ground water

International Borders, Ground Water Flow, and Hydroschizophrenia

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Abstract

A substantial body of research has been conducted on transboundary water, transboundary water law, and the mitigation of transboundary water conflict. However, most of this work has focused primarily on surface water supplies. While it is well understood that aquifers cross international boundaries and that the base flow of international river systems is often derived in part from ground water, transboundary ground water and surface water systems are usually managed under different regimes, resulting in what has been described as "hydroschizophrenia." Adding to the problem, the hydrologic relationships between surface and ground water supplies are only known at a reconnaissance level in even the most studied international basins, and thus even basic questions regarding the territorial sovereignty of ground water resources often remain unaddressed or even unasked. Despite the tensions inherent in the international setting, riparian nations have shown tremendous creativity in approaching regional development, often through preventive diplomacy, and the creation of "baskets of benefits," which allow for positive-sum, integrative allocations of joint gains. In contrast to the notion of imminent water wars, the history of hydropolitical relations worldwide has been overwhelmingly cooperative. Limited ground water management in the international arena, coupled with the fact that few states or countries regulate the use of ground water, begs the question: will international borders serve as boundaries for increased "flows" of hydrologic information and communication to maintain strategic aquifers, or will increased competition for shared ground water resources lead to the potential loss of strategic aquifers and "no flows" for both ground water users?

Introduction

Anderson (1999) suggests that the likelihood and significance of boundary disputes are greater now than at any time since the Second World War, especially with respect to transboundary movements where institutional capacity and international law are in the initial stage of formulation. Much of the growth in ground water use and the "silent trade" of hazardous waste are occurring across international borders. Media reports reveal that the potential for conflict and a greedy "race to the pumps" continues to rise with time. For example, the National Ground Water Association Transboundary Aquifer Interest Group web page indicates that "designer-water" companies are planning to export ground water over vast distances for global exportation and economic gain (http://www.ngwa.org/sig/transummary.htm). The impacts of international trade agreements on local jurisdiction and management of water resources are just beginning to be recognized.

The hidden nature of ground water and the lack of international law governing shared aquifers invite misunderstandings leading to conflict. The uncertainty associated with managing a hidden resource requires rethinking of ground water management as the intensity of development increases with the need for food security (Burke and Moench 2000). The simple use of the common property theory is not sufficient to develop general principles for

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ground water management. This is because the interaction between hydrogeology and social boundaries makes the common property nature of ground water less straightforward than is commonly assumed.

This article is designed to build upon, rather than duplicate, the papers originally presented at a 2000 meeting of the National Ground Water Association special session on transboundary aquifers (Gaines et al. 2003); the Madrid Workshop on Intensely Exploited Aquifers held in 2001, which provided ideas and suggestions to improve water management where there is an intensive use of ground water; and the Valencia International Symposium on Intensive Use of Ground Water held in 2002, which built upon these issues (Llamas and Custodio 2002). This paper is intended as a cursory summary of (1) the current state of knowledge on transboundary ground water resources; (2) the guidelines and agreements that have been developed to manage transboundary ground water resources; and (3) the international efforts to map the world's aquifers. It will also address some of the additional challenges to developing principles of ground water management as well as provide some suggestions for future research in this dynamic and multifaceted arena of ground water research.

Overview of Geopolitics and Ground Water

There are 263 watersheds that cross the political boundaries of two or more countries. These international basins cover 45.3% of the land surface of the earth, affect ~40% of the world's population, and account for ~60% of global fresh water supply (Wolf et al. 1999). These international basins are strongly tied to a deepening global water crisis with the loss of ground water storage exemplified by falling ground water levels in wells, surface water and ground water becoming contaminated, and water delivery and treatment infrastructure aging. Water shortages, water quality degradation, and destruction of aquatic ecology negatively impact socioeconomic development and political stability.

According to Wolf and Giordano (2002), more than 3600 water-related treaties have been signed by riparian countries in international river basins between the years 805 and 1984. Findings from Wolf, Yoffe, and Giordano (2003) indicate that over the past 50 years, cooperative relations outnumber incidents of conflict. Conflicts that have occurred tend to be nonviolent, temporally and geographically localized, result from a narrow range of issues (hydropower and infrastructure), and are largely mediated when adequate institutional capacity exists to address and resolve them. Institutional capacity—whether defined by commissions, technology, or treaties—has been shown to be the primary component influencing the ability of nations to prevent and resolve water-related disputes (Wolf 1998). Examined on the whole, international surface water resources are characterized by a history of resilient cooperation (Postel and Wolf 2001).

