Journal of Hydrology: Regional Studies 4 (2015) 623–643

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Transboundary aquifers along the Canada–USA border: Science, policy and social issues

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ARTICLE INFO

Article history:
Received 9 June 2015
Received in revised form 2 September 2015
Accepted 6 September 2015

Keywords:
Aquifer
Transboundary
Canada
USA
Cooperation

ABSTRACT

Study region: Canada–USA border.
Study focus: Since 2005, Canada has followed international developments in transboundary groundwater issues in cooperation with its southern neighbor the United States (USA) within the Internationally Shared Aquifer Resources Management Initiative (ISARM) of UNESCO. As a result, 10 Transboundary Aquifer Systems (TAS) were identified along the border between Canada and the USA. This study is an extensive review of the current state of the 10 TAS. Documentation of scientifically-based knowledge on TAS is an important step in identifying potential issues in policies that might be adopted to address shared water-resource issues.
New hydrological insights for the region: This analysis emphasizes the need for more scientific data, widespread education and training, and a more clearly defined governments' role to manage groundwater at the international level. The study reviews the current legal framework and summarises the current scientific knowledge for the TAS with respect to the hydrologic and geologic framework as well as some of the major drivers for supply and demand. It also describes the links, approach and relevance of studies on the TAS to the UN Law of Transboundary Aquifers and on how these might fit in the regional strategy for the assessment and management of the TAS. Clear communication, shared knowledge and common objectives in the management of TAS will prepare the countries for future negotiations and cooperative binational programs.

1. Introduction

Worldwide, about 60% of all freshwater runs within cross-border basins; only an estimated 40% of those basins, however, are governed by some sort of basin agreement (UNESCO, 2010a). In an increasingly water-stressed world, shared water resources are becoming an instrument of power, fostering competition within and between countries. The struggle for water is heightening political tensions and exacerbating impacts on ecosystems (Vörösmarty et al., 2000).

It took 44 years for the United Nations Convention (UNWC, 2014) on the Law of the Non-Navigational Uses of International Watercourses to be drafted, adopted, ratified and finally achieved the necessary ratification threshold. And only until most recently (August, 2014), did this United Nations Convention enter into force.

The Convention was concluded on 21 May 1997, as an annex to General Assembly resolution 51/229. Its adoption brought to a close a process the General Assembly had initiated well over two decades earlier. The General Assembly had shown

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http://dx.doi.org/10.1016/j.ejrh.2015.09.006

that it recognized the importance of this field even earlier, when it adopted resolution 1401(XIV) on 21 November 1959. In that resolution, the Assembly had indicated that it was “desirable to initiate preliminary studies on the legal problems relating to the utilization and use of international rivers with a view to determining whether the subject is appropriate for codification”. However, almost two decades passed without full ratification until, in May 2014, Vietnam became the 35th and decisive signatory of the 1997 United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses. As a result, 90 days later, on August 17, 2014, the convention entered into force.

Worldwide, as per 2012, there were 276 cross-border freshwater basins and 270 transboundary aquifers, or 445 if transboundary groundwater bodies, GWB, are included (EU WFD, 2000; IGRAC 2012 IGRAC 2012); see below. Yet no resolutions or conventions on transboundary aquifers had been drafted or adopted by the United Nations, until January 15, 2009. In December 2008, the UN General Assembly adopted resolution A/RES/63/124 “The Law of Transboundary Aquifers. Five years later, recalling its resolutions 63/124 of 11 December 2008 and 66/104 of 9 December 2011, and noting the major importance of the subject of the law of transboundary aquifers in the relations of States and the need for reasonable and proper management of transboundary aquifers, The General Assembly, adopted resolution 68/118 “The law of transboundary aquifers.”(UNGA, 2008).

Perhaps one of the reasons of this apparent disregard on transboundary aquifers was the lack of knowledge. Transboundary Rivers and watersheds have been known for a long time, whereas transboundary aquifers have not, until recently. In addition, they are comingled waters in many watersheds that require the joint assessment of surface-water and groundwater resources.

The UNWC may be applicable to groundwater resources too. The UNWC defines “watercourse” to mean “a system of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus,” and an “international watercourse” as “a watercourse, parts of which are situated in different States.” Parsing out this phraseology reveals a number of important qualifications. Thus, the UNWC clearly applies to many of the world’s groundwater resources; however, it is important to delineate precisely which aquifers are included and excluded from the rubric of the Convention (Eckstein, 2014).

Eckstein (2014) provides a simple and legal interrelation of the application of UNWC to groundwaters. For an aquifer to fall within the scope of the UNWC, it must be a part of a “system of surface waters and groundwaters.” Use of the “system” criterion in the definition implies an interrelationship between multiple and interlinked water bodies. This assessment is supported and complemented by the subsequent definitional language that emphasizes the “physical relationship” and “unitary whole” of the system, and the “common” characterization of a terminus. Hence, solitary transboundary aquifers—such as independent fossil aquifers and rain-fed aquifers—are presumptively excluded from the scope of the UNWC. It is noteworthy that subsequent to drafting the principles for the UNWC, the UN International Law Commission (ILC) submitted a Resolution on Confined Transboundary Groundwater in which it commended states to be guided by the principles of its work product in regulating independent and hydraulically unrelated transboundary groundwater resources. This progressive recommendation was not incorporated into the UNGA’s final version of the UNWC, and remains as a category of transboundary resource not covered by the convention.

In 2002, the UNGA tasked the UN International Law Commission (UNILC) with drafting principles of law for transboundary aquifers based on trends in state practice and customary norms. The resulting Draft Articles are now before the UNGA. While the Draft Articles were modeled largely on the UNWC, there are a number of noteworthy differences. The UNWC applies to certain transboundary and some domestic aquifers as discussed above. In contrast, the Draft Articles apply to all transboundary aquifers, regardless of whether they are hydraulically linked to any other water body (surface or subsurface), and to domestic aquifers that are hydraulically related to a transboundary aquifer. In addition, the Draft Articles are tailored specifically for transboundary aquifers and include references and principles related to protecting recharge and discharge zones, ensuring the functioning of aquifers, and aquifer-related monitoring activities. If the Draft Articles proceed toward an independent legal instrument, which is yet uncertain, the Draft Articles and UNWC will have to be harmonized (Eckstein, 2014).

The coming into force of the UNWC is a significant milestone in the evolution of international water law. While the Convention’s applicability to certain of the world’s groundwater resources may be limited, its growing acceptance and implementation signifies the global community’s broadening commitment to manage and utilize transboundary freshwater resources through peaceful and cooperative means. It also recognizes and affirms transboundary groundwater resources as a legitimate topic of international law.

In Canada, water management is primarily a provincial responsibility. However, the federal government has responsibilities especially when aquifers cross boundaries. When an aquifer extends beneath the border of two jurisdictions, conflict may arise when one jurisdiction depletes groundwater resources that affect the quantity and quality of water available to the other jurisdiction. There are a few places in Canada where use of groundwater resources in adjacent provinces, or with its southern neighbor, have created conflicts. When needed, the equitable and “reasonable” use of shared waters is the most essential principle considered when negotiating a groundwater apportionment method. Other factors considered are: the priority use, the sustainable yield of the aquifer, and the joint apportionment of surface water and groundwater (the rate of recharge is generally included in the sustainable yield). However, to be effective and applicable, all those factors require understanding of hydrogeologic conditions which, in many cases, does not exist.

The U.S.-Canada International Joint Commission (IJC) manages the international practices on transboundary waters in Canada. The IJC follows the 1909 Boundary Waters Treaty, providing the principles and mechanisms to help prevent and resolve disputes relative to water. However, the 1909 Treaty did not mention groundwater; it was not until 1977 that transboundary aquifers were first considered by the IJC. But it took two more decades before any serious recommendation by the IJC was put forward to study transboundary groundwater between the two countries. It was not until the year 2000 that the IJC published an overview of groundwater issues within the Great Lakes Basin (IJC, 2000).

In Europe, the situation relative to TAS has changed since 2012. At the 2012 World Water Forum, held in Marseilles, an updated map of the transboundary aquifers of the World was presented highlighting the work and efforts of the previous years in identifying and delineating the world's transboundary groundwater resources.

To accommodate the European Water Framework Directive EU-WFD, (2000), some important changes were made to the original World Map of TAS (2009). For EU countries (plus Switzerland and Norway) the new global map displays transboundary Groundwater Bodies (GWB), rather than transboundary Aquifers, as adopted by the EU-WFD. Within this framework, EU Member States are obliged to delineate groundwater bodies (managerial units) to identify the risk of failing to achieve "good status" by 2015. In many cases, aquifers are subdivided into groundwater bodies while occasionally groundwater bodies may contain multiple aquifers.

Groundwater bodies, according to Article 2.12 of the WFD, are defined as "a distinct volume of groundwater within an aquifer or system of aquifers". They are units for the management of groundwater resources that are either exploited by man or support surface ecosystems. A portion of an aquifer can be defined as a groundwater body if anthropogenic pressures could lead to one of the status objectives being compromised. As groundwater management units, they reflect the conceptual understanding of the hydrogeology and the source-pathway-receptor model. The technical details of defining and reporting on GWB are provided in the guidance document of the WFD: EU CIS guidance on risk (EC, 2010).

Through combined efforts of many organisations, stakeholders and governments around the world, such as through the recent "Second Assessment of Transboundary Rivers, Lakes and Groundwaters" by the UNECE (UNECE, 2011), we are today aware of 445 transboundary aquifers and GWBs (380 in 2009). Since being first included in this inventory many TAS received further attention, leading to their precise border delineations.

