
Underground Intelligence:

**The need to map, monitor, and manage
Canada's groundwater resources in an era
of drought and climate change**

By Ed Struzik

**For the Program on Water Issues,
Munk School of Global Affairs at the University of Toronto**

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"What makes the desert beautiful is that somewhere it hides a well."

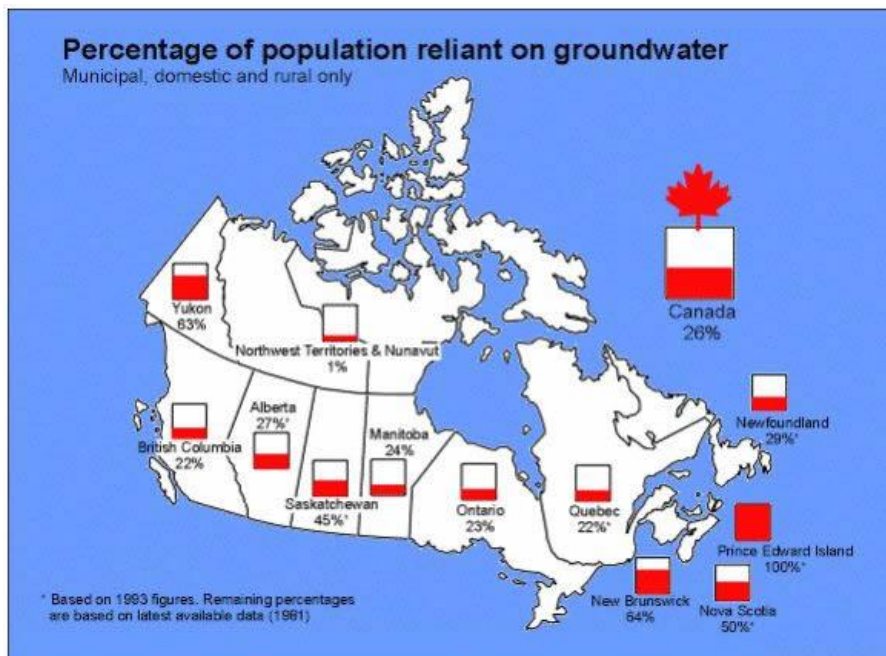
Antoine de Saint-Exupery

1. BURIED TREASURE

Some 98 per cent of the world’s unfrozen freshwater is underground. This groundwater is a vitally important resource, one that sustains industry, agriculture, communities, ecosystems and even ski hills such as Nakiska in the Canadian Rockies which has to make snow from groundwater because not enough snow falls in the area. Life, particularly in rural areas, would be difficult, if not impossible without groundwater. “And yet, like comedian Rodney Dangerfield, groundwater gets no respect,” says Michael Campana, a renowned Oregon State University hydrogeologist who has been on a blogging/tweeting/ public speaking crusade to promote a better understanding of the importance and vulnerability of groundwater. “It is virtually ignored at the annual World Water Week conference in Stockholm even though I apprised one of the organizers – a former student – of that oversight back in 2005.”¹

Here in Canada, we have as much, or more groundwater as there is water in all of our lakes and rivers combined. Groundwater supplies 82 per cent of the rural population, 43 per cent of our agricultural needs and 14 per cent of our industrial needs. Fully a third of Canadians rely on groundwater for domestic purposes.² Very few of these users, however, pay for the groundwater even though it accounts for a good portion of the estimated \$7.8 to \$22.9 billion that water contributes to the Canadian economy each year.³ Those who do pay are charged some of the lowest rates in the world.

Figure 1: Percentage of population in Canada reliant on groundwater



<http://atlas.nrcan.gc.ca/auth/english/maps/freshwater/distribution/groundwater/groundwater>

Despite its economic, social, ecological and cultural importance, we know relatively little about the amount of groundwater we have in Canada, how it behaves, how rapidly it is recharged (replenished), the quality of the groundwater, and how its quality and quantity has changed over time. These concerns have been raised by many experts. In recent years, the Office of the Auditor General of Canada, the Office of the Auditor General of British Columbia, Ontario's Environment Commissioner, the Council of Canadian Academies, the C.D. Howe Institute, the West Coast Environmental Law Centre and the Rosenberg International Forum have all weighed in on the subject.

Groundwater lies below the surface of the earth in aquifers – water-bearing deposits of rock, sand or gravel. Although the boundaries of some of these aquifers have been mapped on a two-dimensional (areal) level, the nature, extent, sustainability and vulnerability of most aquifers across Canada are unknown or poorly understood. This is in part because there is no national groundwater mapping strategy, in part because it is expensive and time consuming, and in part because the use of three dimensional mapping and other geophysical tools that are needed to establish volumes, recharge rates and chemistry are still being developed.⁴ Monitoring the quality and quantity of groundwater is patchy and generally poor in Canada, in contrast to what is done in the United States, for example. As with mapping, monitoring is expensive to carry out over time.

This lack of mapping and monitoring of aquifers is a significant issue because Canada's reliance on groundwater is almost certain to increase as demands rise, as the climate warms and when the next extended drought strikes parts, or all of the country, as one did in 1999-2004. No water can mean no economically viable crops. No water might also mean no oil and gas production. And poor quality water puts farmers, communities, individuals, and ecosystems at risk.

Mapping, assessing and monitoring Canada's major aquifers in greater detail, therefore, are more imperative now than ever before if we are avoid water crises in the future. As noted by Alfonso Rivera, Canada's chief hydrogeologist at Natural Resources Canada (NRCan), "If we don't understand groundwater, there is no practical way of managing it." Rivera also points out that if we don't understand groundwater, we won't be able to defend ourselves if the United States claims at some point in the future that we are over-pumping or abusing aquifers that cross international boundaries.⁵

The challenge is finding ways of mapping, modeling and monitoring groundwater that are visible, sustainable, and self-financing – no easy task considering how politicians are loathe to further tax or burden industry, agriculture, municipalities and taxpayers. But as we describe in this paper, there are technologies for making groundwater visible and options for internalizing costs. We need to embrace these tools. If we do not, if we

continue to treat groundwater, like Rodney Dangerfield, with a lack of respect, we do so at our peril.

What is groundwater?

Groundwater is rain, snowmelt, glacial meltwater and seawater that seeps into the pore spaces and fractures in rock and sediment beneath the Earth's surface. Much of it is contained in aquifers that can yield enormous volumes of water. Although groundwater is in continual motion, it often moves very slowly – so slowly in some cases that hydrogeologists such as Geary Schindel (Chief Technical Officer at the Edwards Aquifer Authority in Texas) joke that they sometimes need a beach umbrella and a six pack of beer to wait for dye samples to move just a few hundred metres from a point of injection in the groundwater recharge system to a spring or well outlet.⁶

Groundwater can be very old – in the range of tens of thousands to millions of years. Deep down in a northern Ontario mine, for example, geologists recently discovered pockets of water more than two kilometres below the surface where it has been sitting for at least 1.5 billion years and perhaps as long as 2.64 billion years.⁷ Ancient groundwater like this is contained in confined aquifers that are sandwiched in between two impermeable layers such as clay that impede the flow of water. No matter how much rain and snow falls on the surface, very little of it trickles down to recharge these types of aquifers. With a few notable exceptions, none of this groundwater percolates up, or leaks out to the surface. Pumping water from these aquifers is like mining; once the water is gone, there is no hydraulic system to replace it.

Unconfined aquifers, on the other hand, are dynamic and very much influenced by precipitation and surface water flow. As precipitation and surface streamflow moves through the ground into these aquifers, it forces stored water back out through underground zones that transmit water to springs, wells, rivers and lakes. This can be a godsend if the soil through which the water passes purifies it, as is the case in the Oak Ridges Moraine in southern Ontario. Or it can be a curse if the water that percolates up into an aquifer is saturated with salt (as sometimes happens in irrigated prairie lands), or if it is laden with minerals such as arsenic that can occur naturally in the rock. In the White Rock-Surrey-Langley area of British Columbia, for example, 43 per cent of the privately owned groundwater wells tested in 2008 had total arsenic levels above the Maximum Acceptable Concentration (MAC) of 0.010 mg/L, which is the maximum acceptable level established by Health Canada.⁸

Figure 2: How groundwater moves and is recharged

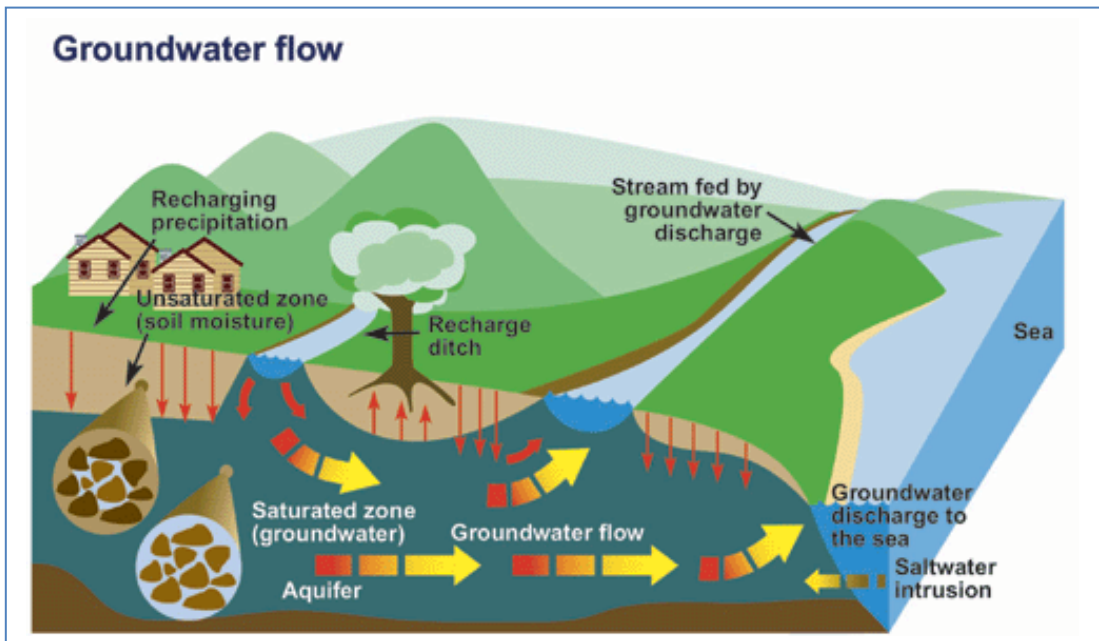


Image source: <http://www.ec.gc.ca/eau-water/300688DC-3EAA-4759-86FF-8DC5895B85CE/a5f2e.gif>

Overpumping an aquifer can cause nearby streams and wetlands to dry up. It can also result in so-called ground failures, or sinkholes – ruptures in the earth’s surface that can swallow up cars, houses or cause serious structural damage to entire subdivisions, as has happened in some parts of the United States. Building roads and houses on the ground above or near an aquifer can affect recharge or replenishment of the aquifer. Growing crops, raising livestock and salting roads near or directly above aquifers can result in contamination, as can the presence of industrial spills, landfills and tailing ponds.

In the permafrost zones that cover most of Canada, groundwater that is melting has the potential to destabilize roads, buildings, airport runways and even forests. The term ‘drunken forest’, which is used to describe the tilted trees found in melting permafrost zones is so common now that it appears in the title of scientific papers.⁹

In a word, groundwater is ‘complicated’. It is not, however, boring.

Very near the top of the world on Ellesmere Island in Canada’s High Arctic, there’s a jet of groundwater that is warm and powerful enough to cut through 400 metres of solid ice. Unique bacteria that live in this harsh environment have caught the attention of NRCan’s Steve Grasby, NASA and the Canadian Space Agency because it may serve as a model for how life may have got started on other planets. Down in Texas, three-inch long

catfish occasionally pop up in groundwater pumped from depths of 800 metres or more in the Edwards Aquifer, which supplies water to two million people. No one knows how the toothless blind catfish, and a host of other creatures like these live, or how they got into this subterranean world. They are, however, unique.

On the prairies, groundwater nurtures a rich variety of orchids and carnivorous plants that seem out of place in a landscape that is covered in snow and ice for most of the year. Wagner Fen, for example, is located just outside of Edmonton. Although it is only 242 hectares in size, it gives rise to 531 species of plants such as cursed crowfoot, skunk current, enchanter's nightshade, nodding beggar-tick and most of the orchids found in western Canada. Many of these plants would wilt and disappear if the groundwater, which flows year-round, dried up or was diverted.

In some places in Canada, groundwater's beguiling qualities have inspired the legends of aboriginal people. Rabbitkettle Lake in Nahanni National Park, for example, is famous for its tufa hot springs. Some of these terraced mounds of calcium carbonate precipitate are 27 metres high and 70 metres in diameter. Ndambadezha, 'protector of the people' is said to inhabit one of the vents. It is this spirit, so a Dene legend suggests, that went down river to drive away two giant beavers that would drown boating hunters with a slap of their enormous tails.

What the recent past can tell us about the future

Meteorologists have been attaching human names to tropical storms and hurricanes since the Second World War because the previous practice of assigning them latitudinal and longitudinal designations was difficult to remember and to communicate. The tradition continues today for that reason. The public has also come to appreciate the fact that powerful events such as these have their own personalities.

Even though droughts often do more economic damage than even the most powerful hurricanes, they don't get similar recognition. One exception is the drought of 2001-2002 in Canada, which actually began in 1999 in some places and ended in 2004 in others.

'Ada,' as that one was unofficially named by Elaine Wheaton at the Saskatchewan Research Council, was responsible for one of the worst natural disasters in Canadian history. At the height of the drought, thirty-two massive dust storms swept across the prairies. Forest fires ignited at five times the ten-year average. Thousands of prairie ponds (or sloughs as they are called in the West) dried up, and tens of thousands of

waterfowl were unable to find suitable wetlands in which to nest.¹⁰ Adding to the woes of farmers and rural dwellers were swarms of grasshoppers that chewed up withering crops, and in some cases, the paint on houses. In one Saskatchewan district, there were as many as 100 grasshoppers per square metre of land.¹¹

“They came in biblical proportions,” recalls Alberta rancher Colleen Biggs who raises grass-fed, antibiotic-free cattle with her husband Dylan in the Hanna region. “We lost 6,000 acres of grass to grasshoppers in six days. They ate everything green that was not ten feet above ground. It was enough to curl the hair in your nose. We ended up shipping our cattle north because we ran out of grass to feed them.”¹²

During the summer of 2001, surface water in rivers and streams which recharges groundwater aquifers, was so scarce in some places that farmers in the St. Mary’s irrigation district in southern Alberta were literally put on rations. On average, they were allocated only 60 per cent of the water they traditionally get.¹³

The winter of 2001-2002 didn’t help the farmers in St. Mary’s and others on the prairies because it didn’t bring the usual snowfall. Heading into the spring of 2002 without any significant amount of snow on the ground, farmers needed 60 per cent more precipitation than they would expect to get in a normal year. What they got instead was 60 per cent less precipitation.¹⁴ Unable to grow crops, or afford feed, farmers and ranchers sold off livestock in record numbers.

It wasn’t just the prairies that suffered. ‘Ada’ dried up virtually every part of the country. In 2001, Vancouver recorded the second lowest amount of precipitation since records started in 1939. At one point during the winter of 2001, the City of Victoria’s reservoir on the west coast of Canada hit a 101-year low. Atlantic Canada had its third driest summer ever.¹⁵

Awe-struck, David Philips, Canada’s most famous climatologist, suggested at one point that ‘Ada’ was ‘unCanadian’. “This monotony is against our psyche as Canadians,” Philips said, just a week before a kilometre-long convoy of tractors, combines and pick-up trucks rolled into Edmonton, the capital city of Alberta, in an effort to try and make people and politicians aware of how drought was crippling their livelihood.¹⁶

The farmers were grandstanding for good reasons. For the first time in a quarter century, farmers across Canada reported negative or zero net-farm incomes. Over 41,000 jobs were lost. The GDP took a \$5.8 billion hit.¹⁷ Had irrigation districts, by far the biggest users of water on the prairies, not shared some of the water they were allocated, many municipal water supplies would have run dry.¹⁸

“If it had gone on for another year,” says John Pomeroy, the Canada Research Chair in Water Resources and Climate Change at the University of Saskatchewan, “managing what little water was left in many parts of the prairies wouldn’t have been as friendly as it had been up until that time.”¹⁹

Bad as things were in those years, people living in exceptionally dry areas such as Stewart Valley in Saskatchewan and the Hanna, Alberta area where the Biggs ranch is located, didn’t suffer nearly as much as communities that pipe in surface water.²⁰ Nor did farmers, industries, municipalities and First Nations communities that draw water from the Assiniboine Delta aquifer in southern Manitoba.²¹ The region of Waterloo in southwestern Ontario, which relies on groundwater, did just fine. That’s because the aquifers that serve these regions didn’t dry up during the drought.

“Groundwater saved us,” says Biggs. “Dry as it is in this part of the country at almost any given time, we are blessed with more groundwater than we need. We had plenty of water in 2001-2002. What we didn’t have was grass. The grasshoppers ate it all up. That’s what forced us to eventually relocate our cattle.”²²

This doesn’t surprise NRCan’s Alfonso Rivera, Canada’s chief hydrogeologist. “It takes much longer for some aquifers to respond to severe drought, and some aquifers don’t respond to drought at all,” he says. “In times of drought, groundwater can act as a very important buffer.”²³

While groundwater can act as a buffer to drought, blindly counting on it would be a mistake if a way were not found to map, model and monitor it in an efficient and sustainable way. Not all aquifers hold up in a drought, and many of those that do are not long-term substitutes for consumption of surface water.

The government of Ontario was bluntly reminded of that during the height of the drought in 1999 when a form of ‘aquifer anxiety’, as the *Globe and Mail* newspaper described it, spread across the province. Many people couldn’t understand how when the province was suffering through one of the worst droughts in memory the Ontario government could consider exporting water in bulk or giving a water bottling company a permit to pump a million litres of groundwater a day from an aquifer in Oro-Medonte Township.²⁴ Groundwater users genuinely feared the day might come when they would turn on their taps and find nothing coming out.

Ironically, Ontario had abandoned its first attempt to monitor groundwater back in the 1980s. In the midst of the drought, with little or no data on groundwater, Ministry of the

Environment (MOE) officials panicked when politicians looked to them for reassurances. In desperation, MOE officials asked municipalities to share their long term monitoring data so they wouldn't look so bad. All this confusion led the *Toronto Star* newspaper to reprint a *Hamilton Spectator* editorial that suggested it was time to update groundwater legislation to ensure that supplies would not be depleted.²⁵

In response to the drought of 1998-1999, the government of Ontario began re-establishing groundwater monitoring stations across the provinces. The monitoring network continues to receive funding. But Ontario and the other provinces are only now, through more sophisticated modeling studies, able to estimate how much groundwater can be pumped from the subsurface without serious consequences in fairly restricted and well-studied areas. They cannot say with certainty whether groundwater, which keeps rivers like the Grand, the Thames and the Credit flowing in especially dry summers will be able to do so in the future.

Like climate change, droughts are a fact of life. "Everyone knows that another big one is coming," says Pomeroy. "They just don't know when and for how long. What we do know is that with each drought that passes, there will be more people and more demands for water by the time the next one comes around."

Groundwater problems in the U.S.: Gunfight at the H₂O corral

Groundwater Quantity

Canada could learn a few lessons from what has happened, and is still happening in the United States where managing groundwater in a sustainable way was, for a very long time, ignored or not taken seriously. In the beginning of 2013, the United States Geological Survey (USGS) released its first National Assessment of Groundwater Depletion. The findings are staggering. USGS found that between 1900 and 2008, the United States has lost one trillion cubic meters of groundwater, which is enough to fill Lake Erie twice. The biggest declines occurred in the Southern Great Plains, the Mississippi River Delta, and the Central Valley of California. Two aquifer systems in the Pacific Northwest show net increases since 1900, but those trends have reversed in the last few decades.

