Addressing socio-economic and institutional dimensions in Transboundary aquifer management by using hydro-economic modeling and serious gaming

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ABSTRACT

Transboundary aquifer management is subject to increasing pressures, complexity, uncertainty and connectedness at higher scales. A recent study reveals that transboundary aquifer management is based on the traditional engineering approach with a strong focus on hydrogeological aspects. Increasingly, this approach is criticized and adaptive management is recommended as an alternative that addresses socio-economic and institutional dimensions more explicitly. This paper addresses how hydro-economic modelling and serious gaming may support these dimensions of the process of transboundary aquifer management. Hydro-economic modelling may identify the consequences of groundwater extraction for other international stakeholders and the costs and benefits of (non-)cooperation. Serious gaming may be used to raise awareness, to analyze socio-economic conditions and institutional settings, to build trust between stakeholders and to facilitate discussions and negotiations over sharing transboundary aquifer resources.

Key words: transboundary aquifer management**,** hydro-economic modelling, serious gaming

1. TRANSBOUNDARY AQUIFER MANAGEMENT CHALLENGES

Management of transboundary aquifers (in addition to 'regular' management of domestic, non-shared water resources) is subject to increasing pressures, complexity, uncertainty and connectedness at higher scales. Increased pressures arise from growing water demand in order to meet the food security of an increasing population. Increased complexity results from changes in thinking about water management: from a more centralized top-down and engineering approach to a more participatory water governance type, including many scales and stakeholders simultaneously. Additionally, increasing complexity is caused by acknowledging the regulating, supporting and cultural ecosystem services of groundwater beyond its traditional use value. Climate and global change is causing a high level of uncertainty on the future water availability and on future water demand. Globalization stretches the interconnectedness from local and regional scales to even global scales. Hoff (2009) describes global tele-connections between water systems: rapid irrigation development in India (often groundwater-based) has affected the monsoon mechanisms in a large region including India and East-Africa; increasing food demand in China has lead to a situation that China's food is partly produced in countries like Brazil leading to environmental issues (e.g. groundwater depletion).

It is clear that the management of transboundary aquifers (TBA) must be seen in a wider context of country dependencies, increasing pressures, complexity, uncertainty and connectedness at various scales. Socio-economic and institutional aspects of TBA management are at least equally important as the technical (hydrogeological) side of it (Allan, 2003) in these rapidly changing contexts. This paper addresses how the hydro-economic modelling and serious gaming may support the process of transboundary aquifer management.

2. CHALLENGES AND NEW DIRECTIONS FOR ISARM

One of the authors of this paper is involved in a current study issued by the Global Environmental Facility, International Water (GEF IW) to assess the use and generation of science in the GEF IW portfolio. This portfolio includes ISARM-projects. Preliminary results from this study reveal that particularly hydrogeological research is dominating the science in reviewed TBA projects. Moreover, that this research is often in a descriptive mode using various surveying tools and occasionally in a forecasting and decision-making mode using tools like groundwater flow models. A limited number of the assessed GEF IW groundwater projects has or had institutional components. Socio-economics is modestly present in several of the projects.

This strong focus on hydrogeological research in the assessed projects is not surprising. TBA management is predominantly carried out by water resources managers. Water resources management has a strong engineering tradition based on controlling environmental problems with technical solutions (Pahl-Wostl, 2008). It is only human nature to reduce complex, multi-faceted problems into more simple, one-issue problems in order to try to solve them. So, the group of mostly geologists, hydrogeologists, hydrologist and civil engineers assigned with the task of the management of TBAs tend to reduce this complex problem (a social dilemma) comprising socio-economic, institutional and legal dimensions and frame it into a more or less hydrogeological exercise that can be tackled with surveys and modelling studies. There often appears to be a strong belief among the group of hydrogeologists, hydrologist and civil engineers that understanding the hydrogeological system is of primary importance in order to be able to manage TBAs.

There is also a methodological reason to focus on the technical (hydrogeological) aspects of TBA management, at least in its earlier stages. Management of TBAs can easily become a highly politicized exercise as groundwater resources in the shared aquifer are of national security concern for some countries. Both ISARM and GEF IW acknowledge that interests and claims on the shared (ground)water resources may diverge widely between countries and potentially form sources for tension and conflicts. Here, TBA management is viewed as a process where countries incrementally cooperate with each other. It starts with doing least-controversial activities like sharing of non-political data (often technical data on the aquifer systems) or doing joint-fact finding on this. Only after a period of joint learning, a stage of certain mutual trust is reached and more controversial parts of joint management are exercised (Scheumann and Herrfahrdt-Pähle, 2008).

Increasingly, the traditional engineering approach to water resources management (and natural resources management in general) is being criticised. As mentioned in the first section transboundary aquifers are subject to increased pressures, complexity, uncertainties and connectedness. In the engineering approach the non-linearity of dynamics, the interaction between environment, technology and humans tend to be under-estimated. Janssen et al. (2005) argues that the scientific tools commonly applied in the engineering approach such as groundwater models only have limited validity. Such tools should only be used when there is unified scientific knowledge and unified institutional interests among the stakeholders depending on the results of such tools. When the objectives are vague or diverse and if technical information is surrounded by uncertainty, complexity problems become part of a political process. For such processes, other tools are more suitable. Adaptive water management is being proposed as better alternative. In this latter approach, the understanding of the dynamics of physical systems (here the transboundary aquifers) is less important and knowledge on human society using and managing the physical systems is considered more explicitly.