As per 2009, a total of 73 TAS have been inventoried in the American hemisphere (UNESCO, 2010b), ten of which along the Canada–US border. However, there are no water directives as in the EU; there are a few agreements and one strategy on transboundary aquifers for the whole American continent; these are the Guarani Transboundary Aquifer Agreement (Acuerdo, 2010); the TAAP agreement designed to share information between the USA and Mexico (Alley, 2013); and the bulletin 319 from the IBWC/CILA (Minute 319, 2012) also between the USA and Mexico that also mentions sharing water. There is also the Great Lakes Water Quality Agreement signed between Canada and the USA, which has always been directed to surface waters; and the Great Lakes Charter Annex, which was written in 2001 and recently ratified (2010) but not yet implemented; the Charter addresses groundwater extraction through its general prohibition on large-scale diversions from the Great Lakes Basin (IJC, 2010b). A few of these are described below.

2. UNESCO ISARM-Americas

The Internationally Shared Aquifer Resources Management Initiative (ISARM) came about as a result of recognition by the International Association of Hydrogeologists (IAH) in 1997 that there was insignificant worldwide guidance on transboundary aquifers and their management. The IAH established a Commission to gather scientific data on these aquifers, which had been known to hydrogeologists as 'regional aquifer systems' in the past, but that knowledge had remained dormant within a closed community. By the year 2000 there was global interest on transboundary river basins in the context of potential inter country rivalry for scarce water resources, yet groundwater was not mentioned at all. Consequently, IAH working together with UNESCO-IHP launched a worldwide initiative, which has been running as an UN-supported programme until today. As of 2014, there are global inventories of these aquifers and a series of maps depicting about 270 of them; their hydrogeological features have been published by WHYMAP and IGRAC (Puri and Aureli, 2009). In addition to the hydrogeology of these aquifers, the social, institutional legal and economic aspects have been assessed in many regions, with furthest advance having been made in the ISARM Group of the American hemisphere.

At the outset of the launch of ISARM, a Framework Document was prepared, setting out a series of guidelines for conducting the inventories. That document was provided as a base for the start-up of every ISARM activity and helped to ensure consistency across the world for the basic data. Generally ISARM activities were started up by UN Member States themselves arranging regional meetings, involving neighbouring countries, often under the additional support of a regional economic commission; for instance, in the case of the Americas, the Organisation of American States (OAS). This type of multiagency support to ISARM ensured that in addition to often pre-existing science-based cooperation, there was also the potential to gain from aspects related to economic, legal and social cooperation.

At the end of more than a decade of ISARM activities, there are important lessons learned by hydrogeologists and water managers.

Primarily, the lessons are that as long as hydrogeologists only "talk to themselves", key elements of the natural and built environment will remain out of the understanding of decision makers. In general, scientists and managers lack sufficient communication. Secondarily, while there is good cooperation among hydrogeologists working across their own borders, this is insufficient and it is only through relevant cross-disciplinary dialogue that essential water resources (and everything that follows on from this) can be managed for social, economic and environmental security.

A final lesson that may be drawn from ISARM activities relates to the adoption by the UN of a Law on the Use of Transboundary Aquifers which is also a direct outcome of the ISARM initiative. That was a clear outcome of how hydrogeological science is transformed into a global legal instrument. This instrument was drafted with direct involvement of hydrogeologists, who had to undertake significant intellectual effort to establish a solid definition of key hydrogeological terminology, so that they were scientifically correct, yet legally consistent, and made legally binding; i.e., a direct, solid and very fruitful cooperation between hydrogeologists and lawyers. The result is a well-developed science-based legal tool for the use by the World Member States of the UN. Since then, more work is being done to help and support Member States in adopting these guidelines. Some of these new activities involve hydrogeologists with the support of the IAH; other member states are applying and undertaking the principles of the Law of Transboundary Aquifers independently.

The ISARM-Americas group has moved its activities a further step in designing a strategy for the American Hemisphere: “Regional Strategy for the Assessment and Management of the Transboundary Aquifer Systems in the Americas” (Rivera, ed. 2015). This strategy is discussed below.

Since 2005, the Geological Survey of Canada (GSC) has participated in the ISARM initiative led by UNESCO. As a result, 10 Transboundary Aquifer Systems (TAS) were identified along the border between Canada and the USA. The available information on the 10 TAS was collected by the GSC and its American partners and summarized as part of the three books published by UNESCO on the TAS of the American Hemisphere (Da Franca et al., 2007; UNESCO, 2008, 2010b).

The GSC involvement in ISARM-Americas has facilitated and promoted international sharing of information and knowledge required for sustainable groundwater resources development and management between Canada and the U.S. This has resulted in a number of activities and products; this paper summarizes the most recent results.

2.1. Strategy of the American hemisphere

The Regional Strategy for the Assessment and Management of the Transboundary Aquifer Systems of the Americas (Rivera, ed. 2015) is contained in the 4th Book of the ISARM-Americas Series. It is the result of more than 10 years of successful and fruitful collaboration of UNESCO-IHP and the OAS with members of 24 participating countries in the America hemisphere.

The strategy adopted the vision of “Achieving improved sustainable management and protection of transboundary aquifer that goes beyond the boundaries of the participating countries.” And the mission: “Increase the generation and exchange of knowledge concerning the Transboundary Aquifers, developing communication pathways, cooperation and joint work between participating ISARM Americas countries.”

The strategy arises from the achievements made through the work done by the countries in the framework of ISARM Americas and it takes into account the information collected in the three previous publications of the ISARM-Americas programme where a total of 73 TAS were inventoried (as per 2009, UNESCO, 2010b), ten of which are along the Canada–US border.

The strategy aims to provide guidelines taking advantage of the existing scientific knowledge and consensus on this topic, in order to have an overview of groundwater resources and the social, economic and institutional aspects that characterize the geographical area of influence of the Transboundary Aquifer System. This information should become an important tool for the development of policies and standards for management of TAS, providing relevant information to guide member countries in decision-making. As much as this strategy is critical and fundamental, the missing link is knowledge and collective assessment. One important message from the strategy was that projects should be funded to provide a healthy framework of data, monitoring, analysis, and synthesis for joint management and development. Where there are no funds, there are no projects, no knowledge and there is potential for conflicts.

The management of TAS must take into account the criteria of sustainability with responsibility, considering available best practices, as well as the scientific and technical knowledge base required to implement the strategy. Having available an agreed strategy for managing the TAS calls for collaboration and neighborliness practices; common criteria for national policies on sustainable management are encouraged. The key principle is to achieve a balance between economic and environmental requirements of the countries sharing TAS and joint funding of the monitoring and assessment of the resources.

There is a need for the institutions and governments in charge of managing TAS to have sufficient evidence and support tools for their management, and this is also desirable for local, regional and community governments. Likewise, groundwater users are significant actors in this context as final beneficiaries of the governance set for the TAS. However, in countries like Canada and the USA, this international aspect of the resource falls beyond the jurisdiction and financial resources of States and Provinces who cannot be in charge of international affairs, so they are in need of national support.

The strategy focuses not only in existing cooperation mechanisms for water management, but also in existing experiences while also seeking the creation of new mechanisms to support consensus building and good practices in the management of TAS.

In support of the strategy, the ISARM-Americas group has adopted five long-term goals, with a 20-years horizon. The definitions of these objectives reflect the outcome of the working group meetings conducted by the National Coordinators of the participating Member States. This includes the critical importance of understanding and cooperation as the basis for the sustainability of the aquifers that cross the jurisdiction of two or more countries in the Americas, as well as the articles of the UN Resolution on Transboundary Aquifers (A/RES/63/124 and A/RES/68/118). The objectives are:

- Generate knowledge about the status, conservation, use and supply of groundwater resources of the TAS.
- Ensure generation of guidelines for the management of transboundary aquifers, including sanitation, sustainability and vulnerability of the aquifer, and connectivity and conjunctive use with surface waters in transboundary basins.
- Contribute to the exchange of information and scientific and technological knowledge, cooperation and communication between Member States sharing transboundary aquifers to promote innovative sustainable strategies.
- Intensify the development of common standards, protocols and scientific consensus related data, information, parameters and procedures, as well as joint hydrological simulation of TAS validated by countries for groundwater management, promoting its adoption by the Member States.
- Encourage the development and establishment of ad-hoc legal and institutional frameworks related to groundwater management, drawing on international instruments where appropriate.

The strategy of the American hemisphere agreed on the following conclusions and recommendations:

- The trust between countries sharing TAS is essential in order to promote effective cooperation and exchange of information for a shared management. In this sense, the process developed by ISARM Americas for over 10 years has been successful in achieving tangible results: three publications, plus a strong network of national experts.
- The international legal instruments in the Americas are still very incipient. The only agreement on integrated transboundary aquifers in South America is the management of the Guarani Aquifer System: "Joint Declaration - San Juan, Argentina, August 2, 2010 Agreement on the Guarani Aquifer – Argentina, Brazil, Paraguay and Uruguay" (Acuerdo, 2010).
- Nationally, in most American countries groundwater does not have a clearly defined legal framework. Therefore it is recommended that in the future simple and clear legal frames be developed.
- In the public sector, agencies involved in managing water are not the only actors involved, since the multiplicity of regulations governing border areas invites other organizations to which the municipal or provincial authorities with jurisdiction in the area of TAS are added.
- The implementation of actions on TAS is not the responsibility of central government agencies, but also local and regional agencies (provincial, state, municipal), and society as a whole.
- In general, the collection and processing of hydrogeological data, studies and execution of works for the management and protection of aquifers have high costs. Most developing countries face other basic priorities of their society having little capacity for public investment, which makes it difficult to provide funds for activities related to the management of transboundary aquifers.
- In general, no conflicts between countries sharing the TAS have been registered. However, some conflicts have arisen, and could increase in the TAS of North America where competition for groundwater resources (all uses) is much more obvious and prominent (for instance some non-governmental Mexican groups have tried to file law suits against the lining of the All American Canal). Cooperation and exchange of knowledge has been crucial in preventing conflicts.
- In most countries of the Americas, policy responses to some extent reflect the times of global change and large uncertainties, which depend on: (a) good information; (b) a good dissemination of information; and (c) a good understanding of that information.
- As a result of the UNESCO/OAS ISARM Americas initiative and through the efforts of the network partners of the American countries, it was concluded that where institutional mechanisms for the assessment of TAS already exist, considerable efforts will be needed for these to take effect and facilitate bi-or multi-national assessments; while where there are no such mechanisms, it will be necessary to create them.
- The challenges are to combine scientific and technical advice on the proposed strategy with the many legal and institutional instruments of the 24 countries and the UN Resolution on TAS. The strategy is designed to build links between science and policy and the instruments for the management of TAS. So the main message is: "a strong science-based strategy that can be the backbone for making well-informed decisions."

