A REVIEW OF TRANSBOUNDARY GROUNDWATER APPORTIONMENT

Prepared for the PPWB
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PRAIRIE PROVINCE WATER BOARD

EXECUTIVE SUMMARY

Groundwater provides an important component of water supply in the Prairies providing approximately 25% of the domestic water supply in Manitoba, Saskatchewan and Alberta. In rural areas, 90% or more of rural domestic water supplies and a significant percentage of livestock drinking water supply come from groundwater. Groundwater also contributes significantly to surface water flow, especially during dry periods.

There are nineteen aquifers spanning interprovincial boundaries in the Prairie Provinces. 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. Groundwater is currently not apportioned between the provinces because i) there has not been enough information on the extent of interprovincial aquifers to adequately apportion resources; ii) there has not been a structure or method for apportionment of the resources; iii) adequate supplies of surface water have, for the most part, been available on the Prairies and, therefore, apportionment of groundwater is not a priority; and iv) with the exception of the Hatfield/Helina system in the Cold Lake area, interprovincial aquifers have not been extensively used and, therefore, no significant issues have arisen. Nevertheless, as the importance of groundwater is growing, the Prairie Provinces Water Board (PPWB) wants to prevent possible transboundary issues by developing concepts for managing and apportioning interprovincial aquifers. In the present study, a literature review of policy and procedures for groundwater apportionment elsewhere has been undertaken to assist the PPWB in its work.

The activities of the U.S.-Canada International Joint Commission, the U.S.-Mexico International Boundary and Water Commission and other international legal and administrative bodies were reviewed for formal and informal policies and procedures governing groundwater. In addition, ten other specific arrangements for managing transboundary groundwaters or combined transboundary surface water and groundwaters were also reviewed for details on apportionment and protection of transboundary aquifers. As well, the groundwater aspects in the Israeli-Palestinian negotiations and a dispute between Czechoslovakia and Hungary concerning groundwater were considered.

The Helsinki and Seoul Rules adopted by the International Law Association establish the generally accepted customary principles applicable to water shared between jurisdictions including groundwater. These principles include i) the obligation not to cause appreciable harm to another state through the use of shared water resources; ii) the equitable and reasonable use of shared water resources; iii) the obligation to give prior notice of any water resource development that has the potential to affect another state; and iv) the duty to negotiate in good faith for the resolution of conflicts between states. The Helsinki and Seoul Rules set the stage for development of the Bellagio Draft Treaty, an outline of an agreement to guide the allocation and management of transboundary groundwater between nations. While the Bellagio Treaty and international law provide an administrative framework to be used as a guideline for negotiating agreements, technical details on the allocation and protection of each transboundary aquifer need to be developed through negotiations between jurisdictions.

Although the review concluded that international policies and procedures for apportioning transboundary aquifers is at a preliminary stage, the administrative principles that were identified provided a useful basis to build upon. The equitable and reasonable use of shared waters is the most essential principle to consider when negotiating a groundwater apportionment method for the interprovincial aquifers of the Prairie Provinces. Other factors that need to be considered in any apportionment scheme are:

i) the priority of use;

Although a similar priority of use has been established in each province, the priority needs to be considered in allocations of groundwater from an interprovincial aquifer. Flexibility in the interjurisdictional transfer of water would allow for higher priority use to supersede the rights of lower priority uses of the other jurisdiction provided that they would be fully compensated for reasonable economic losses resulting from the loss of water supply through transfer.

ii) the sustainable yield of the aquifer;

Aquifer management plans that include estimates of sustainable safe yields should be developed for each of the interprovincial aquifers and used for the equitable apportionment of the resource.

iii) the joint apportionment of surface water and groundwater;

A method for incorporating surface water/groundwater interactions will have to be developed for interprovincial aquifers. The joint apportionment of surface water and groundwater will complicate the development of an apportionment agreement because conceptual differences related to basin boundaries, response times, resource magnitudes and units of measurement will have to be resolved with surface water hydrologists.

iv) the specification of pumping locations and amounts;

Pumping limitations may need to be imposed to prevent excessive drawdowns near the boundary and to minimize degradation of transboundary water quality.

v) the existing PPWB apportionment agreement;

Changes in streamflow or lake levels due to groundwater withdrawals should be included in water balances when aquifer management plans have been formulated for those aquifers interacting with interprovincial lakes or streams.

vi) the provincial allocation methods.

Similar practices are used in each of the Prairie Provinces to allocate groundwater; however, unlicensed domestic use is defined differently in each of the provinces. Allocation of each province's share of groundwater in a common aquifer can be done using existing allocation methods but it is suggested that unlicensed domestic uses, if significant, be estimated from water well inventories for transboundary aquifers and included in the apportionment.

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(1) INTRODUCTION

Groundwater represents slightly more than 30% of the fresh water resources in the world. The majority of fresh water (68.7%) is in the form of glaciers and permanent snow. Less than one percent of the total amount of fresh water is found in lakes, streams and other surface bodies of water (Eckstein, 1998). Because surface water is visible and readily accessible, the importance of groundwater and its susceptibility to pollution are frequently overlooked. In parts of the world, population growth and industrial developments have caused an increase in water demand that cannot be met by surface water alone. As a result, the rate and quantity of groundwater consumption and diversion is increasing, and potentially causing drawdown and depletion of aquifers in some areas.

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. However, there are only a limited number of existing treaties and laws to guide the management of the transboundary aquifer. Most international water treaties are limited to surface waters, failing to include groundwater (Caponera and Alhéritière, 1978).

Approximately 24% of the population in Manitoba, 27% in Alberta and 54% in Saskatchewan rely on groundwater for their domestic water supply (Hess, 1986). Since these statistics were compiled, however, the city of Regina has switched from about 38% to less than 5% of its water supply from groundwater; therefore, the percentage of population in Saskatchewan that relies on groundwater has likely dropped to values similar to those in Manitoba and Alberta. Nevertheless, groundwater provides an important component of water supply in the Prairies providing 90% or more of rural domestic water supplies and providing a significant percentage of livestock drinking water supply. Groundwater also contributes significantly to surface water flow, especially during dry periods.

There are several interprovincial transboundary aquifers in the Prairie Provinces of Alberta, Saskatchewan and Manitoba. Thirteen transboundary aquifer systems that span the Alberta-Saskatchewan boundary have been identified and there are six aquifer systems identified as spanning the Saskatchewan-Manitoba boundary (Table 1). There are also several deeper geologic formations such as the Clearwater oil sands spanning the interprovincial boundaries that contain nonpotable saline groundwater. Many small Quaternary aquifers that are currently poorly defined may also straddle the interprovincial boundaries.

The Prairie Provinces Water Board (PPWB) administers the Master Agreement on Apportionment that governs the apportionment of interprovincial streams flowing eastward through Alberta, Saskatchewan and Manitoba. Several committees have been formed to monitor the provisions of the agreement. Through its Committee on Groundwater, the parties mutually agree to consider groundwater matters that have implications affecting transboundary surface and groundwater, to refer such matters to the Board and to consider recommendations of the Board on these matters (PPWB, 2000). However, groundwater is currently not included in the PPWB surface water apportionment calculations because i) there has not been enough information on the extent of interprovincial aquifers to adequately apportion resources; ii) there has not been a structure or method for apportionment of the resources; iii) adequate supplies of surface water have, for the most part, been available on the Prairies and, therefore, apportionment of groundwater is not a priority; and iv) interprovincial aquifers have not been extensively used and, therefore, no significant issues have arisen.

One notable exception to the use of interprovincial aquifers is in the area of Cold Lake that straddles the Alberta-Saskatchewan boundary. During periods of drought when the lake recedes to a predetermined level, water users (most notably Imperial Oil) switch their water

Table 1: Interprovincial Aquifers in the Prairie Provinces

ALBERTA-SASKATCHEWAN	LOCATION	SASKATCHEWAN-MANITOBA	LOCATION
· Wiau Buried Valley	Township 72	· Hatfield Buried Valley System	Townships 22-23
· Helina-Hatfield Buried Valley	Townships 63-64	· Rocanville Buried Valley	Townships 15-16
· Vermilion/Big Meadow-Bronson Buried Valley System	Townships 59-62	· Carbonate Aquifer	Townships 53-63
		· Swan River Formation	Townships 33-46
· Rex Buried Valley	Township 52	· Welby Sand Plain	Townships 17-18
· Lloydminster Buried Valley	Townships 50-51	· Odanah Shales	Townships 1-14
· Wainwright-Battleford Buried Valley	Township 42		
· Sibbald-Eyre Buried Valley	Township 27		
· Calgary and Lethbridge-Tyner Buried Valley System	Townships 22-23		
· Johnsborough Buried Valley	Townships 13-14		
· Jaydot Buried Valley	Township 3		
· Belly River-Judith River Formations	Townships 1-53		
· Eastend/Ravenscrag Formations	Township 7-8		
· Bearpaw Formation sandstone members	Townships 6-8		

source to local aquifers in the Helina valley. The lake directly overlies the Hatfield/Helina aquifer system, a major interprovincial buried valley aquifer system. There is a strong hydraulic connection between the lake and the aquifer system. Because of the concern that heavy use of the aquifer could have an effect on Cold Lake and groundwater in Saskatchewan, the PPWB directed its Committee on Groundwater (COG) to evaluate and make recommendations on whether or not groundwater use should be included in the apportionment of water in the Cold Lake basin (PPWB, 1996). Although the Committee concluded that there is not an immediate need for apportionment of groundwater in the Cold Lake area, it recognized a need to develop a concept for apportionment of transboundary aquifers. The COG proposed this study to examine international policy and procedure for the management of transboundary aquifers.

The purpose of this study is to compile information on groundwater apportionment procedures in transboundary aquifers and prepare a literature review. As the importance of groundwater is growing, the PPWB wants to be prepared to respond to possible transboundary issues by developing some concepts for managing interprovincial aquifers. Transboundary groundwater apportionment principles are identified, and general procedures for developing an apportionment agreement are outlined. Based on consideration of these principles and procedures potential approaches for apportioning groundwater resources along the Alberta-Saskatchewan and Saskatchewan-Manitoba borders are suggested.

Preliminary identification of information related to transboundary aquifers was made using Internet searches. Specific agencies were contacted to request further information on details of particular agreements including types of data collected and maintained in a database for the management of the agreement. Information was also collected using interlibrary loans, online orders, and from specific agencies through mail.

(2) TRANSBOUNDARY GROUNDWATER APPORTIONMENT

Groundwater is a component of the hydrologic system in a basin or subbasin and may or may not interact directly with surface water bodies. The nature of groundwater and its relationship to surface water is often misunderstood causing it to usually be treated as a separate resource on its own. Groundwater is not a static component but is subject to subsurface flow and eventual discharge. It is aquifer discharge that gives rise to the base flow component of many prairie streams, without which some would only flow intermittently, mainly at times following periods of rain or snowmelt. Groundwater should be included in any water management strategy especially where a hydraulic connection exists between underground and surface water because changes in the quality and quantity of water in one system may impact the other. The International Joint Commission (IJC) recognizes the interaction between surface water and groundwater in the Great Lakes stating that "surface and groundwater resources are part of a single hydrologic system and should be dealt with as a unified whole in ways that take into account water quantity, water quality, and ecosystem integrity" (IJC, 2000).

i) Principles of Apportionment

The International Law Association (ILA) is a private nongovernmental organization formed in 1873 tasked with the development and nonofficial codification of international law (ILA, 2000). The ILA initially outlined surface water rights and the sharing of waters of international drainage basins including "underground waters" by producing the Helsinki Rules on the Uses of the Waters of International Rivers (ILA, 1966).