"In many of these systems, (40 aquifer systems were studied) we're removing water faster than it is being replenished," says Leonard Konikow, a U.S. Geological Survey hydrologist. "That is not sustainable in the long run."²⁶ The study also revealed that the rate of depletion of groundwater is increasing.

Figure 3: Groundwater depletion in the U.S. between 1900 and 2008

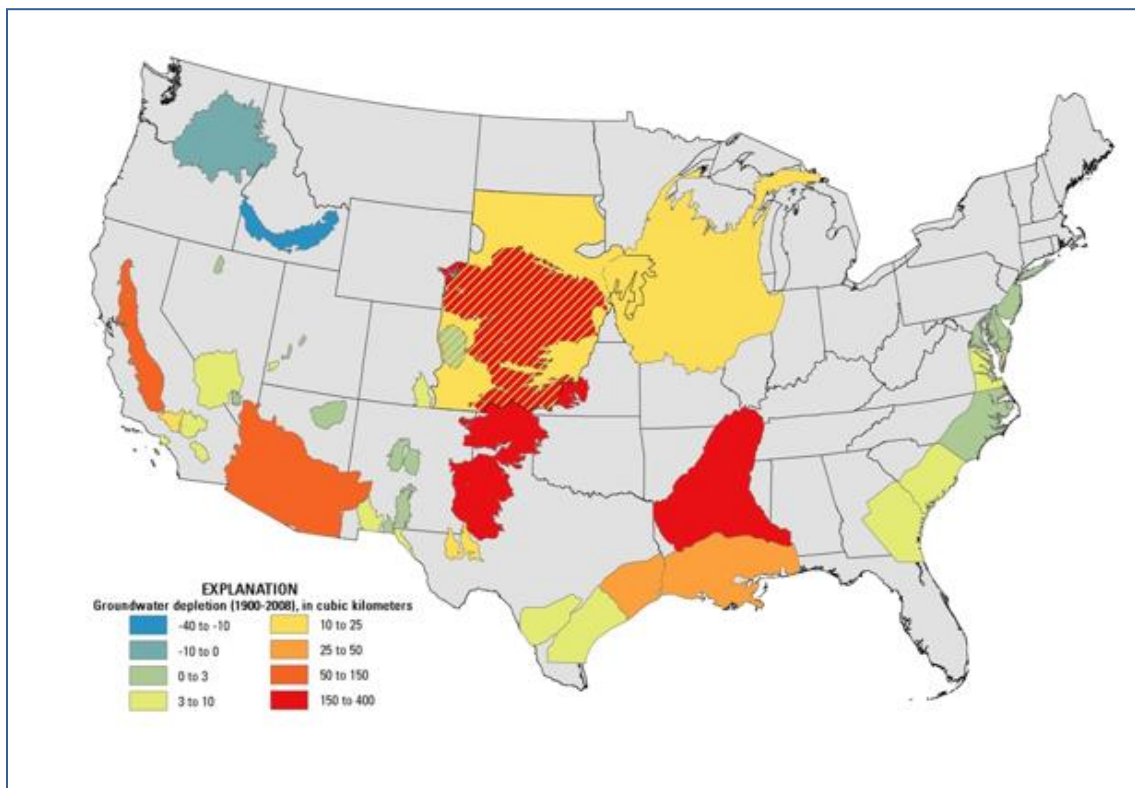


Image source: <http://www.circleofblue.org/waternews/2013/world/since-1900-the-u-s-has-lost-enough-groundwater-to-fill-lake-erie-twice/>

Not a week goes by these days when a major newspaper doesn't deal with water woes somewhere south of the Canadian border. Consider the current situation in Texas, where this kind of news runs almost daily. In January 2013, Cargill, the biggest employer in the town of Plainview, Texas, closed its beef processing facility. That left 2,300 of the 22,000 residents without jobs. The decision, company officials explained at the time, was difficult, but unavoidable because not enough cattle were being raised in the region to justify continuing on with the operation.²⁷ With no water to grow feed or to water livestock, ranchers had been forced to sell off cattle in record numbers.

And with no realistic prospects for employment, families – many of whom trace their roots back several generations – are beginning to leave. “We don't know how long it's going to take for the full effect to kick in,” Mayor Wendell Dunlap told the New York Times. “I think with 2,000 people laid off, there's no way that many people can find work around here. We're going to lose population. We're going to have businesses that are going to have a hard time making it.”²⁸

Most Texans blame this and other similar sad stories on a drought like 'Ada' that has become one of the worst in the state's history. Research at Texas A&M University

estimates agricultural losses for the year 2011 alone at \$7.6 billion.²⁹

It is easy to see how drought has affected the state's surface water – its streams and rivers. Less obvious, but more important is the impact it has had on groundwater resources. About sixty per cent of the 16.1 million acre-feet of water the state uses annually for municipal, industrial and agricultural purposes come from groundwater.³⁰ And this groundwater is being depleted far faster than it is being recharged.³¹

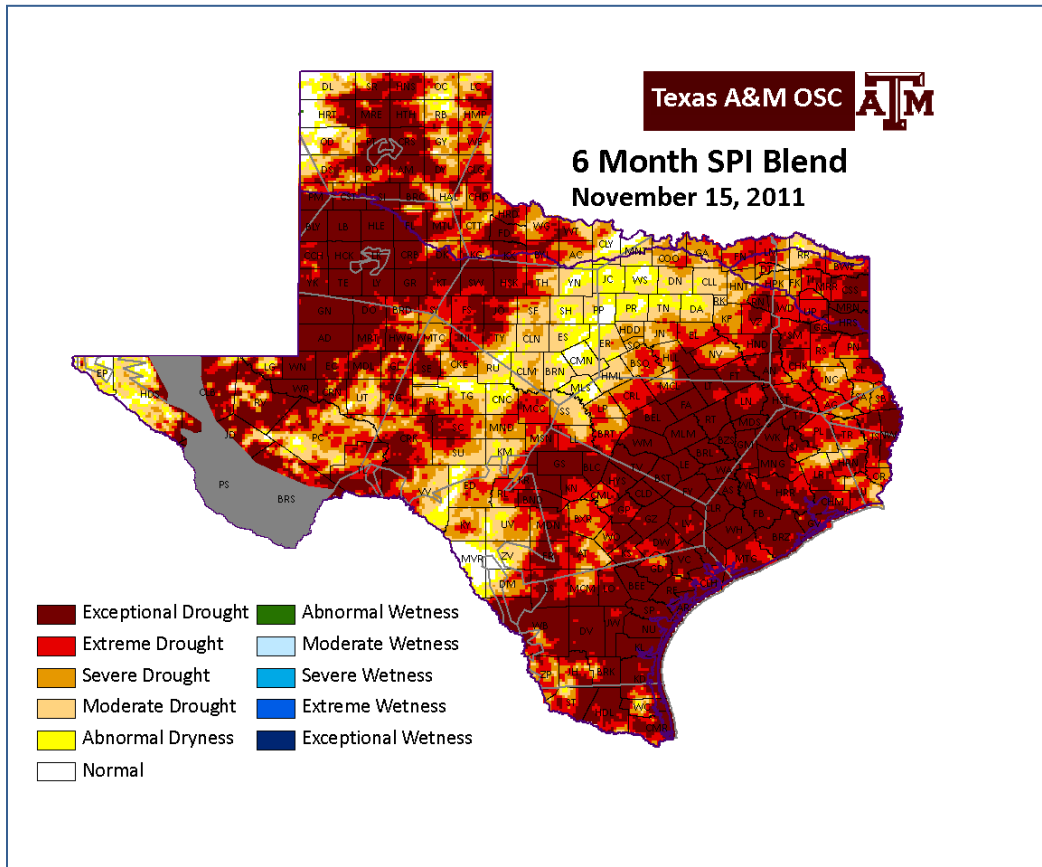
Drought is not the only reason for Texan woes. Another key factor in the State's water stress is decades of overconsumption. 'The End of Abundance', the title of economist David Zetland's book on water, could well be the state logo of Texas. For far too long, Texans responded to the end of abundant water with old ideas and an unwillingness to adopt new tools specifically designed to address water scarcity.

It wasn't so long ago that a single individual in Texas (a businessman named Ron Pucek) drilled the world's biggest water well – big enough to serve the needs of 250,000 people – so that he could operate a catfish farm on his homestead.³² This 'right to capture' – the right to use water located below one's land – has prevailed for decades. Texas lawmakers have tried to regulate groundwater use on private lands, but their victories have been dwarfed by defeats and in a recent landmark court case, landowners successfully stopped the government from doing so.³³

Setbacks such as these have compelled some Texas communities to consider treating water from brackish aquifers or building \$100 million desalination plants, as the City of El Paso has done, to maintain a supply of freshwater.³⁴ The shortage of water has also forced Texas's notoriously stingy lawmakers to push ahead with a State water plan that will cost taxpayers \$57 billion (in 2013 dollars) over the next fifty years.³⁵

"We're going to have to build water," Texas Governor Rick Perry declared on April 29, 2013 when the Texas legislature voted down another plan to invest \$2 billion in new reservoirs that would store groundwater. "Either we build water, or people will quit moving here," he said.³⁶

Figure 4: Drought map of Texas for six months ending November 2011; one year later Governor Rock Perry extended the state Drought Proclamation



<http://ranchesplus.com/ag-requirements/drought-proclamation-declared-by-governor-rick-perry.htm>

Texas isn't the only state that is experiencing groundwater troubles. The High Plains, or Ogallala Aquifer, which supplies 90 percent of the groundwater in Texas, also provides water for Oklahoma, Kansas, Nebraska and parts of South Dakota, Wyoming, Colorado, and New Mexico.³⁷ These states are also pumping water out of the Ogallala faster than nature is putting it back in.³⁸

Nature is not likely to take up the slack any time soon. Other than in Nebraska, where the soils of the Great Sandhills are permeable, the geological formations that lie above the Ogallala aquifer don't allow for significant recharge. Rains can come, but most of the water that falls will run overland to streams and rivers, fill up reservoirs and other storage facilities, and then continue downstream. Little will trickle down to replenish the aquifer.

One of most practical alternatives to using groundwater – tapping into surface water – is no longer feasible in many parts of the American southwest because more water is being drawn out of river basins than nature is putting in.³⁹

The situation is so dire in the American southwest that the State of Texas filed a lawsuit with the U.S. Supreme Court in 2012 alleging that New Mexico is failing to live up to its water delivery commitments under the 1938 Rio Grande Compact.⁴⁰ In April 2013, Texas Agriculture Commissioner Todd Staples and Carlos Rubinstein, Commissioner of the Texas Commission on Environmental Quality, urged the International Boundary Commission and the U.S. State Department to compel Mexico to deliver Rio Grande river water to the United States.⁴¹ In a recent report, Rubinstein’s agency warned that Texas “does not and will not have enough water” to get through a sustained drought.⁴²

However, it must be noted that some progress towards more sustainable use of groundwater is being made in the United States, thanks in large part to advances in mapping and monitoring that have led to innovative conservation and mitigation measures.

The City of San Antonio, for example, now exists on the same amount of groundwater from the Edwards Aquifer as it did in 1994 even though its population has soared 67 percent since then to 1.3 million people.⁴³ City officials are currently looking at ways to improve on that to sustain future growth. The Water Factory 21 Direct Injection Project, located in Orange County, California, has been injecting highly treated recycled water into the regional aquifer not only as a way of recharging it, (it was in serious decline) but to prevent salt water intrusion.⁴⁴ Data from mapping and monitoring groundwater in Utah have also persuaded ranchers and landowners in the Escalante Valley to do what was once unthinkable – pool their water resources so that no one is left high and dry. Even in politically conservative Kansas, farmers in the Northwest Kansas Groundwater Management District agreed in April 2013 to a self-imposed 20 percent reduction in groundwater withdrawals over the next five years.⁴⁵

Figure 4: Water is often on the front page of newspapers in Texas. Between April 26 and May 1, 2013 there were 9 articles on water in the San Antonio and Dallas newspapers



Groundwater Quality

Notwithstanding the above noted pockets of progress towards achieving sustainable use of groundwater, the U.S. news on groundwater keeps getting worse with respect to water quality. The contamination of aquifers is an increasing concern.

Agriculture is one of the culprits. The USGS recently discovered that 14 percent of all the irrigation wells that were tested in the Ogallala aquifer contained at least one pesticide. According to another USGS report, 90 percent of samples taken from shallow groundwater in Nebraska portions of the Ogallala contained chemicals from fertilizers.⁴⁶

Landfills are another major problem. In New York State, for example, more than half of the water used for public and domestic supply needs in 27 of 62 counties comes from groundwater. Seven of these 27 counties, representing a total of 5.3 million people, are nearly 100 per cent dependent on groundwater. Protecting this groundwater, however, is

a problem because of chemicals that are leaching from landfills that are no longer in operation.⁴⁷ Many of these landfills – there were 1600 in 1964 - are unlined and inadequately capped. At 19 of the 42 sites that were being monitored in 2009, 19 had arsenic levels that exceeded federal drinking water standards.⁴⁸ More than 500 represented a significant threat to public health and the environment.⁴⁹

Among the thousands of inactive landfills that are threatening groundwater in New York State, 90 are listed on the Environmental Protection Agency (EPA's) Superfund National Priority list.⁵⁰

Mining and energy developments have had, and continue to have an impact on groundwater quality. EPA records that show that portions of at least 100 drinking water aquifers across the country have been written off because of exemptions that have allowed them to be used as dumping grounds.⁵¹ According to an investigation by Pro Publica, federal officials have given permission to energy and mining companies to pollute aquifers in more than 1,500 places across the country, releasing toxic material into underground reservoirs that help supply more than half of the nation's drinking water. Pro Publica reported that in many cases, EPA has granted these so-called 'aquifer exemptions' in Western states that are suffering from drought and over-consumption of water.

Hydraulic fracturing (fracking) for shale oil and gas in the United States is putting immense pressure on aquifers in at least two, and very possibly three ways. Fracking involves the injection of tonnes of sand, water and chemicals at high pressure into shale formations deep underground, shattering the rock and allowing small pockets of natural gas to escape from the shale.

Depending on geology and how deep a frack must be, as much as 40,000 cubic metres of water is required for fracking over several days. It can be much less depending on the geology.⁵² (This doesn't include the huge amounts of water that are required to keep an exploration camp in operation. A camp of 200 people in British Columbia, for example, requires about 240,000 litres of water a day.⁵³ Some camps are double that size).

In many cases, energy companies inject the wastewater back into aquifers. Many of these aquifers are saline, but some like the one in Wyoming – which Encana proposes to use to inject wastewater from 280 oil and gas wells – produces potable water. Company officials insist that this potable water is far too deep for a well to be practical and too far away from any town that might need the water in the future. Still, the Wyoming Department of Environmental Quality refuses to back the plan, arguing that the aquifer produces drinking water for other parts of the state.⁵⁴

Fracking also has the potential, according to some studies and many environmental experts, to contaminate groundwater in other ways. University of Alberta geochemist Karlis Muehlenbachs has pointed out that boreholes can and do leak when industry doesn't follow the best practices or when cement casings fail.⁵⁵ A 2011 study in the Proceedings of the National Academy of Sciences showed 'systematic evidence' of methane contamination of drinking water in aquifers in northeastern Pennsylvania and upstate New York associated with shale-gas extraction.⁵⁶

One of the latest studies on fracking, which was published in the journal *Science* in May 2013, suggests that the environmental risks associated with fracking can be managed, but only if the understanding of the fate and transport of contaminants are improved, and if long-term monitoring and data dissemination are increased.⁵⁷

This perception that fracking and other industrial activities are potentially harmful to groundwater has resulted in other serious repercussions in the United States. At least two studies show that lawsuits related to the contamination of groundwater from fracking are on the rise in the U.S. with cases pending in Texas, Colorado, West Virginia, Arkansas, Louisiana, Pennsylvania and Ohio.⁵⁸ Resources for the Futures, a Washington-based think tank, has found that real estate prices for homes that draw on groundwater in fracking regions are considerably lower than similar houses in areas where the water supply comes from lakes or rivers.⁵⁹

In parts of the U.S., governments, communities, farmers and businesses are facing a future where supplies of groundwater are depleted, where water levels continue to drop, and where once-pristine groundwater is contaminated with a host of chemicals from agriculture, industries, mining and municipal sources.

Could it happen here in Canada? "Sure as Shootin'"

Could we face our own High Plains groundwater shortages in Canada? Will we need a superfund to finance the management of groundwater contamination? Will fracking disputes end up being resolved by the courts?

To some degree we already face groundwater problems, and they will likely get worse as agricultural activities intensify, as demands on water from cities and industry, mining and energy developments grow, as pollutants migrate from historical and current sources into groundwater and as the impacts of climate change alter precipitation patterns and the storage of water in glaciers, snowpack and reservoirs.

In the Milk River region of southern Alberta, we have our own Ogallala, small as this aquifer is in comparison. Between 1937 and the 1990s, the groundwater in the Milk River aquifer declined by as much as 30 metres or more in some sub-basins. In spite of mitigation measures taken since then to allow for recharge, it hasn't recovered in a significant way because towns like Foremost have no other water sources to draw from.⁶⁰

The Great Lakes Basin hasn't got quite the same problem, but it has a lot more people. A recent report co-authored by NRCan's Alfonso Rivera recently revealed the loss of approximately 5,000 cubic kilometres per year of groundwater storage from aquifers in the Great Lakes region between 2002 and 2009. While that represents just a fraction of the water that is available in the region, it could, according to Rivera, signal a worrying trend for the long term.⁶¹

It was in 2000 that *E. coli* contaminated the municipal water system in Walkerton, Ontario causing 2,500 people to sicken and seven to die. Except perhaps in Ontario where significant progress has been made in protecting groundwater sources of drinking water, not a great deal of progress has been made elsewhere in Canada. At any given time, there are upwards of 1,400 boil water advisories in effect across Canada, which means there are at least 1,400 places where the water is not fit to drink.⁶² It's difficult to determine how many of these are related to groundwater because there is no central 'boil water' repository in Canada and no standard method of conveying warnings to the public. Some provinces do not post boil water warnings.⁶³

The issue, however, is of sufficient concern that the Canadian Medical Association has weighed in on the subject. In the July 2010 issue of the Association's journal, Dr. Jeffrey Charrois of Alberta Innovates-Technology Futures noted that an estimated 13 per cent of Canadians rely on private drinking water supplies, most of which are served by rural groundwater sources. He noted that "it is well documented that rural water wells are not tested as often as suggested by experts on water quality and are frequently contaminated with microbial pathogens and chemical contaminants."⁶⁴

Figure 5: Number of Boil Water Advisories in Canada, May 2013

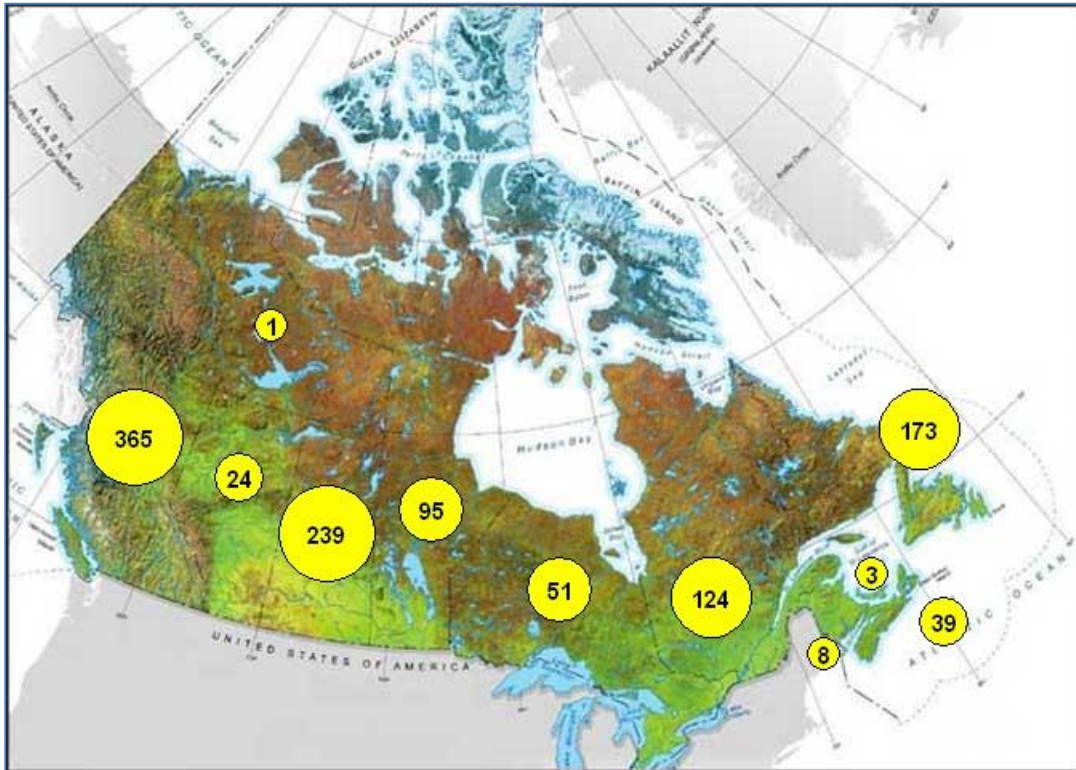


Image source: The Water Chronicles <http://www.water.ca/map-graphic.asp>

In Prince Edward Island, which is 100 percent dependent on groundwater, rising nitrate levels in groundwater have raised legitimate fears about human health and environmental quality. The P.E.I. government was forced in 2008 to set up a commission to investigate and make recommendations on the issue.⁶⁵ Although the government made promises at the time to act on the recommendations, many of them remain unfulfilled today.