In summary, two instruments are available for the assessment and management of transboundary aquifers in the American Hemisphere: the UN Resolution on the Law of Transboundary Aquifers, and the ad-hoc Strategy developed for the American countries (Rivera, ed. 2015).

Up to 2014, there were two working agreements on integrated transboundary aquifers in the Americas. One was the management of the Guarani Transboundary Aquifer System. This agreement was signed by the governments of the four countries sharing the Guarani aquifer in the "Joint Declaration - San Juan, Argentina, August 2, 2010 Agreement on the Guarani Aquifer–Argentina, Brazil, Paraguay and Uruguay" (Acuerdo, 2010). The other one was the TAAP agreement designed to share information between the USA and Mexico in at least three TAS: the Upper Santa Cruz and the Upper San Pedro Rivers basins, and the Mesilla Basin/Conejos-Médanos aquifer system (Alley, 2013).

3. The case of Canada/USA

Early bibliographic research showed that Canada had not previously identified any transboundary groundwater bodies of concern (TAS). In 2000, The IJC (2000) listed 10 major rivers and lakes, and recommended studies on groundwater within the Great Lakes Basin, but did not include any TAS. All of its current task forces similarly focus on surface water only (IJC, 2010a). In its original form, the IJC's Boundary Water Treaty (1909) did not mention groundwater; it was not until 2000 that aquifers were explicitly considered by the IJC. Based on available evidence of the time (Grannemann et al., 2000), the IJC summarised the knowledge gaps of aquifers located within the Great lakes Basin noting that "there is a clear need for state, provincial, and local government attention to the . . .protection of groundwater recharge areas" (IJC, 2000). In addition, of the ten US-Canada transboundary water treaties, conventions, and agreements listed on Environment Canada's website, not one focuses primarily on aquifers (EC, 2011).

This historical negligence and lack of scientific data has not only slowed groundwater protection in the transboundary context in Canada, but is paralleled in the domestic legal systems of both nations (Nowlan, 2005). Major water management organizations have also been slow to adapt their strategies for groundwater protection. For instance, the Canadian Council of Ministers of the Environment developed a protocol for consistent reporting of water quality information, but has not yet applied this protocol to groundwater (Forest, 2010).

However, this emerging issue has recently begun to attract more attention. The Abbotsford–Sumas Aquifer, for instance, has drawn notice because dense local agriculture has led to heavy nitrate contamination. Since the aquifer flows from British Columbia to Washington, co-operation is needed to prevent further pollution and transboundary disputes (Mitchell et al., 2003). The Great Lakes region has made strides in addressing transboundary groundwater concerns through acknowledgement in the 2001 Annex (CGLG, 2005); however, the Charter Annex only relates to consumptive use of groundwater as a diversion of waters of the Great Lakes.

Despite the economic and ecological value of groundwater, Canada's legislative framework and institutional capacity for groundwater management have yet to fully mature. The application of the scientific knowledge required for a sustainable management of groundwater remains, with some notable exceptions, under-developed (Mitchell, 2004). This is not an acceptable state of affairs, particularly in view of current or emerging stresses on Canada's groundwater resources among others due to transboundary water challenges and the ongoing need for cooperative management of water resources that straddle or cross the Canada-US border.

3.1. Transboundary water challenges

Disputes about water bodies that span or cross the Canada-US border can challenge sustainable groundwater management. Recent disputes involving surface water illustrate the variety of issues that might arise, such as the introduction of alien species in the Garrison Diversion project and the Devils Lake disputes between Manitoba and North Dakota; the transboundary pollution in the Flathead River originating from a proposed coal mine in British Columbia and flowing into Montana; the mine and energy development proposals that threaten wilderness areas in the Taku and Iskut-Stikine watersheds in British Columbia and Alaska; and the continuing pollution and water-level problems in the Great Lakes (IJC, 2008).

To date, transboundary groundwater tensions have been rarer than surface water disputes in Canada-US relations. This is in sharp contrast with the complex and pressing issues of groundwater sharing along the more populous and arid United States-Mexico border, involving at least 17 shared groundwater basins (Hall, 2004; Rivera, ed. 2015).

The case study on the Abbotsford–Sumas aquifer is one example of a groundwater issue that has generated considerable attention but has so far not abated the nitrate contamination that migrates from Canadian sources (Province of British Columbia) to American wells (Washington State). Pressure on aquifers in the Great Lakes basin will also gain prominence in the coming years as climate change affects lake levels and recharge patterns (see CCA, 2009).

3.2. Institutional mechanisms

The existing institutions involved in transboundary water management have not historically focused on groundwater, although there are signs that groundwater is gaining prominence as an issue that needs attention. The International Joint Commission issued a comprehensive report on groundwater in the Great Lakes region in 2010 (IJC, 2010b). The Great Lakes Charter Annex and accompanying set of agreements between two Canadian provinces and eight American states addresses groundwater extraction through its general prohibition on large-scale diversions from the Great Lakes Basin. In most cases, transboundary Canada-US water disputes are resolved through cooperative mechanisms and information sharing through action bodies such as the Abbotsford–Sumas International Aquifer Task Force, the Great Lakes Council of Governors, and the extensive bi-national cooperative framework of the IJC. However, unilateral state action has prevailed over a negotiated diplomatic solution in the case of the Devils Lake discharges into the Red River basin (North Dakota/Manitoba). After initial overtures to Canada were not accepted, the United States refused to allow the dispute to be submitted by a reference to the IJC (The United States and Canada have a practice of referring matters to the IJC only through joint referral, and never through a unilateral reference, though the Boundary Waters Treaty provides that disputes over transborder water pollution may be referred to the IJC either unilaterally (Article IX), or jointly (Article X); CCA, 2009).

There are other cases in recent years in which provincial and state governments have taken a lead (see Table 2 for mechanisms of cooperation, or agreements, on the 10 TAS). This trend is illustrated by the Great Lakes Annex Agreement, where the national governments allowed the adjacent states and provinces to negotiate an agreement. For the upcoming renegotiation of the Columbia Basin Treaty, the Government of British Columbia, rather than the Government of Canada, has

Table 1
Transboundary aquifers identified along the Canada/USA border (UNESCO, 2010b).

Transboundary Aquifer	Shared by Jurisdictions	ISARM Id no.	Level of assessment
Abbotsford–Sumas	British Columbia/Washington	1N	Sufficient
Okanagan–Osoyoos	British Columbia/Washington	2N	Insufficient
Grand Forks	British Columbia/Washington	3N	Insufficient
Poplar	Saskatchewan/Montana	4N	Non existent
Estevan	Saskatchewan/North Dakota	5N	Sufficient
Northern Great Plains	Manitoba/Saskatchewan/N. Dakota/S. Dakota/Montana	6N	Insufficient
Châteauguay	Quebec/New York	7N	Sufficient
Judith River	Saskatchewan /Alberta/Montana	19N	Non existent
Milk River	Alberta/Montana	20N	Sufficient
Richelieu–Yamaska/Lake Champlain	Quebec/Vermont/New York	21N	Insufficient

been building public understanding concerning the issues at stake and has established the Columbia Basin Trust to promote the applicable science and public education.

There continues to be public uncertainty about the adequacy of Canadian laws to protect water from bulk exports. Although all the provinces, with the exception of New Brunswick, have passed legislation that forbids the bulk export of water, and although federal law prevents exports from boundary waters, laws might nevertheless be changed by a future legislature. Some experts have therefore proposed a new federal 'Model Act' to address the perceived deficiencies in the Canadian legal framework that governs water exports (CWIC, 2008). While the debates and bulk-export proposals usually involve surface sources (e.g., Gisborne Lake in Newfoundland and Labrador), groundwater is, in principle, not immune from diversion and bulk removal (CCA, 2009).

A few case studies were selected and are described in the CCA report from 2009. CCA (2009) selected regions of the country that have a relatively well-developed groundwater knowledge base, and thus they may not be reflective of the national situation. CCA (2009) found that in many of the case studies, a high level of knowledge and management had been attained only after conflicts have arisen; in others, the knowledge base is still relatively poor and sustainability goals have not been reached. Issues that are dealt with include agricultural impacts on groundwater quality, energy extraction, urban development, management at the watershed scale, and transboundary groundwater.

3.3. *The case of the milk river transboundary aquifer*

In Canada, concerns about the Milk River aquifer located in southern Alberta, go back to the 1950s when water levels started to drop because of intensive use by farmers in Alberta. Complicating the situation today are shale gas operators using groundwater from the same aquifer in Montana. Many studies had been made on the Milk River aquifer in Alberta; however it was not until ISARM-Americas included the Milk River aquifer as a transboundary aquifer in their list (UNESCO, 2010b) that the transboundary nature of this aquifer was the object of further unified studies. Thus, the Milk River transboundary aquifer is part of the ISARM-Americas inventory since 2009 (Id # 20N, see Tables 1 and 2).

Most recently, new efforts to characterise and quantify the Milk River Transboundary aquifer in its entirety (Province of Alberta, Canada, and State of Montana, USA), are underway to unify a geological model and conceptual model of groundwater flows, and to build a hydrogeological three-dimensional numerical model by using the physical boundaries of the aquifer, instead of the jurisdictional boundaries. The newly built models are used to study how water moves and migrates underground constrained by the region's sandstone. New field work campaigns have been measuring water levels in wells and collecting water samples for testing. Isotopes reveal how long water has been underground and if it's fit for consumption. The aquifer, named after the Milk River (surface water), stretches far beyond the river cutting through the parched prairie landscape. The aquifer underlines about 30,000 square kilometres of Montana and Alberta (Pétré and Rivera, 2013, 2015; Pétré et al., 2015; Tuck, 1993).

