an essential role in sustaining our rivers, streams, lakes, wetlands and aquatic systems. However, the resource is under threat: contamination of aquifers is pervasive in North America and in many places groundwater is being used faster than nature can replace it. Emerging factors such as the possibility of international trade of water, rapid population growth in water-stressed areas and global climate change will all increase the pressure on groundwater resources. Decades of effort have been expended in Canada, the U.S. and Mexico to protect and restore surface waters, but much less effort has been expended on groundwater. The results of this lack of institutional attention are now becoming apparent.

Many have argued that access to clean water will be the environmental issue of the 21st century. A recent study projects that, if current consumption patterns continue, at least 3.5 billion people or 48% of the world's population will live in water stressed basins by the year 2025 (World Resources Institute, 2000). This, and the other factors noted above suggest that the time to begin a North American dialogue on groundwater is now.

About this report

This discussion paper has been prepared as a background document for the CEC's Expert Workshop on Freshwater in North America. It was prepared using existing, readily available sources of information. Efforts were made to provide equivalent detail for Canada, the U.S. and Mexico, but this was not always possible. Any errors or omissions are the sole responsibility of the author.

THE STATE OF THE RESOURCE

Groundwater is a vitally important North American resource

Extent

Many people in North America associate fresh water with images of flowing rivers and sparkling lakes. In fact, however, most of the world's (and most of North America's) liquid fresh water – 97% by some estimations – is not visible, but lies underground in aquifers (Sampat, 2000, Monroe and Wicander, 1994). Some of this groundwater – cold, clean and slow moving – is a legacy from the past and has been stored in aquifers for as long as 10,000 years (Environment Canada, 1999).

The abundance of fresh water varies widely in North America. Canada, for example, is relatively water rich, and possesses about 9% of the world's accessible, renewable fresh water. Most of this is groundwater, the volume of which has been estimated to be 37 times greater than the volume of water in the country's lakes and rivers. Because of settlement patterns – most Canadians live in a narrow band in the southern part of the country while many of the rivers flow north to the Arctic – 90% of the population has access to only 40% of the water (Labelle and Forge, 2001).

Table 1: Freshwater availability

	Renewable freshwater resources (cubic kilometers/year)
Canada	2,849.5
United States	2,459.1
Mexico	359.5
North America	5,668.1

Source: Connor, 1999 based on various sources.

As shown in Table 1, which uses the availability of renewable freshwater resources as a measure, the United States also possesses extensive freshwater resources. Mexico, by contrast, has significantly fewer.

Human use

Groundwater makes up a significant proportion of the fresh water that is withdrawn annually in North America, especially in the United States and Mexico. However, these figures do not adequately reflect the importance of groundwater.

Table 2: Amount of groundwater withdrawn

Country	Amount of groundwater withdrawn annually (km^3)	Percentage of all fresh water withdrawn
Canada	1	2%
United States	106	23%
Mexico	25	34%

Source: World Water Vision, 1999 based on various sources.

As noted in Table 3, about 198 million North Americans rely on groundwater for drinking, washing, flushing away wastes, and other domestic uses. Over a quarter of Canadian residents, half of those in the U.S. and two-thirds of those living in Mexico use groundwater for their domestic uses.

Table 3: Population relying on groundwater resources for domestic use

Country	Population reliant on groundwater (millions)	Percent of total population
Canada	7.9	27%
United States	130	50%
Mexico	60	66%

Source: Source: World Water Vision, 1999 based on various sources.

Dependence on groundwater varies widely in Canada and the U.S. Only 20% of Quebec residents depend on groundwater, for example, but 60% of those living in New Brunswick and almost 100% of those in Prince Edward Island rely on it for their drinking water needs (Environment Canada, 2001). In parts of Florida, in the area around San Antonio in Texas, and in the area around Albuquerque, New Mexico, groundwater is the only available source of drinking water (NRC, 2000).

In the U.S. and Mexico, most of the groundwater that is withdrawn is used by the agricultural sector for irrigation and watering livestock. In Canada, domestic use rivals agricultural use in importance. About 89% of Canadian farms depend on groundwater for drinking and irrigation (Agriculture and Agri-Food Canada 2000).

Table 4: Groundwater withdrawals by sector

Country	Domestic	Industrial	Agriculture	Total (km^3/yr)
Canada (1991)	43%	14%	43%	1.0
U.S. (1990)	23%	6%	71%	110.0
Mexico (1985)	13%	23%	64%	24.0

Source: Source: World Water Vision, 1999 based on various sources.