Fracking for shale gas is also well underway in Canada and at least one landowner – Jessica Ernst in Alberta – has gone to court to get compensation for damage that was allegedly done to her well.⁶⁶ She is not the only one who is concerned about the potential for accidents, casing failures and cross contamination that could result in gas seeping into water wells.

First Nations in northern British Columbia and the Northwest Territories are weighing their options, as is the government of Quebec, which has ordered a moratorium on fracking in the St. Lawrence Valley because of concerns about potential impacts groundwater.⁶⁷ The government of New Brunswick recently introduced regulations that put limits on the kind of water that fracking operations can use. Because of its value,

groundwater is near the bottom of the list of possible sources.⁶⁸ Even local governments are getting in on the action. In May 2013, municipal councillors in Nova Scotia's Inverness County passed a bylaw that bans hydraulic fracturing.⁶⁹

And yes, Canada does have a superfund of sorts to manage groundwater contamination. Billions of dollars are being spent on abandoned mines sites across Canada to clean up and prevent further groundwater water contamination – bad news for many who live near them, but apparently good news of sorts for the government of Stephen Harper which boasted in October 2012 that Phase II of its Federal Contaminated Sites Action Plan “is expected to create 7,300 jobs in waste management and remediation across Canada, an equivalent of about 1,500 full-time jobs per year.”⁷⁰

If groundwater aquifers are to be exploited in ways that that can be sustained over the long term, regional planners need to know how much water they contain, whether they are being recharged, and at what rate. They need to know where and how the groundwater moves in response to drought, climate change and pumping, and how municipal and energy developments affect groundwater movement and groundwater quality. And if they are to keep fresh groundwater reservoirs pristine, they need to know if and how they are being contaminated. In other words, we need to invest more in mapping and monitoring our groundwater.

It's no easy task. By and large, the Edwards Aquifer in Texas, which supplied water to Ron Pucek's catfish farm, has been mapped and modelled and studied for decades. Notwithstanding the fact that Pucek was finally bought out and the Edwards Aquifer Authority was given the task of allocating groundwater rights more than twenty years ago, the regulation of development and land use to protect the aquifer remains an elusive goal.⁷¹

2. THREATS TO GROUNDWATER IN CANADA

Climate Change

The groundwater situation in Canada is not likely to improve in many places if the climate warms as all climate models predict. According to a report done by the Drought Research Initiative (DRI), which was forced to shut down at the end of 2010 because the Canadian government stopped funding the Canadian Foundation for Climate and Atmospheric Sciences, the amount of water flowing in prairie streams could drop by 37 per cent by 2080.⁷²

Saskatchewan, which relies heavily on the South Saskatchewan River for its water needs is especially vulnerable because there is very little local runoff that flows into that water basin. Most of the water in the South Saskatchewan comes from the Rocky Mountains. The problem with that is that water supplies in the Alberta portion of the South Saskatchewan River system are almost tapped out.⁷³ Conserving and perhaps finding more groundwater, which 43 per cent of the population is dependent upon, will have to be a priority. The Saskatchewan government is already warning farmers, ranchers, towns and cities about the challenges they may face in the future,⁷⁴

“Adaptation will not occur overnight,” Climate Change Saskatchewan warns on its government website. “For some sectors adaptive measures may need to be taken now and other sectors will require shorter lead times. We must recognize that other countries and competing markets will be facing similar adaptation issues, such that our response to this issue will be as one player on a global stage, both affecting and being affected by the decisions made by others.”⁷⁵

As evidenced in some places during the drought of 2001-2002, groundwater can act as a buffer. But many aquifers may not be able to withstand climate change. Resilient as they are, over time they need a good supply of precipitation and surface water to recharge them. If that precipitation and surface water isn't there to do so, they're vulnerable.

These dire projections for the future aren't theoretical. John Pomeroy and his colleagues have been monitoring the Marmot Creek watershed on the east slopes of the Rocky Mountains. This monitoring started in 1962, thanks in large part to meteorologist James Bruce who helped to set it up. Pomeroy's research shows that surface water flow from Marmot Creek has declined by 24 per cent over the last 50 years. While groundwater levels that are being monitored by Alberta Environment are increasing at upper elevations, he says, farther down the mountain slopes they have declined.⁷⁶

“There is no doubt in my mind that the changes in hydrology are directly linked to climate change and are more severe at lower elevations in the mountains. Evaporation of water and snow at lower elevations has reduced streamflow and groundwater recharge.” he says. “The problem is that Marmot Creek has the only high elevation groundwater monitoring stations in the Canadian Rockies. We need to do a better job of monitoring if we’re going to manage this in the future.”⁷⁷

Alberta government officials are apparently taking note, shifting water policy from one that is based on ‘abundance and room to grow’, to one that recognizes ‘a need for enhanced management’.⁷⁸ “There are new realities for demand and a shifting paradigm that is challenging the current system,” says Steve Wallace, the head of groundwater management for the Province. “There is no crisis today, but enhancements are needed to ensure prosperity for future generations.”⁷⁹

Scott MacRitchie, senior hydrogeologist for the Ontario Ministry of the Environment, says that until recently stream flow and precipitation were primarily being used as indicators of how climate change may affect the province’s water resources. But he is now working with his colleagues in the department to add groundwater into the mix. “The importance of the relationship between groundwater and surface water is being recognized, he says. “Under the new Great Lakes Water Quality Agreement (2012) with the United States, for example, there is now an Annex on groundwater that commits both countries to investigate surface water-groundwater interaction.”

MacRitchie says that the research is wide-ranging and includes not only assessing quantity, but examining everything from the chemicals and pathogens that groundwater may transport into streams and lakes to the purifying qualities that groundwater have.

Not all of Canada is going to get drier. If climate models are correct, many parts of the country like southwestern British Columbia are expected to get more precipitation.

Simon Fraser University hydrogeologist Diana Allen’s career took a big turn several years ago when she began applying global climate model data to aquifer models in areas such as Abbotsford-Sumas, Grand Forks, Okanagan Valley and Gulf Islands in British Columbia to see how the hydrogeology of those systems might be affected by climate change over the next 50 years.

The results for the Abbotsford-Sumas speak to the uncertainties that she identified in all of them. Recharge rates in the Abbotsford-Sumas, for example, could change by as little as minus two per cent to positive 24 per cent – a fairly large range of uncertainty, but one

that leans heavily towards the positive.

“Would the aquifer be able to accept all that water if most of the rain fell in one hour as opposed to 24 hours?” she asks. “It’s an important question because some climate models are predicting more intense precipitation events in which more precipitation will fall in shorter periods of time. How aquifers might respond to those kinds of events isn’t known because we don’t know enough about them. That’s why mapping and assessing an aquifer and understanding recharge rates, are so important. We need to communicate this uncertainty to water manager to allow them to plan for a range of future conditions”⁸⁰

Allen is now working in the Gulf Islands to determine how rising sea levels that are being brought on by climate change could result in seawater intrusion into inland aquifers. The answer to this question is vital because most of the communities in the region rely on groundwater.

Environment Canada has been largely silent on the subject of groundwater in recent years. Several requests to interview groundwater/climate change experts in the department were ignored or deflected. Communication officials instead referred without comment to the Canada-U.S. Great Lakes Water Quality Agreement, which was once again committed to by both countries in 2012.⁸¹

This kind of response is a radical departure from the position taken by Liberal governments that were in power during the 1999-2004 drought. Citing climate change as a major threat to water resources in the Great Lakes region, federal Environment Minister Christine Stewart warned during the height of the drought in 1999 that the “old view that we have no conceivable shortage of water” represents “an ecologically primitive analysis that would have been home in the 19th century.

Five years later, federal Environment Minister David Anderson followed up with a report, *Threats to Water Availability in Canada*, which officially summed up what he and Stewart had been saying publicly.

“One can predict that as an important part of the hydrologic cycle, groundwater resources will be affected by climate change in relation to the nature of recharge, the kinds of interactions between the groundwater and surface water systems, and changes in water use (e.g., irrigation). We expect that changes in temperature and precipitation will alter recharge to groundwater aquifers, causing shifts in water table levels in unconfined aquifers as a first response. Decreases in groundwater recharge will not only affect water supply, but may also lead to reduced water quality. There may also be detrimental environmental

effects on fisheries and other wildlife as a result of changes to the base flow dynamics in streams. Other potential impacts include altering the equilibrium in coastal aquifers and reducing the volume of water stored in aquifers with associated potential for increased land subsidence (e.g., California, Mexico City).”⁸²

None of this surprises James Bruce, who had held various high levels positions in Environment Canada before chairing the Council of Canadian Academies Expert Panel on Groundwater in 2009. “This government doesn’t want to talk about climate change.”

Population growth and urbanization

Urbanization can affect groundwater in three major ways – through overuse, through contamination from various sources, and as a result of the conversion of pervious surfaces to impervious surfaces, which alters the recharge of groundwater and the hydrologic cycle.

Okotoks, Alberta

As optimistic as provincial groundwater manager Steve Wallace may sound about the current groundwater situation, the government of Alberta has already recognized that it is running out of water in the southern part of the province. In 2006, the government ordered a moratorium on further withdrawals of surface water from all the river basins south of Red Deer.

This is putting incredible stress on communities such as Okotoks in southern Alberta, which rely on groundwater for domestic, municipal and industrial needs. Several years ago, Okotoks officials commissioned an inventory of their groundwater supply. Recognizing the limited water that was available, councillors subsequently voted on a plan to limit growth to another 2,000 people. But then Mike Holmes, the celebrity repairman came along with a residential and commercial development plan (Windwalk) that would have tapped into their aquifer. Okotoks tried to stop this and another development that was proposed along Okotok’s boundaries. They lost, however, when the Holmes group appealed to the Municipal District of Foothills, which has jurisdiction over boundary regions. Had Alberta Environment not stepped in as it did recently, the developments would have proceeded. As things stands now, they are on hold, pending further hearings.

Figure 6: Location of Okotoks

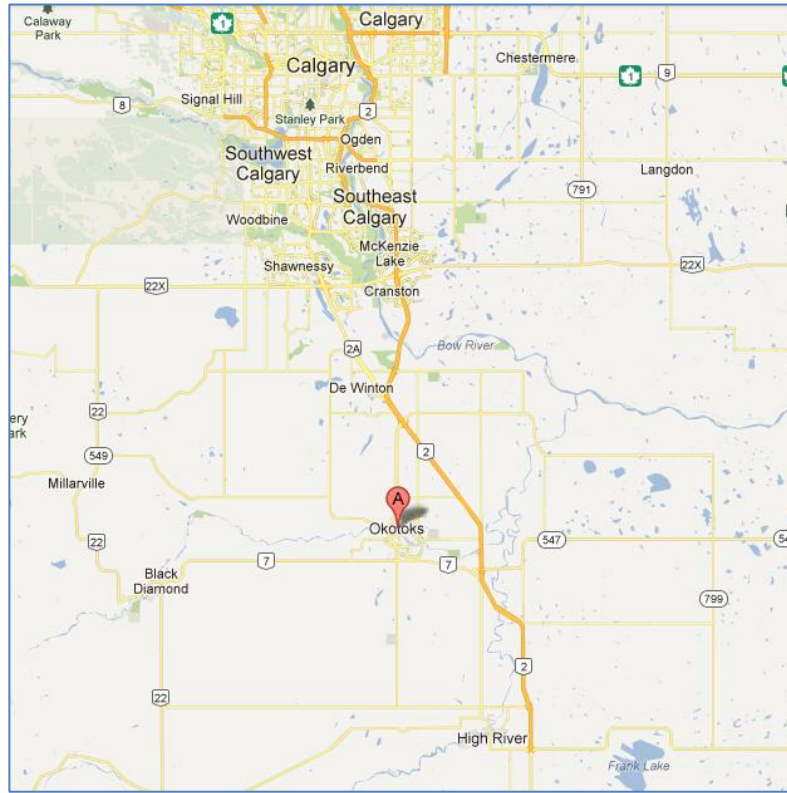


Image source: Google maps

In the meantime, the Town has acknowledged that it has no control over the urbanization that is happening along its borders. So it has abandoned its sensible, slow growth strategy. Okotoks is now looking to buy water from existing licence holders because it knows it is going to run out of groundwater sooner than later. The problem with that, says Mayor Bill Robertson, is that the cost of that water has doubled in the past few years because water is becoming so scarce due to the provincial moratorium,⁸³ and because some of the restrictions on water allocations and trading that are contained within the Water Act.

“What’s the saying?” he asked. “Whiskey is for fishin’; water is for fightin’.” Well, we’ve been fightin’ for a long time. And I don’t know whether we’re ever going to win.”

Okotoks’ plight is becoming an increasingly common one in southern Ontario where one quarter of the population of Canada lives. By rule of thumb, those communities that are located south of Highway 401 tend to get water from Lake Ontario. Those located north of the highway tend to rely on groundwater.

Waterloo Region

The Region of Waterloo, which includes the cities of Kitchener, Waterloo and Cambridge, is heavily dependent on groundwater. Waterloo and Kitchener were identified by the Province of Ontario in the Growth Plan for the Greater Golden Horseshoe as being centres for urban growth. Through their Water Supply Master Plan, the Region of Waterloo is confident that there will be a sufficient groundwater supply to support the growth targets to 2031.⁸⁴ Recent studies have shown that groundwater withdrawals from the aquifers will be sustainable over the long term, while water efficiency and conservation measures have resulted in a decrease in water demand despite population growth. The groundwater-based supply is supplemented by an aquifer storage system where excess flow in the Grand River is stored to be available during periods of high water demand. The water is also of excellent quality.

The Region's strategy for sustainable growth is laid down in its Regional Official Plan, which confines future development to existing urban environments rather than expanding into prime farmland and the natural areas that serve as important recharge zones for the regional aquifers. Developers appealed to the Ontario Municipal Board in 2012, hoping to get more land opened up. In January 2013, the OMB tribunal that rules on land disputes sided with the developers. The ruling means that 1,053 hectares of land could be developed over the next 18 years rather than the 80 hectares that regional councillors had voted on. The Region has appealed to Divisional Court to overturn that decision⁸⁵, and the provincial government plans to intervene in support of the Region.

University of Waterloo hydrogeologist Emil Frind has been studying the Waterloo Moraine aquifer for the past 30 years. Like the Regional planners, he sees the OMB decision as a big mistake. In addition to compromising the aims of both the Provincial Growth Plan and the Regional Official Plan by encouraging urban sprawl, the OMB decision would impact the Region's water supply because some of the potential development areas are also the groundwater recharge areas for the Region's aquifers. Paving over these recharge areas would diminish recharge of the aquifer and so make less water available for use, while road salt and other pollutants would degrade the quality of the water.

The Region's alternative – piping in surface water from Lake Erie – is not a practical alternative for a number of reasons, one being cost. This option came up before in the late 1980s; it was rejected then, partly because of its prohibitive price tag of over \$500 million. The present costs of piping in surface water would be at least double that amount. Waterloo taxpayers, already saddled with paying for large-ticket items such as a new Light Rail Transit system, are not in a mood for higher taxes. There are also the problems of declining water levels in the Great Lakes and poor water quality, particularly

in Lake Erie, which would be the only feasible choice as a surface water source for Waterloo Region.

Meanwhile, in the wake of the 2000 Walkerton tragedy, the Province introduced the *Clean Water Act* of 2006, which requires Ontario municipalities depending on groundwater to draw up detailed Source Water Protection Plans for their water sources. These plans have been completed or are nearing completion for most municipalities in southern Ontario, including Waterloo Region. Some exceptions are communities located close to a convenient surface water source (such as some in the Toronto area) that have chosen to switch to surface water as a more economical option. For Waterloo Region, however, groundwater will remain the source of choice for the foreseeable future.

Oak Ridges Moraine, Ontario

This kind of thinking – piping in Great Lakes water – drives hydrogeologists like Steve Holysh to despair. Holysh, who once worked for Halton Region when it faced similar groundwater challenges, now works for the Conservation Authorities Moraine Coalition, a partnership organization that grew out of opposition to development plans that would have encroached on a recharge area for the Oak Ridges Moraine aquifers that supply York, Durham and Peel.

“The problem in Ontario is we’re too close to the Great Lakes,” he says. “Whenever there is a problem with groundwater, municipalities figure that they can opt out and pipe it in. It absolves them of the responsibility of taking care of a perfectly good, and in many cases, cheaper and better source of water.”⁸⁶

Figure 7: Location of the Oak Ridges Moraine



Source: Ontario Ministry of Municipal Affairs and Housing at <http://www.mah.gov.on.ca/Page1744.aspx>

In the Oak Ridges Moraine, urban development has the potential to threaten future supplies of groundwater that are required for domestic, municipal, industrial and agricultural uses and which form the headwaters of major rivers and creeks. It also threatens the natural areas that are a source of enjoyment for people, as well as habitat for plants and wildlife.