The 3D model will provide the most detailed assessment to date of an aquifer Canada shares with the U.S.; it will estimate the water fluxes across the border. It will also show where the aquifer is recharged—mostly in the Sweetgrass Hills, Montana—how the water flows north and southeast, and how groundwater withdrawals will impact flows. Water from the northern reaches of the aquifer near Taber, Alberta, can be half a million years old, but it tends to be younger—"just" decades to hundreds of years old—closer to the international border (Pétré and Rivera, 2015).

Assessing the dynamics underground is not easy; it has been a challenge getting water users and up to six levels of government to partner on this project. The key is not only in the science, but in bringing the people together. The 3D model, which would be completed in 2016, should lead to better shared management of the aquifer. And it may help lay the groundwork for a formal international agreement between the two countries on how to share the water, following the guidelines and principles described in the Strategy of the American Hemisphere (Rivera, ed. 2015) and the UN Resolution on the Law of Transboundary Aquifers.

Table 2
Brief description and levels of knowledge of the 10 TAS located along the Canada/USA border.

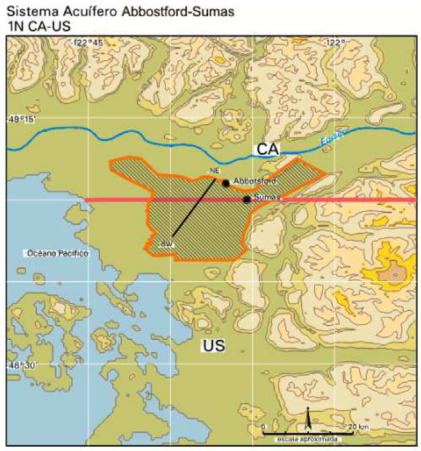
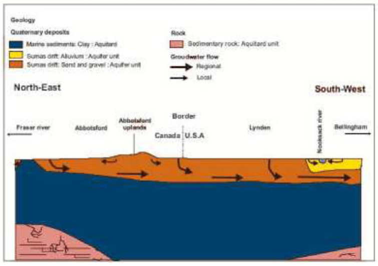
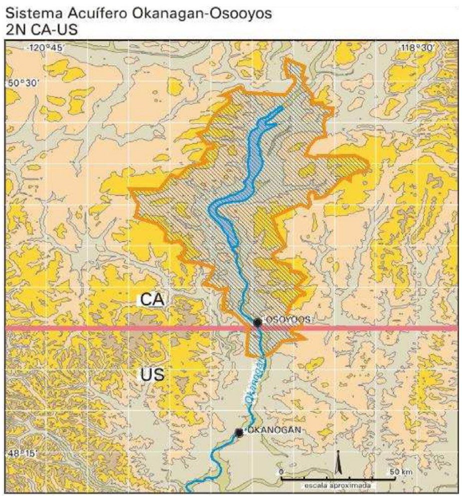
TAS Id	Main characteristics	Maps and cross sections
Abbotsford–Sumas ISARM n° 1N	• Geometry defined • Area: total 260 km^2, 100 km^2 in Canada, 160 km^2 in U.S. • Hydrogeological parameters • Conceptual model • Numerical GW model • Type: Unconfined aquifer • Rock type: Sand and gravel • Groundwater flow: from Canada to U.S. • Recharge: 650–1000 mm/y • Provides water supply to 10 000 people in U.S. and 100 000 in Canada. • Locally intensively exploited and/or overexploited. • Vulnerable to contamination. • Cooperation mechanism: Abbotsford–Sumas International Aquifer Task Force Main references: Golder Associates, Ltd (2012) Scibek and Allen (2005) McArthur and Allen (2005)	 
Okanagan–Osoyoos ISARM n° 2N	• Geometry undefined • Area: 25 km^2 • Type: unconfined aquifer • Rocks: non-consolidated sediments • Aquifer parameters only known in some parts pf the basin • Hydraulic connectivity of various small aquifer units still to be determined • No models built • No agreement or cooperation mechanism Main references: York and Murray (1993) Hodge (1985a,b)	

Table 2 (*Continued*)

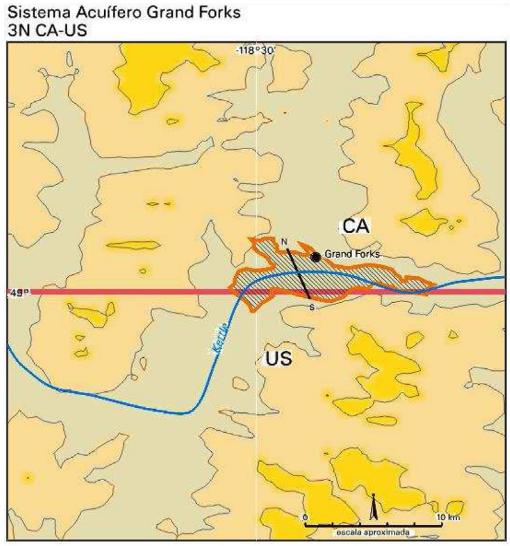
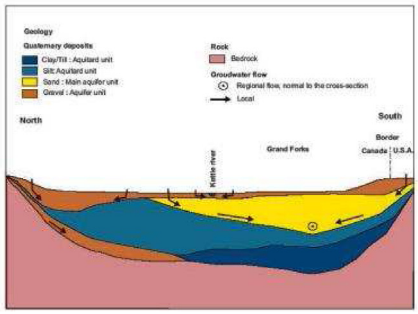
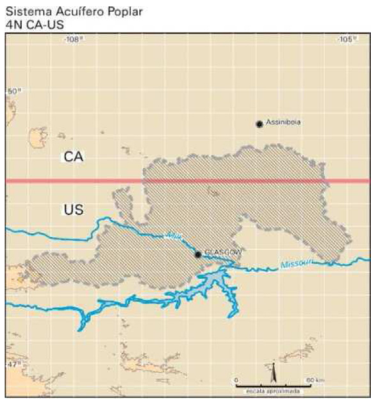
TAS Id	Main characteristics	Maps and cross sections
Grand Forks ISARM n◦ 3N	• Area: 34 km^2 • Type: unconfined, alluvial aquifer • Rocks: non-consolidated sediments • Recharge: 50–100 mm/y • Numerical GW model • No agreement or cooperation mechanism Main reference: Allen and Scibek, 2004.	 
Poplar ISARM n◦ 4N	• Area: ca 10 000 km^2 • Other data and information are limited • No agreement or cooperation mechanism	

Table 2 (*Continued*)

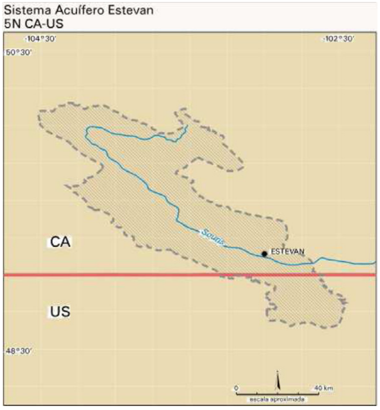
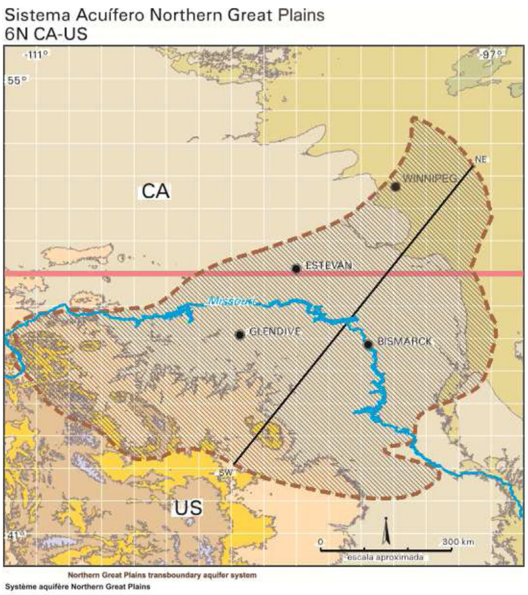
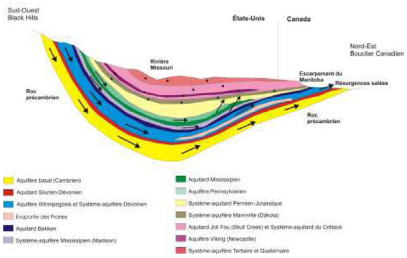
TAS Id	Main characteristics	Maps and cross sections
Estevan ISARM n° 5N	• Area: 280 km^2, ca 80 % in Canada. • Type: a confined, pre-glacial, buried valley aquifer with a length of 70 km and 4 km width • Rock type: coarse-grained sediments confined by moraines and siltstones • Groundwater flow: from Canada to U.S. • Use: 37.5 Mm^3/y in the Canadian side, unknown on the U.S. side. • Conceptual model • No numerical model • No agreement or cooperation mechanism Main references: Maathuis and van der Kamp, 2003. Maathuis and van der Kamp, 2011.	
Northern Great Plains ISARM n◦ 6N	• Area: 500 000 km^2, ca 75% in the U.S., and 25% in Canada • Type: very large multilayered confined aquifer system • Rock type: Sandstone, limestone, dolomite and shale • Groundwater flow: from U.S. to Canada • Recharge: combined with regional-scale in the U.S. and local-scale recharge in Canada • No models built • No agreement or cooperation mechanism Main reference: Kennedy, 2003.	