Article IV of the Helsinki Rules states that "Each basin State is entitled, within its territory, to a reasonable and equitable share in the beneficial uses of the waters of an international drainage basin". Relevant factors that should be considered when apportioning the waters between the states are stated in Article V and include:

1. The geography of the basin, including in particular the extent of the drainage area in the territory of each basin State;
2. The hydrology of the basin, including in particular the contribution of water by each basin State;
3. The climate affecting the basin;
4. The past utilization of the waters of the basin, including in particular existing utilization;
5. The economic and social needs of each basin State;
6. The population dependent on the waters of the basin in each basin State;
7. The comparative costs of alternative means of satisfying the economic and social needs of each basin State;
8. The availability of other resources;
9. The avoidance of unnecessary waste in the utilization of waters of the basin;
10. The practicability of compensation to one or more of the co-basin States as means of adjusting conflicts among uses; and
11. The degree to which the needs of a basin State may be satisfied, without causing substantial injury to a co-basin State.

At its 1986 Seoul conference, the ILA adopted the Seoul Rules on International Groundwater (ILA, 1986) that expanded on the Helsinki Rules as they relate to transboundary groundwater resources. They are the first attempt at developing legislative rules to protect and manage groundwater in international aquifers. The Seoul Rules state:

Article I - The Waters of International Aquifers

The waters of an aquifer that is intersected by the boundary between two or more States are international groundwaters if such an aquifer with its waters forms an international basin or part thereof. Those states are basin States within the meaning of the Helsinki Rules whether or not the aquifer and its waters form surface waters part of a hydraulic system flowing into a common terminus.

Article II - Hydraulic Interdependence

1. An aquifer that contributes water to, or receives water from, surface waters of an international basin constitutes part of an international basin for the purposes of the Helsinki Rules.

2. An aquifer intersected by the boundary between two or more States that does not contribute water to, or receive water from, surface waters of an international drainage basin constitutes an international drainage basin for the purposes of the Helsinki Rules.

3. Basin states, in exercising their rights and performing their duties under international law, shall take into account any interdependence of the groundwater and other waters including any interconnections between aquifers, and any leaching into aquifers caused by activities and areas under their jurisdiction.

Article III - Protection of Groundwater

1. Basin states shall prevent or abate the pollution of international groundwaters in accordance with international law applicable to existing, new, increased and highly dangerous pollution. Special consideration shall be given to the long-term effects of the pollution of groundwater.
2. Basin states shall consult and exchange the relevant available information and data at the request of any one of them.
(a) for the purpose of preserving the groundwaters of the basin from degradation and protecting from impairment the geologic structure of the aquifers, including recharge areas;
(b) for the purpose of considering joint or parallel quality standards and environmental protection measures applicable to international groundwaters and their aquifers.
3. Basin states shall cooperate, at the request of any one of them, for the purpose of collecting and analyzing additional needed information and data pertinent to the international groundwaters of their aquifers.

Article IV - Groundwater Management and Surface Waters

Basin states should consider the integrated management, including conjunctive use with surface waters, of their international groundwaters at the request of any one of them.

The Helsinki and Seoul Rules establish the generally accepted customary principles applicable to water shared between jurisdictions including groundwater (Barberis, 1991). These principles include:

- the obligation not to cause appreciable harm to another state through the use of shared water resources;
- the equitable and reasonable use of shared water resources;
- the obligation to give prior notice of any water resource development that has the potential to affect another state; and

- the duty to negotiate in good faith for the resolution of conflicts between states.

The Helsinki and Seoul Rules also set the stage for developing an administrative framework to govern the management of transboundary aquifers. The Ixtapa Draft Agreement (Rodgers and Utton, 1985) was developed by a group of legal, social and technical experts from the United States and Mexico to guide allocation and management of transboundary groundwater along their common border. In developing the terms of the draft treaty, they recognized that the terms must be designed to:

- insure each party a fair share of the use of transboundary groundwaters;
- encourage the prudent use of the resource over time;
- resolve potential and actual disputes over the use of resources; and
- protect the underground environment of the aquifers.

In 1987, an international conference on transboundary groundwater was held in Bellagio, Italy where experts from many other parts of the world systematically examined the articles of the Ixtapa Draft. Results of this review were used to prepare the Bellagio Draft Treaty (Hayton and Utton, 1989) proposing a framework for the management of shared aquifers in critical areas along international boundaries by a mutual agreement. The treaty provides an administrative framework to be used as a guideline for negotiating specific agreements regulating transboundary groundwater resources that incorporate cooperation and the maximum optimum use of international aquifers.

Comprehensive management plans are outlined in Article VIII of the Bellagio Draft for the rational development, use, protection and control of the waters in transboundary aquifers including a list of factors to consider when allocating groundwater, similar to the factors outlined by the Helsinki Rules. The comprehensive management plan may:

a. Prescribe measures to prevent, eliminate or mitigate degradation of transboundary groundwater quality, and for the purpose may:

(i) classify transboundary groundwaters according to use and coordinate the formulation of water quality standards;
(ii) identify toxic and hazardous contaminants in the Area and require a continuing record of such substances from origin to disposal;
(iii) establish criteria for the safe storage of wastes and maintain an inventory of dumpsites, abandoned as well as active, that have caused or may cause transboundary aquifer pollution;
(iv) propose a scheme for monitoring water quality conditions including the placement and operation of test wells and for remedial actions where required, including pretreatment and effluent discharge limitations and charges; and
(v) provide for the establishment where required of protective zones in which land use must be regulated.

b. Allocate the uses of groundwaters and interrelated surface waters taking into account any other allocation(s) previously made applicable within the Transboundary Groundwater Conservation Area.
c. Prescribe measures including pumping limitations, criteria for well placement and number of new wells, retirement of existing wells, imposition of extraction fees, planned depletion regimes or reservations of groundwater for future use.
d. Arrange, where conditions are favourable, programs of transboundary aquifer recharge.
e. Articulate programs of conjunctive use where appropriate.
f. Prescribe the integration and coordination of water quality and quantity control programs.
g. Include other measures and actions as may be deemed appropriate by the Commission.

All draft treaties noted above lack technical details on the allocation and protection of groundwater between jurisdictions. Consequently, technical details on the allocation and protection of groundwater for each transboundary aquifer need to be developed by incorporating the principles outlined in these international rules and treaties with negotiations between jurisdictions.

ii) Apportionment within a Jurisdiction

Three methods of groundwater allocation have been widely used within the United States. These are absolute ownership, reasonable use and the appropriation-permit system.

(a) Absolute Ownership

The "Absolute Ownership" doctrine is the oldest doctrine that applies to groundwater allocation. Landowners have complete ownership of water beneath the surface of their land and have the right to withdraw unlimited volumes of subsurface water found. Landowners may use the groundwater at their own discretion whether it is for personal use on their own land or to sell it to other people. Landowners are not held responsible for excess pumping causing neighbouring wells to go dry and are not obligated to compensate for harm or expenses that their groundwater withdrawals cause to other people. When conflict develops the person with the deepest well and the largest pump will prevail (Getches, 1984).

This method of allocation was used in Texas until 1993 when the Texas Senate Bill 1477 ended the right of free capture and created the Edwards Aquifer Authority to allocate and manage the resources. The method is no longer commonly used because it imposes few restrictions on the use of the resources and causes accelerated depletion of aquifers.

(b) Reasonable Use

Similar to the rule of absolute ownership, the rule of reasonable use holds that groundwater belongs to the overlying landowner. A landowner has the right to withdraw and use groundwater that lies beneath his land within reasonable limits. "Reasonable use" is simply considered to be any nonwasteful use of water for a purpose associated with the use of the land from which the water was withdrawn.

Any use of water off the land that interferes with the use of water by others is considered to be unreasonable. The landowner is responsible for harm caused to others by unreasonable use of the groundwater. If the use of groundwater interferes with a neighbour's use of groundwater, the user is allowed to continue only if the water use is reasonable. Landowners are not protected from neighbours that are high capacity users unless the neighbour's use is unreasonable (Getches, 1984).

The landowner has only qualified rights, not absolute rights to the use of groundwater. Correlative rights exist primarily when the groundwater supply is insufficient to satisfy the needs of all overlying users. When this situation arises, all users must reduce their use of water in order to share with others (Wright, 1990).

The groundwater in Arizona was allocated by the "reasonable use" method until 1981, when the failure to control groundwater mining led to the adoption of a complex permit system.

(c) Appropriation-Permit System

Most jurisdictions do not recognize private ownership rights in groundwater and consider it subject to management as public property. Groundwater is allocated through the use of permits and permits are issued based on a set of rules on priority of uses. Where there is little or no natural recharge the state must decide whether the resource can be "mined" and if so, at what rate and for what purposes. The objective is to balance the interests of senior users, optimize new economic uses and assure a sustained supply. Liability may be imposed on new groundwater users only for unreasonable harm caused to existing users with vested senior rights. The distinguishing feature of this doctrine is its administrative regulation and management of groundwater (Getches, 1984).

In the United States, some states have imposed the permit system by applying the appropriation statutes for surface streams to groundwater. For example, the state of Nevada allocates groundwater using the prior appropriation method where a permit is required for both surface and groundwater use.

The appropriation doctrine is based on the principle that a water user first in time is first in right. The appropriation-permit method is the basis for the establishment of the modern permit system used today. The permit system is a system that considers seniority of existing uses and their reasonableness as criteria for establishing water use rights. It is the system most closely meeting the principle of equitable use proposed for transboundary groundwater allocation (Caponera and Alhéritière, 1978).

iii)Apportionment between Jurisdictions

It is important to understand the nature of an aquifer so optimum allocation of resources in the aquifer can be made. Groundwater withdrawals that do not deplete the aquifer or negatively impact interrelated surface waters can be allocated without concerns for harm from one jurisdiction to another. Alternately, if the transboundary aquifer is treated as a stand-alone resource, allocations are usually limited to withdrawals that do not create a cone of depression beyond the border of the jurisdiction. This approach alleviates concerns about depletion in other jurisdictions but does not necessarily lead to the optimum development of the water resources.

Apportionment methods should divide the water justly and fairly between the two jurisdictions to minimize the potential for conflict. An understanding of the groundwater system is necessary to apportion transboundary groundwater effectively. Monitoring and data collection including field investigations may be needed to determine the geologic and hydrogeologic characteristics of the basin. In the initial stages of the investigations it is essential to present the hydrogeology in simple conceptual forms with graphical presentations. This should include a characterization of the transboundary aquifer geometry, the flow conditions including recharge and discharge areas and a description of the groundwater quality.

Information obtained from field investigations can be used in the development of a comprehensive database pertaining to transboundary groundwater. Article V of the Bellagio Draft Treaty specifies the creation and maintenance of such a database. An inventory of groundwater data should include aquifer properties such as flow path, travel time, discharge point, porosity, permeability, hydraulic gradient, water levels, water chemistry, well data, etc.

Numerical modelling may be used as a tool to explain the flow of groundwater and to evaluate the effects of various alternative management strategies on the aquifer. If there is mutual agreement on the choice of the model, data input, etc. the parties may use a model to allocate the groundwater according to schedules derived from the model for flow under different hydrologic conditions. However, the uncertainty of the modelling poses a significant risk that the model is inaccurate, in which case the allocation will not accomplish what the parties intended. By using the method, parties may divide risk of shortage any way they see fit, but the likely result is a division designed to reflect local, rather than basin-wide, variations in natural conditions because the modelling is usually done on subbasins rather than the whole basin (ASCE, 1999).

To prevent the depletion of an aquifer, maximum safe groundwater yields can be determined. A method of estimating the "safe yield" of an aquifer entails (ASCE, 1999):

- quantifying the rate of natural recharge to the aquifer;
- determining the quantity and rate of diversion, the consumptive use of water, and the rate of natural discharge from the aquifer;
- estimating changes in underground water storage or flow due to withdrawals; and
- quantifying the relationship between groundwater recharge, water table elevations, and aquifer discharges.