The important hydrologic link between ground water and surface water is recognized but understood at a reconnaissance level even in the most studied basins in the world. While the effects of ground water use may be contained within national boundaries, few states' or provinces' water laws address ground water management due to the "invisible" nature of the resource, or the technical challenges in predicting spatial and temporal changes in the ground water system with increased use. Part of the problem is associated with recognizing the different types of aquifers. For example, sand and gravel aquifers transmit and store ground water differently compared with fractured rocks or karst. Matsumoto (2002), Puri et al. (2001), Puri (2003), and Eckstein and Eckstein (2003) underscore that current international law does not adequately define ground water, much less the spatial flow of ground water.

The need for guidelines to assist nations in the management and allocation of ground water resources is not disputable as the dependence on ground water increases globally. Despite many agreements and international laws acknowledging the growing significance of ground water resources, transboundary aquifers are usually only addressed in a cursory, poorly defined manner due to a lack of consensus regarding applicable international agreements and law to international ground water resources leading to what has been described as "hydroschizophrenia" by Llamas (2005).

A review of international water guidelines specifically addressing ground water listed in Table 1 reveals that many of the guidelines and agreements were developed in the past 50 years and have only recently adopted a definition of an aquifer. Matsumoto (2002) inventoried nearly 400 treaties listed in the Transboundary Freshwater Dispute Database of Wolf (1999) and Wolf and Giordano (2002) and summarized the number of treaties recognizing ground water by continent:

- 35 treaties developed between European countries
- 13 treaties in Africa
- 10 treaties in the Middle East and Asia
- 4 treaties in North America
- No treaties developed in South America.

Protection of ground water quality has only been addressed in the past few years (Morris et al. 2003). The transboundary movement of hazardous wastes into Lebanon described as the silent trade by Jurdi (2002) provides an example of the need to increase the need for "global harmonization" of international water and waste treaties. Of the many international water treaties, few have monitoring provisions, and almost none have enforcement mechanisms (Chalecki et al. 2002).

Given the uncertainty in defining ground water flow, coupled with the uncertainty of the hydraulic connection between ground water and surface water resources, conflicts over water quantity and quality are certain to escalate with increased reliance on ground water to meet demands for drinking water, agricultural and industrial uses, and maintenance of "green" reservoirs—the highland forests and wetlands. Likewise, there are many examples of transboundary aquifers where recharge is received on one side of an international boundary, while natural discharges and better yields are on the other side of the boundary, thus compromising the security of

Table 1
Summary of International Ground Water Guidelines Related to Ground Water (modified after Matsumoto 2002 and Eckstein 2004)

International Guidelines	Date	References to Ground Water
Helsinki Rules	1966	• Defines underground water as part of international drainage basin. • Ignores confined aquifers.
Seoul Rules	1986	• Defines international drainage basin as "an aquifer intersected by the boundary between two or more states that does not contribute water to, or receive water from, surface water of an international drainage basin constitutes an international drainage basin for the purposes of the Helsinki Rules."
Belaggio Draft Treaty	1988	• Recognizes the hydrologic connection between surface water and ground water. • Transboundary aquifer is considered part of an international basin.
Agenda 21, Chapter 18	1992	• Ground water has parallel status as surface water as "fresh water bodies." • Recommends holistic fresh water management. • Ignores transboundary fresh water management.
Non-Navigational Uses of International Watercourses (Draft)	1997	• Recognizes "International Watercourse." • Ignores confined aquifers.
Non-Navigational Uses of International Watercourses (Convention)	1997	• Recognizes "International Watercourse" listed in Draft. • Ignores confined aquifers.
Non-Navigational Uses of International Watercourses (Resolution)	1997	• Recognizes confined aquifers. • Water management rules outlined in Draft may be applicable to transboundary confined aquifers.
Convention on the Protection and Use of Transboundary Watercourses and International Lakes	1999	• Recommends integrated water resources management, inclusive of ground water. • Recommends extending water resources management to transboundary issues.
Law of Transboundary Aquifer Systems (Draft Convention)	2004	• Defines transboundary aquifer system • Defines aquifer system state

the aquifer from armed conflict, terrorism, or pollution (Gleick 2002).

Mapping of the World's Aquifers

Conflicts over transboundary aquifers require a holistic approach to address ecological, multidisciplinary, and multimedia issues. Ground water science is at the core of transboundary ground water issues because international interests and options are not easily defined without the assistance of specialists who can interpret causal chains (Renevier and Henderson 2002; Eckstein and Eckstein 2003). Both intranational and international programs recognize the critical need to collect enormous volumes of spatially registered data on ground water (Puri et al. 2001; Matsumoto 2002; Glennon 2002; Food and Agriculture Organization [FAO] 2003).