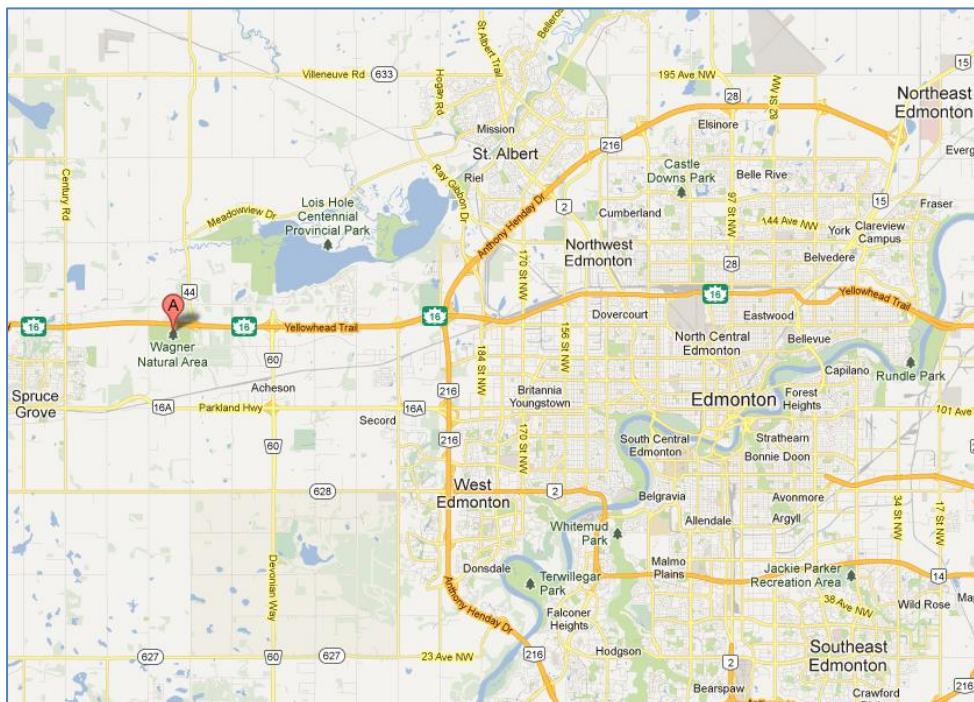
Edmonton, Alberta

While the Oak Ridges Moraine was ultimately saved from development through government intervention, the Wagner Natural Area outside of Edmonton hasn't fared as well in spite of its having similar natural values and significant scientific and community support. The Natural Area contains a peat forming wetland which is sustained entirely by groundwater, as are all fens. Sixteen of Alberta's 26 orchids are found in this one spot.⁸⁷

A series of incremental developments over the past two decades, however, has diverted or drained groundwater away from the site. University of Alberta hydrogeologist Ben Rostron, who went to school with Holysh, is convinced of this because the long term monitoring that he and his students have been doing on site suggests that climate change is not the culprit.

Rostron recently presented these data to a development appeal board in Alberta in the hopes of stopping another industrial development from diverting or draining groundwater away from the fen. He and his supporters lost the first round, and won the second by default. He suspects that their good luck will eventually run out.

Figure 8: Location of Wagner Natural Area



“Personally, I fear for the future of the fen,” he says. “For some reason, no one can wrap their minds around the fact that groundwater can sustain a natural area and that if you build on it, you can affect its flow.”⁸⁸

Intensification of agriculture

The human exodus from rural areas to cities isn’t taking the pressure off the groundwater that farmers and ranchers require for domestic use, livestock and irrigation. The industrialization and intensification of agriculture have resulted in more animals being raised in smaller areas, more fertilizers and pesticides being used to grow crops faster and more water being drawn for irrigation purposes.

The deadly *E. coli* that entered Walkerton’s groundwater supply was but one example of how agricultural activities can contaminate groundwater. Nitrate produced by fertilizer applications and livestock production is another. Nitrate production has increased by about 25 per cent across Canada.⁸⁹ Although nitrate is considered relatively non-toxic at low levels, high concentrations in drinking water can harm infants by reducing the ability of blood to transport oxygen. Blue baby syndrome can result in death in extreme cases.

In Woodstock, Ontario, which is 100 percent dependent on groundwater, rising nitrate levels that come from agricultural production have raised fears about human health and environmental quality. In an effort to solve the problem, county officials purchased land within the wellhead protection area in 2002, and reduced nitrogen loading in the adjacent areas by 40 to 50 percent. While the situation has improved, the problem still persists and the community may be forced to pipe in Lake Huron water from London, Ontario.⁹⁰

British Columbia is similarly struggling with nitrates that are seeping into the Abbotsford-Sumas aquifer. It was long thought that raspberry and poultry farming have been the main sources of contamination, but improvements in farm management in those areas have not resulted in any significant improvements in water quality. Now the focus is on septic tanks, gravel pits and other possible source of contamination.

Energy developments

Canadians have always been ‘hewers of wood and drawers of water’, but in recent years the expansion of mining, oil sands development, and hydraulic fracturing has placed unprecedented pressure on groundwater in some parts of the country.

Oil sands

The oil sands industry produced 1.6 billion barrels of crude every day in 2010.⁹¹ Net freshwater use in oil sands production in 2010 averaged about 3.1 barrels of water per barrel of oil produced by mining operations (2.6 barrels of which came from the Athabasca River). For *in situ* operations, freshwater use averaged 0.4 barrels of fresh water per barrel of oil, most of which is groundwater. Approximately 170 million m³ of freshwater is used per year. That's almost half the water the City of Toronto used in 2010.⁹²

According to Alberta government data for 2009, 34 percent of total water use for *in situ* production came from fresh groundwater, 44 per cent from saline groundwater and 22 per cent from surface water.⁹³

This consumption of water is expected to grow dramatically as production increases. According to at least one study, the oil sands industry could face a potential water supply shortage in the future.⁹⁴

As the ongoing Keystone pipeline debate demonstrates, all of this activity comes at a price to the environment. Oil sands operations return almost none of the water they use back to the natural cycle because it is toxic and therefore subject to a zero discharge policy.⁹⁵ Wastewater that is not recycled is stored in tailings ponds. Wastewater from *in situ* processes is routinely re-injected into aquifers.⁹⁶

Industry and government officials have long contended that contaminants in the tailings ponds are not leaching into the groundwater as some scientists, conservationists and First Nations leaders claim. The fact is, it's hard to make the case. Alberta has very few groundwater monitoring wells for long-term inspections. And as a recent Royal Society report noted, there is also no regional hydrogeological framework in place to assess the cumulative impacts of the oil sands industry on groundwater quality.⁹⁷

But the evidence suggests otherwise. An internal government memo sent to Natural Resources Minister Joe Oliver on June 12, 2012 describes how geoscientist Martine Savard and 18 colleagues detected "potentially harmful, mining-related organic acid contaminants in the groundwater outside a long-established out-of-pit tailings pond." In the study, Savard and colleagues suggest that acids may be reaching the Athabasca River in small amounts.⁹⁸

Hydraulic fracturing

A few hundred kilometres west of the Athabasca oil sands, fracking for shale gas in northeastern British Columbia is raising similar fears about groundwater.

Sale of Crown petroleum and natural gas rights in this region reached a record \$2.7 billion in 2008 followed by a combined total of almost \$1.7 billion in 2009 and 2010. Over 90 per cent of these investments were directed toward the exploration and development of British Columbia's shale gas regions.⁹⁹

Water use is high. In 2012, there were 20 companies operating in an area covering 1.3 million hectares. These camps typically house 200 to 400 people. About 1,200 litres of water is needed for each person daily. Several days of fracking in the region can require as much as 40,000 cubic metres per well. In 2011, 12 million cubic metres of water were approved for use in shale gas development. There is considerable debate about where this water comes from because in B.C. groundwater extraction does not require a license and reporting groundwater use is sporadic.

The B.C. Oil and Gas Commission, however, reports that 60 percent of the water used comes from lakes and streams as well as dugouts and burrow pits, which are huge holes in the ground that are excavated in order to collect groundwater and surface water runoff, or to store water that is transported in by truck. Ten percent of it comes from shallow aquifers containing freshwater and another 10 per cent from confined aquifers that tend to be brackish. The rest is flowback fluid (wastewater from other fracking sites).

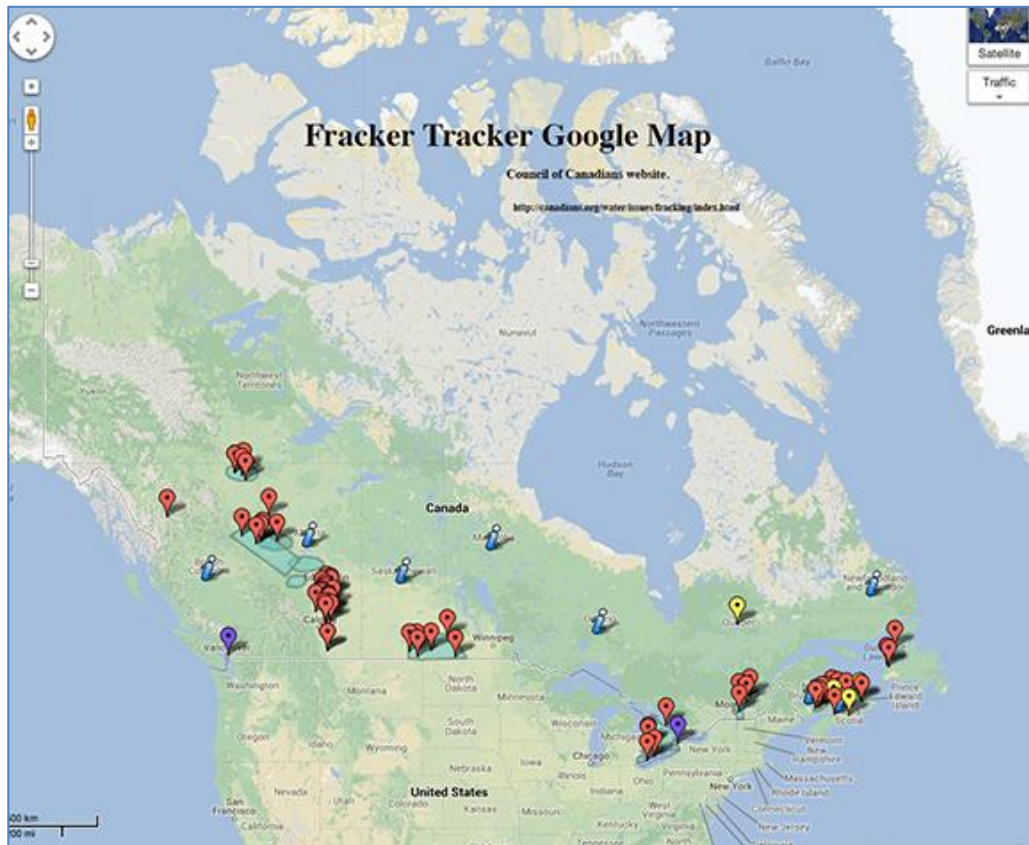
The current level of activity represents just a tiny fraction of the demand that is expected to come. According to the B.C. Oil and Gas Commission, up to 50,000 gas wells may eventually be developed in the Horn Basin, which is just one of a number of basins that are being targeted for shale gas development. The Commission acknowledges that groundwater from shallow non-saline and deep saline groundwater will likely be required.¹⁰⁰

The 14 Cree/Slavey families on the ten reserves that make up the Fort Nelson First Nations are committed to working with the energy companies that are fracking for natural gas in the region.¹⁰¹ What worries them is the potential for groundwater contamination and the amount of water that is being withdrawn for fracking.¹⁰² They are also concerned about the number of dugouts and burrow pits that are being excavated to collect water for fracking purposes. Between April 2011 and April, 2013, energy companies excavated 544 dugouts in the region.¹⁰³

Fort Nelson First Nations are not the only ones who are concerned. In a recent report

from the Auditor General, Scott Vaughan, the former Commissioner of Environment and Sustainable Development, weighed in on the debate about fracking by pointing out that the federal government doesn't have a good understanding of how the cocktail of toxic chemicals – some 800 in total – used in fracking operations affects the environment.¹⁰⁴ Environment Canada apparently agrees and has called on the energy industry to make the recipe public.¹⁰⁵

Figure 9: Fracker tracker Google map showing fracking locations



Source: Council of Canadians accessed at <https://maps.google.ca/maps/ms?ie=UTF8&oe=UTF8&msa=0&msid=212678190210184925094.0004b7b47d93e5ed9eca8>

Gilles Wendling, a hydrogeologist who was recently hired by the Fort Nelson First Nation to advise them on water issues, has other concerns. He has demonstrated that pumping 1,200 litres of groundwater from a dugout every minute for seven days straight can cause an adjacent stream to lose a half metre of water depth in the same amount of time. Dugouts and creeks are sometimes connected, he says.¹⁰⁶

In northeastern B.C. this is not fully appreciated by the B.C. Oil and Gas Commission.¹⁰⁷ This became evident on August 2, 2012 when the B.C. Oil and Gas Commission issued an order temporarily suspending any further water withdrawals from rivers and streams in the region because of a severe drought. The order, however, did not include withdrawals of groundwater from shallow aquifers. “It made no sense whatsoever because they were, in effect, still drawing water away from the rivers,” says Wendling. Lana Lowe, the director of the Fort Nelson First Nations says local hunters noticed that stream levels were dropping dramatically immediately in the days following the ban.¹⁰⁸

The situation could be even worse than it appears. According to statistics that the B.C. Oil and Gas Commission provided to the Vancouver Sun recently, 80 of the 800 deficiencies cited by inspectors in 2012 resulted in charges under the *B.C. Water Act* and the provincial *Environment Management Act*. In addition, there were dozens of warnings, mostly for failing to report how much water is being used.¹⁰⁹

Like the energy industry in the United States, the energy industry has long argued that fracking does not contaminate groundwater. So have Alberta’s Energy Resources Conservation Board (ERCB) and the B.C. Oil and Gas Commission.¹¹⁰ But like EPA and USGS studies, a recent study carried out by geologists Barbara Tilley and Karlis Muehlenbachs demonstrates how this can happen.¹¹¹

“To say that fracking does not contaminate groundwater is simply not true,” says Muehlenbachs. “It has happened here in Alberta and it will happen again. The most recent event in Grande Prairie in December (2012) may have been an accident, as the ERCB has concluded, but the fact is it happened. You can’t ignore that fact.”

Hydraulic fracking, says Muehlenbachs, can cause wellbores to leak more often than run-of-the-mill conventional wells. “The problem is going to get worse, not better.”¹¹²

Not surprisingly, Fort Nelson First Nations want all long-term water licenses for shale gas fracking in the area to be suspended until the B.C. government has thoroughly consulted with First Nations and the public in the development of a “clear, responsible, and effective water management plan”. They insist that this must include “adequate baseline studies, proper regional monitoring, cumulative impact assessment, and protected areas to sustain fish and wildlife habitat.”

“We think that shale gas development can occur without full-scale damage to our rivers, lakes and streams,” says Lowe. “But it’s going to require a commitment from local communities, governments and oil and gas companies to do the right thing.”¹¹³

Mining

Along with oil sands and energy development, hard rock mining in Canada has been one of the key drivers of the Canadian economy. Lessons of the past, however, suggests that the country is a lot more impoverished when effluents from waste rock and tailings ponds get into the groundwater.

From 1948 to 2004, the Giant Mine outside of Yellowknife in the Northwest Territories produced 7.6 million ounces of gold. When Royal Oak, the owner of Giant Mine went into receivership in 1999, the courts assigned responsibility for the site to the federal government. Recently released documents show that Canada will spend \$1 billion on a plan to prevent the 237,000 tonnes of arsenic that is being stored from leaching out into the groundwater that is connected to Great Slave Lake, one of the largest freshwater lakes in the world.¹¹⁴

As with fracking and the process of separating oil from sand, a great deal of water is required for mineral extraction. In 2002, nearly 1,542 million cubic metres of water were used in the mining of metals in Canada. Nearly a third of that was discharged back into the environment. About 78 per cent of that discharge was released into freshwater bodies after undergoing little beyond primary treatment.¹¹⁵

Once ore recovery is complete, previously drained underground workings and open pits refill with water, further diverting ground and surface water flows. “Precise estimates of water intake and discharge associated with mining activities are difficult to obtain because of uncertainties associated with evaporative losses and gains and losses through subsurface flow during both the active and inactive stages of mining,” a report for Environment Canada concluded.¹¹⁶

Transboundary water challenges

There are seven known aquifers that Canada shares with the United States. During the last nine years, Canada has been involved in the ISARM (Internationally Shared Aquifer Resources Management) initiative. ISARM is an UNESCO led multi-agency effort aimed at improving the understanding of the management of transboundary aquifers. While there are currently no committees in place to jointly assess and monitor these seven transboundary aquifers, efforts are being made on both sides of the border.

One of the drivers, says Alfonso Rivera, is the need for water to support unconventional energy exploration such as shale oil and gas fracking. This is especially the case for the Milk River Aquifer, which is a sandstone formation that straddles southern Alberta (Canada) and northern Montana (United States). The energy industry is particularly

interested in this aquifer because of the potential for it to supply water for unconventional oil and gas exploration and development. Rural communities and farmers are also interested because it supplies a considerable amount of freshwater. The problem, however, is no one yet knows how much water it can yield sustainably.

As early as 1910, water wells were drilled into the Milk River aquifer for agricultural, energy and municipal purposes. Most people on both sides of the border assumed that the water would flow forever until it was discovered that between 1937 and 1959, the water table had declined more than 30 metres. Much of the decline was attributed to the town of Foremost, Alberta, which draws its water from the aquifer. But significant volumes were also being lost to abandoned water wells on the Canadian side. Hundreds of them kept flowing well into the 1990s when a five-year reclamation effort put a stop to the leaking.

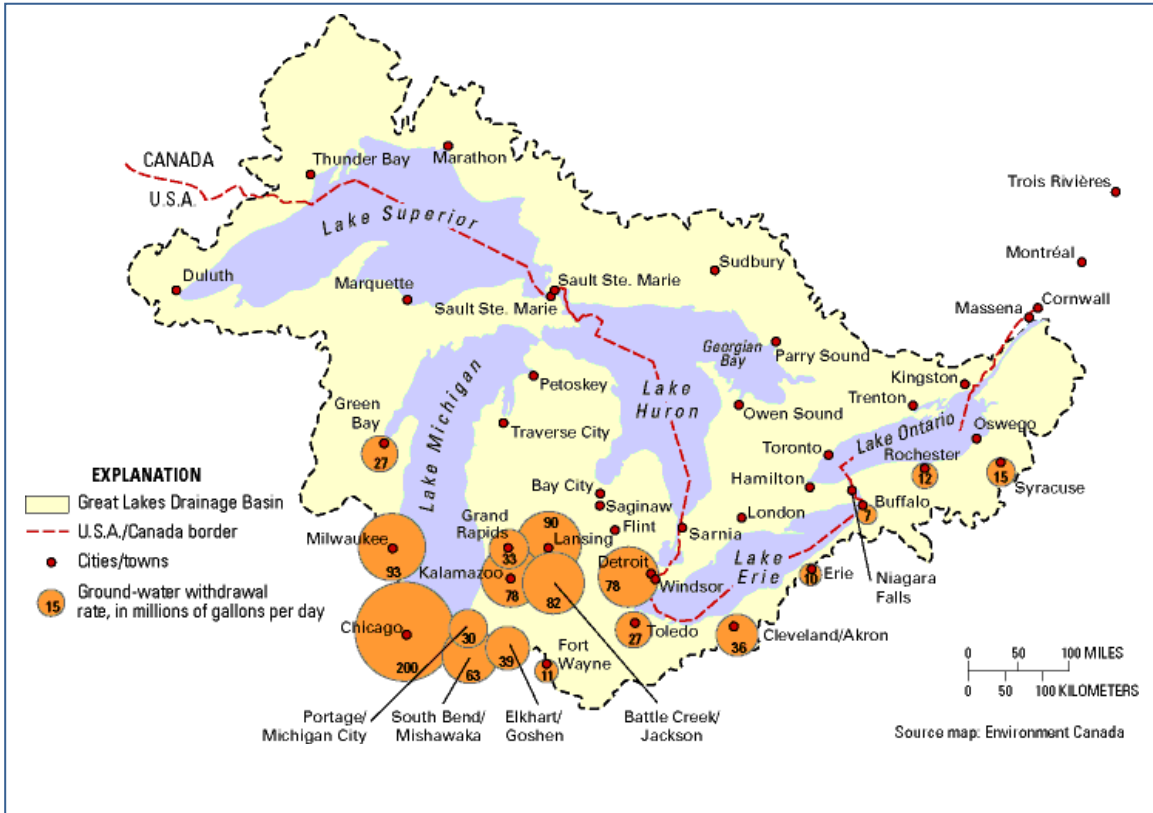
Rivera is in the final stages of mapping this aquifer. Had the mapping not been done, he says, Canada might be vulnerable in the future if there are disputes about how much groundwater Canada is pumping from the aquifer.