Once safe groundwater yields have been determined, the resource can be divided between jurisdictions according to some accepted formula. In principle, it may seem to be relatively straightforward to determine the safe yield of an aquifer but in practice it is very difficult to measure highly variable recharge rates over the area of an aquifer and to measure diffuse discharge to stream baseflow and evapotranspiration from vegetation. Estimates of safe yields frequently contain some unspecified factor of safety and may be revised from time to time as data on the response of the aquifer system to pumping are collected. Frequently, limits are placed on the amount of drawdown (measured regularly in a few wells at or near the border) that can occur at the boundary to safeguard against uncertainty in yield estimates.

Aquifers may be declared "critical" where water quantity is threatened by uncontrolled withdrawals or water quality is being jeopardized (Hayton and Utton, 1989). Possible measures may be taken to protect and remediate the groundwater within the aquifer including the regulation of well spacing and the institution of pumping rates to control withdrawals or in more severe cases, prohibition of any groundwater withdrawals. Public control of groundwater through the permit system and enforcement can make such strict controls possible.

iv) Factors Affecting Apportionment

(a) Data Limitations

The establishment and maintenance of a unified database pertaining to transboundary aquifers would be ideal. However, a complete set of data does not exist for most aquifers. Properties including aquifer quantity, aquifer quality, aquifer geometry, recharge rates, interaction with surface waters, hydraulic conductivity and storage characteristics would be necessary to completely describe the aquifer. Data collected by different jurisdictions may not always be comparable because of different monitoring and data collection methods.

(b) Aquifer/Hydrologic Systems

Aquifers occur in different natural states with various connections to other waterways. Transboundary groundwater found in an isolated aquifer is the most elementary case to consider because there is minimal interaction with other sources of water. The water within the aquifer is a finite resource and shared use would simply involve pumping the aquifer at a rate sustained by the natural recharge through the strata surrounding the aquifer or until the aquifer became dry. However, a completely isolated aquifer would probably be quite small and useable quantities of water would be limited.

It is common for a transboundary aquifer to be connected to a stream, a lake or another aquifer. When an aquifer is hydraulically connected to a stream or lake, diversion and consumption of waters from the aquifer and the river/lake must be considered because changes in the quantity and quality of water in one system may impact the other. A decrease in the water level of the stream or lake may cause the water table to drop in the aquifer whereas an increase in the water level of the stream or lake may cause increased flow into the aquifer and raise the water table. Similarly, changes in the quantity of water in the aquifer may affect water levels of the lake or stream. Large semi-confined aquifers may have a connection to sources of recharge through semi-permeable layers from the surface or from another aquifer. Areas of recharge and groundwater flow between aquifers are therefore part of the transboundary aquifer system that should be defined for allocation purposes (Barberis, 1991).

A more specific case exists where an aquifer found entirely in one jurisdiction is connected to a transboundary lake or stream. If the aquifer is located in the downstream jurisdiction, the use of water by the upstream jurisdiction may affect aquifer recharge. If the aquifer is located in the upstream jurisdiction, groundwater pumping may reduce the volume of water reaching the stream. In both of these scenarios, water use in a noncommon aquifer may still interact with water of the shared hydrologic system (Barberis, 1991).

Under natural conditions, a regional groundwater system exists in a state of approximate equilibrium, and a long-term balance between natural recharge and discharge processes maintains this equilibrium. During wet years recharge exceeds discharge and in dry years discharge exceeds recharge. Because long-term recharge and discharge are in balance, there is no change in groundwater storage (Bouwer and Maddock, 1997).

The long-term, natural flow through an aquifer that is maintained by the balance between recharge and discharge is usually considered to be the amount of groundwater that can be pumped from the aquifer without producing an unacceptable impact (Figure 1a). Such withdrawal captures groundwater that would otherwise discharge naturally to a lake, a river or another aquifer. By lowering the water table slightly, the withdrawal also reduces losses by evapotranspiration such that a new balance between recharge and discharge is established and the pumping does not deplete groundwater stored in the aquifer (Figure 1b). However, the capture of this water will affect other parts of the hydrologic system (e.g. evapotranspiration, baseflow) and, therefore, sound management dictates that the entire system be managed as a single unit. The linkage of surface water and groundwater concepts must be considered in the accounting and allocation of the components of the hydrologic system. In particular, one must be aware that i) the boundaries of surface water and groundwater basins do not necessarily coincide; ii) there is a significant difference in response times for the two systems; iii) accounting procedures must allow for the inherent variance (i.e. an order of magnitude) in groundwater budgets; and iv) groundwater and surface water budgets are not always defined in a common set of units.

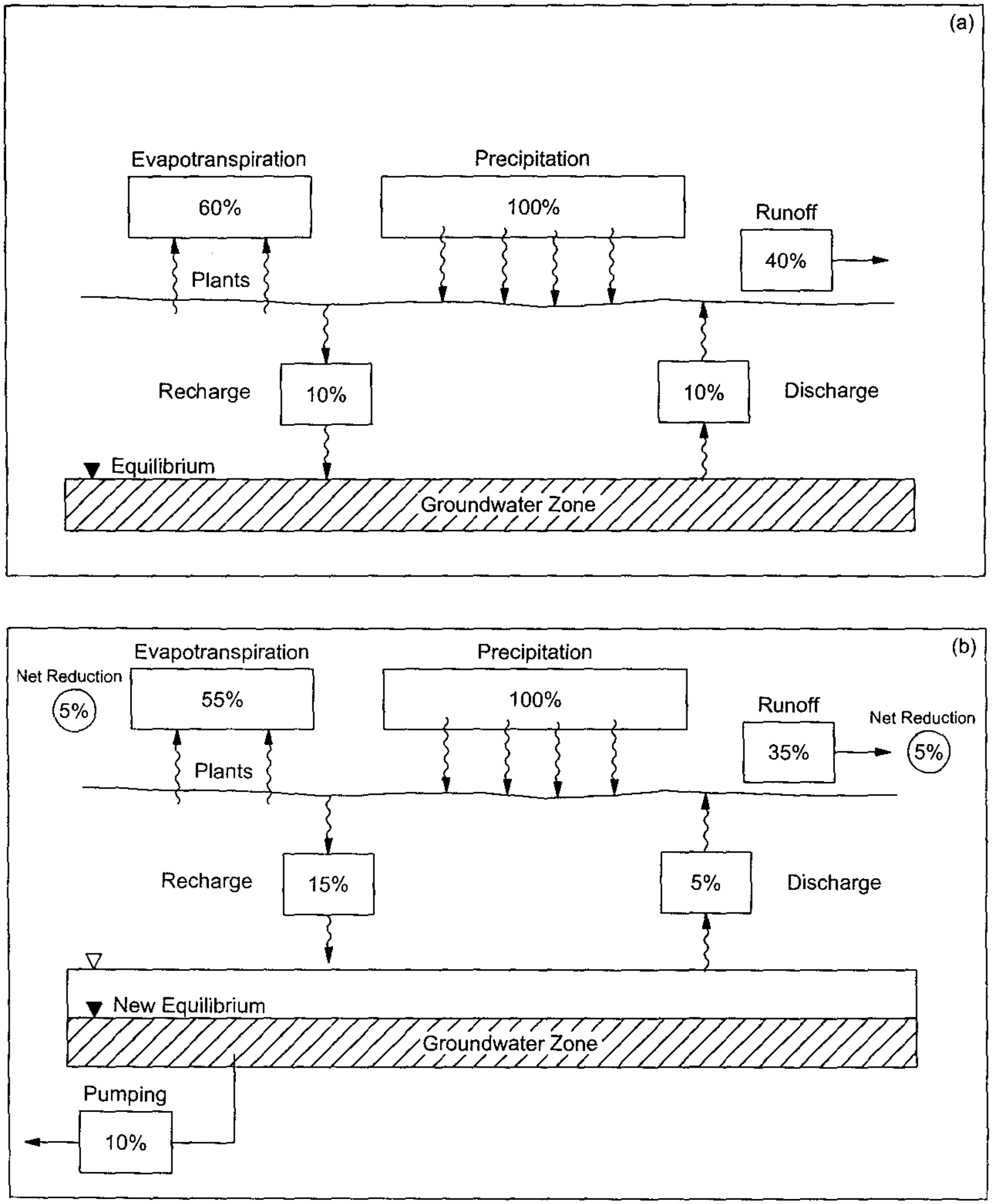

Figure 1. Schematic representation of effects of groundwater development on hydrologic systems: (a) Dynamic balance for predevelopment scenario, (b) Dynamic balance for development scenario

Pumping groundwater from an aquifer causes an imbalance in the system that must be stabilized by increasing the recharge to or decreasing the discharge from the aquifer, by loss of storage in the aquifer or by a combination of these processes. Numerous definitions of aquifer yields have been given (see, for example, Freeze and Cherry, 1979; Saskatchewan-Nelson Basin Board, 1972). These have included yields that are maintained by induced infiltration of water from a lake/stream or another aquifer and economic considerations such as allowing some depletion of storage while maintaining acceptable pumping lifts. A common understanding of the nature, extent and quality of the resource, particularly in the vicinity of interprovincial boundaries must be based on mutual agreement on the classification of aquifers in terms of yield, on the criteria on which a yield figure is based and on the water quality criteria determining the various types of groundwater use.

(3) CURRENT AND PROPOSED INTERNATIONAL PRACTICES

i) North American International Organizations

(a) U.S.-Canada International Joint Commission

The International Joint Commission (IJC) was established under the 1909 Boundary Waters Treaty. The Treaty provides the principles and mechanisms to help prevent and resolve disputes, primarily those concerning surface water quantity and quality along the international boundary between Canada and the United States. One of the responsibilities of the IJC is, at the request of the governments, to review issues that arise regarding transboundary surface waters and make recommendations based on the rules and principles set forth in the treaty (IJC, 1998).

The 1909 Boundary Waters Treaty does not mention groundwater. While the governments have never specifically requested the IJC to address the management of transboundary aquifers, the Commission has made reference to groundwater in a number of its studies.

Transboundary aquifers were first considered by the IJC in 1977 when the Commission was asked to examine the transboundary impacts of the proposed Saskatchewan Power Corporation's thermal power plant and coal mine near Coronach, Saskatchewan on the Poplar River basin and underlying aquifers.

Dewatering of coal seams at the mine was the main concern from a groundwater perspective because groundwater is the main source of supply in the basin. The International Poplar River Water Quality Board set up to conduct the review recommended that groundwater near the international boundary should be monitored on a regular basis to detect chemical quality and water level fluctuations (International Poplar River Water Quality Board, 1979a). The Poplar River Bilateral Monitoring Committee was subsequently formed to carry out all monitoring at the site.

In 1988, the IJC examined and reported upon the potential impacts of a proposed British Columbia coal mine development on Cabin Creek, a tributary of the Flathead River. The Flathead River valley extends along the southeastern corner of British Columbia and the northwestern part of Montana. The impact on quantity and quality of local groundwater resources was one issue addressed. On the recommendation of the IJC the mine was not developed because of the impacts it would have on fish habitat partly as a result of groundwater flows and contaminant transport between the mine site and Howell and Cabin Creeks. The habitat degradation was expected to cause an unacceptable loss to the sport fishery in the U.S. (IJC, 1988).

In a Water Uses Reference given to the IJC in February 1999, the governments requested the Commission to consider groundwater of shared aquifers as part of a review of consumptive uses, diversions and removal of water in boundary and transboundary basins. The IJC was to initially focus on the Great Lakes, then was to consider additional work that may be required to better understand the implications of consumption, diversions and removal of surface water and shared groundwater from other basins along the boundary (IJC, 1999). The final report of the study was released on February 22, 2000 (IJC, 2000). Although the final report focussed largely on the Great Lakes basin, the

Commission said that similar studies should be completed for other shared basins along the boundary.