Worldwide efforts in transboundary hydrogeology have made enormous strides in compiling the baseline information on international aquifers (Puri 2003). Transboundary aquifers are the subject of ongoing work by the International Shared Aquifer Resources Management (ISARM) program that was initiated by the United Nations Education, Scientific, and Cultural Organization (UNESCO) in 2000. ISARM anticipates publishing an inventory of transboundary aquifer systems in 2006. Transboundary aquifer systems currently being assessed by the ISARM include the following:

- The Guaraní Aquifer (South America)
- The Nubian Sandstone aquifer (Northern Africa)
- The Karoo Aquifer (Southern Africa)
- The Vechte Aquifer (Western Europe)
- The Slovak Karst-Aggtelek Aquifer (Central Europe)
- The Praded Aquifer (Central Europe).

The Worldwide Hydrogeological Mapping and Assessment Program (WHYMAP) is a joint venture of UNESCO—International Hydrological Programme; International Association of Hydrogeologists (IAH)—Commission on Hydrogeological Maps (National Ground Water Association 2002); Commission for the Geological Map of the World—Subcommission on Hydrogeological Maps; International Atomic Energy Agency; and German

Federal Institute for Geosciences and Natural Resources (BGR). WHYMAP's goals include summarizing ground water information on a global scale; viewing ground water data on maps, including a ground water map of the world at a scale of 1:25 million; providing sketch maps and inserts at A4/A5 format; providing map information for international discussion on water; and cooperating with the International Ground Water Resources Assessment Center (IGRAC). WHYMAP's progress in meeting their goals is impressive and included delivering the first draft of a map of ground water resources of the world to the World Water Forum in March 2003. The future goals include presenting the final draft of ground water map at a reduced scale of 1:50 million at the International Geological Congress in Florence, Italy, during August 2006, with the final publication in time for the 50th anniversary of IAH in 2006 (see BGR 2004 for PDF files of maps).

The IGRAC is an initiative of UNESCO and many other institutions, which is building upon the momentum started by WHYMAP. IGRAC is a research center with a noncommercial profile, which is currently hosted by the Netherlands Institute of Applied Geosciences at Utrecht. IGRAC's goal is to foster the global sharing of information and knowledge for optimal and sustainable ground water resources development and management by establishing a Global Ground Water Information System (GGIS) accessible via the Internet. According to the International Ground Water Resources Assessment Center (2004), IGRAC is designing a modular design for GGIS with up to six modules. Modules 1 and 2 constitute what IGRAC calls a "Global Overview." In this Global Overview, they are working on a high aggregation level, allowing for much less detail than is required for the final project. Although this Global Overview may seem rather simple at first glance if one visits their Web site at http://igrac.nitg.tno.nl/ggis/start.html, IGRAC has built significant capacity to setting up a dedicated database for transboundary aquifers. IGRAC also is working toward producing and promoting guidelines and protocols for proper and uniform ground water data acquisition and ground water monitoring.

Transboundary ground water issues in the Americas are receiving increased attention by many researchers. According to the Munk Centre for International Studies at the University of Toronto (http://www.powi.ca), ground water is an underappreciated natural resource in the Great Lakes basin, which contributes "… more than 50 percent of the flow from rivers and streams to the Great Lakes." Ground water policy along the United States-Mexico border is studied by The Border Water Project—a joint initiative by the Center for U.S.-Mexican Studies at the University of California, San Diego, and the Water and Society Program of the Colegio de San Luis Potosí Center for U.S.-Mexican Studies (http://usmex.ucsd.edu/water/index.html). According to anecdotal reports by ground water scientists in Mexico, major differences with respect to ground water along the common border of the United States and Mexico have resulted in an effort led by the Mexican Academy of Sciences in conjunction with the National Academies of Science to create a task force to discuss transboundary aquifers because the National Water Commission of Mexico apparently stopped information sharing between ground water scientists and engineers working on United States-Mexico transboundary water issues. Anecdotal reports from ground water scientists working in South America also indicate that there is a major dispute taking place between Chile and Bolivia regarding transboundary aquifers and that there are efforts to encourage a joint Chilean/Bolivian task force to address this conflict.

Hydroinstitutional Challenges

Ground water flow can cross geopolitical boundaries in unpredictable ways due to barriers imposed by faulting, by conduits imposed by fractures, or seasonally due to basin switching in aquifers drained by karst. The limited understanding of recharge mechanics and the uncertainties in the subsurface flow regime within different types of aquifers reveal some of the challenges associated not only with policy development but also with the spatial considerations in ground water management. Given the uncertainty in defining ground water flow, coupled with the uncertainty of the hydraulic connection between ground water and surface water resources, conflicts over water quantity and quality are certain to escalate with increased reliance on ground water to meet demands for drinking water, agricultural and industrial uses, and maintenance of "green" reservoirs—the highland forests and wetlands. Likewise, there are many examples of transboundary aquifers where recharge is received on one side of an international boundary, while natural discharges and better yields are on the other side of the boundary, thus compromising the security of the aquifer from armed conflict or terrorism.