Ecological value

In addition to the human uses that it sustains, groundwater also performs many vital ecological functions. Groundwater is an essential part of the hydrologic cycle in which water constantly moves above, on and below the planet's surface. As such, it plays an important role in sustaining streams, rivers, lakes, wetlands and aquatic communities. For example, groundwater contributes a significant amount to the overall water supply in the Great Lakes, ranging from 22% of the U.S. supply to Lake Erie, to 42% of the U.S. supply to Lakes Huron and Ontario (IJC, 2000).

Groundwater-surface water interactions are complex and variable. Wetlands, such as prairie sloughs, that are located on high ground function typically recharge the aquifers beneath them, whereas those that lie at lower altitudes typically receive most of their water from groundwater. The contribution that groundwater makes to flows in rivers and streams varies according to surficial geology and other factors. In some areas of Ontario where silt and clay soils predominate, groundwater flow contributes less than 20% of stream flow. Where sand and gravel dominate, it can contribute 60% or more of the total stream flow (IJC, 2000).

Groundwater discharge is a key determinant of the biological viability of tributary streams. In relatively undisturbed areas, groundwater discharge provides a stable inflow of water with consistent temperature, water chemistry and dissolved oxygen concentration (IJC, 2000). Changes in groundwater levels can have a major impact on critical habitats such as riparian vegetation and on the wildlife that is sustained by those habitats (NRC, 2000).

In many areas, groundwater is being used faster than it can be replenished

In many parts of North America, groundwater is being pumped out faster than nature can recharge it. This "groundwater deficit" is leading to dropping aquifer levels, saltwater intrusion, land subsidence and reduced groundwater discharge to streams and wetlands.

Dropping aquifer levels

The High Plains (Ogallala) aquifer is a classic example of an aquifer that is being overpumped. This large aquifer underlies parts of eight states, from South Dakota in the north to Texas in the south. The High Plains area is an important agricultural area that provides a significant portion of U.S. corn, cotton and wheat and half of U.S. beef cattle (Monroe and Wicander, 1994). Its rich croplands comprise about a fifth of the irrigated land in the US, and use about 30% of all the groundwater used nationally for irrigation. Groundwater pumping to satisfy irrigation needs has caused the aquifer to drop as much as 30 metres in some areas (NRC, 2000).

In the Chicago-Milwaukee metropolitan region, the aquifer level declines have been greater still. Groundwater pumping reached its peak in 1979, resulting in declines in groundwater levels of 114 metres under Milwaukee and 274 metres under Chicago (IJC, 2000). Lower pumping rates since 1980 have allowed groundwater levels to partly recover in some parts of the region, but levels continue to decline in the southwestern part of the Chicago metropolitan area. Falling groundwater levels are also found in the dry southwest (e.g., the Albuquerque basin of New Mexico) and the Sparta aquifer of Arkansas, Louisiana and Mississippi. (NRC, 2000)

Because of overpumping of aquifers, the U.S. has a groundwater deficit that has been estimated at 13.6 billion cubic metres a year, with most of this accumulated in the High Plains aquifer (Postel, 1999).

In Canada, the major area where falling groundwater levels are a concern is the Kitchener-Waterloo area in Ontario. Here about 250,000 people rely on groundwater for municipal supplies. Depletion of the underground aquifers has led to extensive conservation efforts and exploration of alternate sources, including the possibility of building a 120 km long pipeline to provide water from Lake Huron (Environment Canada, 1996).

A total of 459 aquifers have been identified in Mexico. Of these, 130 have been determined to be overexploited, or at threat of over exploitation (Steele *et al.*, 1997). The Lerma-Chapala Basin is one of these areas: water resources in this rapidly growing area, which accounts for 35% of Mexico's industrial GNP, have been over-committed since the mid-1980s (Scott and Restrepo, 2000). The aquifer that supports the 1.5 million people living in the semi-arid Ciudad Juárez/El Paso region is being drawn down rapidly and is expected to the depleted within 20 years (U.S.-Mexico Foundation for Science, 1998).

In parts of North America, including the U.S./Mexico border areas, groundwater shortages are becoming critical and are the subject of disputes amongst water users and regulators. Dropping aquifer levels have already had a significant economic impact in some areas, leading to increased pumping costs and reduced well yields. On the High Plains, where aquifer levels have dropped significantly, farmers have begun to abandon irrigated agriculture. In 1978, about 5.2 million hectares were irrigated there; in less than a decade, this had dropped by nearly 20% to 4.2 million hectares (Postel, 1999).