Table 2 (*Continued*)

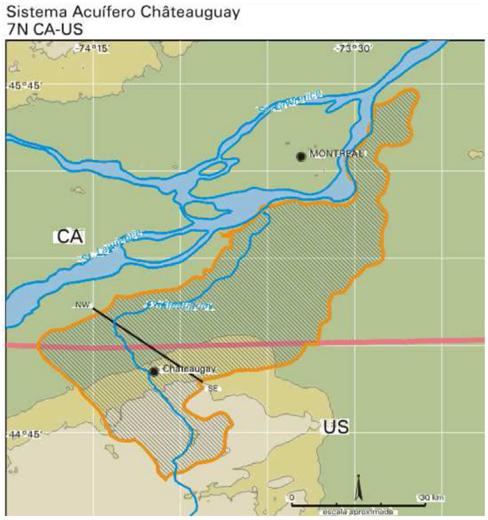
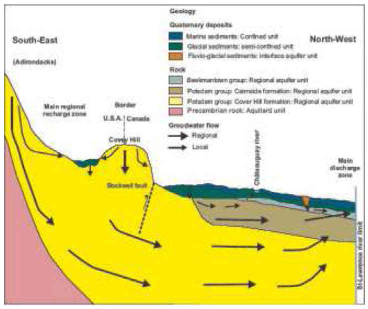
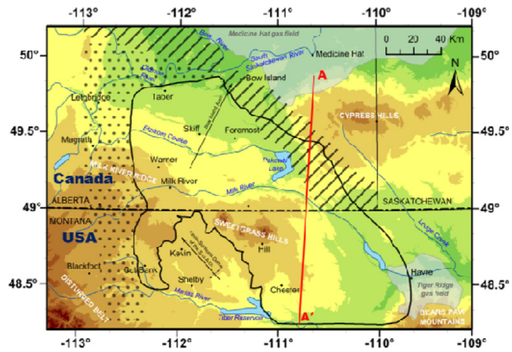
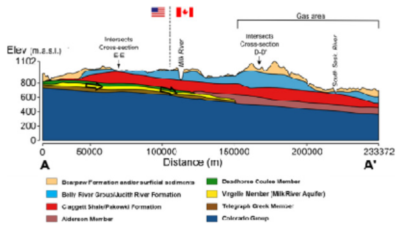
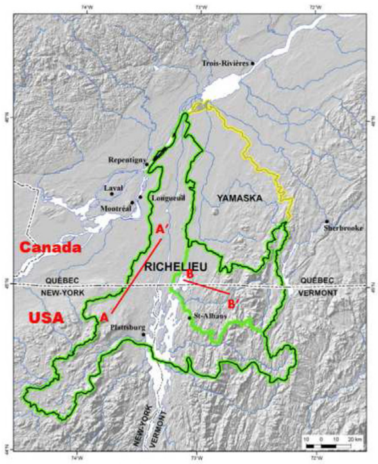
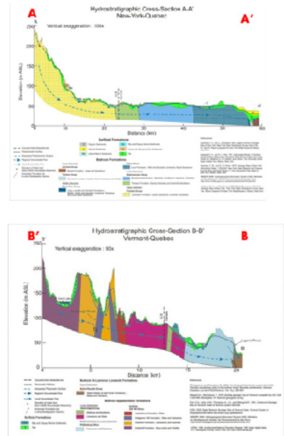
TAS Id	Main characteristics	Maps and cross sections
Châteauguay ISARM n◦ 7N	• Geometry defined • Hydrogeological parameters • Conceptual model • Numerical model • Area: 2500 km^2 1500 km^2 in Canada, 1000 km^2 in U.S. • Type: Unconfined/confined aquifer system • Rock type: Sandstone, dolostone and limestone • Groundwater flow: from U.S. to Canada • Recharge: 86 mm/y • Provides water supply to 10 000 people in U.S. and 100 000 in Canada. • Locally intensively exploited and/or overexploited • Vulnerable to contamination • Cooperation: bilateral scientific cooperation • Signed agreement of cooperation between the Geological Survey of Canada and the USGS. Main references: Lavigne et al., 2010. Croteau et al., 2010.	 
Judith River ISARM n◦ 19N	Not studied. • No agreement or cooperation mechanism	
Milk River ISARM n◦ 20N	• Geometry defined • Hydrogeological parameters • Conceptual model • Numerical GW model (by mid 2016) • Area: 50 000 km^2, ca 45 % in Canada, 50% in the U.S. • Type: Confined multilayered aquifer • Rock type: sandstone confined by shale • Groundwater flow: from U.S. to Canada • A few agreements of cooperation between the Geological Survey of Canada and the United States Geological Survey and between the GSC and other organizations on both sides of the border. Main references: Pétré and Rivera, 2013. Pétré and Rivera, 2015 Pétré et al., 2015	 

Table 2 (*Continued*)

TAS Id	Main characteristics	Maps and cross sections
Richelieu-Yamaska /Lake Champlain ISARM n° 21N	• Geometry defined • Hydrogeological parameters • Conceptual model • No numerical model • Area: 16 500 km^2, 9000 km^2 in Canada, 7500 km^2 in U.S. • Type: Unconfined/confined aquifer system • Rock type: Sandstone, dolomite, limestone, shale • Agreement of cooperation between the Geological Survey of Canada and the USGS. Main references: Beaudry et al., 2011. Benoit et al., 2013.	 

4. Science knowledge

4.1. What is a transboundary aquifer?

The key features of transboundary aquifers, as originally described by Puri (Puri, 2001), include a natural subsurface path of groundwater flow, intersected by an international boundary, such that water transfers from one side of the boundary to the other (Fig. 1). In many cases the aquifer might receive the majority of its recharge on one side, and the majority of its discharge would occur in the other side. The subsurface flow system at the international boundary itself can be visualised to include regional, as well as the local movement of water. Very few international boundaries follow natural physical features, and water resources can cross them unhindered (see Fig. 3). Scientists estimate the resources that cross these boundaries for good

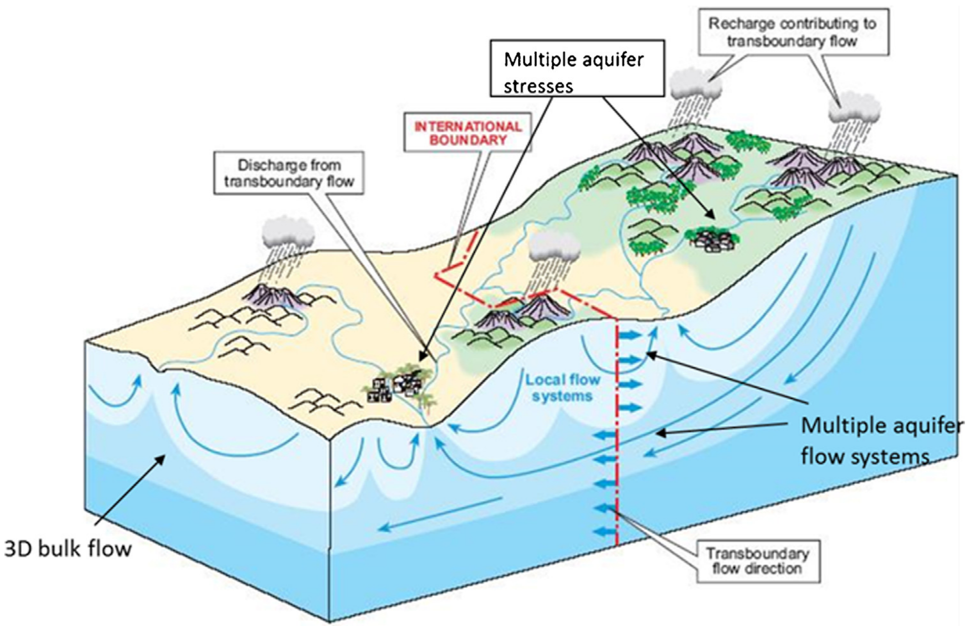


Fig. 1. Diagram of the components selected within a cross-border regional hydrological system (modified from Puri and Arnold, 2002).

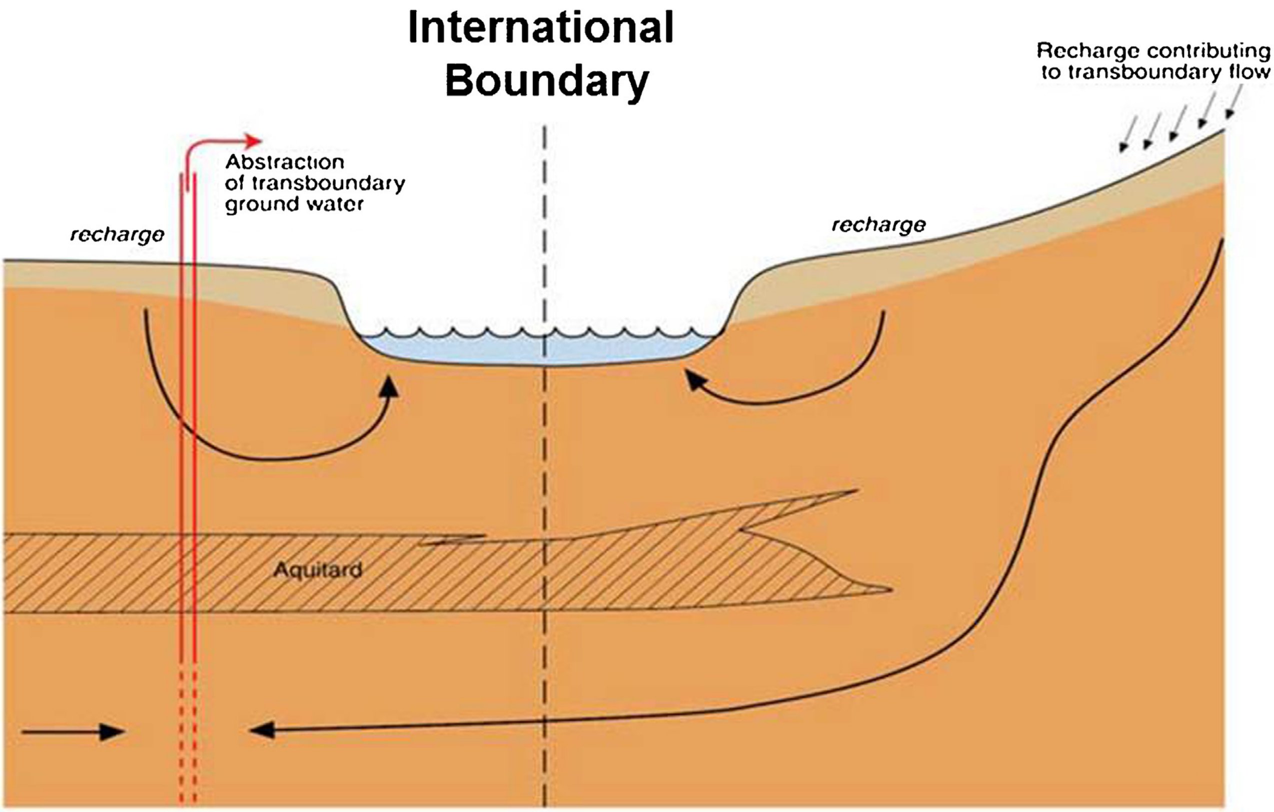


Fig. 2. River boundaries over transboundary aquifers (modified from Puri, 2001).

management and fair share of these resources. In hydrogeological terms, these crossing resources can only be estimated through good observations and measurements of selected hydraulic parameters, analogous to the estimation process of other transboundary resources such as habitat, fisheries, and wildlife, each requiring statistically sound observations and monitoring.

