Managing Transboundary Aquifers for Climate Change: Challenges and Opportunities
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The paper focuses on managing transboundary aquifers and aquifer systems for climate change, in recognition of the challenges and opportunities that will be presented by climate change. The first part is understanding the complex impacts of climate change on transboundary aquifers. The second part is managing affected aquifers and aquifer systems to minimize adverse implications of climate change. The third part is the exploration of opportunities for aquifer management to adapt to climate change and mitigate greenhouse gas emissions.

Key words: aquifers, climate change, salination, adaptation, mitigation

1. INTRODUCTION

Managing transboundary aquifers for climate change provides significant challenges and opportunities. This topic is divided into three aspects, with the first part being understanding the impacts of climate change on aquifers. The second part is managing aquifers to minimize adverse climate impacts and to take advantage of positive impacts. The third part is exploring opportunities for states to use aquifer management to adapt to and mitigate climate change

In recent decades, use of deep and shallow aquifers has increased dramatically. Aquifers are essential to human life and agriculture in many regions, sustaining streams, wetlands, and ecosystems, and resisting land subsidence and salt water intrusion into fresh water. Water is never lost to the hydrologic cycle, so it is not possible to experience global peak water. If water is extracted from aquifers and rivers faster than nature can replenish it, there is the potential for regional peak water. Water from some aquifers and lakes and glaciers can be thought of as non-renewable, and subject to peak and decline when they are depleted faster than the natural recharge rate. There is also the concept of peak ecological water, or when a water supply is depleted to the point of causing irreversible damage to local ecosystems that depend on it (Palaniappan, 2009).

These considerations of aquifer use and scarcity contribute to the complexity of transboundary aquifer management. Some key climate impacts for water quantity and quality are saline intrusion and contamination of aquifers. Changes in seasonal and annual precipitation, flooding, temperature and extreme weather events also affect the recharge and discharge of aquifers, and could lead to contamination of aquifers even where there is no water scarcity. Last, climate impacts for aquifers may be greater for coastal aquifers, or in arid and semi-arid regions, such as the Mediterranean, Middle East and northern Africa.

Management of transboundary aquifers may minimize the adverse implications of climate change. There are also opportunities for aquifers to assist in adaptation and mitigation of climate change. Appropriate aquifer management could alleviate surface water scarcity and contamination, reduce seasonal, annual and inter-jurisdictional flood risks, and help sustain aquatic and terrestrial ecosystems dependent on aquifers. For example, water could be abstracted from transboundary aquifers when necessary, and re-injected when beneficial, so the aquifer functions as managed water storage system for all aquifer states.

Transboundary aquifers could also have a beneficial role for climate mitigation. For example, aquifer states could individually or jointly sequester greenhouse gases in deep saline aquifers, which provide the greatest global potential for the storage of greenhouse gases. Further, these aquifers have a key role in facilitating future energy development, such as natural gas in shale rock formations. If appropriately done, this development would not adversely affect aquifers, and could result in lower carbon energy sources.

2. IMPACTS OF CLIMATE CHANGE ON TRANSBOUNDARY AQUIFERS

2.1 Changes in Water Quantity and Quality

Due to the importance of aquifers, changes in water quantity and quality will affect food availability, stability, and access and use, particularly in arid, semi-arid and coastal regions, as well as function and operation of water infrastructure, such as hydro facilities, flood defences and irrigation systems. Climate change can heighten and change extremes in temperature and precipitation, whether flood or droughts, and can affect the severity of pollution and contamination. Changes in water quantity due to climate change are already the subject of much concern and debate, as there are significant gaps in understanding aquifers even in the absence of climate change.

It is not altogether clear globally if whether climate change will result in an increase or a decrease in water quantity. For example the Mediterranean, research suggests that despite local variations, for the region as a whole, precipitation will decrease seasonally and annually, while the level and frequency of extreme temperatures increase, adversely affecting aquifer exploitation and recharge. If greenhouse gas levels double within this century as many climate models predict, other areas of the globe could experience increases in the rate of groundwater recharge, permitting additional exploitation. This necessitates carefully monitoring and modeling at a local and regional level in order to understand aquifer impacts.

For example, Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) found that the rate of aquifer recharge could be increased by the changes in precipitation and temperature caused by elevated greenhouse gases. The scientists developed a method for simulating the effects of elevated greenhouse gas levels, then applied that method to a subtropical and Mediterranean locales within Australia. The Mediterranean location responded more to temperature changes, while the subtropical location was more influenced by the frequency and volume of precipitation. In both locations, changes caused to soil, precipitation and plant transpiration by simulated climates led to significant increases in the rate of groundwater recharge (Green, 2007).