Saltwater intrusion

Saltwater intrusion can be a serious problem in coastal areas where groundwater pumping rates are high enough to cause sea water to invade freshwater aquifers. In the U.S., it is especially a concern along the Atlantic coast, from Cape Cod to Miami (NRC, 2000). Once contaminated with salt water, aquifers cannot be used for drinking and irrigation purposes, and will remain brackish for a long time.

Land subsidence

Large scale groundwater extraction can lead to consolidation of aquifers and subsidence of land. Areas of the U.S. in which groundwater pumping has led to subsidence include California's San Joaquin Valley, Houston-Galveston in Texas, Baton Rouge in Lousiana and the Phoenix area in Arizona (NRC, 2000). Parts of Mexico City have subsided as much as 10 metres in the last 70 years (Environment Canada, 1999). Subsidence is not known to be a problem in Canada at this time.

Subsidence can cause widespread damage to sanitary sewers, water lines, foundations, canals, aqueducts, roadways and well casings. In Mexico City, subsidence has caused the average level of the city center to fall to 2 metres below the bottom of Texcoco Lake, leading to an increased risk of flooding (World Resources Institute, 1997). Perhaps most important, though, is the irreversible nature of land subsidence due to overpumping of aquifers: when aquifer sediments are compacted, the aquifer's capacity to store water is permanently reduced.

Impacts on surface water, vegetation and wildlife

A recent United States Geological Survey (USGS) report details the complex interactions between ground and surface waters and the sensitivity of wetlands and riparian zones to changes in groundwater quality and quantity (Winter *et al.*, 1998).

One area where overuse of groundwater is affecting surface water is the San Pedro Valley. The San Pedro River flows north from the desert grasslands of Sonora, Mexico to Arizona. It is a rarity -- one of the last remaining southwest's last remaining streams to flow virtually year round – and its flow is sustained by groundwater. The lush river corridor forms a linear oasis in the middle of two of North America's largest deserts. It is one of the most important flyways for migratory birds that overwinter in Mexico and breed in the U.S. and Canada, and has been called "a unique and special place of national and continental importance" (CEC, 1999). Parts of the upper San Pedro River have been declared a Riparian National Conservation Area by the U.S. Congress, and the Mexican portion of the watershed has been proposed as a reserve as well (Arias, 2000). However, excessive lowering of the water table is reducing river flows, affecting riparian vegetation and putting at risk many wildlife species that depend on this habitat (American Rivers, 2000; Arias, 2000; and Varady et al., 2000).

The Florida Everglades present another example of how overuse of groundwater can affect surface water resources. Here, intensive exploitation of groundwater resources (coupled with flood protection works and other factors) have led to wholesale changes in the water balance and adverse effects on the region's ecology (NRC, 2000).

Many aquifers are contaminated

Point sources

Untold numbers of aquifers across North America have been contaminated from point sources such as septic systems, leaking underground storage tanks, spills or improper disposal of industrial chemicals, and leachate from solid and hazardous waste landfills. The most notorious of these – sites such as Love Canal in Niagara Falls, New York and Woburn, Massachusetts – have triggered multi-million dollar attempts to clean up or contain the plumes of contaminants. Contamination of groundwater from industrial waste has been noted as a problem on both sides of the U.S.-Mexico border in the Nogales, Sonora region (Mumme, 2000).

In many North American cities, “brownfield” sites – sites that once housed industries such as foundries and coal tar distillation plants – now sit vacant, the soils and groundwater beneath them contaminated with industrial chemicals.

Non-point sources

Contamination of groundwater from non-point agricultural and urban sources is widespread. Agricultural run-off can lead to contamination of aquifers by nitrates, pesticides and bacteria. Canadian studies have shown that nearly all the groundwater underlying agricultural land is contaminated by nitrates, although the concentrations are usually below the Guidelines for Canadian Drinking Water Quality. While historical data suggest that nitrate levels have not changed in 50 years, well water sampling from Ontario suggests that the incidence of bacteria in well water has almost doubled over the same period. In a 1992 survey of groundwater quality in Ontario, 34% of the wells had more than acceptable numbers of coliform bacteria. Across the country, pesticides such as atrazine, dicamba and 2,4-D are found in the groundwater in most areas where they are used, but nearly always at concentrations well below guidelines (Agriculture and Agri-Food Canada, 2000).