The report states the importance of groundwater's contribution to streamflow and lake levels of the Great Lakes. Groundwater recharge is mainly from percolation of precipitation in the Great Lakes basin; therefore, when discharge exceeds recharge in the basin, water may be drawn from streams and lakes into the groundwater system, thus reducing the amount of water discharged to the Great Lakes.

The report also states that groundwater consumption and groundwater recharge in the Great Lakes basin are misunderstood for the following reasons:

- There is no unified, consistent mapping of boundary and transboundary hydrogeological units.
- There is no comprehensive definition of the role of groundwater in supporting ecological systems.
- Although some quantitative information is available on consumptive use, in many cases the figures are based on broad estimates and do not reliably reflect the true level and extent of consumptive use.
- There are no simplified methods for identifying large groundwater withdrawals near boundaries of hydrologic basins.
- Estimates of the effects of land-use changes and population growth on groundwater availability and quality are needed.
- There is inadequate information on groundwater discharge to surface water streams and inadequate information on direct discharge to the Great Lakes.
- There is no systematic estimation of natural recharge areas.

Although there is uncertainty and a lack of adequate information about withdrawals of groundwater, it is estimated that about 5% of all withdrawals in the basin are from groundwater. Consumption of groundwater does not currently appear to be a major factor with respect to Great Lakes levels. It is nevertheless a matter of considerable concern and importance to the more than 20% of the basin's population who rely on groundwater (IJC, 2000).

(b) U.S.-Mexico International Boundary and Water Commission

The International Boundary and Water Commission (IBWC) was developed by the governments of the United States and Mexico to exert the regulations of various boundary and water treaties to resolve disputes between the two countries through a joint international commission. The IBWC is composed of federal, state and local agencies from both the United States and Mexico. The IBWC's jurisdiction extends along the United States-Mexico boundary, and inland into both countries where they may have international boundary and water projects (IBWC, 1996).

Treaties exist for apportionment of surface water in the international rivers that form about two thirds of the boundary between the United States and Mexico. Similar apportionment does not exist for surface streams that cross the boundary and for groundwater basins straddling the boundary (Ybarra, 1999, personal communication).

In the 1973 agreement on a permanent and definitive solution to the international problem of the salinity of the Colorado River, the governments of the United States and Mexico provide for groundwater development in the Colorado River area pending the conclusion of a comprehensive agreement on groundwater in the border area. Point five of IBWC Minute 242 establishes a protective and regulatory groundwater pumping arrangement between the governments of the United States and Mexico "limiting pumping of groundwaters in border territories within five miles of the Arizona-Sonora boundary near San Luis to 160 000 acre-feet (197.4 million m^3) annually". In order to supply the annual volume of Colorado River flow guaranteed to

Mexico under the Treaty of 1944, the United States proposed to supply approximately 140,000 acre-feet (172.7 million m^3) to Mexico from its allocation of this groundwater resource in the border area (Caponera and Alhéritière, 1978).

Point six of Minute 242 requires the United States and Mexico to consult with each other "prior to the undertaking of any new development of either the surface or the groundwater resources, or undertaking substantial modifications of present developments, in its own territory in the border area that might adversely affect the other country" (IBWC, 1998).

The United States and Mexico have been exchanging groundwater data along the U.S.-Mexico border since 1974. By doing this they have identified the aquifers that lie on the international boundary and integrated official groundwater data from the United States and Mexico into one database that is maintained by the IBWC. In recent years, binational data gathering efforts have led to a general characterization of the aquifers along the Rio Grande in the El Paso-Juarez area where high groundwater use has caused significant drawdowns at the border. Along the Rio Grande, the Mesilla aquifer from Las Cruces, New Mexico to El Paso, Texas and the southeastern Hueco aquifer extending 88 km downstream of El Paso county were investigated in the same study but groundwater development in these aquifers is much less in the vicinity of the U.S.-Mexico boundary (Texas Water Development Board and New Mexico Water Resources Research Institute, 1997). Similar programs have started for the Rio Grande from Amistad (near Del Rio, Texas) to Falcon (about 120 km downstream of Laredo, Texas) dams and along the Santa Cruz River in Southern Arizona-Northern Sonora (Ybarra, 1999, personal communication).

ii) Groundwater Arrangements

(a) Poplar River

The Poplar River basin straddles the Canada-U.S. international boundary (Figure 2) with the upper third located in southern Saskatchewan and the lower two thirds lying in Montana. The Poplar River has three main tributaries which include the East Poplar River (East Fork), Poplar River (Middle Fork) and West Poplar River (West Fork in Montana), each originating in Canada. These rivers drain parts of Saskatchewan and Montana and are tributary to the Missouri River near Poplar, Montana. In 1977, the IJC was asked to examine the transboundary impacts of a proposed thermal power plant and coal mine on the basin and its underlying aquifers. From a groundwater perspective the main concern was the dewatering of coal seams for the strip mine. Groundwater from the Poplar River basin is the main source of water in Coronach, Saskatchewan and surrounding areas and is the only source of water for the population of Scobey, Montana; thus, impacts from the mine on the underlying aquifers could have serious effects on both countries.

The IJC based its assessment primarily on existing groundwater and chemical data obtained from a number of available sources. In addition, ten new wells were drilled in the East Poplar River subbasin near the international border and in northern Montana for water level measurements and water samples for chemical analysis. Results from the tests were compared to the earlier data results to check reliability of the existing data. The new wells also provided information on hydraulic continuity, hydraulic properties and critical observation points for monitoring changes in groundwater quantity and quality as a result of the power plant (International Poplar River Water Quality Board, 1979b).

Figure 2. General location of North American transboundary groundwater arrangements

Numerical models were used to simulate the long-term behaviour of the Poplar River basin by combining effects of recharge, discharge, and hydrogeologic boundaries. Properties required to run the models included hydraulic head, specific yield, flux in and out of the aquifer, pumping rate, storage coefficient, and layer thickness. A finite element model was used to evaluate the effects of dewatering and natural recharge by precipitation and a finite difference model was used to estimate the water levels within the aquifer system (International Poplar River Water Quality Board, 1979b).

Since September 23, 1980 the Poplar River Bilateral Monitoring Committee composed of technical representatives from the governments of Canada, the United States, Saskatchewan and Montana has been responsible for the exchange of monitoring data and information collected in Canada and the United States, at or near the international boundary. The Committee submits an annual report to the federal, provincial and state governments that summarizes the monitoring results for quantity and quality of surface water, groundwater and air quality and evaluates apparent trends. The annual data exchange between countries includes groundwater quality data (including chemical parameters such as TDS, pH, conductivity, concentrations of specific elements) and groundwater level data (Poplar River Bilateral Monitoring Committee, 1998).

The emphasis of the Committee has been on the development of standard procedures for the collection of all data on either side of the boundary and an accepted system for data assessment. Field and laboratory quality assurance/quality control programs are regularly undertaken to ensure comparability and reliability of the data. However, the data are not kept in a dedicated database and the original numerical modelling to assess the impacts of the groundwater pumping has not been maintained.

Groundwater pumping was originally used for mine dewatering. However, in 1990, due to drought conditions, SaskPower began using the dewatering wells as a supplementary water source for the Cookson reservoir that was built on the East Poplar River to provide cooling water to the power plant. The original modelling of mine dewatering predicted a maximum drawdown of 0.7 m near the international boundary after 35 years of dewatering. Groundwater level monitoring indicates that a nearly stable drawdown cone has developed since pumping began in 1978 and drawdowns at the boundary have remained less than 1m.

(b) Hueco-Tularosa and Rio Grande Aquifers

The Hueco-Tularosa and Rio Grande aquifers (Figure 2) are the key source of water for the cities of El Paso, Texas and Juarez, Mexico and for military installations and smaller cities in New Mexico, Texas and Mexico. Groundwater is also used to supplement irrigation water from the Rio Grande during dry periods. The drawdown cones from municipal wells in El Paso and Juarez interact with one another and heavy pumping in these well fields is causing the salinity of the groundwater to increase. In 1973, the International Boundary and Water Commission initiated the exchange of groundwater data between El Paso and Juarez in recognition of the need for the development of a comprehensive agreement on groundwater management. However, this initiative has met with political opposition in Texas (Day, 1978). Furthermore, groundwater was viewed as private property belonging to individual landowners (i.e. absolute ownership) in Texas until 1993 when the Texas Senate ended the right of free capture of groundwater resources.

The IBWC has continued to promote binational data gathering efforts leading to a general characterization of the aquifers in the El Paso-Juarez area and the development of a common database and a model (Texas Water Development Board and New Mexico Water Resources Research Institute, 1997). Types of data included within the database are land use, well data (construction, ownership, well use, etc.), core descriptions, groundwater levels in wells, and results of groundwater quality analyses and pumping tests. The study used well established hydrogeological, hydrochemical and numerical modelling techniques to trace groundwater flow paths, to assess regional water quality, and to define aquifer recharge and discharge areas and areas susceptible to contamination.

The binational technical working group established to complete the aquifer study has recommended that a formal procedure and time table for binational groundwater exchange should be established; that a binational aquifer water level and water quality monitoring network with agreed upon monitoring frequencies and protocols should be set up; and that the working group should extend its work on aquifer characterization and seek technical solutions to common groundwater problems.

(c) Abbotsford-Sumas Aquifer

The Abbotsford-Sumas aquifer (Figure 2) is the largest unconfined aquifer in the Lower Fraser River valley in British Columbia and the Nooksack River valley in Washington State. This aquifer is highly vulnerable to contamination from surface activities and is widely used as a source of water for industrial, irrigation, municipal and domestic uses, as well as providing baseflow for surface water streams tributary to the Fraser (linked indirectly by Sumas River), Nooksack and Sumas Rivers. The predominant direction of groundwater flow is from the upland recharge area in British Columbia, southwards, into the state of Washington. Over the past forty years, various government agencies on both sides of the border have collected data and documented a deteriorating trend in groundwater quality as nitrate concentrations have increased and trace levels of pesticides and volatile organic compounds have been detected.

In 1992, the British Columbia/Washington Environmental Cooperation Council created the Abbotsford-Sumas Aquifer International Task Force to make recommendations to the Council on both water quality and water resource management issues on both sides of the border. The current state of the aquifer has spurred the Task Force to take a proactive role in identifying solutions to current and future issues, to recommend long term strategies to solve the systemic problems facing the resource and to coordinate transboundary groundwater resource management and protection efforts among various agencies in British Columbia and Washington. To date, the Task Force has cooperatively (Ringham and Thompson, 1994):

- identified and delineated the extent of the aquifer;
- determined agricultural and urban/nonagricultural land use issues and their impacts on the groundwater resource;
- identified existing government legislation for the protection of groundwater resources;
- identified water management issues, including water allocation and water use;
- identified the public health issues associated with contaminated groundwater;
- developed a list of technical data regarding the aquifer; and
- outlined an educational and public awareness campaign, including publication and distribution of two information brochures.

The Task Force has established a water rights memorandum of agreement to provide for consultation and information sharing between provincial and state agencies on water resource allocation where such allocation has the potential to significantly impact water quantity and quality across the border. The memorandum reaffirms that jurisdiction over water resource allocation rests with the province of British Columbia and the state of Washington. The Task Force is also preparing a memorandum of agreement related to the sharing and exchange of groundwater information on the Abbotsford-Sumas aquifer. This memorandum is designed to facilitate sharing and exchange of groundwater information among the agencies by documenting procedures for collecting and storing groundwater data, by preparing listings of monitoring sites and by compiling a reference list of reports on the aquifer.

The Task Force meets on a regular basis, generally twice a year to report on aquifer protection and management activities, new funding and study initiatives and current groundwater quality conditions. The Task Force is currently working on completion of a water quality status report. Other initiatives include a water budget study; continued outreach to the academic arena to do research on the aquifer; and enhancing public awareness.