Contamination of aquifer can occur by diffuse loading, such as from agriculture, flooding or storm water runoff; or from point sources, such as industry and hydrocarbon development. Contamination of aquifers is a risk even in areas when the waters contained in those aquifers are not being depleted, and is the main risk to aquifers that are not significantly exploited or over exploited. Consider the example of the Po River in northern Italy, and related contamination between the aquifers and river. The main aquifer for the region's groundwater supply is the top of four sandy aquifers. This aquifer is separated at the top, through a clay layer, from an unconfined aquifer. Recharge to the main aquifer occurs partly by leakage from the upper shallow aquifer, and mainly by lateral recharge from the Po river, which is in contact with the confined aquifer. Groundwater contamination from land fill sites within the river basin areas has been detected in the shallow and in the main confined aquifer. (Zavatti, 1995)

2.2 Saline Infiltration

Salination of coastal aquifers is a global phenomenon that places at risk the present and future uses of aquifers. It causes health problems, decreases agricultural yields and profits and can destroy agricultural lands. It also affects livelihoods, increases costs of infrastructure maintenance and industrial processes, and can modify eco-systems. Saline intrusion of coastal aquifers may occur due to sea level rise, flooding or storm surges, and can extend significantly inland, impacting other aquifers and surface waters (IGRAC, 2009). Salination of aquifers can also result from over exploitation of deep aquifers for agriculture, human and industrial uses, or from natural gas or oil extraction. Where drilling or exploitation has occurred for water or hydrocarbons, a deeper saline aquifer may contaminate a shallower fresh water aquifer.

Saline intrusion is an important concern in the Mediterranean region where high seasonal water demand, primarily for tourism, has resulted in aquifers being over exploited (Inglesias, 2007). Saline intrusion is also very important in regions that are already below sea level such as the Netherlands, which a relies on ground waters to meet much of their domestic supply, due to the contamination of surface waters from transboundary rivers such as the Meuse and Rhine Rivers which originate in Belgium, France and Germany. It is costly for the Dutch to sanitize contaminated surface waters or to desalinate the ground waters.

2.3 Contribution of Groundwater to Sea Level Rise

The possible contribution of groundwater to sea level rise was mentioned in the IPCC Third Assessment Report. However, it was noted that the uncertainty was large and that the positive contribution of groundwater depletion may be offset by impoundment in reservoirs and associated recharge of surrounding aquifers. For this reason, anthropogenic contributions to sea level rise are not quantified in IPCC Fourth Assessment Report, although they are mentioned as the possible cause for the discrepancy between observed sea-level rise and the sum of the known sources. Global groundwater depletion has been increasing since the 1960s and is likely to increase further in the near future, while the increase of impoundment by dams has been decreasing since the 1990s. Recent research suggests that the contribution of groundwater depletion to sea-level rise may become increasingly important in the coming decades, and could contribute as to much as one quarter of the overall sea level rise (Wada, 2010). This research illustrates the complex and coupled interactions between ground water use and impacts of climate change.

2.4 Coastal Aquifers and Aquifers in Arid and Semi-Arid Regions

The vulnerabilities of coastal aquifers to salination have already been discussed. Coastal aquifers, and aquifers in arid and semi-arid regions, can be viewed as overlapping categories of aquifers, with shared vulnerabilities. This is particularly true for the Mediterranean, which is defined here to include the Middle East and northern Africa. For example, climate change projections for the Mediterranean, driven by socio-economic scenarios, result in temperature increases and precipitation decreases in most of the region. The projections indicate an increased likelihood of drought and variability of precipitation seasonally and in intensity. The combination of long term change and greater extremes will increase water demand, with further impacts on ecosystems. Under all scenarios, available water decreases while irrigation demand increases. Ground water is used extensively in arid and semi-arid regions, including the Mediterranean region, for agriculture. While technology and need are resulting in desalination becoming affordable for domestic water uses, it is too costly for the large water demands of agriculture in the Mediterranean (Inglesias, 2007).

3. MANAGING TRANSBOUNADARY AQUIFERS TO MINIMIZE ADVERSE CLIM ATE IMPACTS

3.1 Management Frameworks for Aquifers and Climate Impacts

Climate change may alter the reliability of current water management practises, due to future changes in hydrological characteristics, so this management will have to be adaptive, and based on accurate and ongoing scientific measurements. Management responses to climate change for aquifers need to be closely linked to different sectoral policies (agriculture, energy, food security, health, nature conservation etc.). Non-confined aquifers require linkages with the management of and connecting river basins, lakes and seas. For all aquifers, whether confined or non-confined, management will need to consider those aquatic and terrestrial ecosystems where waters may be discharged.