In the U.S., contamination of groundwater from non-point agricultural and urban sources has also become pervasive. A recent National Research Council study cited examples of high nitrate concentrations in southeastern Washington State and high incidences of contamination by volatile organic compounds and pesticides in the urbanized Coastal Santa Ana basin (NRC, 2000). Sampling of wells in two counties in Texas in the Lower Rio Grande Valley showed that over 50% of wells exceed the national drinking water standards for nitrates (Mumme, 2000). In California’s San Joaquin-Tulare Valley, nitrate levels in groundwater increased 2.5 times between the 1950s and 1908s, reflecting a six-fold increase in fertilizer applications. The persistent soil fumigant, dibromochlorpropane or DBCP, is still found at high levels in the area’s groundwater, even thought its use was banned in 1977 (Sampat, 2000).

Salinization of groundwater due to overpumping has been noted as a problem in many areas, including in the Colorado River Basin(Mumme, 2000).

The use of untreated wastewater for irrigation has been implicated as a source of nitrate and bacterial contamination of groundwater in Mexico (Steele et. al., 1997). More than half of the wells tested in the Yucatán peninsula had nitrate levels above 45 mg/liter, the national health guideline (Sampat, 2000).

One contaminated transboundary groundwater system on the Canada/U.S. border is the Abbotsford aquifer, which is an important source of water for the Lower Mainland in British Columbia and the State of Washington. In some areas, nitrate levels are more than four times greater than the Canadian Drinking Water Guidelines, and concentrations of four pesticides exceed either Canadian or American guidelines (Environment Canada, 1996).

Human Health

As public understanding of groundwater contamination grows, so has concern about the quality of drinking water from groundwater sources. In Walkerton, Ontario in 2000, seven people died from drinking municipally supplied groundwater contaminated with *E. coli*. This tragic event triggered the adoption of more stringent provincial regulations and policies on drinking water protection, treatment and reporting.

The transmission of water-borne diseases is also a concern in the U.S./Mexico border areas, where inadequate waste treatment has led to incidences of cholera, amoebiasis, hepatitis A, giardiasis and other diseases (U.S.-Mexico Foundation for Science, 1998). In some areas, depletion of aquifers has caused groundwater to become contaminated with naturally occurring arsenic (Ozuna and Williams, 1993).

Nitrates are a potential health concern in groundwater. High levels of nitrates in drinking water (levels greater than 10 mg/liter) can cause methemoglobinemia, or “blue baby” syndrome. The digestive systems of infants convert nitrate to nitrite, which blocks the ability of a baby’s blood to carry oxygen, and which can lead to suffocation and death. (Cattle and sheep can suffer similar effects if levels of nitrate exceed 100 mg/liter in drinking water). (Self and Waskom, 1992).

Recognition of the risk of contamination of groundwater has led many users to adopt point of use treatment devices, such as carbon filters. One study showed that 50% of Saskatchewan farm households used home water treatment devices because of concerns about bacteria and parasites in well water (Environment Canada, 1996).

Problems will worsen in the future

Climate Change

As concerns about the impacts of global climate change have grown, researchers have attempted to understand its effects on water resources. While acknowledging that there is a major information gap with respect to the impact of global warming on groundwater, scientists have a high confidence that rising sea levels will exacerbate the problem of saltwater intrusion into freshwater aquifers. The risks of this are expected to be greatest for shallow island aquifers (such as those in Hawaii and Nantucket) and heavily used coastal aquifers (such as those in Long Island, New York and central coastal California) (Gleick, 2000).

There are many uncertainties associated with climate change predictions. Most scientists believe that the timing and regional patterns of precipitation will change as global warming occurs, but exactly how those changes will manifest themselves in different regions of the continent is unclear. There is a high degree of confidence, however, that average precipitation will increase in the higher latitudes, as will annual average runoff (Gleick, 2000).

In northern parts of the continent, where warmer temperatures are predicted to lead to more precipitation falling as rain than snow, scientists predict that there will be less snow melt, it may come earlier in the year, and soil moisture levels will drop. As a result of this, groundwater recharge will decrease, groundwater levels will fall and many wells will become unusable. As groundwater levels fall, less groundwater will be discharged to streams and wetlands. Stream flows will decrease and water chemistry and temperatures of streams will change. This will affect biological communities and the ability of streams to assimilate wastes such as agricultural run-off (Agriculture and Agri-Food Canada, 2000).

