

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. First, it is necessary to understand the complex impacts of climate change on transboundary aquifers. The next issue is managing affected aquifers and aquifer systems to minimize adverse implications of climate change. Last, it is important to explore opportunities 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. The first aspect is understanding the impacts of climate change on transboundary aquifers. The second aspect is managing aquifers to minimize adverse climate impacts, and to take advantage of positive opportunities. A third aspect is exploring opportunities for states to use aquifer management to adapt to and mitigate climate change. Transboundary aquifers have increased dramatically in importance in recent years. Aquifers are essential to human life and agriculture, providing vital sources of water for drinking and agriculture. Some transboundary aquifers, such as the Nubian Sandstone Aquifer System, contain non-renewable fossil. Aquifers sustain streams, wetlands, and ecosystems; and resist land subsidence and salt water intrusion. Climate change may increase aquifer uses and rates of depletion, thus increasing complexity and challenges of aquifer management.

Key climate impacts for aquifers are changes in recharge and discharge zones and volumes, contamination and saline infiltration. Changes in seasonal and annual precipitation, flooding, temperature and extreme weather events will modify the recharge and discharge of renewable aquifers. Flooding and extreme weather events could contaminate all types of aquifers. Coastal aquifers will increasingly be vulnerable to saline intrusion as sea levels rise and aquifers are depleted. Aquifers in arid and semi-arid regions, such as the Mediterranean, Middle East and northern Africa, are likely to be affected by higher temperatures, decreased precipitation and increasing water scarcity, as well as greater water uses. Links between groundwater depletion and sea level rise are also being considered.

Appropriate management of transboundary aquifers can minimize the adverse implications of climate change. Aquifers can assist in adaptation to climate change. Aquifer management could alleviate surface water scarcity and contamination, reduce seasonal, annual and inter-jurisdictional flood risks, and sustain the aquatic and terrestrial ecosystems dependent on the aquifers. For example, water could be abstracted from transboundary aquifers, and re-injected when beneficial, so the aquifer functions as a managed water storage system for all aquifer states. Linkages between aquifers and surface, coastal and marine waters necessitate integrated approaches.

Transboundary aquifers could also have a beneficial role for climate mitigation. 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, transboundary aquifers could facilitate future hydrocarbon development, whether traditional or non-conventional sources such as natural gas or shale gas. If appropriately done, this development would not adversely affect freshwater aquifers, and could result in the development of lower carbon energy.

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. There are significant gaps in understanding aquifers even in the absence of climate change.

It is not clear if whether climate change will globally result in an increase or a decrease in water quantity. For example, research suggests that despite local variations, with the Mediterranean region, 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 will experience increases in precipitation, and thus groundwater recharge, permitting additional exploitation. Careful monitoring and modeling is required at the local and regional level to understand impacts on aquifers.

The Commonwealth Scientific and Industrial Research Organisation of Australia found that aquifer recharge could be increased by changes in precipitation and temperature caused by elevated greenhouse gases. Scientists developed a method for simulating the effects of elevated greenhouse gas levels, then applied that method to subtropical and Mediterranean locales. The Mediterranean locale responded more to temperature changes, while the subtropical locale was more influenced by the frequency and volume of precipitation. In both locales, changes in soil, precipitation and plant transpiration led to significant increases in 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 or over exploited. Consider the example of the Po River in northern Italy, and related contamination between the aquifers and river. Recharge to the main aquifer occurs partly by leakage from the upper shallow aquifer, and by lateral recharge from the Po river, which is in contact with the confined aquifer. Groundwater contamination from landfill sites in the river basin was detected in the shallow and main confined aquifer (Zavatti, 1995). The last example also illustrates links between surface water bodies (rivers, lakes and seas) and subterranean aquifers. Abstraction and depletion in one can affect the other.

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, which defined to include North Africa and Middle East, where high seasonal water demand for agriculture, tourism and urban

development has resulted in aquifers being over exploited (Inglesias, 2007). The Great Man-Made River Project transports five million cubic metres of water per day from the Nubian Sandstone Aquifer System through the Sahara desert to the Libyan coast. These additional waters were necessary as the coastal aquifers were depleted and subject to saline infiltration.

Saline intrusion is also very important in regions already below sea level such as the Netherlands which relies on groundwaters to meet much of their domestic supply. This is due to the contamination of their surface waters from the Meuse and Rhine Rivers which originate in Belgium, France and Germany. It is costly to sanitize contaminated surface waters or to desalinate the ground waters, so the Dutch also rely on hydraulic engineering and managed aquifer recharge.

2.3 Contribution of Groundwater to Sea Level Rise

The possible contribution of groundwater depletion to sea level rise was mentioned in the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report, but it was noted that the contribution of groundwater to sea level rise could be offset by reservoir storage and aquifer recharge. 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. Recent research suggests that the contribution of groundwater depletion to sea-level rise may become increasingly important in the coming decades, and could amount to up to one quarter of the overall sea level rise (Wada, 2010). This illustrates the complex and coupled interactions between ground water use and climate impacts.

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

Coastal aquifers, and aquifers in arid and semi-arid regions, are related aquifers with shared vulnerabilities. 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 intensity. The combination of long term change and greater extremes will increase water demand, with further impacts on ecosystems. Under all scenarios for the Mediterranean, available water decreases while irrigation demand increases.