Transboundary aquifer management requires monitoring, data collection and modelling for those aquifers and within their recharge and discharge zones to understand how these aquifers are impacted by both gradual climatic changes and extreme events. For example, a global, coastal database is being investigated in a model based on a simple, unconfined, coastal aquifer to explore the impacts of climate change on saline intrusion. A basic database provided temperature, precipitation, population density and evapotranspiration. Because evapotranspiration is not forecast in climate models, a value will be predicted from a linear correlation with the temperature data. When fully developed, these calculations could be incorporated into the Dynamic Interactive Vulnerability Assessment model and used to investigate salt water intrusion into estuaries, beach erosion, land-loss and other parameters.

Management may also require the development of appropriate tools and processes, including legal and institutional frameworks. This concept will be explored further in the final paper and presentation. For example, though it may not be essential, it could be useful to have explicit references to climate and ground water issues in bilateral, regional and international agreements concerning aquifers, and related river basins, watersheds, and coasts.

3.2 United Nation Approaches and Projects

Relevant United Nation (UN) agreements for aquifers include the UN International Law Commission's Law of Transboundary Aquifers, and the UN Economic Commission for Europe's Water Convention and Guidelines on Water and Adaptation to Climate Change. The UN Economic Commission for Europe is working on climate change and transboundary aquifers, and in the past had limited activities on groundwaters. Assessments currently under preparation include groundwaters, and a study on the applicability of the Water Convention to transboundary aquifers is currently underway with a workshop on transboundary aquifers tentatively being scheduled for 2011.

The UNESCO International Hydrological Programme, and particularly its UNESCO Cairo office, is actively engaged on aquifers and climate impacts. Water scarcity is noted as constraint on social development in the Arab world, and population growth and expansion of agriculture exacerbates these impacts. For example, Egypt experiences climate impacts of changing precipitation in the Nile basin, challenges of drought, flooding and sea water intrusion. The UNESCO-sponsored GRAPHIC project promotes and advances sustainable groundwater management considering climate change and linked human effects. In does this by providing a platform for exchange of information, and through providing scientific and policy recommendations.

The Kampala Statement on Groundwater and Climate in Africa addresses ground water and climate issues, including developing water policies at national and regional levels that strike balance between renewable ground water and demand, and recognizing the role of ground water storage and importance of ground water discharge to dependent ecosystems. The eighth point of this statement notes that management of Africa's transboundary aquifers requires a regional approach involving technical cooperation and joint monitoring among nations, and recommends strengthening of institutional structures at continental and regional scales, and development of legal and institutional frameworks.

3.3 European Union Approaches and Projects

The European Union's Water Framework Directive (WFD) and the EU Groundwater Directive are based on principles of river basin management planning and designing programmes of measures to achieve good status objectives. The WFD does not contain an explicit reference to climate change, but requires monitoring at regular intervals and the achievement and maintenance of the objectives. The Groundwater Directive similarly includes risk assessments, achievement of good status, programmes of measures and ongoing monitoring. The EU Flood Directive and the Communication on water scarcity and droughts address some of anticipated impacts of climate change, including impacts on ground waters. There is a significant consideration of water and climate within the White Paper on Adaptation to Climate Change of 2009, and extensive EU projects. The Genesis project may be the most relevant for groundwater, as it considers aquifers and associated aquatic and terrestrial ecosystems. It will include case studies of important geologic formations and aquifers; different climate regions; ecosystems including lagoons, oasis, springs, streams, wetlands; and economic developments and drivers of climate change (Quevaviller, 2010).

4. UTILIZING TRANSBOUNDARY AQUIFERS TO ADAPT TO AND MITIGATE CLIMATE CHANGE

4.1 Aquifer Storage and Recovery

Aquifer storage and recovery is being investigated by the United States Environmental Protection Agency Water Resources Adaptation Program. The focus is to evaluate the potential of aquifer storage and recovery as a practical climate change adaptation tool. Investigations have focused on technical feasibility, regulatory implications, and engineering techniques for field applications considering the need to mitigate water budget imbalance; environmental impacts and potential regulatory implications; and adaptation techniques and engineering guidelines for sustainable development. Preliminary research supports the feasibility aquifer storage and recovery in adaptation to climate changes, and provides the basis for developing engineering techniques with managed environmental impacts.