In the densely populated middle reaches of the Rio Grande River, providing an adequate supply of water to meet the needs of a rapidly growing population is already a major issue. During years when little snow falls in the mountains, many areas have to supplement surface water supplies with groundwater. With climate change, the situation is expected to get worse: groundwater levels (already low in the eastern and southeastern parts of the state because of irrigation withdrawals) are expected to drop even further due to the impacts of climate change (U.S. EPA, 2001).

A recent report by the Water Sector Assessment Team examined the effects of climate change on U.S. water resources. It concluded that the impacts of climate change "have the potential to affect international relations at the nation's northern and southern borders, where shared watersheds can lead to local and international political disputes" (Gleick, 2000).

Population Growth

In some parts of North America, rapid population growth will be an additional stress on groundwater resources. This is particularly so for the rapidly growing "sun belt" areas of the southwest and the U.S./Mexico border region, where in many cases, water is already in short supply. The population of the communities living in the U.S./Mexico border region is growing at a faster rate than either the U.S. or Mexico, and is expected to double over the next 20 years (U.S.-Mexico Foundation for Science, 1998). Between 1940 and 1995, the population of the twin cities of El Paso, Texas and Cuidad Juárez, Chihuahua, increased by 3 times and 19 times respectively, fuelling water demand that threatens to exhaust the area's aquifer by 2025 (Hume, 2000). The total Mexican population is estimated to grow to 125 million by 2025, causing "water stress" in certain regions, (World Water Vision, 2000).

CURRENT MANAGEMENT OF THE RESOURCE

Groundwater is not adequately protected from land use changes

In general, recharge areas are not well protected from changes in land use. Urban sprawl that paves over soils through which water would normally infiltrate has been cited as a contributor to declining groundwater levels in Chicago (Egan, 2001). A coalition has fought for two decades to stop urban development on the Oak Ridges Moraine in the rapidly growing area north of Toronto, Ontario. One of the major goals of the coalition is to prevent the paving over of land that currently recharges area aquifers and which sustains the flow of dozens of streams and rivers (STORM, 2001).

In addition to urban development, other changes in land use can have dramatic effects on groundwater resources. These include the drainage of land, the construction of levees and reservoirs, and the removal of natural vegetation (Winter *et al.,* 1998).

A recent report on the protection of the Great Lakes Basin noted that “there is a clear need for state, provincial, and local government attention to the …protection of groundwater recharge areas” (IJC, 2000).

Management does not take an ecosystem approach

Effective management of any resource should be ecosystem based, but this has not generally been the case with groundwater. Too often, institutional rather than ecological boundaries have been used to manage the resource. Although groundwater is an integral and vital part of the hydrologic cycle, in most cases, water managers do not adequately consider its interactions with surface water systems and potential impacts on non-human species. Rarely, are economic, social and environmental concerns integrated in decision-making on groundwater.

In some cases, differing jurisdictions share the same aquifer, but do not work together to use it in a sustainable manner. The twin cities of El Paso and Juárez, for example, depend on the same aquifer for municipal water supplies, yet do not have a region-wide plan to address looming water scarcity. The two cities pump at will from either side of the U.S.-Mexico border (Chávez, 2000).

The regulatory regime is patchwork

The regulatory approach for managing groundwater varies widely across North America and responsibilities are shared among different levels of government. In Mexico, water is a federal resource and it is managed in a centralized way by federal agencies. In the U.S., groundwater rights are defined by the individual states. Most of the northern states use a “prior appropriation/permit” system in which permits specify the rate of withdrawal, location of wells and purpose. Other northern states rely on a “reasonable” use doctrine that entitles landowners to make reasonable use of the groundwater pumped from underneath their property. A third approach is used in the state of Texas where there is no statutory regulation of groundwater pumping at all, and owners owner of land have the “right to capture” water that flows under their land. (CEC, 1999). In Canada, groundwater is a public resource. Management of aquifers and allocation of water is a provincial responsibility, except where the aquifers cross provincial and international boundaries (Federal Commissioner of the Environment, 2001).

An inherent difficulty in managing groundwater is that the law has traditionally divided water into separate legal classes depending on its place in the hydrologic cycle. The unnatural division of groundwater from surface water, and the application of different laws to the ownership and use of different “classes” of water makes “integrated water resource management difficult, if not impossible” (U.S.- Mexico Foundation for Science, 1998).