Ground water use is increasing because it is a "pure common pool" resource, available to anyone with the financial resources to drill, equip, and power a well (Dietz et al. 2002; International Water Management Institute [IWMI] 2003a; Giordano 2003). Because ground water is a common pool resource, the geographic nature of ground water use by humans becomes not only a spatial relationship between humans and their environment as described by Giordano (2003) but also a temporal relationship when considering resource development by artificial means. The spatial problem is multidimensional, incorporating two-dimensional spaces traditionally addressed by the geographer through maps and the vertical dimension traditionally the realm of the geologist, and integrating both with time. The global expansion of irrigated agriculture by center pivot irrigation systems provides an example of the human-environment spatial relationships tempered by time. Ground water use has changed the socioecology of many cultures with the advent of vertical well technology and inexpensive power to pump the resource (IWMI 2003; Lightfoot 2003). The current challenge for geoscientists is to assist states and governments with the management of the ground water resource to minimize conflicts over use and protect the quality of the water (Freeze 2000; Glennon 2002; FAO 2003).

The concept of the Tragedy of the Commons was made famous in an article by Hardin (1968), which attempted to describe the mechanisms through which unowned, or "common," resources are overexploited. There has been considerable effort to shift the discourse on the commons problem to a differentiation between open-access resources, something closer to what Hardin originally envisioned, and common property resources, resources for which communities and groups develop shared, as opposed to a private, management responsibility (Ciriacy-Wantrup and Bishop 1975).

With this finer differentiation, the problems of ground water management as typically described should now more accurately be attributed to the open-access problem rather than the common property problem per se. In essence, the problem occurs when individual, communal, or administrative, e.g., city, ground water users pump water from the aquifers below them. Because effective abstraction rules have not been established, each individual entity can take as much water as desired, subject only to their own pumping costs, and enjoy the full benefits of that water privately. At the same time, the costs of their use in terms of lower water tables and hence increased abstraction costs are shared by all. As water tables decline, a race to the pumps can ensue as each user attempts to get "their" share before the resource is gone, thus further hastening resource decline.

The large body of theory related to common property and open-access resource management, especially that related to water and irrigation, can help provide clues to the successful construction of ground water management institutions (Ostrom et al. 2003; Ostrom et al. 1999; Ostrom and Gardner 1993; Ostrom 1990). However, closer observation of the hydrogeologic setting of aquifers indicates that the open-access problem is in fact only one form of the commons problem to which aquifers are susceptible. To understand potential variation of ground water use outcomes within the commons framework, there are two issues of primary importance. The first is the existence of domains of use for actual or potential ground water users. These domains are typically demarcated by some boundary, which could be the property line of an individual landholder, the municipal jurisdiction of a city, or the international border between two nation-states. The second issue is the relationship between these domains of use, ground water, and ground water movement.

An overview of the hydroinstitutional forms developed by Barberis (1991), Matsumoto (2002), and Eckstein and Eckstein (2003) can be discerned as depicted in Figures 1 and 2. Additional variation and combinations are possible as described by Barberis (1991) and Eckstein and Eckstein (2003). An examination of these hydroinstitutional forms reveals subtle differences between them with respect to the resource-use decisions and the nature of the commons problem. While in the first case, ground water exists as an open-access resource in the traditional sense, in the second case, for example, something akin to the open-access condition exists but with respect to the river, which recharges the aquifer rather than accessing storage within the aquifer itself. On the basis of work by Giordano (2003), the types can be further categorized into additional forms based on a more exacting delineation of their common nature: open-access ground water resources, fugitive ground water resources, and bidirectional ground

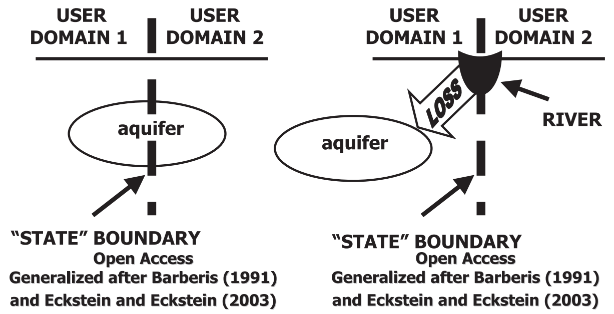

Figure 1. Schematic topology of transboundary aquifers.

water resources. Open-access resources, as described previously, are those in which exclusion from using the resource, at least with respect to the two parties in the example, is not possible and are the classic examples of the commons problem. In fugitive resources, the resource moves from one user to the other in a consistent, single direction. With bidirectional resources, the resource moves from one user to another but then back again.