In many countries, including Australia, the potential to store harvested storm water using managed aquifer recharge is significant. Within Australia, concepts of aquifer storage and recovery are being developed further, as constructed wetlands are being used to provide the initial water treatment for managed aquifer recharge and recovery schemes. For example, in Sydney, Perth, Brisbane, and Cairns, the volume of urban storm water runoff is larger than the volume of water supplied by the water system. Managed aquifer recharge is a cost effective solution where suitable urban aquifers are present, and research is underway to map the potential for managed aquifer recharge and recovery in Australia. Urban aquifers in Perth, Adelaide and Melbourne show significant potential storage capacity.

4.2 Desalination,Water and Energy Research

Desalination research is being conducted on the production of fresh water from brackish water using such technologies as reverse osmosis membranes, and on the prevention of saltwater infiltration through modification of aquifer field and pumping design. To prevent aquifer salination, one technique applied in developed countries is to construct hydraulic barrier and inject it with water from aquifers further inland, or to use purified, recycled wastewater. This technology can not be applied in developing countries due to cost. So instead of constructing hydraulic walls as a preventive measure, adaptation techniques create commercial, community and individual desalination plants using solar energy. Research into water and energy conservation and efficiencies are also being explored, and offer significant possibilities for decreasing water demand and the associated carbon footprint of the extraction of groundwater.

4.3 Carbon Sequestration in Saline Aquifers

Carbon sequestration in saline aquifers provides significant mitigation opportunities for greenhouse gases. In the sequestration process, CO_2 captured from industrial emissions are pumped into deep-saline aquifers. The depths of these aquifers provide pressures high enough to keep the CO_2 supercritical in a single fluid phase with physical properties similar to those of a liquid rather than a gas. Some CO_2 will become dissolved in the aquifer and react with other dissolved salts in the brines and rocks to form carbonate minerals that will permanently fix part of the CO_2 as a rock. These aquifers are unsuitable as resources for drinking water, so there are no adverse consequences for fresh water aquifers. The best industrial facilities are coal-fired power plants where as much as 90 per cent of the CO2 emissions could be captured, or other large emitters such as oil refineries, cement plants and oil sands facilities.

4.4 Natural Gas Development and Aquifers

Shale gas development is occurring on a global scale, and can result in a lower carbon form of energy development. There is some dispute as to the impact of hydraulic fracturing on adjacent aquifers. The best way to protect groundwater during shale gas development is with high quality casing, good cement, and proper water-handling procedures. Provided shale gas development occurs in consistent regulatory framework, this natural gas development can assist in the mitigation of climate change.

5. CONCLUSIONS

This paper briefly touches upon the managing transboundary aquifers for climate change, and the challenges and opportunities that will arise. More detailed discussion and case studies will occur at the ISARM 2010 conference.

6. BIBLIOGRAPHY

Burchi, S. et al, *Groundwater in international law: Compilation of treaties and other legal instruments.* United Nations Food and Agriculture Organization, Rome, 2005.

Green, T.R et al. 2007. Potential Impacts of Climate Change and Human Activity on Subsurface Water Resources. *Vadose Zone Journal.* Vol. 6 No. 3, p. 531-532.

Inglesias, A, et al (2007). Challenges to Manage the Risk of Water Scarcity and Climate Change in the Mediterranean. *Water Resources Management*, Springer, 21: 775-788.

Leduc, C. *Summary report of the Side Event*, Hydrological Changes in Semi-Arid and Arid Areas under Climatic and Human Influences: Focus on the Mediterranean Region, September 2006, Tunis.

Kampala Statement Groundwater and Climate in Africa, *Groundwater and Climate in Africa*, June 24-28, 2008, Kampala, Uganda.

Palaniappan, M. and Gleick, P. Chapter 1: Peak Water, *World's Water 2008-2009*, Island Press, Washington, 2009.

Quevaviller, P. *EU Research on Climate Change Impacts on Groundwater Resources, European Groundwater Conference*, May 20-21, 2010, Madrid, Spain.

Rapaglia, J et. Al (2010). Forecasting Salt-Water Intrusion into Coastal Aquifers Due to Climate Change, *World Environmental and Water Resources Congress 2010: Challenges of Change,* Providence, Rhode Island.

UNESCO IHP (2008), Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (GRAPHIC): A Framework Document (GRAPHIC Series No. 2).

Van Weert, F. et al, *The Global Overview of Saline Groundwater Occurrence and Genesis*. International Groundwater Resources Assessment Centre (IGRAC), Utrecht, 2009.

Wada, Y et al. (2010), Global depletion of groundwater resources, *Geophysical Research Letters*, doi:10.1029/2010GL044571, in press.

Zavatti, A. Aquifer pollution vulnerability maps in the Po River plain — northern Italy, *Assessing and Managing Health Risks from Drinking Water Contamination: Approaches and Applications*, (IAHS Publication No. 233), International Commission on Groundwater, Rome, 1995.