Adequate transboundary mechanisms do not exist

The mechanisms for managing transboundary water resources on the U.S.-Mexico border include the 1906 and 1944 treaties on boundary waters, the International Boundary and Water Commission, and the Border Environment Cooperation Commission (CEC, 1999). However, these mechanisms deal mainly with allocating surface waters, and were not intended to apply to groundwater. Groundwater was addressed in 1973 through the signing of the International Boundary and Water Commission’s Minute 242. In this document, the U.S. and Mexico acknowledged the need to develop a comprehensive groundwater agreement for the water-stressed border region. This has not taken place, however, and groundwater management practices in the border region have been characterized by some as being “poorly institutionalized and generally deficient for purposes of achieving a sustainable yield of the resource.” Most groundwater withdrawals in the region remain unregulated, and with a few exceptions, ground and surface waters are not managed in an integrated manner (Mumme, 2000).

Water issues along the U.S.-Canada border are greatly influenced by the 1909 Boundary Waters Treaty that created the International Joint Commission (IJC). The 1909 Treaty provided principles and mechanisms to help resolve disputes over boundary and transboundary waters and prevent future ones (CEC, 1999). To date, however, the IJC has not become involved with groundwater issues.

The international agreements that cover the shared watersheds on the U.S./Mexico and U.S./Canada borders do not include provisions for explicitly addressing the risks of changes in water quality or availability that are caused by climate change (Gleick, 2000).

Pricing schemes work against sustainability

Water management in North America has long been driven by the principle of supply management: governments and utilities have built ever-bigger dams, reservoirs, aqueducts, treatment plants and pumps to meet the water demands of users. With clean, adequate water becoming a scarce resource in many parts of the continent, water management has begun to shift from supply to demand management. Demand management provides the user with incentives (economic or otherwise) that make it worthwhile to conserve water and protect freshwater resources.

Much work has been done to develop and improve water efficient technologies such as low flow toilets, closed loop systems, and high efficiency irrigation systems. Many argue that we have access to the technologies we need to become more sustainable in terms of our water use (Postel, 1999). However, in many parts of North America, pricing schemes actively discourage water efficiency and conservation. These economic “disincentives” include lack of water meters in homes, flat rates for water users, and subsidized rates for large industrial or agricultural users. In Texas, for example, irrigators get a break on their income taxes – a “depletion allowance” – for pumping enough water so that the water table under their land drops (Postel, 1999).

In Canada, the need for appropriate water pricing has been recognized as a key issue in water sustainability since the Inquiry on Federal Water Policy in 1985 (Environment Canada, 1996). Despite the recognition in all three countries of the need for appropriate water pricing, it has not widely been embraced. There are many challenges to achieving appropriate water pricing, including the difficulty of defining "full cost", the difficulty of valuing non-economic (i.e., ecological) impacts, addressing issues of equity and ability to pay, and adjusting for regional discrepancies in availability and use (Connor, 1999).

We have large gaps in our knowledge

Our ability to effectively manage groundwater and a resource is hampered by the large gaps in our knowledge of the groundwater resource. The knowledge base for groundwater has been characterized as being fragmented and incomplete. It is an irony of the issue that huge amounts of groundwater data exist, but most of it is local in nature. At this time, there is little assessment of groundwater resources at regional, national and North American scales.

Concerns by the U.S. Congress about the declining state of information on groundwater led to a 1998 USGS Report to Congress that outlined a strategy to address key issues including dropping aquifer levels, saltwater intrusion and reduced discharge to streams (USGS, 2001). A subsequent report by the National Research Council, *Investigating Groundwater Systems on Regional and National Scales*, found that there was "little ongoing assessment of the nation's groundwater resources at regional and national scales" and identified key areas for research (NRC, 2000). The USGS has recently identified the following areas of research as priority areas for their work:

- the development of better data analysis and predictive tools to support sound aquifer management decisions;
- improved knowledge of recharge rates, processes and estimation techniques;
- study of shallow aquifers that are particularly vulnerable to contamination and sensitive to drought and climate change;
- study of saltwater intrusion in coastal aquifers;
- gaining a better understanding of groundwater-surface water interaction;
- gaining a better understanding of groundwater flow in karst and fractured bedrock aquifers; and
- better three dimensional mapping of aquifers and improved modeling to adequately assess groundwater resources and determine the effects of groundwater withdrawals (USGS, 2001).