Even where international boundaries may follow such features as rivers, the aquifers underlying them may not reflect the true transfer of groundwater flows from one side to another, as illustrated in Fig. 2. In any legal agreements to be drawn up for the equitable share of transboundary resource, the initial step must be the correct identification of flow and movement of water, followed by its quantification. In reality, socio-economic pressures may have either already initiated withdrawal of water, or have such a priority that legal agreements cannot keep pace. Institutional weakness and political pressures may fail to address all the relevant issues, potentially leading to severe environmental impacts and unsustainable development and use.

4.2. The features of transboundary aquifers

Transboundary aquifers (as any other type of aquifer) basically represent bulk 3-dimensional systems with local, intermediate and regional flow systems (Fig. 1). The replenishment, or recharge, of TAS may take place from any, or all of 3 dimensions. Resources may be extracted from and used extensively over the TAS outcrop and/or the TAS subcrop. Although replenishment can be slow, abstraction can continue over longer periods of time. The impact of the abstraction (pumping or natural discharges) can be much slower, it can be tens of years before it is noticeable; it could have an equal impact on both upstream and downstream riparian states. Furthermore, there is slow movement of pollutants and the transport may be controlled by local hydraulic properties and abstraction rates, which is not necessarily a cross-boundary impact. An operating well, for instance, may induce 'upstream' movement toward itself. To further exacerbate the complexity of TAS, these may be composed of multiple aquifer flow systems (Fig. 1) having multiple aquifer stresses. If parts of the TAS are in phreatic conditions (shallow aquifer at atmospheric pressure), they may be connected to rivers, in which case, simulation of conjunctive use with regional aquifer models would be needed to fully understand the complex relations between climate, land/water use and surface/subsurface flows within the watershed/aquifer and across the international boundary.

Fig. 3 shows four cases of the presence, or absence, of transboundary groundwater flow. In the first case (Fig. 3(1)), the jurisdictional border coincides with the surface water catchment and groundwater divide; there is little transboundary

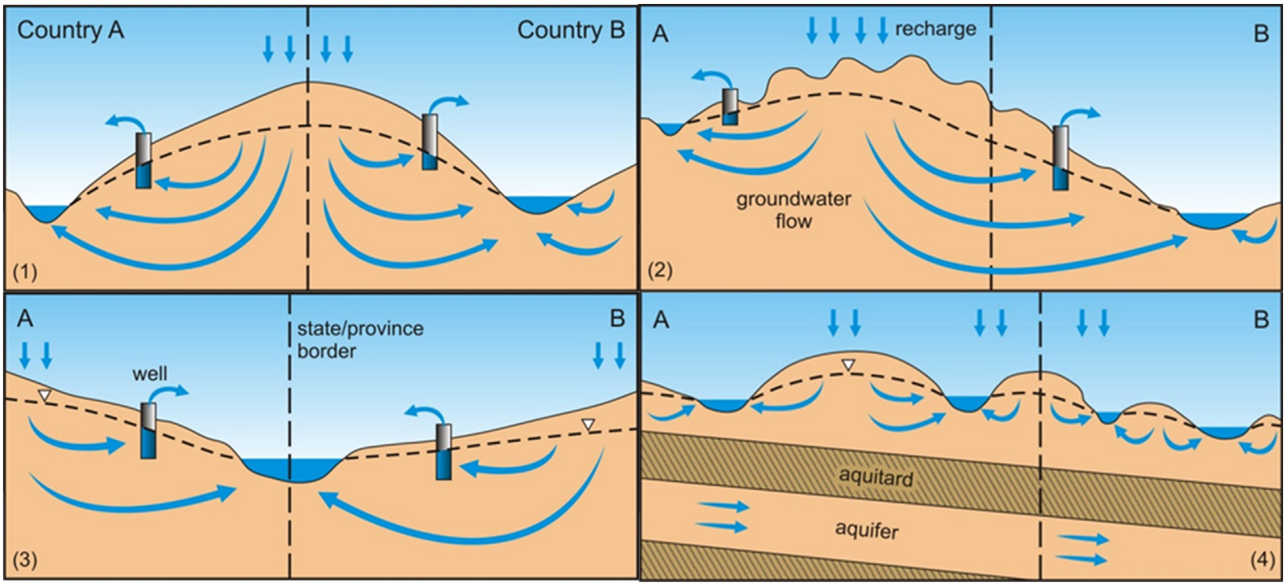


Fig. 3. (1) Jurisdictional border coincides with the surface water catchment and groundwater divide. (2) Surface water and groundwater divides separate from state border; recharge in one country, discharge in the adjacent country. (3) State border coincides with a major river or lake; alluvial aquifer connected to river. (4) Large deep aquifer, recharge far from border, not connected to local surface water and groundwater.

groundwater flow. The second case (Fig. 3(2)) shows the surface water and groundwater divide separated from state border; recharge is in one country and discharge in the adjacent country; there is transboundary groundwater flow. In the third case (Fig. 3(3)) the state border coincides with a major river or lake; an alluvial aquifer is connected to river; there is little transboundary flow. The fourth case (Fig. 3(4)) represents a large deep aquifer, recharge is far from the border, it is not connected to local surface water or groundwater; there is regional transboundary groundwater flow.

In some cases, there is no apparent underground flow from one country to another even when hydrogeological continuity exists between the two, as shown in Fig. 3(3). The TAS in this case, has a common discharge as a base-flow level to the river representing the international border. In that case, the extraction of groundwater by pumping in wells on one or both sides of the border may reduce the groundwater levels, thus reducing the base flow in the river; in turn this may affect coastal ecosystems (vegetation, wetlands, wildlife...), and/or catchments to surface water, or diminishing volumes subject to existing international treaties of surface water runoff. If the bulk of extraction in one of the countries is of sufficient magnitude, it could intercept all of the discharge from the aquifer to the river, induce a change of hydraulic head from its course, diminish the availability of surface water, and eventually cause the disconnection of the two inducing groundwater movement across the international border. This particular case would convert this system into a transboundary groundwater flow.

There are other examples where transboundary groundwater flow crosses more than two countries, further complicating the analysis, as is the case of the Guarani transboundary aquifer system crossing four countries in South America (OAS, 2009).

Fig. 4 shows another type of transboundary groundwater, a type that is not defined in the ISARM guidelines, and which may not be a transboundary aquifer per se but which is relevant and interesting for the conditions of the Canada/USA border. The figure shows independent, non-transboundary alluvial aquifers, connected to a large lake which represents an international border. At first sight, there is little or no transboundary flow from the alluvial aquifers. However, the groundwater fluxes of the aquifers contribute to the water balance of the lake's basin; should it then be considered as transboundary?

As long as the groundwater fluxes on each side of the lake remain in hydrodynamic equilibrium, with respect to the lake's water balance, there are no transboundary groundwater fluxes across the international border. However, if the aquifers are pumped in such a way that the groundwater withdrawal diminishes the base flow of the rivers that feed the lake, a condition of non-equilibrium may be reached in the lake's water balance, thereby reducing the lake's storage and eventually causing an impact on the other side of the border. Furthermore, under climatic changing conditions, the overall balance of the basin, which is shared by the two countries, may be disrupted.

4.3. Monitoring and assessment

Managing a natural resource system adequately, such as a transboundary aquifer, is only possible if sufficient and reliable data and information are available. These data and information should include a characterisation of the system to be managed, and also of its state, the use of its resources, and the impacts this use and the system's changing state have on people, communities and ecosystems. Assessment and monitoring are needed for the acquisition of such data and information (Kukuric et al., 2008).

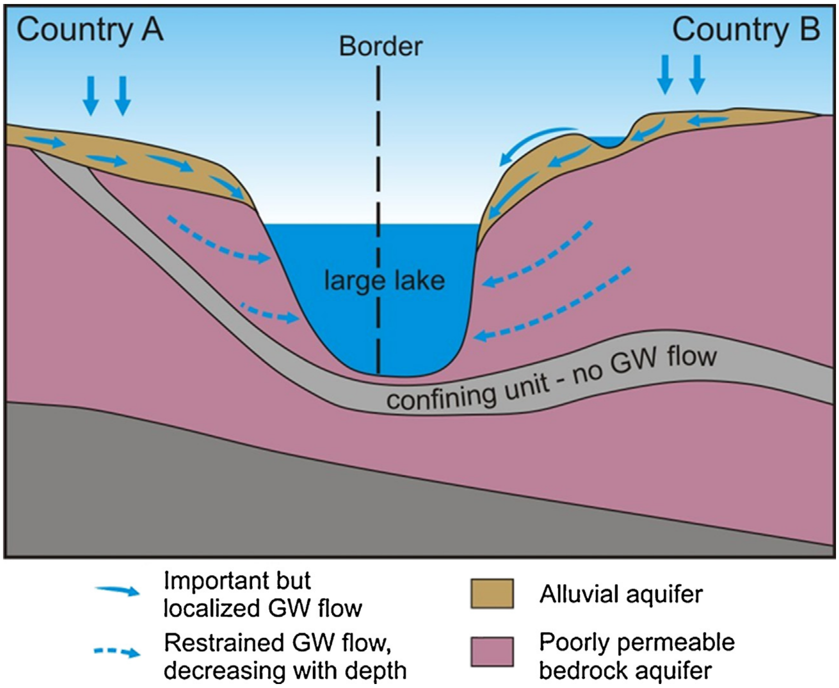


Fig. 4. Independent, non-transboundary alluvial aquifers, connected to a large lake which is an international border.