The high level of interest and cooperation among the various levels of government in British Columbia and Washington, and other agencies has been exceptional. In spite of resource and time limitations, the Task Force continues its goals of ensuring that long term strategies for the effective management of this highly sensitive international aquifer are developed jointly.

(d) Palouse Basin

Water resources from the Palouse basin are shared between Washington and Idaho. Groundwater is the sole source of water for the cities and surrounding regions of Pullman, Washington and Moscow, Idaho for domestic, municipal and industrial use. The majority of the Palouse basin aquifer system lies in Washington. Recharge occurs areally across most of the basin but there is evidence that suggests that most of the younger water is recharged primarily on the Idaho side along the margins of the basin where the basalt aquifers abut the granitic uplands.

Declining water levels led the cities of Pullman and Moscow, the University of Idaho and Washington State University to create the Pullman-Moscow Water Resources Committee in 1967 to manage the groundwater of the common aquifer. The Committee was renamed the Palouse Basin Aquifer Committee in 1997 and is currently represented by members from Pullman; Moscow; Latah County, Idaho; Whitman County, Washington; the University of Idaho; and Washington State University (Palouse Basin Aquifer Committee, 2000).

In response to Idaho concerns about possible mining of Palouse basin groundwater resources, the Pullman-Moscow Water Resources Committee issued a groundwater management plan for the Palouse basin aquifers in 1992. The Committee adopted groundwater management goals and strategies, which the stakeholders are voluntarily undertaking, to overcome the obstacles of governmental boundaries and to avoid state-mandated management. The primary goal of the plan is to provide all parties with groundwater while conserving the aquifer for the future by minimizing damage to water quality by aquifer depletion (Pullman-Moscow Water Resources Committee, 1992; Palouse Basin Aquifer Committee, 2000).

A groundwater model developed by the U.S. Geological Survey in 1987 was used to guide groundwater development in the basin. The model indicated that the present rate of pumping was sustainable and that groundwater levels would stop declining if withdrawals were to stabilize at a constant level (Lum et al., 1990). Therefore, in the plan, annual pumping increases are limited to one percent of the average annual pumping volume for the last five years and at no time shall the accumulated total pumping exceed 125% of the 1981-1985 average for each of the parties.

Efforts are underway to counter increasing groundwater pumpage through water conservation, exploration into increased recharge methods and the use of wastewater effluent to replace current irrigation and other less stringent requirements for a high quality water supply. The Committee carries out field investigations to develop an understanding of the basin's properties and maintains a database of groundwater levels and usage that can be used to refine the model. They promote public awareness regarding basin management issues by informing users about conservation and reuse of water (Pullman-Moscow Water Resources Committee, 1992; Palouse Basin Aquifer Committee, 2000).

Within both states, the appropriation-permit method is used to allocate groundwater and similar groundwater management principles are followed. Groundwater allocation is designed to provide a safe sustainable yield to present water users. The safe sustainable yield criteria include the protection of feasible or economic pumping lift and protection against impairment of present or senior users. Groundwater use must not exceed the average annual recharge to the basin. Groundwater management areas can also be designated in areas of existing or potential water (quality or quantity) supply problems. The states' water-rights agencies may deny future water right applications and reduce present use in these areas (Pullman-Moscow Water Resources Committee, 1992).

(e) Edwards Aquifer

The Edwards aquifer (Figure 2) is the primary source of water in eight Texas counties including the city of San Antonio. The Edwards Aquifer Authority was created by an Act of the Texas legislature in 1993 and began operations in 1996 following the Texas Supreme Court decision to overturn a lower court ruling that the Act was unconstitutional. It is the Authority's responsibility to develop a comprehensive water plan for the aquifer that includes conservation, future supply development and demand management. It is also their responsibility to limit the quantity of water withdrawn from the aquifer and prevent the aquifer from being polluted in order to protect species at Comal and San Marcos springs that are designated as threatened or endangered under federal law.

Aquifer withdrawals are limited by the Act to 450,000 acre-feet (555.1 million m^3) annually and are to be reduced to 400,000 acre-feet (493.4 million m^3) annually by 2008 unless modified by the Edwards Aquifer Authority board of directors based on the results of research (Edwards Aquifer Authority, 1998). A set of principles has been included in the Act to control groundwater apportionment:

- Groundwater withdrawals from the aquifer not exceeding 25 000 U.S. gallons per day (94.635 m^3/day) for domestic or livestock purposes may be made without a permit.
- Pre-existing users are granted preference over new users and are guaranteed two acre-feet (2467 m^3/acre) yearly for the maximum number of acres irrigated during the 1972-1993 time period, whereas new users are not.
- Water marketing is allowed when transfers take place within the aquifer region. Municipal and industrial permit holders are allowed to market all of their water whereas irrigators may only sell half of their water.

Because the Edwards aquifer is located entirely within the jurisdiction of Texas, water marketing offers a means to minimize conflicts over the reallocation of water from lower economic valued agricultural uses to higher valued domestic, industrial, environmental and recreational uses (Kaiser and Phillips, 1998).

(f) Australian Border Zone Groundwater Agreement

South Australia and Victoria signed the interstate Border Groundwater Agreement in 1985 to manage groundwater from the Murray Group Limestone (MGL) aquifer and the underlying but largely unused confined Renmark Group sand aquifer within a 40-km wide zone straddling the border. Both states use groundwater (mainly from the MGL aquifer) as their primary water source for domestic, stock, irrigation and municipal purposes. Recharge occurs at the basin margins to the east of the border in Victoria, with groundwater moving slowly into South Australia where discharge occurs to rivers and the sea over 100 km west of the border.

The area along the border is divided into 22 zones, consisting of 11 paired zones on either side of the border. The Agreement states that the available groundwater in each paired zone shall be shared equitably between South Australia and Victoria. Initially, the groundwater in each paired zone was allocated equally to each state but reapportionment of the resources based on differential land use on either side of the border has been approved by the states in some zones.

The available volume of groundwater is estimated for each zone based on the annual vertical recharge for the various land types in each zone (Allison and Hughes, 1978; Holmes and Colville, 1970); lateral throughflow calculated using a flow net analysis in each zone; and a volume equivalent to a drawdown of storage of 0.05 m/year (South Australia/Victoria State Border Groundwater Sharing Committee, 1982). Permissible annual volumes of available groundwater calculated for each set of paired zones is specified in the Groundwater (Border Agreement) Act 1985. With the exception of wells for stock watering and domestic use, each state issues licences for withdrawal of its share of the resource. Extraction licences or permits may be granted or renewed up to the limit of the permissible annual volume for each zone. A

Border Groundwater Agreement Review Committee was created by the Act and is composed of representatives from both states to jointly manage the groundwater resources in the border area. Applications for withdrawals within one kilometre of the border must be referred to the Committee for approval and the Committee may declare a period of restriction in any zone.

The Committee may review the Agreement from time to time and may make recommendations for amendments (e.g. specifications for permissible levels of salinity) for approval by the state governments. The Committee must review permissible annual volumes of extraction, rates of drawdown and permissible levels of salinity, if specified, every five years and may make changes taking into account trends in groundwater levels, groundwater quality and the impact of land use changes on the quantity and quality of the resource. Monitoring programs and special investigations are used to better define the aquifer systems in the border area, including geological and hydraulic characteristics, flow patterns, recharge rates and water quality.

Each state carries out its own monitoring and stores data in its own database but the Committee has insisted on a unified monitoring program for all of the border area. Data are freely exchanged between the two states and a joint report on groundwater trends is prepared every five years. Groundwater modelling has been used in some zones to predict long term water level and salinity changes for various pumping scenarios and to estimate inter-aquifer leakage flows (Border Groundwater Agreement Review Committee, 1995).

iii)Surface Water Agreements including Groundwater

(a) Apalachicola-Chattahoochee-Flint River Basin Compact

In 1997 the legislatures of Florida, Alabama and Georgia passed legislation creating the Apalachicola-Chattahoochee-Flint (ACF) River Basin Compact. The compact provides for the establishment of an "allocation formula" which focuses mainly on surface water. The formula is basically a set of rules for managing the water in the reservoirs and streams of the ACF basin (Figure 2) to provide municipal, industrial and agricultural water requirements to the year 2010 while maintaining flows within historical ranges at specified sites for in-stream flow needs. The compact recognizes that groundwater withdrawals in an area along the Flint River in Georgia directly impact surface water flow. Therefore, groundwater demands to the year 2010 in this area are part of the discussion of the interstate allocation formula. Numerical modelling is used to determine streamflow reductions resulting from groundwater withdrawals in the ACF river basin. The formula is currently being negotiated by the three states with a final agreement expected by May 1, 2000 (Northwest Florida Water Management District, 1998).

Monitoring and reporting procedures including meteorology, streamflow, reservoir release and elevation, water quality and biological data are described in the compact. Monitoring and reporting data are compiled in a series of interconnected databases using electronic connection, access and dissemination techniques. The database includes data that describe the hydrology, water quality and biological conditions in the ACF basin.

(b) Bear River Compact

The Bear River Compact is an interstate agreement between Idaho, Utah and Wyoming. The primary purpose of the agreement is to distribute, based on priority of rights and without regard to the boundary line, the surface waters of the lower portion of the Bear River including Bear Lake reservoir that flow from Idaho to Utah (Figure 2). An accounting method is used to account for the delivery of natural flow and stored water. It is recognized that groundwater impacts the flow of the surface waters so groundwater is being gradually included in the accounting. A list of all groundwater rights with flow rates greater than 170 L/min has been prepared by Idaho and Utah and both states are committed to include appropriate groundwater effects in their water accounting and administration (Bear River Commission, 1997).

(c) Upper Niobrara River Compact

The Upper Niobrara River Compact between the states of Wyoming and Nebraska was ratified in 1962. The major purpose of the compact is to provide for the distribution of the surface water supply of the Niobrara River basin (Figure 2). Groundwater is considered in Article VI of the agreement because of the impact it has on the depletion of the Niobrara River surface water flow but the available data are not adequate to make any apportionment of the groundwater. Nebraska and Wyoming with the cooperation of the U.S. Geological Survey are undertaking groundwater investigations and installing observation wells to obtain data that can be used to apportion groundwater in the basin. These data are reviewed at least every two years to determine the desirability or necessity of apportioning the groundwater. The two states will negotiate a supplement to the compact apportioning groundwater when results of the groundwater investigations indicate it is needed. To date no amendments have been made to the compact (Wolf, 2000; Teclaff and Utton, 1981 pp. 386-390).

iv) Other Transboundary Groundwater Issues

Sharing of groundwater resources has been noted for several international aquifers in the literature but apportionment of the resources has not been negotiated or information on agreements is not known for these cases. Jordan and Saudi Arabia use the Disi aquifer. There is no apparent source of recharge to the Disi aquifer; therefore, the high rates of pumping in Saudi Arabia are mining the stored groundwater and causing significant drawdowns in this aquifer (Adams et al., 1999).

Jordan also shares the Azraq aquifer with Syria. Since 1980 groundwater levels have fallen up to 5 m and salinity has increased possibly due to increased pumping in Syria (Adams et al., 1999). Saudi Arabia, Qatar and Bahrain share the Um-Al-Ruduma aquifer and the Nubian Sandstone aquifer underlies Libya, Egypt and Sudan.

In the Netherlands, observations of hydraulic heads at depths of 530 m in Early Tertiary aquifers indicate a steady decline in water levels in the Roer Valley graben. Hydrogeological modelling has shown that dewatering for lignite mining in Germany may cause the observed drawdowns. However, reductions of hydraulic heads are not observed at depths shallower than 150 m because an extensive marine clay and fine sand aquitard separates the shallow and deep aquifer systems. The deep aquifers are not generally used because they contain poorer quality water (Netherlands Institute of Applied Geosciences TNO, 2000).