There is also growing concern about the Great Lakes region where 8.2 million people – 82 percent of the rural population – rely on groundwater for their drinking water. Groundwater in the basin supplies agriculture and industry with 43 and 14 per cent of their needs respectively.¹¹⁷ With a population of over 8 million people, metropolitan Chicago is already up against a wall because Lake Michigan water is already being used at its court-mandated limit and rock aquifers are being pumped at or above recharge levels. With the population expected to rise by another 20 per cent by 2020, planners now are homing in on shallow sand and gravel aquifers that have not been well mapped or modeled.¹¹⁸

The International Joint Commission (IJC) noted in a recent report that “the Great Lakes cannot be protected without protecting groundwater resources in the Basin.”¹¹⁹ The Commission noted that the threats to groundwater – viruses, nutrients and pesticides, human waste, leaky underground storage tanks, hazardous waste sites and thousands of abandoned wells – are causing serious concerns about this shared resource. It also noted that these concerns will grow as the population increases.¹²⁰

Groundwater flow in the Great Lakes Basin is a lot more complicated than it already appears to be. The so-called aquifers in this case are really a series of bedrock and glacial sediment aquifers that are not necessarily continuous across the international boundary. They are also difficult to map owing to the localized nature in many cases.¹²¹

Figure 10: Groundwater withdrawal on the U.S. side of the Great Lakes. Similar data on groundwater withdrawal on the Canadian side are not available.



Source: USGS report 00-4008 "The Importance of Groundwater in the Great Lakes Region" accessed at <http://water.usgs.gov/ogw/pubs/WRI004008/figure04.htm>

3. WHY MAPPING AND MODELING ARE VITAL FOR ACHIEVING GROUNDWATER SUSTAINABILITY

To map and fully understand groundwater flow, hydrogeologists need to determine how and where water gets into an aquifer, how water in the aquifer is distributed and stored, and where that water is discharged into lakes, rivers, streams, wells and springs. To understand how this water behaves in this subterranean environment, scientists build models that attempt to measure inflows and outflows in relation to demand and the amount of precipitation that falls. The chemistry of the water is often part of the equation. It isn't easy, not by a long stretch because there is so much to consider that is difficult to evaluate: evapotranspiration that is difficult to quantify, faults that may or may not divert groundwater flow, and multi-porous structures such as those found in karst aquifer systems that make it difficult to determine what is a conduit and what is a barrier to water flow.

Computer programs such as MODFLOW, which was developed by the U.S. Geological Survey, go a long way towards helping modelers digest and synthesize all of the variables required to solve the groundwater flow equations

A groundwater model, however, is as much a concept as it is mathematical representation of what is happening in the subsurface. Sometimes, the assumptions that go into the concept are wrong. Some hydrogeologists for example, used to assume that recharge of the Paskapoo, one of the biggest and most important aquifers in western Canada, comes from Rocky Mountain runoff. But Steve Grasby has found that prairie sloughs created by snowmelt and spring rains are what really replenish this aquifer.¹²² This, he says, accounts for why some Paskapoo water tastes great in some areas and it tastes terrible in other regions. It's the presence or absence of pyrite and sulphate in the till the groundwater flows through that accounts for the good or bad taste.¹²³

Maps and models are important because they can help farmers, industry, municipalities, and even managers of natural areas decide how much groundwater can be pumped from an aquifer without running it dry. Maps and models can help scientists predict how groundwater will respond to stresses such as over-pumping, sea water intrusion, drought and climate change. Maps and models have helped University of Waterloo hydrogeologist David Rudolph track the movement of nitrates from farmers' fields in Woodstock, Ontario to water wells that serve the town. It has also helped him and his colleagues evaluate the positive role that uncultivated riparian areas can play in reducing nutrient loading to streams in agricultural watersheds.

Models are currently helping the EPA in the United States dramatically lower the cost of remediating abandoned mine sites that are polluting the environment. Instead of building \$30 million water treatment plants that cost a million dollars a year to operate, U.S. EPA is now using models to help them divert groundwater away from the contaminated sites. This is also happening in Faro, Yukon, where ground and surface water was passing through the tailings of an abandoned lead-zinc mine

Inventories and databases go a long way towards helping scientists map and model and understand groundwater. They also help groundwater users determine whether water in their wells is safe to drink or whether it is being contaminated by outside sources. For example, a 'benchmark' water quality sample taken at the time of drilling can be compared to future samples to evaluate if there have been any negative water quality changes. Typically, databases contain information about individual water well drilling reports, chemical analysis reports, springs, flowing shot holes, test holes, and pump tests that have been conducted on the wells. The Alberta Water Well Information Database site, for example, contains a database of approximately 500,000 records with nearly 5,000 new drilling reports added annually. (This is a bit misleading. There are 500,000 entries but some wells have multiple entries (e.g. one for drilling the well, one for chemistry, one for abandoning the well, i.e. 3 entries for one well). By way of comparison, Ontario's database contains 679,168 records. The database provides no chemistry data, just data from drilled wells and abandoned wells. On average about 15,900 records are added each year.¹²⁴

4. MAKING GROUNDWATER VISIBLE

Mapping groundwater is an evolving multi-step science, and geologists and hydrogeologists often have different approaches depending on the information they are hoping to derive. The key, says NRCan's Hazen Russell, is to have geologists and hydrogeologists integrate their different perspectives and interests within a single study.¹²⁵

In the past, hydrogeologists went out into the field and drilled a bunch of boreholes, and collected water well records to produce a three dimensional interpretation of the aquifer. These maps had a lot of uncertainty because they were constructed from drill hole data that generated a spatially sparse set of one dimensional profiles.¹²⁶

These maps, however, were and still are useful in that they show the extent to which the geology of an area may provide clues to the occurrence, distribution, and movement of groundwater. The picture they provide, however, is static and fails to appreciate that what is happening below the ground can be much more dynamic, especially if the groundwater is being pumped significantly. Being a single representation or interpretation of what is happening at the time, such maps need to be updated on a regular basis, especially when new wells are drilled and new information is captured.

The modern era of regional water mapping and modeling in Canada began in the early 1990's. One of the early and most pivotal developments was the mapping of the Oak Ridges Moraine, an important groundwater recharge region that stretches 160 kilometres from Trenton in the east to the Niagara Escarpment in the west. More than 200,000 people are serviced by the Moraine's groundwater every time they turn on their taps.¹²⁷ It also forms the headwaters of some 65 rivers that flow both north and south.

Efforts to preserve and protect this natural area from development have been ongoing for more than 60 years. The battle, however, came to a head when a number of large subdivisions were proposed in the municipality of Richmond Hill in 1999. The fear was that the East-West green natural linkage would be severed by these developments. In relatively short order, fierce opposition and legal challenges to the project forced the Ontario Municipal Board, the City of Toronto and the Province to get involved. There were genuine fears that the development could alter groundwater and surface flows.

Realizing that they lacked vital information for making an informed decision, the municipalities of York, Peel, Durham, which have planning approval jurisdiction over a significant portion of the moraine, formed a coalition to help them better understand how developments might affect both groundwater and surface water flows through the region.

That's around the time when the Geological Survey of Canada which is part of NRCan stepped in. Adopting a basin analysis approach that is commonly used in the petroleum industry, NRCan's David Sharpe coordinated a multidisciplinary collaboration involving experts from government and university. The team used a suite of tools to get the job done. This included archival and legacy data, remotely sensed airborne and satellite data, ground-based geophysics, field sedimentology, and field hydrogeological techniques.¹²⁸

They also did the old fashioned thing. They collected reports that came from water well drillers and from geologists who had worked on previous studies in the area. This data mining and synthesis resulted in the development of a conceptual model of how sand, gravel rock and clay are stacked underground.

With a working hypothesis in place, they went into the field and conducted seismic surveys. Borehole drilling was done at strategic points along the seismic line to confirm or 'ground-truth' the seismic data that was collected. This was followed up by detailed fieldwork to build a landform and sedimentological understanding. Additional data were collected by airborne thermal sensors to look for thermal signatures of springs and physical hydrogeological data were collected to quantify stream discharge and constrain possible flow paths through groundwater age dating.¹²⁹

The data were put into a database, standardized to a common geological model and modeled again in a software program that produced a much more detailed image than what one would get from a two dimensional map based on borehole drilling. The model was then handed over to a coalition of Conservation Authority personnel led by Steve Holysh where it continues to be updated and has also been used for numeric groundwater modeling. Mapping the Oak Ridges Moraine was, to say the least, time-consuming and extremely complicated.

New approaches

Although there are more sophisticated tools that can be used for mapping and modeling groundwater, most of them have been traditionally used by the petroleum industry that can afford the high costs. The money simply hasn't been there to allow hydrogeologists this kind of technological luxury. But the tide is turning in some places like Alberta where water quality and quantity are increasingly becoming a concern.

Applying stable isotopes in groundwater model calibration, for example, can help distinguish whether groundwater contamination is coming from a natural source or from energy and mining developments.¹³⁰ In short, it's a form of fingerprinting.

3D seismic surveys, typically used by the energy industry to determine the location of petroleum reservoirs, are also being used by hydrogeologists. 3D seismic surveying uses ground motion sensors, a controlled energy source and an explosive or a vibrator to cause the ground to move. Sound waves are then shot in. Once the waves reach the boundaries of geological materials, the sensors at the surface detect the waves of sound that are being reflected. With the help of software and a good analyst, a three dimensional picture of the subsurface stratigraphy (layering) can be constructed.

As well, evolution in the use of old, established techniques such as electrical resistivity is leading to the creation and quantitative interpretation of two and three-dimensional images of the subsurface.

Although expensive, airborne electromagnetic survey that measure alternating magnetic fields from natural or artificially induced sources in the subsurface, are promising. A survey such as this, which uses helicopters or fixed wing airplanes, can detect changes in rock type, fluid density, and the presence of a fault that may contain significant amounts of water. The geologic signature coming from this fault will be very much different from that coming from other subterranean formations.

The SkyTEM airborne survey system has proved to be an invaluable aid in the large-scale mapping of groundwater resources in Denmark and other countries, through the detailed mapping of the subsurface resistivity. NRCan recently used airborne electromagnetic surveys to map the Spiritwood Aquifer in southern Saskatchewan. The Alberta Geological Survey experimented with it in mapping groundwater along the Edmonton/ Calgary corridor. NRCan's Dave Sharpe was impressed by the results. "What we got was this amazing pattern of nesting bodies in the subsurface up to 150 metres deep. On the surface you'd never know it was there."¹³¹

Figure 11: The SkyTEM airborne survey system

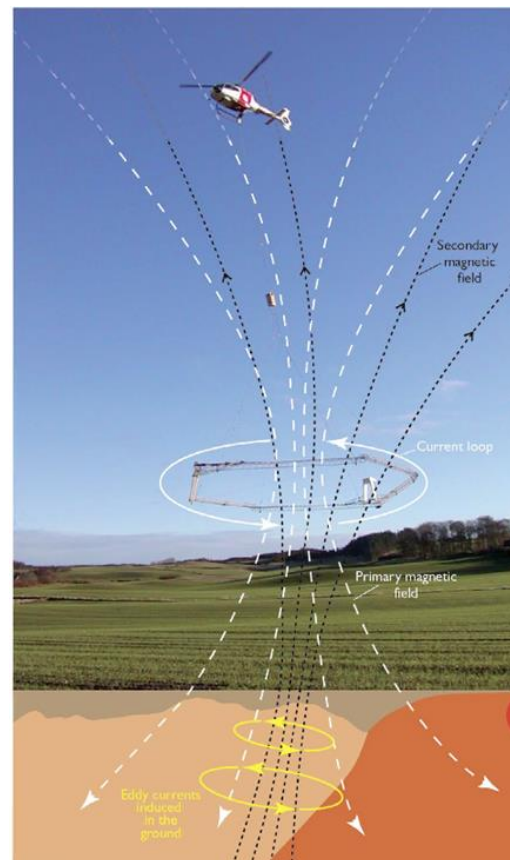


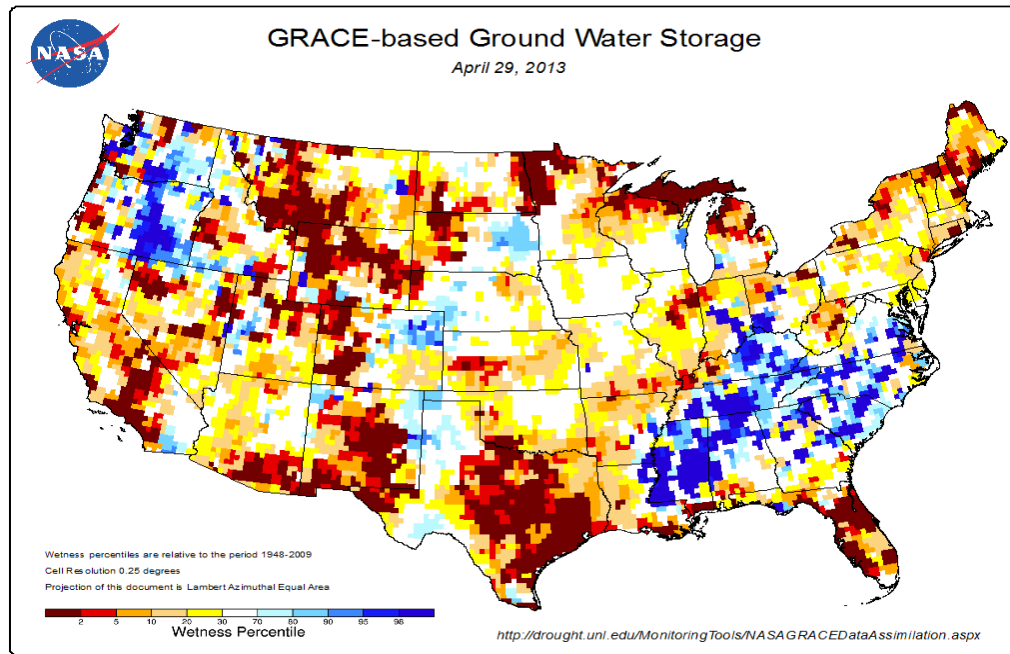
Image courtesy of Aarhus University, HydroGeophysics Group and GEUS)

Dan Palombi, section head for groundwater mapping for the Alberta Geological Survey, was also impressed with the results his team got from the airborne electromagnetic survey they conducted. But he also points out that there was a lot of noise in the data that was likely caused by roads, buildings and power lines.¹³²

The limits of mapping and monitoring have literally reached new heights in the past decade, especially in monitoring groundwater storage on vast scales with leading edge technologies such as GRACE, the Gravity Recovery and Climate Experiment run by NASA and the German Aerospace Center. GRACE, via twin satellites launched in March 2002, measures Earth's gravity field in a way that allows scientists to better estimate gains and losses in groundwater storage.¹³³

“The primary measurement is not of Earth’s surface, but the distance between the two satellites, which is perturbed by changes in gravity from place to place,” says James Famiglietti, a professor of earth system science and civil and environmental engineering at UC Irvine and leader of the University of California Center for Hydrologic Modeling.

Figure 12: Groundwater storage map generated with data from GRACE



Source: NASA at http://drought.unl.edu/nasa_grace/GRACE_GWS.pdf

“As the pair orbit around the globe, the mission collects millions of these inter-satellite distance measurements, which are exceptionally accurate to the sub-micron level and uses them to produce a map of our planet’s gravitational field. Taking the difference

between these maps yields the time-variable component of the gravity field. The major topographic and geologic features of Earth do not change on a monthly basis: their contribution to Earth's gravity field is static. Consequently, owing to the fact that water is one of the heaviest materials on Earth, the time-variable component of the gravity field is largely a reflection of changes in water storage each month.”¹³⁴

GRACE has helped measure changes in everything from the Greenland ice sheet to the amount of groundwater storage in the Mississippi Basin. Alfonso Rivera, who used the technology in determining how much groundwater is declining in the Great Lakes basin, is excited about its possible future use in Canada.

Remote sensing of groundwater has been referred to as the Holy Grail in the hydrology community. But Famiglietti cautions that it is not the entire answer to management of the world's groundwater. “It cannot measure the total amount of water stored in a river basin, an aquifer or any other region of interest. It can only tell us the change between successive measurements of the gravity field.”

Figure 13: Animated visualization of seasonal and long term changes in groundwater levels around the world on the Nasdaq screen in Times Square, 2012 based on data from GRACE; animation designed by Richard Vijgen.