Assessment produces a time-independent image of the system: in the case of groundwater it identifies aquifers and aquitards, explores their limits, defines system parameters such as permeability and porosity, estimates volumes stored and fluxes exchanged with other components of the water cycle, and makes a snapshot of state variables such as groundwater levels and a diversity of water quality parameters. Some assessment activities are rather costly, e.g., geophysical exploration surveys and exploratory drilling programmes; thus there is a need for cooperation between provinces and provinces and federal governments to share costs and data (Hanson et al., 2015). Monitoring, on the other hand, focuses on variation in time and has the purpose of producing time series of relevant variables. In a narrow sense, these are time series of state variables of the groundwater system, but in reality monitoring may have to go beyond this narrow scope in order to facilitate causal chain analysis and a holistic approach to planning and management. One of the main challenges in monitoring is to keep monitoring networks operational over a period of many years (Tujchneider et al., 2013).

Assessment and monitoring activities are undertaken for a wide range of purposes, which results in a great diversity in scope and degree of detail. In the category of less intensive assessment and monitoring activities come projects or programmes that have the purpose to identify aquifers that deserve priority in being addressed. An example is GEF's (Global Environmental Facility) ongoing Transboundary Waters Assessment Programme (TWAP) that uses a set of indicators to define these priorities. These indicators are based on field data. At the other end of the spectrum come activities with the objective to plan and implement groundwater resources management at the level of aquifers or parts of aquifers. Such activities, especially if supported by numerical simulation models and if adaptive management is opted for, require many data with high resolution in space and in time. As previously mentioned, focusing on near-boundary pilot zones is an attractive option in large aquifer systems where the cost of an aquifer-wide assessment and monitoring would become prohibitively expensive. Concerted efforts to use indicators and integration of monitoring data across all provinces in Canada are underway in a strategic vision for water led by the Council of Canadian Ministers of Environment (CCME, 2010).

Data scarcity and limitations in accessibility and quality of the data will have a negative impact on the sustainable management of groundwater resources within the transboundary context. It is important that adequate groundwater monitoring data is generated not only during a project but also beyond, especially if adaptive management is embraced. This implies that projects also have to pay attention to making arrangements for post-project activities and monitoring.

In Canada there are networks of monitoring wells run by all provinces, which are used to update the status of the major aquifers, but these are not compared across regions. Such comparisons would permit the detection of large-scale climate change or land-use impacts on recharge, or of a regional over-use that could affect interprovincial surface supplies from source areas. Groundwater monitoring networks designed for the study and share management of transboundary aquifers located along the Canada/USA border are non-existent. Integration of inter-provincial and international databases for transboundary aquifers where water demand is likely to increase (e.g., Alberta-Saskatchewan border; Alberta-Montana border) is desirable.

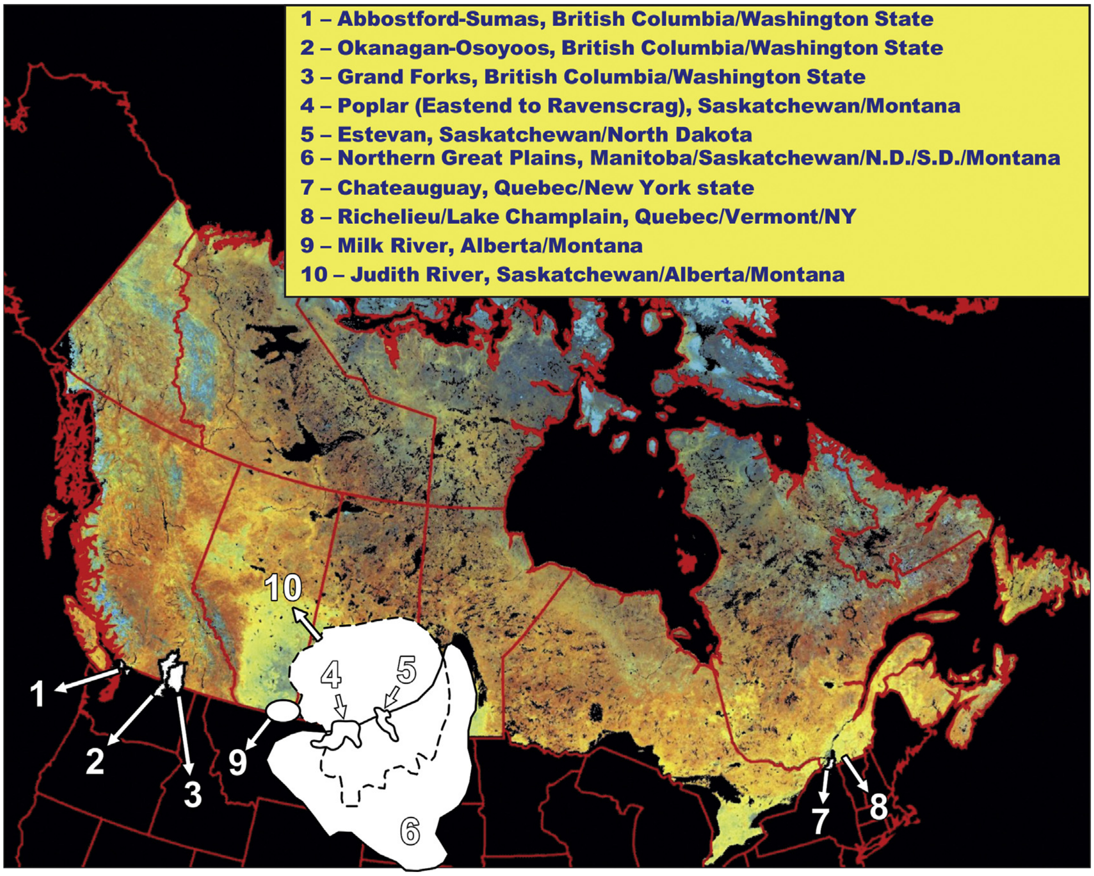


Fig. 5. Transboundary aquifers located along the Canada/USA border (Rivera, ed., 2014).

5. The Canada-US border region

Canada and the United States of America share one of the largest international jurisdictions in the World with circa 8000 km of border, and over 20 million Canadians live in watersheds and aquifers that cross that border (over 17 million people of them reside in the Great Lakes-St Lawrence watershed).

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

As a result of the ISARM-Americas initiative, ten transboundary aquifers have been identified along the Canada-US border as per 2009 (UNESCO 2010b); hundreds of wells extract groundwater from shared aquifers located on both sides of the border, but there are no formal legally-binding agreements in any of the ten TAS identified. Only four of the ten TAS have been fully mapped and their hydrodynamics partially assessed; it is likely that other TAS are yet to be identified.

Table 1 lists the ten transboundary aquifers along the Canada/USA border with the jurisdictions sharing the aquifers on both sides of the border. Fig. 5 is a map of Canada showing the location of the ten transboundary aquifers identified.

5.1. Status of knowledge: the conditions of the 10 TAS

Following the definitions in the ISARM-Americas Strategy on the level of knowledge of TAS (Rivera, ed. 2015), it has been evaluated that the 10 transboundary aquifers along the Canada/USA border have unequal levels of knowledge. Of the 10 aquifers evaluated in this study, 5 have a clearly defined geometry; 6 have a full range of hydrogeological parameters; 5 have a detailed conceptual model; and only 4 have a predictive numerical hydrogeological model.

Table 2 summarizes the main characteristics and existing knowledge of the 10 TAS, including preliminary maps and cross sections of each TAS.

5.2. Legal and policy aspects

In the previous sections we have presented and discussed the hydrogeological aspects of transboundary aquifers; however, understanding and managing TAS involve more than hydrogeology, these should also include environmental aspects, socioeconomic aspects, legal aspects and institutional aspects.

The assessment of TAS should be systematic, multidisciplinary and multijurisdictional; it is the only approach capable of preventing conflict through cooperation. The current facts and circumstances unfortunately point in another direction, inaccessibility of groundwater-related information and general lack of data. Furthermore, "transboundary" implies a sensitive topic for some countries.

Some short descriptions of the legal and policy aspects related with TAS are discussed below with emphasis in Canada.

Given the confederation of Canada, the contexts for groundwater laws and policies that could be applied to TAS are numerous: international laws, national laws and provincial laws. It has been a long practice in Canada that water laws replace, or add, to the common law rules. Provincial regulations dictate who is entitled to a groundwater use right, to a permit or licence, to allocation between competing water users, and when to remove or curtail those rights.

Some features of water laws in Canada include: integration of water management in a holistic law and administrative structure; formation of a water strategy; assertion of public ownership; and statement of the purpose of the law or regulation.

Most water or regulations contain objectives or purposes statements that link water management to environmental or sustainability objectives. They do not include "efficiency" as an objective but make specific reference to allocation and/or groundwater in the purposes section of a general water law. Mostly they are located in the regulations; for example in the Province of Quebec, the groundwater catchment regulation states: "Promote the protection of groundwater for human consumption, and govern groundwater catchment in order to prevent the catchment of that water by an owner or operation from causing abusive nuisance to its neighbors . . ." etc.

Environmental impacts of groundwater withdrawals are considered in most Provinces. As the knowledge on hydrogeology has grown, laws have evolved, water laws have grown out of need for consumptive uses; and environmental impacts of water withdrawals have become more evident.