A recent paper on managing transboundary groundwater on the Mexico-U.S. border noted that, despite significant efforts to improve information, fundamental data on groundwater quantity and utilization rates are still incomplete in large areas of the border region (Mumme, 2000). It has been observed that "the inadequacy of information on water quantity and quality [in Mexico] is a major obstacle to effective water management" (CEC, 1999).

In a recent report on the protection of the Great Lakes, the IJC noted that "there is a serious lack of information on groundwater in the [Great Lakes] Basin, and governments should undertake the necessary research to meet this need" (IJC, 2000). The report noted that at present there is:

- no unified, consistent mapping of boundary and transboundary hydrological units;
- no comprehensive description of the role of groundwater in supporting ecological systems;
- inadequate information on the level and extent of consumptive uses;
- no simplified methods for identifying large groundwater withdrawals near boundaries of hydrologic basins;
- inadequate predictions of the effects of land use changes and population growth on groundwater availability and quality;
- inadequate information on groundwater discharge to streams and the Great Lakes; and

- no systematic estimate of natural recharge areas.

To address these needs, the IJC recommended that work be done to:

- describe groundwater hydrology, quality and availability in shared basins;
- identify current groundwater uses in the transboundary region;
- quantify the factors that are likely to affect those uses in the future; and
- set medium and long-term research priorities for groundwater management in the boundary region.

The need for improved knowledge about groundwater in the Great Lakes Basin was underscored by the most recent report of the Canada's Federal Commissioner of the Environment and Sustainable Development. The Commissioner recommended that federal departments develop enough knowledge of groundwater in the Basin to understand its contribution to the availability of surface water. Specifically, the Commissioner called for governments to gain a better understanding of key aquifers, their geology, potential yields and current withdrawals (Commissioner of the Environment, 2001).

The need to examine the broad dimensions of the issue was recognized by Stephen Mumme in a recent paper on the management of transboundary groundwater on the U.S.-Mexico border. He argued that we need to strengthen "our understanding of transboundary groundwater problems and our capacity to solve them, not just at the geophysical or hydrological level, but at the environmental, public health, socio-economic and institutional levels as well" (Mumme, 2000).

Adequate knowledge is a fundamental requirement for effective and sustainable resource management. Lack of a basic understanding of how much groundwater exists in North America, the quality of that groundwater, how much is being used, how it flows and how it interacts with surface water systems is a huge, if not insurmountable, barrier to achieving sustainable use of the resource.

MOVING TOWARDS SUSTAINABILITY

This section of the Discussion Paper outlines some of the key steps that are necessary to move towards sustainable use of groundwater in North America. Regulators need to improve the knowledge base, improve reporting and access to information, use an ecosystem approach to manage groundwater, adopt a goal of sustainable use, and increase efforts on water efficiency. Key questions are posed in each of these areas.

Regulators need to improve the understanding of groundwater

It is widely recognized that our knowledge of groundwater as a resource is deficient and needs to improve so that assessments can be made at the regional, national and North American scales. Identified priority areas for research, monitoring and data gathering include:

- amounts;
- levels;
- flows;
- recharge rates;
- usage (consumptive uses);
- quality;
- groundwater/surface water interactions including interactions with biological systems;
- impacts of land use changes;
- groundwater flow in karst and fractured rock aquifers; and
- effects of climate change.

U.S., Canadian and Mexican governments have developed programs to enhance monitoring and conduct studies to address some of these key knowledge gaps. In Canada, Natural Resources Canada has committed to developing a national groundwater strategy by 2002 and a national database on groundwater by 2003 (Commissioner of the Environment, 2001).

Questions:

How do we prioritize information needs (in terms of achieving sustainable use of the resource)?

How can we effectively address information needs for transboundary aquifers?

How can we best address information needs in areas that cross traditional disciplines, such as groundwater-surface water interactions?

Are there new sources of information available that we need to know about?

Regulators need to improve reporting and access to information

The ability to assess the state of groundwater in North America is limited, not only by the information gaps outlined above, but also because the information that does exist is scattered among many organizations and is difficult to access. It has been noted that public access to data and information is key to achieving a participatory and inclusive approach to water management (World Water Vision, 2000). Governments need to improve public access to information, the sharing of information and reporting.

Questions:

How should governments report on groundwater as a resource?

How can accessibility to information be improved?