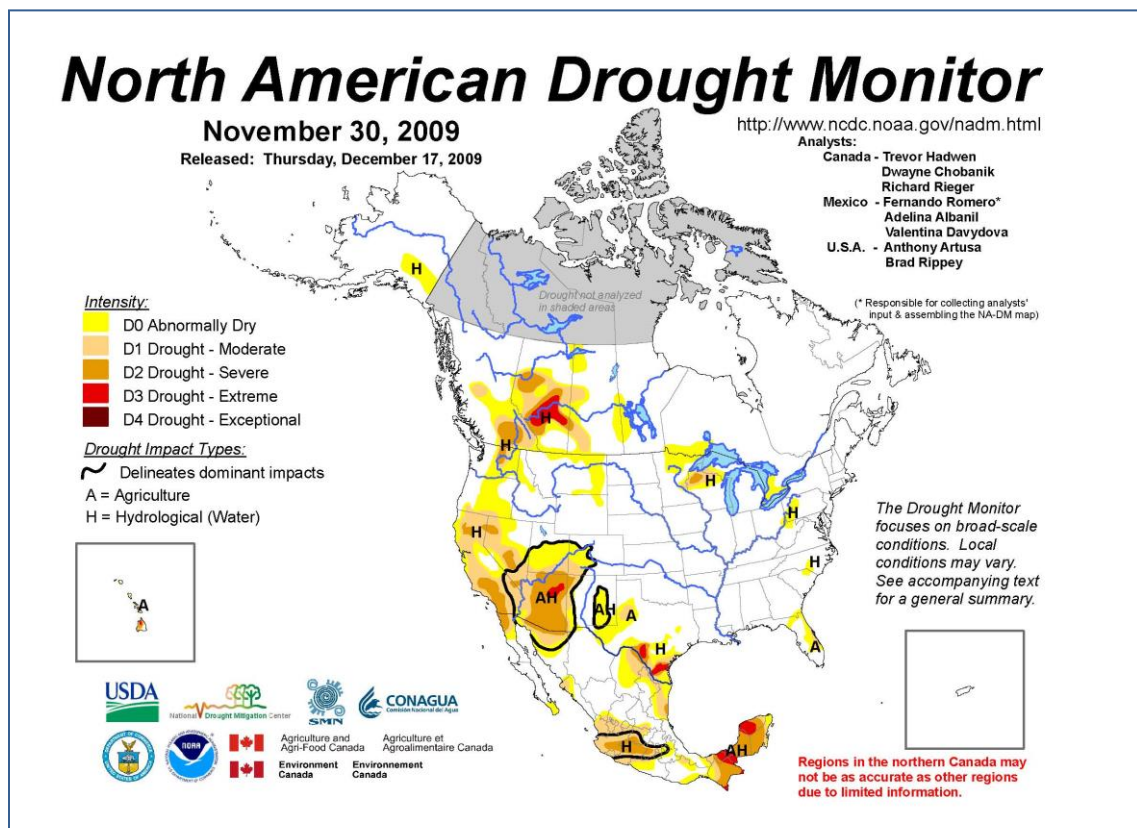
Source: <http://www.circleofblue.org/waternews/2012/world/satellite-perspectives-nasas-grace-program-sees-groundwater-from-space/>

University of Calgary hydrogeologist Laurence Bentley is one of a growing number of hydrogeophysicists and hydrogeologists who routinely integrate geophysics into their hydrogeologic studies. What Famiglietti says about GRACE, he points out, can be said about other mapping and monitoring tools

“Geophysics is not a magic wand. We always need a few boreholes or other direct observations to ground truth our interpretations of the data and validate our interpretations of the images we have made. All methods have a degree of uncertainty associated with them. When we’re mapping aquifers, we’re looking at complex processes that have many aspects to them – recharge, the hydraulic conductivity distribution, the storativity distribution, where water comes out – they are generally very complicated systems. Most of our measurements are related to the hydrogeologic properties of interest in an indirect and sometimes non-unique way. And, even when we have a water well, it’s only one point in a space. What we have to do is bring a variety of tools to the game and find interpretations of a groundwater system that are consistent with everything we’ve measured,” he says. “One measurement or one type of measurement isn’t going to tell the whole story.”¹³⁵

One initiative to marry remote sensing with other sources of data is the North American Drought Monitor initiative, a cooperative effort between drought experts in Canada, Mexico and the U.S. to monitor drought across the continent on an ongoing basis. Maps are generated monthly and can show great variability over time.

Figure 14: Map generated by the North American Drought Monitor



Source: NOAA at <http://www.ncdc.noaa.gov/temp-and-precip/drought/nadm/nadm-maps.php?lang=en&year=2012&month=2&submitted=true#map>

Data management and access

NRCan's Hazen Russell says there is a growing need to provide new, improved, and detailed 3D geological information for addressing issues of conflicting land use, water quality and water resource allocations, site characterization, dwindling aggregate resources, industrial agriculture, and alternative energy supplies. Providing this much-needed geological information, he says, requires a tremendous amount of data that can be presented in understandable formats and accessible to as many people as possible.

“It's a daunting task, especially when there is a lot of money needed to do it,” he says. (Alberta is spending \$12 million over three years, in addition to the salaries of three new groundwater experts, to get a clear picture of the state of groundwater) “That's why there's got to be more cooperation between the federal government and the provinces and between industry and government. We also have to learn from successes and failures of others. The challenge is overcoming the technical problems and minimizing the cost of mapping, modeling, assessing and delivering data to the public.”¹³⁶

Delivering data to the public, however, continues to be a problem. As the Council of Canadian Academies Expert Panel on Groundwater noted in 2009, record-keeping with respect to groundwater withdrawals varies across Canada. All provinces (except for Quebec and British Columbia) have databases on allocations to large groundwater users. Only Alberta and Saskatchewan, however, record the amount of water that is actually used. Ontario and Manitoba are now making the transition to recording actual water use, but regardless of where you are in the country, the data are difficult to obtain and decipher. NRCan's Steve Grasby found this out a few years ago when he and his colleagues attempted to do a single groundwater assessment. It took them nearly 18 months to find and access the data.¹³⁷

Environment Canada continues to operate a national voluntary survey that collects data from over 2,500 municipalities encompassing over 90 per cent of the Canadian population. But reporting is voluntary and more than half of the municipalities don't participate.

This is in stark contrast to the level of effort and the amount of data on groundwater collected in the United States. The U.S. does not have a comprehensive national groundwater database. Instead, data on the quality and quantity of groundwater is collected and stored by federal water agencies, most state agencies and some local governments. Much of what is collected is available on the internet. The National Water Information System (NWIS), for example, supports the acquisition, processing and dissemination of information on ground and surface water collected at over 1.5 million

sites across the country. It contains data on groundwater levels and quality, and also the quality, flow and discharge of surface water. According to the Council of Canadian Academies, the NWIS “provides continuous access to data collected over the last 100 years, as well as telemetered surface water, groundwater and water quality data. The real-time data processing feature enables data transmitted via satellite or other telemetry to be processed and made publicly available on the website within 5 to 10 minutes after transmission. Currently, more than 1,000 wells have real-time groundwater level instrumentation”¹³⁸.

Figure 15: USGS data portal for the National Groundwater Monitoring Network

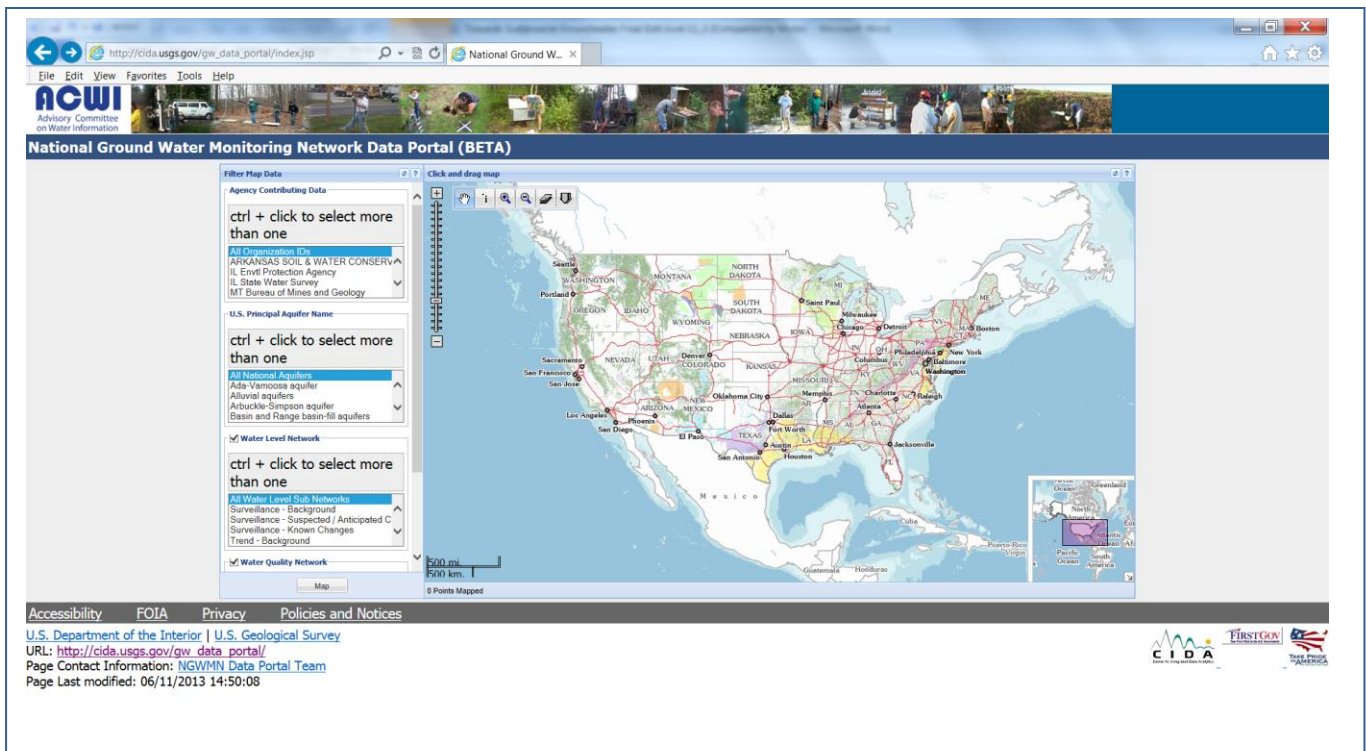


Image source: http://cida.usgs.gov/gw_data_portal/index.jsp

5. OPTIONS FOR INTERNALIZING THE COSTS OF GROUNDWATER MAPPING AND MODELING

Mapping and modeling groundwater is not cheap. The cost to NRCan of mapping the relatively small Spiritwood Aquifer in southern Saskatchewan was \$300,000.¹³⁹

But neither is mapping and modeling fossil fuels cheap. Geo-mapping for Energy and Minerals (or GEM), the federally funded geomapping program that has been helping the energy industry find new sources of fossil fuels since its inception in 2008 has a budget of \$100 million over five years. GEM was established not just to help energy companies find fossil fuels, but to inform government on land-use decisions such as the creation of national parks and protected areas.¹⁴⁰ The expectation is that there will be another round of funding for GEM when the five-year program expires at the end of 2013.

By way of comparison, federal funding for groundwater mapping – which is crucial in the exploration and natural gas reserves, not to mention its importance to agriculture, industry, domestic use, and conservation – gets about \$3.5 million a year.¹⁴¹ “There’s a disconnect here,” says James Bruce. “It can be argued that water is as valuable as or more valuable than oil and gas. The thinking on this has got to change.”

Complicating the challenge is the patchwork nature of the regulatory regime in which groundwater is managed across Canada. The federal government is responsible for groundwater aquifers that lie under First Nations lands and those that cross international and provincial boundaries. Everywhere else, the role of regulating groundwater and giving out permits or licences rests with the provinces and the territories.

Confounding the situation even further is the fact that municipalities and regional governments are pretty much left to themselves to find and map the groundwater they need.

Finally, there the unavoidable and largely unappreciated fact that ground and surface water are interconnected and that evaluating the sustainability of one while ignoring the other is a mistake.

Some of the options for internalizing the costs of groundwater mapping and modeling are discussed in the following sections.

When in Texas, do the “Texas Two Step” (the Rusk County way)

In a struggling economy, severe drought, and limited financial resources, the Rusk County Groundwater Conservation District (RCGCD), in Henderson, Texas managed to overcome the problem of monitoring its groundwater wells with the following approach:

- Step 1: It implemented a rule that requires exploration companies to either plug or have their water well inspected within 180 days of the oil/gas rig leaving the site.
- Step 2: To overcome the financial burden of making sure that it’s done right, the local government charges an inspection fee to cover the cost of the district’s time and equipment to do this.

Rusk County charges \$250 per well inspection. When asked why they don’t charge more, Len Lascomb, the man who heads up the program, stated bluntly: “We don’t need it; \$250 is enough to pay for the camera, the equipment and manpower we need to get the job done.” He also added that the county has used the fees to hire a hydrogeologist who is now mapping and modeling the groundwater resources of country.¹⁴²

When in British Columbia, tap into infrastructure funding

Gibsons, a town of 4,300 people on the west coast of British Columbia, is one of the few communities in Canada that has mapped an aquifer largely on its own. The idea of mapping the Gibson Aquifer, which supplies about two-thirds of the population, first arose in 2004/2005 when the Town embarked on a strategic plan that would ensure that residents and businesses would have a sufficient supply of clean, potable water to sustain modest growth that would amount to about 10,000 people. Residents were justifiably proud of the purity and taste of their water. In 2005, Gibsons’ water won the Berkeley Springs International Water Tasting contest, which bills itself as “the largest and longest-running water tasting competition in the world.”¹⁴³ Over 60 municipalities from Sweden, France, Scotland, Switzerland and the United States competed.

Town planners, however, ran into a roadblock early in the planning process when they discovered that they had a very limited understanding of the capacity, operation and boundary limits of the aquifer. The decision was made then to hire a consultant who could guide them through the process of mapping the aquifer and managing it as an asset so that it could be operated and maintained in the way sewer systems, bridges and other infrastructure are managed.¹⁴⁴ Funding for the mapping project came largely from British Columbia’s ‘Towns for Tomorrow’ program, which was launched in 2006 to address the unique challenges that small towns like Gibsons face in maintaining infrastructure. Eligible projects include everything from water projects to public transit systems.¹⁴⁵

The mapping, which cost in the range of \$500,000, is now complete. A metering program, which was partially paid for by the British Columbia Water Improvement Program, is also in place. Revenues are intended to recover the full costs of operating, maintaining and replacing the assets, including the monitoring for contaminants, seawater intrusion and impacts on recharge rates of the aquifer.

The cost to the Town of installing meters is being partially offset by the savings that came from water conservation and from the discovery that existing wells are sufficient to meet rising demands for the foreseeable future. Although the Town hasn't ruled out the need for a new well to sustain future growth, the prospects look good. In the past twelve months total water use is down by 18 per cent and water demand from the Gibson aquifer is down by 27 percent.

Dave Newman, the town's Director of Engineering, says the buy-in from residents was and still is extremely high. Mapping and monitoring the aquifer, he says, means that the Town's goal of providing clean, unchlorinated potable water to about three-quarters of a population of 10,000 people is now assured.¹⁴⁶ The cost, which amounts to about \$50 per person in the community, is not a lot especially if the amount is amortized over a period of time.

Water Taxes: When in Denmark... do not go Dutch

The Canadian government or the provinces could use existing revenues to pay for the cost of groundwater mapping, or they could do, as Denmark has done, impose a temporary water tax on consumers and industry to pay for it.

Denmark, which is almost entirely dependent on groundwater for its drinking water supply, is two to three years away from mapping the most important groundwater regions of the country.¹⁴⁷ By and large, this groundwater is so pure that it requires only the simplest of treatments. Aeration, pH adjustment and filtration are applied before it is distributed to nearly 5.5 million consumers.¹⁴⁸ Danes are justifiably proud of the fact that there is no need for costly chlorination. Groundwater has very high public profile and politicians have made it a priority to keep groundwater and drinking water clean.

Denmark may well have one of the best groundwater mapping and management systems in the world, but its water wasn't always as secure as it is today. Severe droughts in the summers of 1975 and 1976 dried up many rivers and streams and exposed the country to the vulnerability of its water supply. So eventually did the contamination of groundwater resulting from the intensive use of manure, fertilizer and pesticides by farmers. Agricultural lands cover 62 percent of the country¹⁴⁹ and Denmark's farmers produce 22 million slaughter pigs per year and maintain 580,000 dairy cows for milk production.¹⁵⁰

Recognizing the warning signs, in 1987 the Danish parliament approved a national plan aimed at reducing nitrate leaching to the aquatic environment by 50% and phosphate leaching by 80% within five years. The plan has been a qualified success. The upward trend in nitrate concentration was reversed around 1980, and there has been a larger downward trend in nitrates in the youngest groundwater compared with the oldest groundwater.¹⁵¹ That said, nitrate contamination in some regions continues to be a problem.

In 1994, the Danish Government developed a 10-point program designed to protect and conserve its groundwater reserves. This included bans on certain pesticides deemed to be injurious to the health of people and the environment, a tax on pesticides, the encouragement of organic farming, cleanup of contaminated soil, special protection for areas with valuable groundwater resources, and a plan to reforest areas where aquifers are vulnerable and need surface protection.

The cost of doing this is borne largely by the consumer. In the municipality of Aarhus, for example, consumers not only pay a fee for groundwater, they pay levies for metering systems and for wastewater disposal. Including the 25 percent VAT, the total cost for an average household was € 900 per year in 2008 prices – approximately 1.6 percent of the average family income.¹⁵² This is close to the amount that Danes pay for electricity. The metering of all water use and high prices has decreased the groundwater pumping with more than 30% per year since 1976.

By the end of 1997, all of Denmark was classified according to the degree of drinking water interests. These classifications were based on need, supply and quality of the resource. Once that was done, the government embarked on mapping groundwater aquifers within the 40% of Denmark (17,000 km²) that is designated as valuable for drinking water interests and for public waterworks. This was to be funded by a temporary groundwater mapping tax.

The temporary tax that pays for this mapping in Denmark is not an onerous one. A family of four, for example, pays about €12 or \$15.72 per year.¹⁵³ The collection of the groundwater mapping tax, which came into effect in 1998 was supposed to end in 2015 when the mapping is complete. Two years ago, the Danish parliament decided to continue collecting the tax after 2015. But no decision has made on mapping groundwater in the rest of the country.

“The mapping that is in now place gives farmers in Denmark a clear idea of what is going on with the groundwater below them,” says Richard Thomsen, who headed up the Geological Survey of Denmark and Greenland for 25 years before he retired in January

2013. “If they do not adjust their operations to the municipality’s approval of their fertilizer plan they will get a fine.” The approval is regulated in response to contamination that is detected.

Economist David Zetland is wary of water taxes. He observes that “the Dutch, for example, pay a groundwater fee that varies directly from province to province. The fee is very small, but effective because it directly funds groundwater management. The tax, however, which was national, was supposed to be ‘win-win-win green tax.’ It promised to simultaneously provide revenue to government, reduce the relative burden of other taxes and improve environmental outcomes. It didn’t. I can accept the idea of a water tax, but only if the revenue goes directly to water”. (In Denmark the water tax is earmarked only to groundwater mapping until the end of 2015).¹⁵⁴

Water trust funds: “In water we trust”

In the state of Vermont, approximately 246,000 people draw their domestic water supply from groundwater wells. Another 117,000 rely on public water systems that draw from the ground.¹⁵⁵ This represents about 57% of the state’s population.

In 2008, State lawmakers passed a law that made both ground and surface water a public trust. Under the new system, it is the responsibility of the State to map, monitor and allocate water resources. There were many reasons for the decision, including a mine that drew so much groundwater for its operation that local landowners found themselves wanting at times. The number of contaminated water wells in the state was also increasing.

The event that galvanized public opinion most, however, was a water bottling proposal that would have drawn 250,000 gallons of water per day from a spring near East Montpelier. A Canadian bottling company was already drawing considerable amounts of water from the region and many people were worried that this new proposal might affect their ability to shower, flush the toilet and water their lawns and gardens. Others objected to the idea that their precious water resource was going to be exported in plastic bottles.¹⁵⁶

Under the new system, anyone other than farmers, water utilities and fire districts requires a permit to pump more than 57,600 gallons per day. (Ontario, by way of comparison, requires a permit for taking more than 10,000 gallons per day) In times of drought or water shortages, homeowners and farmers are first in line.

Vermont's plan has received a great deal of praise from public advocacy groups such as the Council of Canadians.¹⁵⁷ The State, however, has a serious problem on its hands because ground and surface water fees do not generate the revenues needed to map, monitor and manage groundwater and clean up the environmental messes that were made in the past.

Vermont is now looking for ways to finance a statewide water quality trust fund to pay for this. It's a long list they're looking at to find the money needed. Financial tools being examined include the implementation of statewide stormwater fees, surtaxes on personal income tax, and liability and excise taxes on motor fuels, fertilizers, pesticides, bottled water and flushable consumer products. The State is also considering fees on everything from drinking water to non-motorized boats.¹⁵⁸

Mike Winslow, staff scientist for the Lake Champlain Society, thinks this is good idea, but he wonders whether taxpayers will tolerate more taxes. "The depressing part about this is even if we raise enough money to clean up our act, we're still left with a legacy of pollution that accounts for 40 per cent of the problems. They're not going to go away."¹⁵⁹

Groundwater authorities: "The wisest has the most authority"

As grim as Texas' groundwater challenges are, notable progress has been made in some parts of the state. The Edwards Aquifer, for example, is an artesianal aquifer from which about 900,000 acre-feet of water is drawn yearly. Some two million people, including those who live in San Antonio, the seventh largest city in the United States, depend on the aquifer for their water needs. For nearly a century, ranchers, farmers, industry and municipalities have been engaged in costly court battles to determine who owns, controls and can use the aquifer. In the end, it was the fate of a handful of blind, colourless animals whose lives depend on the aquifer that resolved the issue.