There exist many common ways for regulators to address these impacts, such as cumulative impacts and protection of the natural ecosystem during licensing decisions; conservation requirements; and in-stream or environmental flow protection (Fishers' Act). Other indirect methods include: wetlands legislation, drought policies, and restrictions on water exports.

Other laws also regulate groundwater extractions: laws for provincial environmental assessment (CEAA 2012); municipal land use and development; special management areas (Ontario's ORM); utilities (water supply, health standards); Oil (oil-field injection), gas (fracking) and mining (Commissioner of the Environment and Sustainable Development 2001, 2012Commissioner of the Environment and Sustainable Development 2001, 2012).

Some Canadian provinces still use water management clauses, doctrines, and acts created to suit conditions prevalent at the time of the settlement in the late 1800s and early 1900s. The law of groundwater allocation, like most water laws, has proved adaptable. Progress is being made in adapting to new priorities such as watershed planning and environmental flows (Quebec, Ontario, British Columbia). Progress is slow and much remains to be made. A major impediment to efficient legal instruments has been the knowledge gaps of groundwater resources (Rivera, ed. 2015). It has become evident that the characterization and assessment of aquifers is crucial to better management. Knowledge about groundwater hydrodynamics in Canada would provide a scientific foundation for developing policy; however, that knowledge is still incomplete.

The 1987 Federal Water Policy committed to a number of actions, such as developing national guidelines for groundwater assessment and protection, and measures to achieve appropriate groundwater quality in transboundary waters. The policy presents the federal government's philosophy and goals as to how water should be managed in Canada in the best interest of Canadians, now and in the future, under a joint and cooperative management approach with the provinces. To this day, the policy remains largely unimplemented and remains in the public domain for information purposes only.

The different spheres of responsibility for groundwater management in Canada overlap and therefore sometimes conflict. The problem is not so much complexity as fragmentation, often intra-jurisdictional, with a lack of coordination (CCA, 2009). For example, permit allocations made by provincial regulators may diminish baseflows to streams critical for fish habitat and biodiversity maintenance, two areas of federal responsibility (Saunders and Wenig, 2006). Another example occurs when provincially managed groundwater violates health guidelines for drinking water, affecting a municipality's ability to use that source for municipal supply. This is complicated further where groundwater migrates across the Canada-US border, which impacts on American consumers and farmers, as in the case of the Abbotsford–Sumas aquifer discussed before. Resolving these overlaps and conflicts is an essential prerequisite for sustainable groundwater management of TAS.

In some cases, a question is asked on whether legal instruments are really needed. In the absence of national governmental interests and involvement on either side of the international borders, some authors advocate an alternative approach, one that sidesteps the respective federal authorities. For instance, Eckstein (2013) proposes that subnational entities at the regional and local level pursue cooperation in the form of locally-specific, cross-border arrangements. These may take the form of informal memorandum of understanding, or more structured contracts for goods or services. Such arrangements are likely more achievable and apt to create viable cross-border pacts that would be respected by the local communities. Moreover, they are more likely to achieve a sustainable and water-secure future for the border, its communities, and the natural environment. Some cases already exist, for instance under the unique circumstances of the Mexico-U.S. border.

In the Canada-U.S. border, the Abbotsford–Sumas TAS is following a similar approach as advocated by Eckstein (2013) one that sidesteps the respective federal authorities. It proposes that subnational entities at the regional and local level pursue cooperation in the form of locally-specific, cross-border arrangements (Province of British Columbia and State of Washington).

Bottom up is a good approach but not without a top–down framework that would allow and support this approach, otherwise this could lead to litigation. This cuts across Federal vs States rights in the US, and Federal versus Provinces rights in Canada. Only Federal governments have the right to enter into agreements with other sovereign nations. The practice in Canada, however, has always been consensus between Federal government and provincial governments, as it has been the case for the Great Lakes agreements.

5.3. Social issues

The main driving forces behind the growing interest in TAS are human activities, energy development, and environmental impacts.

Recognizing the particular importance of transboundary aquifers, nations and international agencies around the world have begun exploring mechanisms for governing these hidden resources. These include formal efforts to manage and regulate transboundary aquifers, such as the rigorous scheme implemented on the Genevese Aquifer along the French–Swiss border, to more general cooperative regimes, such as the Guarani Aquifer Agreement in South America, to instruments aimed mainly at an initial exchange of scientific data, as developed for the Nubian Sandstone and North Western Sahara aquifer systems in Northern Africa. It also includes informal efforts forged by subnational political entities, like the unofficial arrangements crafted for the Hueco Bolson aquifer underlying the cities of Juárez and El Paso on the Mexico–United States border, and for the Abbotsford–Sumas Aquifer between the American state of Washington and the Canadian province of British Columbia.

People need water to survive, ecosystems need it to sustain themselves; a range of important socio-economic actors rely on water for their daily businesses. Even energy is heavily dependent on water. Shale gas requires tremendous amounts of water to operate and hydropower, obviously, relies on the availability of water in a specific region. Taking into account the importance of water for society, one would assume that we all know where our water comes from (Sindico, 2015). But the reality is that almost all available freshwater resources in the world are an invisible natural resource. In fact, groundwater accounts for a staggering 97% of available freshwater resources. This fact alone calls out for greater attention for groundwater management, but a further facet is also seldom recalled in the literature, let alone in the media or at policy level. The "political" challenges of managing an invisible resource that is divided between two or more countries should be apparent immediately. However, information about transboundary aquifers, let alone the very existence of TAS, prevents people from being concerned, considering the myriad of other challenges we have to face in the field of natural resources. Policy makers and diplomats have already enough on their hands in trying to deal with, for example, climate change. As of 2010, both Canada and the USA agree on the existence of 10 transboundary aquifers located along the Canada/USA border (Table 2), and it is suspected that many others exist.

Assessing the dynamics underground is not easy, but in addition to the science, it is also a challenge getting water users and various levels of government to partner on projects to assess TAS. In dealing with TAS, the key is not just the science, but in bringing the people together. For instance during the course of the assessment of the Milk River transboundary aquifer, six jurisdictions (federal, state, provincial and regional) agreed to co-operate on the project, but a group of indigenous Native Americans in Montana didn't agree to participate.

For such groups, sometimes social participation is much more important and more relevant than the political or economic aspects of a project, if they do not feel themselves "proprietors" of the project, they will refuse to cooperate. Thus social participation should be sought at the very early stages of a TAS project. TAS require a review of socioeconomic and cultural issues pertaining to the shared management of transboundary aquifer systems. In the design of a TAS study that may include two or more jurisdictions, all type of benefits should be listed, industrial and agricultural development, economic growth, poverty reduction, food security, better health conditions, and improved livelihoods.

The creation of mechanisms to promote equitable and reasonable utilization considering diversity and needs of people sharing the aquifer go a long way in the success of the study results. The incorporation of shared rights and obligations with a common vision for sustainable TAS will build trust and avoid conflicts in societies sharing the TAS. The ISARM-Americas group has prepared a regional strategy for the Assessment and Management of the Transboundary Aquifer Systems of the Americas (Rivera, ed. 2015). This strategy strongly encourages the implementation of actions on TAS to be taken not only by central government agencies, but also by local and regional agencies (provincial, state, municipal), and society as a whole (Rivera et al., 2015).

6. Summary and recommendations

Canada's involvement with ISARM, combined with increased communication and information sharing between Canadian and American organizations, suggests that groundwater will play a major role in future relations between these two nations.

Although groundwater's importance is increasingly being recognized in the US and in Canada, substantial research and institutional changes are needed to adequately protect these resources. Groundwater's vulnerability to depletion could lead to future conflicts over use, especially in the Prairie regions, so it is also important that researchers examine scientific processes, sustainable yield and priority use. Some feel that the threat of bulk water transfers will be the push needed for governments, politicians, and the public to recognize the enormous value of aquifers. This body of literature emphasizes the need for more scientific data, widespread education and training, and a more clearly defined governments' role to effectively manage groundwater at a national and international levels.

Existing problems in transboundary aquifers and the impact of groundwater on surface waters shared by Canada and the United States will grow as population and usage increase. Although the International Joint Commission (Canada–US) has, at times, interpreted the Boundary Waters Treaty to include groundwater, this is a somewhat imperfect treaty for the purpose. The United Nations General Assembly has prepared a detailed resolution on Transboundary Aquifers that should be considered for adoption by Canada and the United States. Examples of transboundary issues involving groundwater include the Abbotsford–Sumas aquifer, the Milk River aquifer and the Great Lakes Basin. Public attitudes have also been evolving, with an increasing emphasis on environmental values. Although the United States has long recognized the importance of their groundwater resources, never before has the quality and availability of groundwater been of greater importance for Canadians.

Many challenges remain, and many actions are needed: Legal and institutional instruments; shared management practices; social participation; innovative S&T to assess TAS; policy based on informed decisions; open communication and education.

A more participatory approach would be required to trigger cooperation between the two countries and make available groundwater-related information locked at national and local levels. A systematic approach of data collection to establish cohesive and accessible databases in order to allow global comparison and discovering of data/information gaps would be a first step. A good example of a potential type of agreement to assess TAS is the mechanism of "minutes" used by the US and Mexico for assessing TAS through the IBWC (Minute 319, 2012). Canada could learn from this practice, which could reaffirm the top–down framework that allows bottom–up local agreements subject to some limited review/approval process.

We hope that this paper has classified core issues to identify variables from the managers' viewpoint on scientific, political and social aspects. As such it represents a source for this body of knowledge readily available to others confronted with scientific, social or political analyses and/or studies. Basically, the studies aim at strengthen transboundary water management by facilitating information sharing and knowledge management.

Conflict of interest

None.

Acknowledgements

The author would like to acknowledge the important technical support provided by The Geological Survey of Canada (Groundwater Geoscience Program), and the ISARM-Americas (joyous) group. This is an Earth Science Sector contribution 20150114. This paper has benefited from the generous comments of Randy Hanson, and two Journal reviewers, Norman Grannemann and an anonymous reviewer.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ejrh.2015.09.006.

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