The differentiation of common property ground water resources based on the characteristics just described has important implications for ground water management and the nature of ground water management regimes, which may be acceptable to different user groups, because the categories are governed by differing economic incentives. For open-access resources, each party gets full benefit of its own abstraction but shares at least some of the costs, for example, in terms of future reductions in exploitable supply, with the other party. Since each party gets full benefit from its own exploitation but the cost of that exploitation is partially shared between both, the incentive for overexploitation exists. This is the essence of the commons problem and illustrates the spatial mechanism behind the classic example of open access in grazing lands. With fugitive resources, the initial exploiter gains all benefits from exploitation but may not bear all the costs and instead shares them with the downstream party. If the nature of the commons is bidirectional, the economics are similar to those of the open-access case but depend on seasonal changes in the ground water system such as basin switching in karst terranes.

Ground Water Management Nexus

Water management programs have historically relied upon science-based criteria of increasing resource

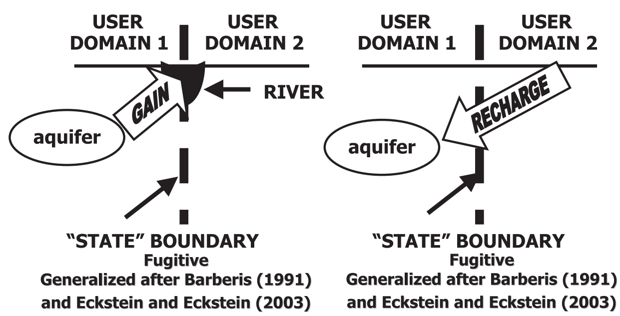

Figure 2. Schematic topology of transboundary aquifers.

efficiency or managing water that is integrated and basin wide typically along the lines of Integrated River Basin Management (IRBM) models. Yet, the actual experiences suggest that building institutional capacity built around achieving fairness and equity and meeting the needs of cultural values of bordering parties (Blomquist and Ingram 2003). Work by IWMI (2003b) found that IRBM models are poorly suited for the different hydrologic, demographic, socioeconomic, and organizational conditions that prevail in developing countries. Recognizing the limitations in traditional arenas of water management, Moench et al. (2003) recommend rethinking ground water management approaches as the intensity of development increases with increased need for food security, while moving toward adaptive management strategies that acknowledge existing social trends and responses to a limited number of prioritized ground water problem areas.

An emerging trend in ground water management that is often overlooked is evaluating the effects of international trade agreements on water management. According to Mann (2003), a state or the traditional users of water resources may not lose jurisdiction over water in a strict legal sense due to trade or investment regimes; however, he indicates that existing agreements may place limits on how and in whose interests the jurisdiction can be exercised. Likewise, Mann (2003) further suggests that ongoing negotiations on trade, investment, and the services sector may limit the ability of governments to manage water resources and services. These situations may lead to a lack of ground water data dissemination between states sharing ground water resources due to perception of economic competition over water resources.

Conclusions

Management of transboundary aquifers appears to suffer from hydroschizophrenia due to myriad hydrogeologic settings, hydroinstitutional settings, and how ground water is perceived in developing vs. developed countries. The pathway to a cure focuses on government agencies serving as "guardians of ground water" by partnering with local stakeholders in ground water administration, protection and monitoring, and broader water-resource planning and management strategies. The thematic statement for ground water at the Third Water Forum indicates that the sustainability of ground water is linked to micro- and macropolicy issues influencing land use and surface water. Kemper (2004) indicates that while practical advances are urgently needed, no "blueprint" for action exists. The International Hydrology Program of UNESCO suggests that efforts to develop international transboundary aquifer treaties may come to fruition in ~10 years. International trade agreements, which may limit jurisdiction and management of water, need to be considered as treaties, and guidelines addressing transboundary ground water are developed over the next 10 years. Likewise, international efforts are needed to limit the transboundary migration and the silent trade of hazardous wastes through transboundary aquifers.

Greater effort needs to be expended on promoting the "positive" flow of constructive dialogue on ground water policy issues and into sharing international experience in best practices for aquifer management and protection. The mapping and data management and sharing efforts by ISARM, WHYMAP, and IGRAC are giant steps toward increasing the positive flow of ground water information.

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