(a) Israeli-Palestinian Negotiations

Since the 1967 Arab-Israeli war Israel has controlled development in the West Bank and Gaza Strip regions of the Middle East. These areas are considered by the Palestinians to be their land. Three principal aquifer systems exist in a complex sequence of interbedded limestone and dolostone that underlies the West Bank area west of the Jordan River. These are the Western aquifer that flows westward toward the Mediterranean coast in Israel, the Northeastern aquifer that discharges into northern Israel and the Eastern aquifer that flows eastward toward the Jordan Valley. All of these aquifers are recharged in the mountainous region in the centre of the West Bank. In the Gaza area, groundwater flows westward from Israel beneath the Gaza Strip toward the Mediterranean Sea (Sabbah and Isaac, 1995; Farinelli, 1997).

Over the years Israel has developed the groundwater resources of the West Bank and Gaza Strip and integrated the water supplies and distribution systems between these areas and Israel making it difficult to apportion the resources in any negotiations for Palestinian autonomy in the West Bank and Gaza Strip. A 1995 Israeli-Palestinian interim agreement transferred powers and responsibilities for water and sewage for Palestinians in the West Bank and Gaza Strip from the Israeli side to the Palestinian side in anticipation of a negotiated permanent agreement (Committee on Sustainable Water Supplies for the Middle East, 1999). A schedule in this interim agreement provides for the distribution of specified sustainable yields for the three aquifers in the West Bank. Based on existing usage, Israel retains control of the bulk of the resources in the Western and Northeastern aquifers. The largest portion of the 70-80 million m^3 of additional water for future Palestinian needs is to be developed from the Eastern aquifer. The balance of the new water supply is to come from groundwater in the other aquifers and the existing Israeli water system.

In assuming control of their water resources, a water policy must be developed that includes a set of specific principles to manage the groundwater resources of Palestine while ensuring the future of a safe water supply. The following principles are outlined in the report by Sabbah and Isaac (1995):

- observation of aquifers' safe maximum yields to avoid overpumping;
- adequate provision of a secure domestic water supply;
- efficient and productive agricultural and industrial sectors;
- fair water pricing systems; and
- water exchange between the aquifers as well as the two jurisdictions involved.

Sabbah and Isaac (1995) suggested a Palestinian water authority be created to manage Palestinian water allocation once access rights were determined. One of the highest priorities of the agency should be to conduct hydrological, hydrometeorological and hydrogeological studies for water resources planning. By installing observation sites in all groundwater regions of

Palestine, parameters including rainfall, evapotranspiration, streamflow, floodflow, baseflow, sediment load quality and quantity and groundwater quality can be observed and monitored. Palestinians suggest using pump tests to determine permeability, transmissivity, storage coefficient and safe yield. Geophysical well logs could be used to identify thicknesses and boundaries between aquifers. Chemical analyses could be performed on samples to determine water quality by testing for harmful and unwanted elements.

Numerical groundwater modelling should be used to aid in the development of a Palestinian water strategy by predicting drawdowns and pumping lifts for various well field schemes and to simulate groundwater flow in different reservoirs (Sabbah and Isaac, 1995).

Water resources including groundwater in Israel, the West Bank and Gaza Strip are either overexploited or exploited near their sustainable limits and there is limited opportunity for allocation of unused resources in negotiations. Changes in the quantities and qualities of water available in one area will have impacts on the quantities and qualities available in others. The Committee on Sustainable Water Supplies for the Middle East (1999) recommended that responsible regional and international agencies take a regional approach to future water resources planning in the Middle East.

(b) Slovak-Hungary Dispute

The Czechoslovak-Hungarian Treaty of 1977 authorized the development of a series of dams, canals and hydropower plants along the Danube River that bordered and flowed through the two countries. Hungary began to question the environmental impacts of the project in 1982 and suspended construction of a dam at Nagymaros, Hungary in 1989 which was part of their obligations under the 1977 Treaty. However, Czechoslovakia continued their construction at Gabcikovo, on their side of the border based on a modified plan. In May 1992, Hungary terminated the Treaty because of potentially severe environmental consequences. Five months later, Czechoslovakia implemented the modified version of the original plan by diverting the Danube River, which impacted Hungary's water resources. Water levels in Hungary dropped two to four metres destroying aquatic life and area flora. Lowering of the water table caused aquifer contamination and many village water wells to go dry in Hungary (Eckstein, 1995).

The dispute between the two countries was submitted to the International Court of Justice (ICJ) for resolution and a decision was made on September 26, 1997. The ICJ based their judgement solely on state obligations as defined in the original treaty of 1977. The absence of scientific consideration in the Court's decision implies that the Court did not regard environmental concerns as being sufficiently important to override or modify treaty obligations. The Court failed to address the following issues (Stec and Eckstein, 1997):

- Whether environmental concerns can be so significant as to permit termination of treaties.
- Whether the precautionary principle is accepted under international law to make a project proponent responsible for the ecological justification of large-scale projects.
- Whether principles of international water law are now accepted as part of customary international law.

The situation between Hungary and Slovakia exemplifies the need for the application of international water law governing the use and control of transboundary groundwater resources. States, international organizations and international tribunals such as the ICJ must be educated on environmental issues and they must be pressed to recognize the existence, significance and usefulness of international water law for decision-making affecting surface and groundwater resources (Stec and Eckstein, 1997).

Table 2: Proposed and Existing Groundwater/Surface Water Agreements

AGREEMENT	TYPE**	INTEGRATED SW / GW	JOINT DATABASE	MODEL	MANAGEMENT PLAN	REFERENCES
Poplar River Basin	Informal monitoring and data exchange arrangement between Saskatchewan and Montana	NO	NO, Each jurisdiction has its own databases. However, an annual monitoring report with monitoring data from each jurisdiction is prepared by a joint committee.	NO	NO	*International Poplar River Water Quality Study 1979 - Main Report - Appendix B: Groundwater Quantity and Quality *Poplar River Bilateral Monitoring Committee 1997 Report
Hueco-Tularosa & Rio Grande Aquifer	Informal international agreement between U.S. & Mexico	Limited	YES	YES	NO	*Transboundary Aquifers of the El Paso/Juarez/Las Cruces Region Texas Water Development Board & N.M. Water Resources Res. Inst.
Abbotsford-Sumas Aquifer	Informal international agreement between British Columbia and Washington signed by Premier of BC and Governor of Washington State on May 7, 1992.	NO GW only	NO, Each jurisdiction has its own databases but they are accessible to each other for information	NO	YES	*1993 Annual Report to the Environment Cooperation Council *Marc Zubel, P. Eng. B.C. Ministry of Environment, Lands and Parks
Palouse Basin	Informal interstate agreement between Idaho and Washington	NO GW only	NO	YES, used to guide GW management in the basin	YES	*Pullman-Moscow Water Resources Committee GW Management Plan, 1992 *Steve Gill, University of Idaho
Texas Edwards Aquifer	Formal intrastate agreement among 13 Texas counties ratified 1996	NO GW only	NO	YES, but not for GW management purposes	YES	*Edwards Aquifer Authority, 1998 Groundwater Management Plan, 1998-2008
Australia Border Groundwater Agreement	Formal interstate agreement between Victoria & South Australia ratified 1985	NO GW only	NO, Each state carries out its own monitoring and stores data in its own databases, but data are freely interchanged and a joint reports is prepared every five years.	YES, flow models used in critical areas for drawdown Predictions, inter-aquifer flows and solute transport.	YES	*Groundwater Act, 1985 *A Management Proposal for the GW Resources along the State Border of South Australia and Victoria *10th Annual Report to 30 June 1995
ACF River Basin Compact	Proposed formal interstate agreement among Florida, Georgia and Alabama expected to be signed by May 2000	YES	YES, a centralized database mutually accessible by the states including data on water flow, water quality, reservoir data and biological data.	YES, modelling used to determine streamflow reductions resulting from groundwater withdrawals	YES, using proposed interim allocation formula	*ACF Water Allocation Formula ~ Draft
Bear River Compact	Formal interstate agreement among Idaho, Utah & Wyoming ratified 1978	YES	?	?	For surface water only	*Bear River Commission - Interim Procedures for Lower Division Water Delivery, Adopted November 18, 1997
Upper Niobrara River Compact	Formal interstate agreement between Wyoming and Nebraska ratified 1962.	YES	?	?	For surface water only	*Upper Niobrara River Compact - Article 7

****A formal agreement is considered to be an agreement that has been passed by legislature.**

NOTE: See preceding text for discussion of these agreements.

(4) CURRENT GROUNDWATER ALLOCATION IN THE PRAIRIE PROVINCES

i) Current Allocation Practices in Manitoba, Saskatchewan and Alberta

(a) Groundwater Allocation in Manitoba

The Manitoba Water Resources Branch administers water use in the province through The Water Rights Act. The Act provides that all ownership of water and all rights to use or divert water are vested in the Crown in the right of Manitoba. A licence is required to divert water or to construct or maintain works for the use or diversion of water. Domestic water uses up to 25 m^3/day or the construction of a well for domestic uses are, however, exempt from licensing.

Licensing precedence, or the rights of water users relative to each other, is established on the first-in-time first-in-right principle, based on the date of licence applications. If a water supply conflict arises between two licensed water users, seniority rights apply. Rights based on applicant seniority can be superseded in favour of a higher priority water user in limited circumstances subject to compensation. The highest water use priority is for domestic purposes followed by municipal uses, then agricultural, industrial, irrigation and other uses. Because they are unlicensed uses, domestic uses and water for in-stream environmental uses are protected by reservations and licensing limits established for specific sources.

(b) Groundwater Allocation in Saskatchewan

SaskWater controls the allocation of groundwater in the province of Saskatchewan. Legislation is contained within The Groundwater Conservation Act and The Water Corporation Act. All groundwater users must obtain approval from SaskWater before they are permitted to consume or divert water resources. Domestic use, which is classified as the use of groundwater for household and sanitary purposes, stock watering, noncommercial crop spraying and watering of residential lawns and gardens, is exempt, however, and has no volume restrictions placed on it. Each project and its associated impacts are evaluated on an individual basis. Exceptions to this occur in the Regina and Yorkton areas where existing data indicate the local aquifers are fully allocated. In these areas, new proponents are informed that further groundwater is not available. SaskWater requires each groundwater project to complete a three-step approval process.

1. Permit to Conduct Groundwater Investigation

- To be obtained prior to undertaking any drilling investigations.
- SaskWater will outline investigation requirements and supply the user with groundwater information that SaskWater has on file. SaskWater will also indicate special concerns or considerations that should be taken into account in the investigation.
- The proponent must then submit an investigation report to SaskWater. This report must outline the impacts of the project and mitigation measures if required.

2. Approval to Construct

- SaskWater reviews the investigation report and determines the impacts of the project on the water resources and surrounding users.
- If deficiencies in the investigation are suspected, additional work may be required before approval is further considered.

3. Approval to Operate

- Issued when regulatory and investigation requirements along with any mitigative measures that may be necessary are met. The permit will contain conditions requiring submission of water level, water quality and production data and may specify maximum drawdowns or minimum pump settings.

SaskWater may deny an approval to a project if the project is not sustainable or impacts on existing users cannot be mitigated. Approvals issued by SaskWater can be appealed by concerned parties. If SaskWater denies an application, proponents may also appeal.

(c) Groundwater Allocation in Alberta

Effective January 1, 1999, the Water Act is the legislation governing the allocation of surface water and groundwater in Alberta. A licence must be obtained for diversion and use of surface water and groundwater under the Act unless the diversion is exempted from requiring a licence as specified in the regulation or through a Code of Practice. As well, the diversion and use of water for 'household' purposes, as defined in the Act, does not require a licence. The volume of water defined for household use is 1250 m^3 annually, and the volume applies to both surface water and groundwater sources.