In 1991, the Lone Star Chapter of the Sierra Club filed a lawsuit against the U.S. Fish and Wildlife Service, claiming the agency was failing to protect endangered species such as the Texas blind salamander, the Comal Springs beetle, the San Marcos gamusia and several other aquatic and subterranean species that live in the aquifer and are found nowhere else in the world. After a two-year trial, a federal court judge ruled in favour of the Sierra Club and other groups that eventually joined in the litigation. The judge ordered the Texas legislature to come up with a regulatory plan that would limit withdrawals from the aquifer in order to maintain adequate habitat for the species in question. Failing to do that, he warned, would result in him enacting his own plan.¹⁶⁰

Figure 16: The Edwards Aquifer Region of Texas

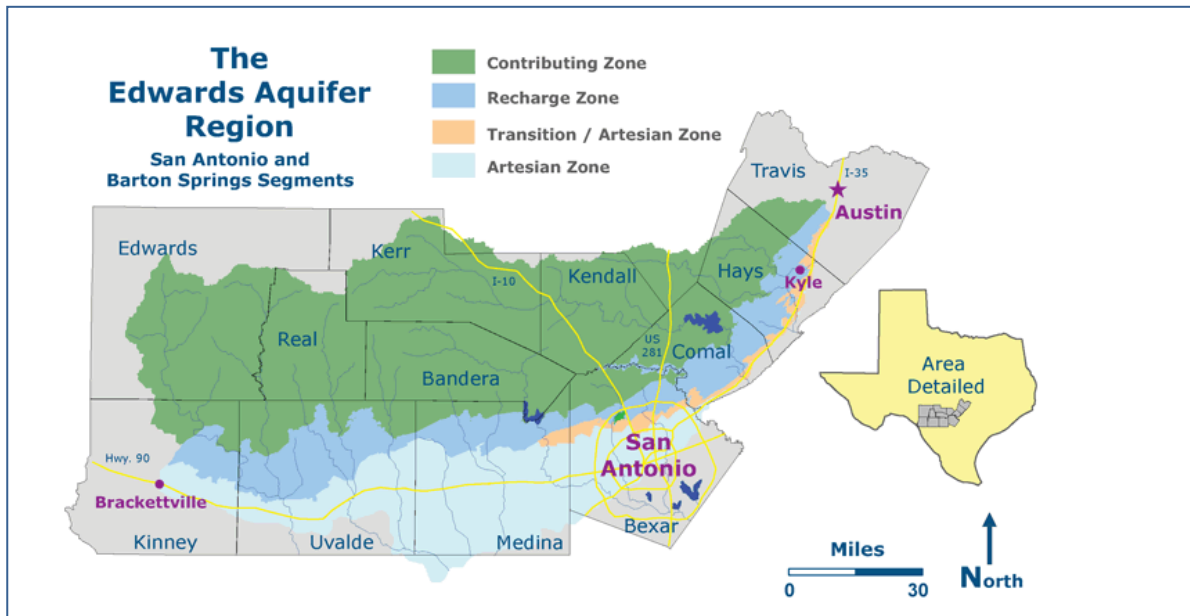


Image source: <http://www.edwardsaquifer.net/>

Seeing that they had little other choice, except perhaps to turn ownership of the aquifer over to the federal government, State lawmakers replaced the Texas Underground Water Conservation District with the Edwards Aquifer Authority.¹⁶¹

The Authority is run by an executive consisting of the General Manager, Public Policy Officer, and the Executive Assistant. The executive oversees all aspects of the organization, with particular oversight of policy development and the activities of the Authority's general counsel. The Authority is responsible for the study, protection, and enhancement of the Edwards aquifer through the administration of research and regulatory programs. This includes administering water quality regulations, monitoring the aquifer's recharge zone, maintaining water quality protection and response programs, overseeing well construction and well closings, supervising range management and conservation easement programs, developing and conducting hydrogeologic studies and collecting basic hydrologic data such as aquifer water levels, surface water, springflow, and groundwater quality samples.

The Authority receives no money from the State to run its show. A General Fund is supported by revenues generated through the assessment of an aquifer management fee of \$47 per acre-foot; and an Edwards Aquifer Habitat Conservation Fund, supported by revenues generated through the assessment of a \$37 per acre-foot program aquifer management fee.¹⁶² (One acre-foot equals 300,000 gallons per day.)

The Authority's groundwater permit program serves as an effective tool to manage use of the region's primary water resource by limiting withdrawals from the Edwards Aquifer to 572,000 acre-feet per year, (500 million gallons per day) as required by *the Edwards Aquifer Authority Act*.¹⁶³

The Authority communicates with the public through television newscasts that routinely display how drought may be stressing groundwater supplies. Depending on the level of stress, customers are often asked to restrict the amount of water they use for non-essential purposes. Failure to do so can result in a fine in places such as San Antonio. The Authority and its customers also have a plan in the event that the 'drought of record' in the 1950s occurs again. Everything from irrigation suspension to a complete ban on watering urban landscapes will be considered.

Legislation: Learning a lesson from coal

Regulation can balance the economic, social and environmental interests of citizens who want it all – jobs, tax revenues, clean water and cheaper energy. With the passage of Ohio Senate Bill 315 in 2012, state law now requires a company planning to drill for natural gas to conduct baseline water quality monitoring of any water wells within 1,500 feet of their proposed drilling operation. According to the Ohio Environmental Law Centre “this is a start, but there is no requirement for ongoing water monitoring, or for post-drilling monitoring.”¹⁶⁴ In Alberta, the Canadian Association of Petroleum Producers has outlined a program that compels companies to test domestic water wells within 250 metres of shale gas, tight gas and tight oil development, and to participate in longer term regional groundwater monitoring programs. The purpose of these programs, according to CAPP is to establish baseline characteristics of the groundwater pre-development, and to analyze whether there have been changes over time. Critics, however, suggest that this does not go far enough because participation is voluntary.¹⁶⁵

So why not pass legislation that forces companies to carry out baseline water quality monitoring and make the data available to everyone? The cost to industry is relatively small considering the potential for returns and the liability insurance this covers. In Ontario, this is done sporadically depending on the user site and the scale of the development. Steve Holysh suggests that it should be applied beyond the energy industry and the information should be stored in a database that links the water quality to the well location, geology etc.

Economist, David Zetland suggests that the energy industry should be begging for this kind of regulation. He notes that “water quality is expensive to monitor but not nearly as expensive as having to clean it up if a mistake is made or an accident occurs. I'm not a fan of the precautionary principal, but I think it is reasonable to look at a production site

and say we're baselining your water quality and don't go below this or we will shut you down and fine you a great deal of money.”¹⁶⁶

Bonds: Lessons learned from mining in northern Canada

It can be argued that withdrawing groundwater is – like oil sands development and shale gas fracking – a form of mining. As with mining, bonds could be put in place to cover liabilities that might result from drawing groundwater or drilling for oil and gas. The amount of the bond needs to reflect the cost of potential impacts, not an easy task considering how difficult it is to measure the value of nature.

Until the 1990s, the Canadian Government did not collect sufficient financial security from mining companies operating in the Yukon and Northwest Territories (which included Nunavut at the time) to cover the costs for the eventual cleanup and closure of mine sites. There were, in fact, legislated limits to the amount of financial security that could be collected. In retrospect, this does not make economic sense. The average amount the federal government received each year in royalties from 1966 to 2002 was about \$4.16 million (for a total of \$150 million). According to the Auditor General of Canada, the cost of cleaning up these abandoned mine sites amounted to more than \$4.5 billion.¹⁶⁷

There is no guarantee that bonds will compel companies to map and monitor groundwater. But if energy and mining companies are required to conduct baseline water quality monitoring of any water wells, bonds could be a powerful incentive to map and monitor because failure to do so could result in forfeiture of a sizable bond.

Tax credits: Giving credit where credit is due

In 2012, the Manitoba Department of Finance introduced a Riparian Tax Credit that aims to encourage farm operators to upgrade their management of lakeshores and river and stream banks. It also recognizes those who have already done so. Benefits are available to agricultural and livestock producers across Manitoba who agree to make a five-year commitment to protect a strip of agricultural inland along a waterway.

A similar tax credit could be applied to anyone in agriculture and industry who invests in monitoring groundwater in Canada and makes the data public. While a tax credit would not produce the direct revenue required to make mapping and monitoring self-financing, it may encourage developers, the energy industry as well as farmers and ranchers to provide information that could fill in the many blanks needed monitor groundwater in the country. Like the Manitoba farmer who gets a \$100 per acre tax credit for not planting crops near a shoreline, the same farmer might get a tax credit for recording data from monitoring wells on his or her property. The energy industry, on the other hand, might

get a tax credit for monitoring aquifers and water wells in areas in which they are fracking. Oil sands operations could get a tax credit for improvements in recycling groundwater that is used in production.

Royalties and water fees: “When the well is dry, we know the worth of water”

The fossil fuel boom in the United States has been good news for many small rural towns in the United States. The bad news is that much of the water-demanding exploration is occurring in drought stricken areas. Energy companies are now buying the water they need for fracking from ranchers, farmers, and municipalities. Seeing the end-game in all of this, the town of Carlsberg in New Mexico has tripled fees not so much for the revenue, but for the need to conserve. “This is a harbinger of things to come,” says Kenneth Medlock, a fellow in energy and resource economics at Rice University’s Baker Institute. “I think water rates will increase in a major way across the country in the next year just because of demand.”¹⁶⁸

In contrast to Texas and many other parts of the world, groundwater in Canada is generally free to pretty much anyone who wants to use it, including oil sands companies and utilities that deliver and charge customers for water. All that is required to drill a well in most places is to apply for a licence, which costs almost nothing. In British Columbia, you don’t even need to do that. As a result, untold amounts of groundwater are being used for free, and in the oil sands and fracking industry, after its use the resulting wastewater is either reinjected into the aquifers or stored in massive tailings ponds.

Economist David Zetland regards this as big mistake. “Back in the old days, there was enough water for everyone. Cheap water was and still is used as a development tool. Industry and landowners love cheap water: it makes worthless land valuable. Governments love it because development brings tax revenues and power. But those days of abundant supplies are coming to an end, even in Canada. The solution is to make people pay for water.”¹⁶⁹

University of Alberta professor and economist, Vic Adamowicz suggests that price or fees on water could solve a number of water management issues. “The fact is we typically do not pay for the full cost of delivering and treating water,” he says. “This has led to overuse. Put a price on water and users will start looking for ways to conserve. This often leads to innovations and savings as well as better management of the resource.”¹⁷⁰

Adamowicz is not alone in suggesting this. Clement Bowman, who was once vice-president of Esso Petroleum, a former President of the Alberta Research Council and one-

time research manager at Syncrude Canada, recently co-authored a paper in which he and his colleagues used a systems methodology approach to investigate water quality and quality problems in Canada's oil sands. "Water issues, such as large-scale water usage and troublesome polluted water disposal concerns connected to Canada's oil sands industries, must be resolved," Bowman and his co-authors say at the outset.¹⁷¹ In evaluating five alternatives that include continuing with the status quo, setting performance standards, putting a price on water, establishing tradable water rights and storing water for future use, they conclude that water charges and trading rights are the best way to ensure water security for the industry while balancing environmental and social impacts.¹⁷²

The status quo, they suggest, is the worst way to move forward. "This approach does not encourage private companies to develop and employ new technologies related to water reduction. This system, they say, has the advantage of avoiding worst-case scenarios in terms of ecology, but it does not help in reducing costs related to economic activity."¹⁷³

Petroleum geologist Bruce Peachey suggests that industry might be willing to consider pricing so long as it applies to everyone. "Remember, farmers are by far the biggest users of water on the prairies," he says. "You can't just blame the energy industry for using too much water. Everyone has to share in the cost if pricing is introduced."¹⁷⁴

Some progress on surface water is being made in this area. The Ontario government collects a fee of \$3.71 per million litres of water from some industrial water users who withdraw more than 50,000 litres per day of ground or surface water, or who draw from a municipal system.

In 2011, the Quebec government introduced a water royalty targeting businesses in the industrial and commercial sectors that draw 75 m³ of water or more per day either directly or from water mains. The royalty does not apply to the residential, institutional or farm sectors.¹⁷⁵ As in Ontario, the rate is extremely low – \$2.50 per million litres for businesses using water in their production processes and \$0.07/m³ for those using water as a component of their products. Moreover, the royalty does not apply to all industries.

In B.C., all industries and business pay for using water from rivers, streams and springs. Groundwater, however, is exempted.¹⁷⁶ Given the intricate relationship between ground and surface water, it may be instructive to note that B.C. charges natural gas exploration companies about \$2.75 for enough hydraulic fracturing water to fill an Olympic-sized swimming pool. By way of comparison, Quebec charges a \$175 water-use fee for the same volume.¹⁷⁷

There is increasing recognition in the energy industry that the oil sands and shale gas companies could cut water use by cooperating with regulators and sharing infrastructure with other users operating in the same region.¹⁷⁸ Shell Canada did this recently by building a \$14 million wastewater treatment facility for the Town of Dawson Creek in return for the Town allowing it to use wastewater for its fracking operations. The deal virtually eliminates the need to draw on freshwater. It has also taken water trucks off the road. In 2012, trucks that delivered water to Shell's fracking operation travelled a total of 16 million kilometres. But at the same time, it results in wastewater being injected into the ground.

6. THE NEED FOR STAKEHOLDERS TO BUY INTO GROUNDWATER MANAGEMENT

Water experts such as Oregon State University's Michael Campana insist that approaches to groundwater management are fraught with danger if governments attempt to use a big legal stick to get stakeholders to comply.

South of the border in Utah, for example, ranchers, farmers, and residents living in the Escalante Valley objected when legislation was passed in 2006 to give the State the power of managing groundwater that had been grossly over-allocated for decades. The debate that followed was, according to the *High Country News*, political, legal and very ideological.¹⁷⁹

Almost no one was happy with the State engineer's plan to reduce groundwater use by half over 90 years. Many long-time ranchers and farmers concluded that this would eventually put them out of business; others who had been around for less time feared that they would lose all of their water rights. At one point, the debate got so nasty that the State engineer in charge of groundwater management resigned over the community's insistence that they pool their water resources to ease the burden or reductions.

Hoping to find a compromise, the State passed legislation in May 2010, which essentially gave the community what it wanted. The revised plan aims to reduce groundwater consumption by half over 180 years instead of 90. This time, the buy-in from users was nearly unanimous.

Public/private partnerships in managing groundwater have worked in Canada. In southern Manitoba, stakeholders who use the Assinboine Delta Aquifer resolved the issue of groundwater use before it became a serious political issue. Tucked under 3,885 sq. km of land, the aquifer contains about 12 million-acre feet of water and has a recharge capacity of 166,000 acre-feet per year. In the 1990s, farmers, ranchers, landowners and one First Nations community became increasingly concerned about the viability of the aquifer when the proportion of water used for irrigation rose to nearly 78 per cent. There were also fears that the judicious use of fertilizers to grow these crops would contaminate the water below.

To address these concerns, a round table was held in the town of Carberry in December 2001. Forty-three stakeholders representing ten municipalities, six communities, one First Nation, two planning districts and 24 other organizations came to discuss ways of protecting the aquifer and make sure that future water withdrawals were sustainable.¹⁸⁰

What emerged four years later was a groundwater management plan that calls for monitoring and data analysis, water quantity and quality measures, irrigation co-management and education. Once the stakeholders realized how vulnerable the aquifer is to drought and to future climate change scenarios, they agreed to a plan to limit human use to half the aquifer's recharge capacity. The other half is left to nurture wetlands and other important ecological areas.¹⁸¹

Figure 17: Location of the Assiniboine Delta Aquifer

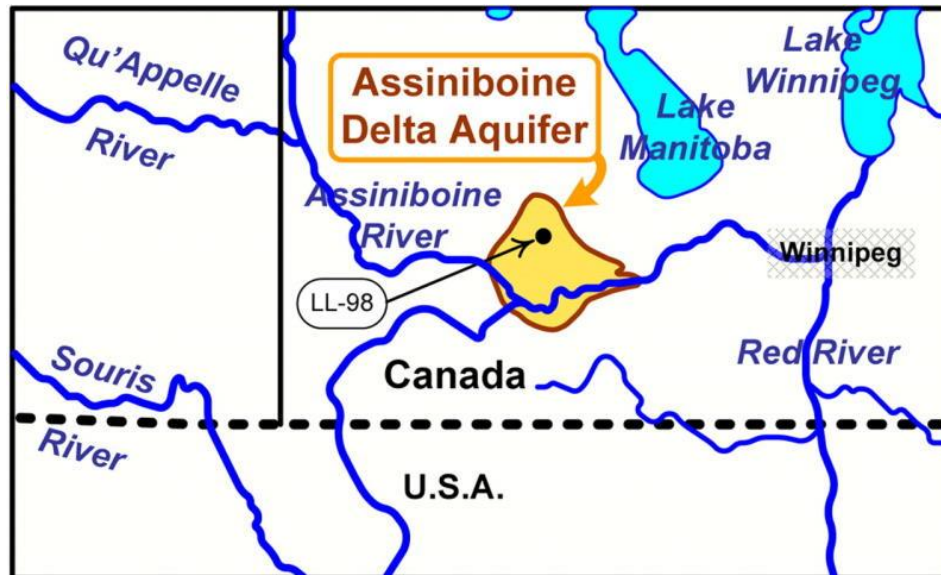


Image source: <https://www.soils.org/images/publications/vzj/7/3/865fig13.jpeg>

Currently, more than 100 wells are routinely monitored by Groundwater Management Section of Manitoba Water Stewardship. The entire cost is borne by the Province. The one exception is at the McCain Food potato processing plant. The company voluntarily monitors groundwater beneath its property. It is restoring important recharge areas that were once used as dumping grounds and it is selling groundwater that it processes to local irrigators for a cost of \$1 a year.

“It’s the proudest achievement of my career,” says McCain’s Bob Hyra who was in on the negotiations from the beginning.