Who should monitor the adequacy of the knowledge base? (I.e., How will we know when we know enough?)

Management of groundwater needs to be ecosystem based

Groundwater resources need to be managed at an appropriate ecological (regional) scale and, where needed, on a bi-national basis. The IJC has pointed out that water managers need to consider groundwater basins that may have "boundaries that are considerably different from the boundary of the surface water basin under which the groundwaters lie." In fact, the Commission notes that in any area there may be several groundwater basins layered at different depths, and each may have a different geographic extent which may or may not coincide with a surface physiography such as river drainage basins (IJC, 2000).

In the U.S., the National Research Council has argued strongly that "groundwater, surface water, and aquatic systems are now seen to be closely interrelated and can no longer be managed and regulated independently" (NRC, 2000). How exactly this principle should be put into practice is not clear, however. It will be challenging to effectively integrate the management of groundwater with existing approaches to surface water management (including Ontario's watershed planning processes, Mexico's River Basin Councils and the IJC's proposed International Watershed Boards), given the multiplicity of interests, different approaches and ecological realities. As noted by many observers, these challenges will be compounded when aquifers cross provincial, state and national borders.

Integrating social, economic and environmental considerations in decision-making on groundwater also poses enormous challenges (as it does for any natural resource). Consumptive uses and land use changes can have significant and irreversible effects on groundwater. Studies in Mexico's Lerma-Chapala Basin, for example, suggest that "in water-short basins, the sustainability of groundwater trends is inextricably linked to the management of surface water, and is highly sensitive to the area and type of crops irrigated, as well as surface water management practices" particularly those involving recharge (Scott and Restrepo, 2000). Changing how people use groundwater (such as reducing the amount of water set aside for irrigation) can have significant social and economic impacts that must be recognized.

While many groups, including the World Water Council have argued for including the economic value of groundwater in decision-making (World Water Vision, 1999) there are many economic and institutional barriers to achieving this in practice.

Questions:

What ecological units should be used to manage groundwater resources?

How can we best integrate the management of groundwater with the management of surface water and aquatic systems?

Are there examples of cases in which social, economic and environmental considerations have been effectively integrated in decision-making on water resources?

Management of groundwater must aim for sustainability

It is clear that overpumping or "mining" of groundwater in North America has severe ecological, social and economic impacts. To avoid these impacts, water managers need to adopt the long-term sustainability of groundwater resources as a management goal. One definition of sustainable groundwater resource development is " the amount of groundwater that can be legally extracted from a hydrologic basin over the long term without causing severe economic, social, ecological and hydrologic consequences " (NRC, 2000). Implicit in this goal is achieving a balance between water-taking and natural rates of recharge and providing better protection of key recharge areas from land use changes.

Sandra Postel argues that to date "governments have…failed to tackle the task of regulating access to groundwater. To prevent a tragedy of the commons, it's necessary to limit the number of users of the common resource, to reduce the quantity of the resource that each user can take, or to pursue some combination of these two options" (Postel, 1999). The question of how to fairly allocate groundwater resources, especially in water-stressed areas, is a rich one for discussion.

Sustainable groundwater use also includes the notion that the quality of the resource should be maintained over the long term. The extent of contamination of groundwater at present suggests that more effort needs to be spent on controlling point source and non-point source pollution, particularly from farms.

Questions:

Are there examples of institutional arrangements that have been set up to provide sustainable use of groundwater?

What are the key indicators that could be used to measure sustainable groundwater use?

Governments must increase efforts on water efficiency

It is a sad irony that in a world in which access to clean water has been dubbed by many as "the issue of the 21st century", governments have not embraced demand management tools such as full-cost pricing for water. Achieving sustainable groundwater use – that is, ensuring that future generations have access to adequate amounts of clean groundwater – requires us all to use water as efficiently as possible. This means removing the incentives to waste water, and providing incentives to conserve it. For governments, this means adopting full-cost pricing for water, mandating the use of water efficient technologies in homes, businesses and industries, and removing subsidies for growing water-intensive crops and tax exemptions for exhausting supplies. Governments also need to increase efforts to educate the public on water issues and promote awareness of water efficient technologies. The need for education cannot be overerstated, because sustainable groundwater use cannot be achieved without an aware and involved citizenry. Action begins with the understanding of the importance of groundwater: we need to care about it and look after it because it is a vital part of our life support system on this planet.

Questions:

Are there examples where governments have effectively adopted demand management approaches to conserve groundwater?

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