1. Licence to Divert Groundwater

When an application under the Water Act is made for the diversion and use of groundwater, an approval to explore for groundwater may be required as the first step in the licensing process. This approval may include conditions that require the proponent to design and carry out an exploratory program to assess:

- groundwater availability; and
- potential impact of the proposed diversion on the aquifer and surrounding water users/sources.

The program normally includes:

- a field-verified survey of neighbouring water supplies;
- pumping test on proposed water well(s); and
- monitoring of dedicated observation well(s) and/or nearby water sources during the pumping test.

Following the submission of the information required by the approval, consideration is then given to issuance of a licence granting the allocation and use of the groundwater. The licence may be issued provided that there is evidence the water source can supply the needs of the licensee and that the diversion of water does not cause negative effects on the aquifer, surrounding users and the environment. Licences will usually include conditions that require the licensee to submit water-monitoring data, quantities of water diverted, and investigation of users impacted by the licensee's diversion. The monitoring data may include some or all of the following: quantities of groundwater diverted, water levels in the production wells, water levels in nearby wells, and/or flow rates in nearby springs.

As part of the overall licensing process, including the approval to explore, notification of the application is provided to the public. Those who are potentially impacted by the application have the opportunity to submit statements of concern in response to the application. Where the requested volume of water exceeds 62 500 m^3/year, a licence fee is assessed prior to issuance of the licence.

2. Registrations for Traditional Agriculture Uses

The Act recognizes the historical use of water by traditional agricultural users, defined as water used for watering of animals or spraying crops, and provides the opportunity for these users to fully protect their rights to water through a registration process. Diversion and use of water from surface water and groundwater sources for these purposes are eligible under the registration process. The maximum volume of water allocated through the registration is 6250 m^3/year per farm unit (farming operation).

Registration differs from the licensing process in that the registration only applies to those water sources in use at the time the Act came into effect. Notification of the application is not given, no fees are assessed, and the registration is effectively tied to the land.

ii) Comparing Current Allocation Practices of the Three Prairie Provinces

Current allocation practices in Manitoba, Saskatchewan and Alberta are similar in the aspect that all three provinces treat groundwater as a stand-alone resource allocating it separately from surface water. A licence/approval system much like the prior appropriation method of allocation described earlier in the report is used to allocate groundwater resources in each of the provinces. However, authorization is not required for domestic and household use in the three provinces.

Different legislative approaches are taken in each of the three provinces in defining domestic use. Alberta and Manitoba place limits on permitted volumes of groundwater consumed/diverted for domestic and household purposes. In Alberta, the household right is established by the Water Act and is solely for household uses including watering gardens and trees. That is, any volume of water granted under such a right would not allow for traditional domestic uses such as stock watering on a significant scale to be accommodated. Although no scientific basis was used to come up with the 1250 m^3/year volume limit, it is noted that such a volume is more than sufficient to accommodate household needs for up to four humans.

In Manitoba, domestic use is defined as the use of water from a source other than a municipal water distribution system at a rate of not more than 25 m^3/day for household and sanitary purposes, for watering lawns and gardens, and for watering livestock and poultry. The volume of groundwater granted for domestic use is higher in Manitoba than Alberta because Manitoba includes livestock and poultry watering in their definition of domestic use. The volume is a carryover from historical regulations that exempted stock watering on the small homesteads during early settlement in the province.

Saskatchewan has no restrictions on volume allowable for domestic wells. As long as domestic wells are being used for noncommercial uses, approval is not required in Saskatchewan.

Under current practices in the Prairie Provinces, most groundwater is allocated on the basis of single point withdrawal. However, with the exception of a few aquifers (e.g. Regina and Yorkton aquifers), the provinces do not have sufficiently detailed aquifer management information to be able to fully account for the availability of natural recharge and, therefore, the sustainable yield of the aquifer. While proponents have to demonstrate that their use is sustainable and must include existing users in their analysis, consideration of the impacts of cumulative withdrawals on the aquifer may be hampered by the lack of a management plan.

In the case of interprovincial aquifers the cumulative discharge of licensed and unlicensed withdrawals in each jurisdiction may exceed the sustainable yield of the aquifer and result in problems such as significant drawdowns and/or decrease in the rate of natural discharge. There is nothing legally restricting a province from overallocating the shared aquifer and perceived inequities may arise because of different allocation methods such as the definition of domestic use within each of the Prairie Provinces.

iii)Master Agreement on Apportionment

The Prairie Provinces Water Board (PPWB) administers the Master Agreement on Apportionment, signed on October 30, 1969, that governs the apportionment of interprovincial streams flowing eastward through Alberta, Saskatchewan and Manitoba.

Within the Master Agreement, Alberta and Saskatchewan have an agreement where Alberta may, in general, use one half of the natural flow of water arising in the province of Alberta and must permit the other half of the natural flow of each such watercourse to flow into Saskatchewan. Likewise, Saskatchewan and Manitoba have an agreement that Saskatchewan may take one half of the water arising or flowing into the province of Saskatchewan and they must release the other half of the natural flow of each such watercourse to flow into Manitoba.

The PPWB established a method to determine the quantity of water that "naturally flows" across the common boundary. Natural flow is defined as the flow of water that would occur in a particular river if that river had never been affected by the activities of people. The procedure is based on flow occurring over the course of a twelve month period in all eastward flowing streams, measured at the closest location to the boundary as possible. Minimum flows can be set.

Although the first PPWB Committee on Groundwater meeting was held in May 1980 the Master Agreement was only amended in 1992 to provide for the PPWB to consider water quality and groundwater issues that affect transboundary surface water and groundwater. The PPWB may consider groundwater projects and activities that have interprovincial implications and make recommendations to governments on these matters. However, the Board currently has not developed any objectives or guidelines in the Prairie Provinces as to how groundwater of interprovincial aquifers is apportioned.

(5) CONSIDERATIONS FOR FUTURE APPORTIONMENT OF INTERPROVINCIAL AQUIFERS

i) Apportionment Principles

The obligation not to cause appreciable harm, the equitable and reasonable use of shared waters, the obligation to give prior notice of water resource developments and the duty to negotiate in good faith are the overriding principles applicable to use of waters shared between jurisdictions. Of these principles the equitable and reasonable use of shared waters is the most essential to consider when negotiating a groundwater apportionment method for the interprovincial aquifers of the Prairie Provinces. In addition to this basic principle several factors need to be considered in any apportionment scheme. These include:

- the priority of use;
- the sustainable yield of the aquifer;
- the joint apportionment of surface water and groundwater;
- the specification of pumping locations and amounts;
- the existing PPWB apportionment agreement; and
- the provincial allocation methods.

Each of these principles and factors are discussed in the following sections.

(a) Equitable Use

Allocation of water in a transboundary aquifer should ensure that each province is entitled to a fair share of the groundwater resource. The alternative is first in time, first in right on a provincial basis without regard to proportional sharing of the sustainable yield and this alternative has led to accelerated depletion of aquifers in other jurisdictions.

Article V of the Helsinki Rules states that the proportion of a drainage basin that lies in each state should be considered when developing an apportionment scheme. In the discussion of groundwater agreements, the Palouse basin aquifer shared between Washington and Idaho is said to lie 95% in Washington but the data suggest that most of the younger water is recharged in Idaho. The Palouse Basin Aquifer Committee is more concerned with the sustainable management of the aquifer than its geographic distribution. If the future brings water scarcity, state-mandated apportionment based on the aquifer geometry could be detrimental to the parties.

Nevertheless, an equitable solution to apportionment of interprovincial aquifers would be that the volume that each province may withdraw would be proportional to the area of aquifer lying within its territory. This requires knowledge on the geography of the aquifer and extent in each province, as well as the hydrology of the basin including the water contribution to the aquifer by each province.

(b) Priority of Use

Article V of the Helsinki Rules states that unnecessary waste in the use of waters of a basin should be avoided. The optimum use could be achieved in the Prairie Provinces by recognizing a priority of uses common to transboundary aquifers. The greatest water priority is domestic use as outlined in the agreements described in this report as well as currently used in the allocation methods in each of the three Prairie Provinces. This use is followed by municipal use, agricultural use, industrial and irrigation use.

The priority of actual use may differ on either side of the border. For example, municipal use may be important in a small town on one side of the border whereas irrigation usage may predominate on the other side. Therefore, a need for flexibility in the interjurisdictional transfer of water is suggested. In situations where a water shortage may occur, flexibility would allow for necessary groundwater transfers to take place and for higher priority use to supersede the rights of lower priority uses of the other jurisdiction provided that they would be fully compensated for reasonable economic losses resulting from the loss of water supply through transfer.

(c) Sustainable Yield

In international arrangements for apportionment of transboundary groundwater, several approaches have been used for setting the yields of aquifers. In the Australian Border Agreement and the Israeli-Palestinian interim agreement, sustainable yields have been estimated for the shared aquifers and these estimates are included in the agreement. In the Australian agreement, these estimates must be reviewed every five years. For the Palouse basin and the Edwards aquifers, the aquifer yields have been based on total groundwater withdrawals at a set point in time. In both cases, the increases in pumping rates are known to be nonsustainable based on declining water levels in the aquifers. Management plans call for a 10% reduction in groundwater withdrawals for the Edwards aquifer and for limits on the rate of increase of pumping in the Palouse basin aquifer but the sustainable yields of these aquifers have not yet been determined. Aquifer yields have not been defined for the Poplar River basin, the Abbotsford-Sumas aquifer or the Hueco-Tularosa and Rio Grande aquifers.

The mutual determination of the safe or sustainable yield of transboundary aquifers must be based on a common understanding of the nature, extent and quality of the resource in the vicinity of the interprovincial boundary. This common understanding is based on extensive knowledge of the hydrogeological and hydrogeochemical properties of the aquifer including aquifer geometry, recharge and discharge areas and rates, groundwater levels and groundwater quality. Aquifer management plans that include estimates of sustainable safe yields should be developed for each of the interprovincial aquifers and used for the equitable apportionment of the resource.

(d) Apportionment of Surface Water and Groundwater

The interaction between surface water and groundwater is widely recognized by water management agencies but presents difficulties in negotiation of agreements and has basically been ignored by the International Court of Justice in its judgement on the dispute between Hungary and Slovakia over diversion of the Danube River. The Apalachicola-Chattahoochee-Flint River basin, the Bear River and the Upper Niobrara River compacts in the United States attempt to include groundwater withdrawals in the apportionment of surface waters in each of the agreements. However, in each case, methods are still being developed or refined and additional data need to be collected to account for groundwater in the water balances.

Groundwater and surface water are hydraulically connected, so ideally should be included in the same apportionment scheme. The PPWB has concluded that groundwater, surface water and land are interrelated factors that should be managed as a single unit (PPWB, 1991). Therefore, development of an apportionment method for the interprovincial aquifers of the Prairie Provinces should include a methodology for incorporating surface water/groundwater interactions. The joint apportionment of surface water and groundwater will complicate the development of an apportionment agreement because conceptual differences related to basin boundaries, response times, resource magnitudes and units of measurement will have to be resolved with surface water hydrologists.

(e) Pumping Locations

Besides splitting the resource between jurisdictions it is important to control groundwater withdrawals, so that adequate water supplies and water quality will be conserved for the future. As suggested in Article VIII of the Bellagio Draft Treaty, pumping limitations should be imposed and measures should be taken to minimize degradation of transboundary groundwater quality.

Furthermore, if one province takes its share close to the boundary it could effectively prevent the other from using its share by creating excessive drawdowns in the aquifer while leaving part of the aquifer undeveloped further from the border. In this case it may also be necessary to specify how each province allocates its share. Models may eventually be developed and used to assist with determining locations and amounts of allocations.