7. MOVING FORWARD

Groundwater is not just a serious political, economic and complex legal issue, it is quickly becoming a cultural obsession, one that has played out in movies such as ‘The Woburn Water Case’ starring John Travolta, ‘Erin Brockovich’ starring Julia Roberts, ‘Gasland’ the 2010 documentary by Josh Fox, and ‘The Promised Land’ with Matt Damon. Everyone from Yoko Ono to Lady Gaga has been getting in on the fracking/groundwater debate. Even German brewers have weighed in by calling on Chancellor Angela Merkel’s government to put a stop to hydraulic fracturing because it has the potential to contaminate groundwater and taint the purity of the country’s celebrated beer.¹⁸² But as American water law expert Robert Glennon has argued, crises and conflicts associated with water stress open the door to legal, technical and administrative initiatives that can result in positive resolutions.¹⁸³

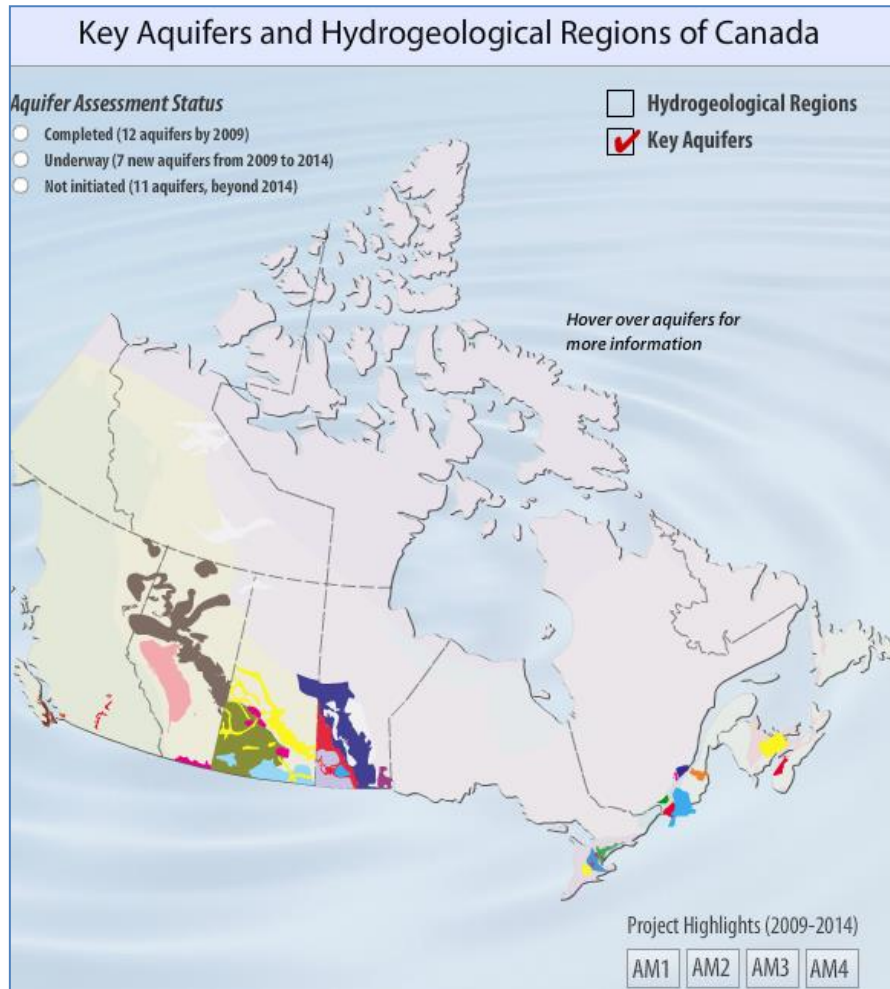
Scientists with NRCan have mapped 12 of 30 ‘key’ aquifers in Canada. Seven more are to be completed by 2014. The time lines for mapping the remaining eleven are uncertain, partially because of cost and the uncertainty associated with current and future budget cuts.¹⁸⁴ Figure 18 shows the location of the key aquifers.

Provinces such as Ontario, Saskatchewan and Alberta are conducting their own mapping projects. Some critical groundwater aquifers, such as those lying beneath the Athabasca oil sands, have been, are continuing to be mapped by industry, but the data from these mapping exercises are not being shared with the public.

The fragmented nature of this mapping data makes it difficult, and in some cases almost impossible for land use planners and politicians to make informed decisions about proposals for groundwater withdrawals and land use developments. In B.C, for example, the Town of Langley had to hire a private consultant to explore sixteen aquifers because groundwater mapping done by the federal and provincial government proved to be lacking.¹⁸⁵

As British Columbia’s Auditor General reported in 2011, the Province’s information about groundwater is “insufficient to enable it to ensure the sustainability of the resource.” Auditor General John Doyle also concluded that “control over access to groundwater is insufficient to sustain the resource and key organizations lack adequate authority to take appropriate local responsibility.”¹⁸⁶

Figure 18: Federal mapping of key aquifers in Canada



Source: Map provided courtesy of NRCan

<http://www.nrcan.gc.ca/earth-sciences/about/current-program/groundwater-geoscience/4106>

Figure 19: Summary of provincial aquifer mapping and groundwater monitoring programs as of 2007

Summary of Aquifer Mapping and Groundwater Monitoring Programs (August, 2007)		
Province	Does the province have an inventory of aquifers?	Does the province have a program to measure groundwater levels in a monitoring network?
Newfoundland and Labrador	No	Yes — up to 25 wells in the network; the data are not accessible to the public.
Prince Edward Island	No (only one main aquifer) ¹⁹	Yes — 13 wells are monitored in a partnership agreement with the federal government; data are accessible over the web.
Nova Scotia	No	Yes — 24 wells are monitored; data are available on a public website.
New Brunswick	Yes	Yes — up to 25 wells are monitored; the data are available by request.
Québec	No	Yes — 25 to 50 wells are currently monitored with plans to expand to between 200 and 500 wells; data are available on a public website.
Ontario	Partially — a series of consultant-led studies were undertaken in the vicinity of the municipal supply wells and the studies contain some aquifer information. There is no systematic program to develop this further.	Yes — about 460 wells are monitored in a partnership with watershed authorities; data are available only to the watershed authorities via a password-protected website.
Manitoba	Yes — at a regional scale since most of the aquifers are bedrock-related. In areas dominated by glacial sediment aquifers, there are maps that address the likelihood of finding a suitable aquifer.	Yes — 550 wells are monitored regularly, mostly in areas of groundwater withdrawals; data are available by request; the intent is to put data on the web.
Saskatchewan	Groundwater maps address the likelihood of finding groundwater supplies.	Yes — 50 to 100 wells are monitored; long-term data are available on a website.
Alberta	Groundwater maps address the likelihood of finding groundwater supplies.	Yes — over 197 Groundwater Observation Wells are monitored; data are available on a website.
British Columbia	Yes — inventory of some 900 aquifers — not necessary to delineate the full extent of the aquifer (e.g., could be delineated on the basis of a number of wells using same unit).	Yes — 163 wells are monitored; data are available on a website.

¹⁹ In Prince Edward Island, since there is a single sandstone aquifer covering the province, further aquifer mapping is unnecessary from a geological perspective.

Image source: The Sustainable Management of Groundwater in Canada, Council of Canadian Academies (2009).

Lessons in the mapping and management of groundwater in Canada can be taken from the way surface water and forestry projects are managed. Since the 1970s, the provinces and the federal government have done a good job of sharing the cost of monitoring surface water in rivers, streams and lakes. They have created maps that show how fast glaciers in the Rockies are retreating and they have a reasonable handle on how snowpack volumes are responding to climate change. Under the *Canada Water Act*, the federal government has the power to initiate a national groundwater program similar to the surface water mapping and monitoring that has been taking place.

Canada's National Forestry Inventory, on the other hand, monitors a network of sampling points covering one per cent of Canada's land mass on an ongoing basis. The aim is to provide accurate, timely and consistent data on the state and sustainable exploitation of Canada's forests. In cooperation with the provinces and the territories, the program is coordinated by the Canadian Forest Service, under the guidance of the Canadian Council of Forest Ministers. The federal government provides the infrastructure to manage the data, and leads in the analysis of data and generation of reports.

Recommendations

1) Adopt a Federal Model for a national groundwater mapping strategy

Geo-mapping for Energy and Minerals (GEM), the geomapping program that it is currently in place to help the energy industry find new sources of fossil fuel could be used as a model for a national groundwater mapping strategy.¹⁸⁷ So too could the National Forestry Inventory program.¹⁸⁸ This could satisfy those who wonder why the government shouldn't pay for mapping and monitoring when the government already pays for the monitoring of surface water and air quality and for the estimates that are required to assess surface water allocations.

2) Impose a mapping tax

A GEM-like model, however, is at best a kick-start, and not necessarily a long-term solution, especially given the tendency of governments to become disinterested in monitoring programs like these when economic times get tough or when public interest wanes. Consider the case of the Ontario government abandoning its groundwater monitoring program in the 1980s. That decision came back to haunt it in 1998-99 when back-to-back droughts raised questions about the sustainability of some aquifers. Or consider the case of Alberta, which led the country in groundwater mapping from the 1960s to the 1990s with the cutting research that Joe Toth and his associates at the Alberta Research Council conducted. That investment was either discontinued or severely reduced for about twenty years and now the province is scrambling to catch up

and restore public confidence that has been eroded by groundwater issues related to oilsands developments and fracking.

The federal government or the provinces could follow the lead of Denmark by imposing a temporary water tax on consumers and industry to pay for mapping of aquifers. Revenue from this tax could go to a cost sharing fund in which provinces and municipalities pay a dollar for every dollar the federal government puts up to pay for the cost of mapping and monitoring.

The issue of whether the federal government has the power to do this is a grey area in constitutional law. Andrew Gage, staff counsel for the West Coast Environmental Law, has this to say:

“In general the provinces have jurisdiction over groundwater. Each provincial government has its own laws related to groundwater. So these are the obvious bodies to make requirements in relation to groundwater management, including any requirements related to mapping. The *Canadian Constitution Act, 1867* does not clearly give either level of government control over the environment or inland water resources generally. If a federal government really wanted to regulate groundwater mapping, I would not want to leap to the conclusion that they could not.

At its narrowest, the federal government could likely assert some jurisdiction over groundwater in particular cases. Cases in which aquifers cross provincial or national boundaries, or where groundwater extractions might have a significant impact on fish or navigable waters, spring to mind. Mapping related to determining whether such impacts could be occurring in relation to a particular aquifer could arguably fall within federal powers.

It is not inconceivable that a determined federal government might try to assert a broader authority citing Supreme Court of Canada jurisprudence (*R. v. Hydro-Québec*, [1997] 3 S.C.R. 213) that has held that prohibition of environmentally harmful acts may fall within the federal criminal law power.”¹⁸⁹

Lawyer Bill Donahue has similar thoughts:

“Generally, water is one of those things of which the feds and the provinces tend to cooperate in the management and regulation. Although the Constitution is silent on the issue of water, I would assume that power to tax water consumption rests with the provinces, because they have jurisdiction over management and

distribution of water as a resource and under s. 92(2) they have the power to create a tax within the province to raise revenue for a provincial purpose. That said, there is a large body of law that says the federal government has the authority and responsibility to manage water under a number of their enumerated constitutional powers (s. 91 of the *Constitution Act*) as well as under the broad federal power to act in the interest of national "peace, order, and good government", in terms of interprovincial pollution or other matters where provinces can't adequately manage a national problem/issue. The federal government also has a broad power of taxation under s. 91(3)."

Like Gage, he says:

"It would come down to how hard the feds wanted to push to collect money to pay for such a program, because I'm certain the provinces would challenge that authority. However, the feds could probably simply create another tax for a national mapping/monitoring program, because no province would be able to do it by itself and the national program could be undermined by any province refusing to take part." When it comes to managing the groundwater, he guesses that "It would fall back into the constitutional grey area, with the provinces having a strong case to resist federal management of it".

The last word on this goes to David Percy, former Dean of Law at the University of Alberta, who is now Borden Ladner Gervais Professor of Energy Law and Policy:

"The federal government has the power to make laws in relation to the raising of money by any mode or system of taxation. This part extends to both direct and indirect taxation. However, by and large the provinces 'own' the groundwater within their boundaries (with the possible exception of some clearly transboundary aquifers) and thus clearly have the bulk of legislative authority over groundwater.

It is conceivable that the federal government could place a tax upon certain types of groundwater use, but highly unlikely. As the provinces generally own groundwater, they can gain revenue from its use, as they do, for example, in relation to other resources such as forestry. As a result, the provinces clearly have the right to take revenue from groundwater use and to apply it to the costs of mapping, etc.

This is probably the only scheme that makes practical sense, as the provinces also have the power to control groundwater use. Sensible licensing decisions obviously require information about the extent of the groundwater resource and the monitoring of groundwater use. The jurisdiction in charge of regulation of

groundwater needs to collect and have available the information that allows for sensible regulation.”¹⁹⁰

3) Consolidate responsibility for ground and surface water

At the federal level, groundwater mapping is the responsibility of the Geological Survey of Canada. Surface water is the responsibility of Environment Canada. Given that groundwater and surface water are part of the same system, it’s time that the two should be put under one department along with climate experts at the Meteorological Service of Canada. Given technological advances in communication, it does not mean that they all have to be in one building. The need for integration has been recommended previously by the Council of Canadian Academies¹⁹¹ who noted that “sustainability requires that groundwater and surface water be characterized and managed as an integrated system within the context of the hydrological cycle in a watershed or groundwatershed”.

4) Regulate monitoring

Provincial regulations are needed to ensure that baseline groundwater quality monitoring is carried out before energy and mining exploration and major urban development take place. The cost of doing this should be borne by industry. The cost of oversight should be borne by the provinces. It’s also time to integrate groundwater monitoring and surface water monitoring.

5) Require bonds for major projects

For major developments such as fracking and large urban development projects, governments should compel companies to put up bonds that would cover the cost of cleanup if an accident or mistake results in groundwater contamination. The mining industry is required to do this. There is no reason that the energy industry and large urban projects should be exempted. Faced with the possibility of having to forfeit a bond, companies may be more inclined to map and monitor groundwater.

6) Provide funding through national infrastructure programs to small communities

Rural communities generally do not have the resources to map and monitor groundwater. British Columbia’s ‘Towns for Tomorrow’ program points the way in which funding can be directed to those communities, many of which are on ‘boil water’ advisories.

7) Create Centres of Excellence and provide tax credits

University of Saskatchewan geoscientist Lee Barbour was recently presented with a \$2.6 million research chair dedicated to groundwater behaviour courtesy of funding from Syncrude and the Natural Sciences and Engineering Research Council (NSERC). (For the record, Barbour declined to be interviewed for this paper). It may be argued that this is a public subsidy for a multi-billion-dollar company that has the resources to finance this

kind of research on its own. NSERC money would be better spent on financing University Chairs and Centres of Excellence on groundwater right across the country. In lieu of NSERC funding, companies like Syncrude should get tax credits for mapping and monitoring as long as the data are made public.

8) Adopt a regional, cooperative approach to groundwater governance

With the exception of transboundary aquifers and aquifers that lie beneath First Nations lands, responsibility for groundwater protection and management should remain with the provinces. But a regional, cooperative approach to groundwater management is essential if the cumulative impacts of groundwater withdrawals are to be efficiently managed.

9) Develop and maintain groundwater inventories

Canada needs to do what the U.S. Geological Survey is doing with the National Ground Water Monitoring Network (NGWMN). The goal of this program is to provide information needed for planning, management, and development of ground-water supplies to meet current and future water needs and ecosystem requirements. USGS aims to do this by collecting and aggregating suitable ground-water data from local, state, and federal organizations to provide information on the quantity and quality of groundwater in principal and aquifers across the country. A consensus-based framework document was developed to provide guidance to ensure that the data were comparable and could be included in a nationally consistent network.

10) Set a price on water

Water is one of Canada's most important natural assets, one that contributes between \$7.8 and \$22.9 billion to the economy each year. It's time for more jurisdictions to start putting a price on groundwater and on surface water. The cost of groundwater mapping, ongoing modeling and monitoring could be covered by nominal fixed charges for consumers, as opposed to a mapping tax.

But as Brock University economist Steven Renzetti points out, maps, models and monitoring will not yield anything meaningful unless we have some notion of how much groundwater is worth to a farmer, to a fracker, to the oilsands, to a utility, to a real estate developer like Mike Holmes, to a natural area, and to the Deh Cho people who pay homage to Ndambadezha, the 'protector of the people' who inhabits a groundwater vent in Nahanni National Park

This brings us to price signals, an issue which goes beyond the scope of this paper. If one accepts that Canada is approaching the so-called 'end of abundance' of groundwater, then some form of per unit charge will eventually be necessary to conserve and protect this resource. This is going to be challenging because not all consumers are equal in their

ability to pay. Not all parts of the country are equally constrained in their groundwater resources. There may need to be differences in the pricing mechanisms for ground and surface water.

It should also be noted that pricing also doesn't always work as a conservation tool. In the American southwest, for example, rising prices for groundwater have, in some cases, resulted in water mining companies buying up farms and ranches so that they can extract water and sell it to the energy industry, to municipalities and to water thirsty hotels in Las Vegas. Pricing has also failed to stop many people in Texas from watering their lawns and flowers in times of severe drought.

Finally, pricing will challenge the widely held view in Canada that access to water is a basic human right.

Wrapping Up

We have a history in Canada of making decisions without using or seeking out value information such as that which comes from mapping, modeling and monitoring of groundwater. We give groundwater away so that less valuable resources such as oil and gas and minerals can be extracted. We inject much of the groundwater we give away back into the ground in a polluted state. We rarely, if ever, recognize groundwater for the ecological goods and services that it provides or the spiritual value that it represents to the First Nations of Canada.

Groundwater management in Canada needs to move forward. While conflicts over groundwater in Canada may not now be as fierce, or as serious as they have become in Texas and other parts of the American southwest, it is only a matter of time before we reach some crisis points. At some point, someone will have to decide whether it's the farmer or the fracking company that gets the groundwater. Someone will eventually have to decide whether the oil sands industry gets to continue to extract and pollute groundwater at the expense of wetlands, First Nations, the Northwest Territories or even future farmers. If urbanization continues to deplete or degrade groundwater at the expense of homeowners, farmers and industry, someone is going to have to step in. Canada will also have its hands full if the United States decides to challenge the way we manage groundwater reservoirs that straddle international boundaries.

If one accepts the principle that value information is needed to make good decisions, then we need to gather that information if we are to put a value on water. The science has to come first, however, if we are to make good decisions. The value of groundwater is

dependent on quality, quantity, recharge rates and other things that are beyond the grasp of economists and decision-makers.

Groundwater mapping and modeling can help farmers, industry, municipalities, and even managers of natural areas plan on how much groundwater can be pumped from an aquifer without running it dry. Mapping and modeling can help scientists predict how groundwater will respond to stresses such as over-pumping, seawater intrusion, urbanization, drought and climate change. Mapping and modeling have the potential to solve groundwater contamination problems.

‘Free’, therefore, is not the price we should put on groundwater. Giving groundwater away for free is not going to give us the scientific answers we need to figure out how to control, sustain, and manage a resource that does all these things. It is not going to give us what we need to build inventories. Giving away groundwater does not help us identify aquifers that could be used to store water for future droughts and climate change extremes.

Consider once again the damage that was done during the drought of 1999-2004. Since then, the population of Canada has grown. Demands for water have increased. New demands for water needed for mining and for exploration of unconventional energy sources have come on stream. The climate has heated up, and it is, by all accounts, going to get warmer and in some places dryer. During the last major drought in Canada over 41,000 jobs were lost and the GDP took a \$5.8 billion hit. Had irrigation districts, by far the biggest users of water on the prairies, not shared some of the water they were allocated, many municipal water supplies would have run dry.

Elaine Wheaton and her colleagues at the Saskatchewan Research Council nicknamed the 2001/ 2002 drought ‘Ada’ in respect for its severity and in recognition of the acronym for the project they were working – Agricultural Drought Adaptations. It also uses the first letter of the alphabet for the first major drought in the 21st century.

In May 2013, the first of a series of dust storms started blowing across southern Saskatchewan and Alberta where the soil was remarkable dry in some places, even after a snowy winter. Driving through one of them, hydrologist John Pomeroy wondered whether this was a signal that the next big drought, which is overdue, is coming. Will it be named ‘Boris’ (warrior) or ‘Botan’ (long-lived) like ‘Ada’, the rare cross-prairie drought that also affected nearly every corner of the country? Will the next drought and the others that follow be worse, as climatologists expect them to be?¹⁹²

How much will the next nation-wide drought cost? Will there be enough groundwater to buffer many of us from the impact?

To get answers and to avoid what is happening now in many parts of the United States, we need to expedite the mapping of aquifers in Canada. We need to assess and monitor them. We need a national groundwater monitoring network. If we continue to ignore groundwater, we do so at our peril.

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