Aquifers, including coastal aquifers, are used extensively in arid and semi-arid regions for agricultural and domestic water. While desalination may be a more affordable option for domestic water uses, it is too costly for the larger demands of agriculture (Inglesias, 2007). One solution, Libya's Great Man-Made River ships vast quantities of water from the transboundary Nubian Sandstone Aquifer System to the coast to offset the contamination and salination of coastal waters.

3. MANAGING TRANSBOUNDARY AQUIFERS TO MINIMIZE ADVERSE CLIMATE 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.). Aquifers management 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 aquatic and terrestrial ecosystems where waters may be discharged. Ground water directly and indirectly contributes 80 percent of the water flowing from the watershed into Lake Michigan. Large groundwater withdrawals in southeastern Wisconsin have reduced groundwater flow to Lake

Michigan and, in some locations, have reversed flow. Groundwater is included in the international management of these lakes by the International Joint Commission (IJC, 2004).

Transboundary aquifer management requires monitoring, data collection and modelling for aquifers 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 provides temperature, precipitation, population density and evapotranspiration. Because evapotranspiration is not forecast in climate models, a value is predicted from a linear correlation with the temperature data. When fully developed, these calculations could be incorporated into a dynamic interactive vulnerability assessment model and used to investigate salt water intrusion into estuaries, beach erosion, land-loss and other parameters.

Management may require the development of appropriate tools and processes, including legal and institutional frameworks. For example, explicit references to climate and ground water issues could be included bilateral, regional and international agreements for aquifers, and river basins, watersheds, and coasts. It could also be useful to have international agreements for managed aquifer storage and recovery, and managed aquifer recharge.

3.2 United Nation Approaches and Projects

United Nation (UN) agreements for aquifers include the International Law Commission's draft Law of Transboundary Aquifers, and regional agreements such as 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, as well as the 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. It 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 anticipated impacts of climate change on groundwaters. There is a significant consideration of water and climate within the White Paper on Adaptation to Climate Change of 2009, and EU projects such as the Genesis project. The Genesis project considers aquifers and associated aquatic and terrestrial ecosystems (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 to evaluate the potential of aquifer storage and recovery as a practical adaptation tool. Preliminary research supports the feasibility of aquifer storage and recovery for adaptation, and for developing engineering techniques to manage environmental impacts. The potential to store harvested storm water using managed aquifer recharge is significant. Managed aquifer recharge is a cost effective solution where suitable urban aquifers are present. For example, research is underway in Australia to map the potential for managed aquifer recharge and recover. Constructed wetlands in some instances to provide the initial water treatment for managed aquifer recharge and recovery. 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, while urban aquifers in Perth, Adelaide and Melbourne have significant storage capacity.

4.2 Desalination, Water and Energy Research

Research is being conducted on the production of fresh water from brackish water using technologies like reverse osmosis membranes. Saltwater infiltration is prevented through modification of aquifer field and pumping design, such as constructing hydraulic barrier and inject it with water from aquifers further inland, or using 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 include 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. Though there are significant ecosystem risks, proposals are beginning to consider the use of saltwater for agriculture, and significant diversions of saltwater inland for marine fisheries, shipping and urban settlements.

4.3 Carbon Sequestration in Saline Aquifers

Carbon sequestration in saline aquifers provides significant mitigation opportunities for greenhouse gases. In the sequestration process, CO₂ captured from industrial emissions are pumped into deep-saline aquifers. These aquifers have pressures high enough to keep the CO₂ supercritical in a single fluid phase, with physical properties similar to a liquid. Some CO₂ will become dissolved in the aquifer and react with other dissolved salts to form carbonate minerals that will permanently fix part of the CO₂ as a rock. These saline aquifers are unsuitable as resources for drinking water, so with appropriate engineering techniques there may be no adverse consequences for fresh water aquifers. Significant CO₂ emissions could be captured for coal fired power plant, or other large emitters like oil refineries, heavy oil upgraders, and cement plants.

4.4 Hydrocarbon Development and Aquifers

Natural gas development, including shale gas development, is occurring on a global scale, and can result in a lower carbon energy development. It is increasingly important in arid regions such as Saudi Arabia, which are experiencing increasing energy and water uses, as well as reliant on fossil

water supplies in aquifers. There is concern for related greenhouse gas emissions, and the impact of hydraulic fracturing of shale gas extraction on adjacent freshwater aquifers. The best means of protecting freshwater aquifers is high quality well casing, good cement, and proper water-handling procedures. If development occurs in a good regulatory framework, it can mitigate climate change.

5. CONCLUSIONS

This paper briefly touches upon the managing transboundary aquifers for climate change, and the challenges and opportunities that arise. Statements by Global Environmental Fund (GEF) at the ISARM 2010 conference indicate the vital role of national and transboundary aquifers in adapting to and mitigating climate change. In closing remarks, Mr Al Duda, Senior Advisor on International Waters of GEF, referred to links between aquifers, climate, freshwater, and sustainable development, as well as carbon storage opportunities in aquifers. Aquifers and groundwaters need to be considered in the context of integrated water resource management, with climate change transforming the role of aquifers. GEF is engaged in using aquifers a balancing mechanism, for managed recharge to alleviate drought, and for sustainable development. Aquifer projects in the Mediterranean such as the the GEF-UNDP-UNESCO Protection and Sustainable Use of the Dinaric Karst Aquifer System (DITKAS) illustrates how GEF funding can support international aquifer management in a region vulnerable to climate change.

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