(f) PPWB Agreement

Apportionment methods developed for groundwater should not contradict the existing methods for surface water apportionment in the Prairie Provinces. Current apportionment procedures are based on calculations of natural flow in each of the eastward flowing rivers. Changes in streamflow or lake levels due to groundwater withdrawals can be included in natural flow or lake level calculations when detailed aquifer management plans have been formulated for those aquifers interacting with interprovincial lakes or streams. Apportionment of groundwater that is not related to interprovincial surface waters could be specified in supplementary amendments to the existing agreement.

(g) Provincial Allocation Methods

The allocation of groundwater in each of the three Prairie Provinces is based on point withdrawals but the methods of allocation in each province are currently based on different criteria. The Prairie Provinces Water Board's Committee on Groundwater previously recognized that "because different criteria and procedures are used by each province in the allocation and protection of groundwater, the potential exists for conflicts or mismanagement of an aquifer shared by two jurisdictions" (PPWB, 1992). Adopting a common set of allocation practices to manage interprovincial aquifers could alleviate possible future conflicts caused by different provincial allocation methods. However, this would require modifications to legislation and/or regulations governing allocation methods in each of the provinces. Allocation of each province's share of groundwater in a common aquifer can be done using existing allocation methods but it is suggested that unlicensed domestic uses be estimated from water well inventories for transboundary aquifers because domestic use is defined differently in each of the provinces.

ii) Apportionment Procedures

(a) Aquifer without Surface Stream

Aquifers that have no connection to surface water (Figure 3a) should be assessed to estimate the magnitude and extent of the water source. These aquifers are sometimes considered to be exhaustible supplies because their only source of recharge is rainfall. Withdrawal from exhaustible aquifers should be closely monitored and limits should be put on the quantity of groundwater that parties are allowed to extract based on rates of recharge. By installing observation wells at or near the border, water levels could be regularly monitored.

One possible apportionment scheme for an interprovincial aquifer is to apportion the water in the aquifer on the basis of the proportion of the aquifer lying in each jurisdiction as described in the previous section. The sustainable yield should be determined and each province's share of groundwater would be based on the proportion of the aquifer in their jurisdiction. For example, if 75% of the aquifer lies in Alberta with the remaining 25% lying in Saskatchewan, Alberta would receive 75% of the sustainable yield leaving the other 25% for Saskatchewan. This approach assumes yield is uniformly distributed throughout the entire aquifer. Nevertheless, apportionment of groundwater using this approach is simpler than methods based on annual water balances or computations of groundwater flow. The more complex apportionment formulae are frequently limited by a lack of technical information on the aquifer whereas the aerial extent of the aquifer is usually fairly well known from available water well records.

The natural flow in the aquifer is assumed to result from natural recharge to and discharge from the aquifer. As natural flow in large aquifers could cross the interprovincial boundary in opposite directions in different parts of the aquifer, the aquifer may need to be divided into subunits for purposes of groundwater apportionment. This is similar to the Australian Border Zone Agreement where the aquifer is divided into eleven two-part zones.

(b) Aquifer with Surface Stream

The interaction between water in an interprovincial stream and an aquifer spanning the boundary (Figure 3b) must be known for apportionment purposes. Withdrawals from groundwater with a direct hydraulic connection to streams will capture water from the stream by reducing the rate of flow of groundwater into the stream (gaining stream) or by increasing the rate of seepage from the stream (losing stream). Such groundwater is said to be tributary to the stream (Bouwer and Maddock, 1997). The reduced discharge

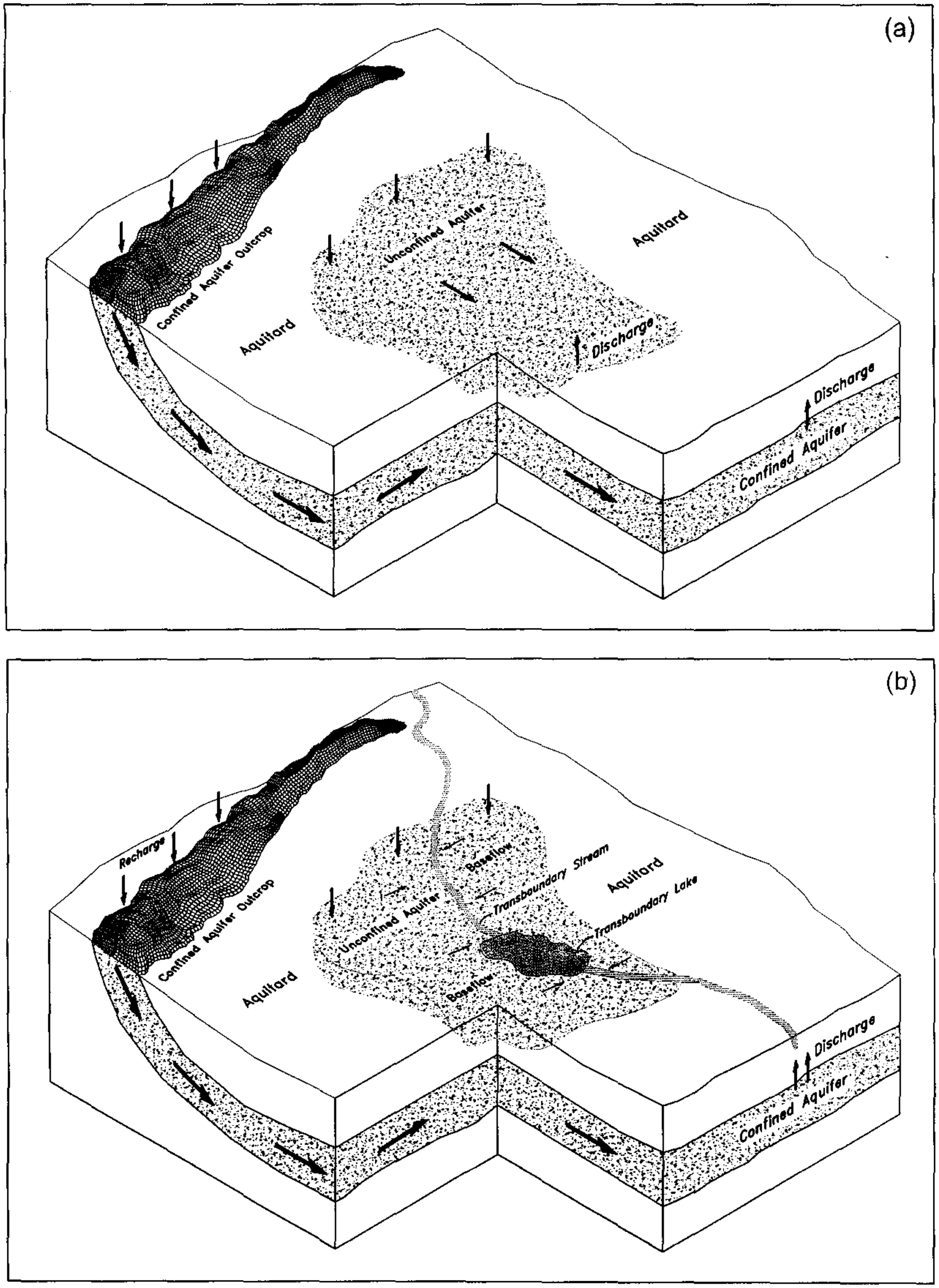

Figure 3. Example of transboundary aquifers (a) Without a lake or stream (b) With a lake and stream

or increased recharge due to groundwater development in the aquifer is directly proportional to the difference between the groundwater and surface water levels. It can be calculated by a flow net analysis or simple analytical model and included in the computations of flows for apportionment of interprovincial streams.

If groundwater levels are below the base of the stream or pumping is far away from the stream then groundwater withdrawals have a minimal impact on streamflow and apportionment of the water in the aquifer would be similar to an aquifer without a surface stream, that is, the sustainable yield of the aquifer would be apportioned on the basis of the proportion of the aquifer in each jurisdiction. In this case, however, the sustainable yield of an aquifer whose water table lies below the base of the stream may include some seepage value determined by the permeability of the streambed sediments in the calculation of the sustainable yield. Bouwer and Maddock (1997) discuss groundwater-streamflow interactions in detail and present some simple criteria for determining when groundwater is tributary to a stream.

(c) Aquifer with Interprovincial Lake

Like interprovincial streams, the apportionment of the water of an interprovincial lake connected to an aquifer system (Figure 3b) is dependent on the natural flow between the lake and the aquifer. Groundwater that can be shown to be tributary to the lake by the measurement of groundwater flow directions or the definition of groundwater divides should be included in the natural water balance of the lake. The groundwater in the aquifer(s) would not be apportioned but adjustments would be made for reduced inflows or increased outflows in the water balance of the lake due to any groundwater development in the interconnected aquifer(s).

The feasibility of these apportionment schemes depends completely on the development of a thorough knowledge of the aquifer geometry, groundwater flow including recharge and discharge areas and groundwater quality characteristics. Detailed knowledge on aquifer behaviour is expected to be a requirement for any scientifically based apportionment plans. In addition, this detailed knowledge is required in the individual agencies for the efficient allocation of that agency's share of interprovincial groundwater in terms of pumping rates and locations.

PRAIRIE PROVINCE WATER BOARD

CONCLUSIONS

(6) CONCLUSIONS

International policy and procedure for the management of transboundary aquifers is at a preliminary stage. Various law-related organizations have developed administrative principles for the management of transboundary aquifers but these principles lack technical content. Most international water treaties are based on surface water and do not include groundwater. However, a number of formal and informal transboundary groundwater agreements exist and have been obtained and described within this report. By combining the administrative principles of international law with apportionment principles and procedures in existing and proposed groundwater agreements, a set of principles and procedures for groundwater apportionment in the Prairie Provinces has been developed.

Each jurisdiction should be entitled to a fair share of the groundwater from a transboundary aquifer. One way to do this would be to base apportionment on the proportion of the aquifer that lies in each jurisdiction and the sustainable yield of the aquifer. Groundwater and surface water should be included in the same apportionment scheme when they are hydraulically connected because activities in one system may have impacts on the other. The effects of groundwater withdrawals on streamflow or lake water balances should be computed and included in apportionment calculations for these water bodies. Both land and surface water usage influence the quality and quantity of groundwater and groundwater usage may have an influence on in-stream flow needs for riverine ecosystems. The groundwater component forms an integral part of the hydrological environment and is significant to virtually all aspects of basin management. Because groundwater systems have longer response times and much smaller fluctuations in flow, calculations of groundwater quantities may only need to be revised periodically for apportionment calculations for lakes and streams.

A permit system is the administrative method used for allocating groundwater resources in the Prairie Provinces. Although a common groundwater allocation protocol would be desirable to alleviate conflicts when negotiating a transboundary groundwater apportionment agreement, existing allocation methods can be used provided unlicensed domestic uses, if significant, are inventoried for transboundary aquifers because of differences in defining domestic use in each of the provinces. Pumping locations and limits may need to be specified to ensure equitable development of the aquifer for all parties and to preserve groundwater quantity and quality for future use.

The determination of what is equitable and the determination of the importance to be given to the seniority of existing water use rights or to the type of use is gradually yielding to the criteria of reasonable and beneficial use and in some cases to optimum use. Of course, this change in criteria creates debate on what is a reasonable, beneficial or optimum use but it provides the opportunity to propose alternative means of satisfying the water requirements of each jurisdiction and to promote cooperation between the parties concerned. When developing a method of apportioning transboundary groundwater, a need for flexibility exists in the negotiations between jurisdictions in order to allow for water transfers and compensation when resources are limited and interests of the two jurisdictions are different.

A complete understanding of the aquifer is necessary to apportion the groundwater effectively. This may involve research including field investigations to collect data, long-term monitoring and numerical modelling to predict aquifer behaviour. A common set of data and comparable procedures for data collection should be established. The exchange of data and development of a unified database that includes each jurisdiction's available groundwater data will likely be necessary to prepare aquifer management plans and estimate the sustainable safe yields for the interprovincial aquifers.

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