We argue that for bringing ISARM to a next level, the adaptive water management approach should be fully adopted. By doing so, non-technical aspects of transboundary aquifer management, such as socio-economics and institutional issues are taken into account more explicitly. Furthermore, within the framework of adaptive water management, TBA management is regarded as a process of social learning. In this process, various stakeholders at international, national and local scales continuously interact and learn from each other (vertically and laterally) increasingly building trust between them.

Environmental economics and management science have already developed and applied various tools that are applicable in social learning processes. In the next sections, we focus on two of such tools/approaches that are useful addressing socio-economic and institutional dimensions of TBA management. Firstly, attention is paid to hydro-economic modeling which combines hydrological modeling (supply) with economic modeling (demand) of groundwater. Secondly, the role of serious gaming in awareness raising, socio-economic and institutional analysis, social learning and trust-building in TBA management is discussed.

3. HYDRO-ECONOMIC MODELLING AND TBA MANAGEMENT

Water users often consider only private costs and benefits in their water extraction decision. Because (ground)water extraction imposes externalities on other stakeholders (even in other countries), private costs and benefits do not equal social costs and benefits. Market mechanism are often not able to allocate water efficiently (often these mechanisms are even completely absent). However, when all affected individuals reside within one single country, government intervention can enforce efficient water allocation. In TBA, multiple countries are involved and independent international organisations often lack the power to enforce efficient outcomes.

From a pure economic point of view, countries are only willing to cooperate on TBA-management when its cost-benefit ratio is less than in the case of non-cooperation. Various economic analysis tools exist that articulate such cost-benefits ratios in an objective language that is intelligible to the stakeholders involved (Qadummi, 2008). Such tools may identify the consequences of groundwater extraction on other stakeholders. The use of such economic analytical tools is assumed to increase the degree of objectivity in the sometimes highly political exercise of TBA management. One of the tools that contribute to this objective is integrated hydro-economic modeling.

In the hydro-economic modeling approach, the aquifer is regarded as one entity regardless of its geographical borders. The model exists of a hydrological (supply) part and an economic (demand) part. Water allocation is simulated or optimized by maximizing economic benefits, constrained by water availability, physical feasibility, minimal water flow requirements and water use technology. Integrated hydro-economic modeling covers part of the IWRM approach by focusing on the benefits of water use for different economic sectors, both spatially and over time (Brouwer and Hofkes, 2008). Two modeling approaches exist: the compartment approach and the holistic approach. It is important to notice that in literature, few examples of integrated hydro-economic modeling exist applied to groundwater aquifers.

The holistic approach integrates the economic and hydrological aspects fully. The compartment approach keeps the economic and hydrological aspects separated in two models; the two models are coupled (the water supply in a certain node enters the economic model in the water availability constraint) so that the model output of one model is input for another. The choice between two model types is a trade off between information transfer difficulties in the compartment approach and the simplified economic and hydrological model in the holistic approach (McKinney et al., 1999).

An example of the holistic approach can be found in Gürlück and Ward (2009). In their paper, they present a dynamic, non-linear basin scale model for the analysis of several policy options in the Nilüfer River Basin of Turkey. The model includes hydrological aspects of the river basin, determining water supply in several nodes. The model's economics accounts for agricultural water demand, recreational values and water demand from industries. The model output shows the effects of policy measures on water flows, water volume, water depletion, agricultural land use and production, and total economic costs and benefits for several irrigation districts. One of the lessons learned is that the basin scale modeling approach provides a general framework for formulating water management policies, consistent with the principles underlying the EU WFD (Gürlück and Ward, 2009). Other examples following the holistic approach include Rosegrant et al., (2000) and Cai and Wang (2006). Lekoff and Gerelick (1990) follow the compartment approach by linking an economic, hydrologic and agronomic model in their study.

Several applications of hydro-economic modeling to transboundary water problems exist in literature. Fisher et al., (2002) apply integrated hydro-economic modeling to the Israel, Jordan and Palestine region. These countries share surface water resources such as the Jordan River and the Yarmuk River but also groundwater resources. Israel created a nationwide conveyance system to bring water from the Sea of Galilee tot urban centers and agricultural areas throughout the country. Jordan and Gaza also developed conveyance systems, but less complex as in Israel. The model is a single-year model that maximizes net benefits of water use. Water demand is calculated for various sectors, such as agriculture, households and industry. Maximum water supply in a certain district is calculated using a hydrological model and is used as a constraint in the optimization model. In this study, the effects of several (international) infrastructural measures on water availability and welfare are analyzed from an international point of view.

The study concludes that integrated hydro-economic modeling is helpful for policy makers in their water management and policy decisions, not only at a national level but also for transboundary issues. The use of integrated hydro-economic modeling for transboundary water management has two aspects. First, property rights in water are reduced to monetary values making it easier to measure water against other things and therefore support international negotiations. Second, water agreements that divide water quantities are not optimal. Instead, water trade and cooperation in combination with infrastructure development will mutually benefit.

4. SERIOUS GAMING AND TBA MANAGEMENT

Increasingly, serious gaming is being applied in natural resources management. Serious gaming comprises of a suite of game-like approaches in which stakeholders interact socially in fictitious settings. Serious gamers improve their understanding of the perspectives, preferences, interests, constraints and concerns of other actors (Pahl-Wostl 2007). Historically, simulation gaming has been used extensively in the military, by athletes and by scientists to discover effective new strategies and techniques as well as to develop skills needed to implement them.

Serious gaming approaches transboundary water resources management explicitly from a process perspective in which stakeholders constantly contemplate and exercise cooperation and/or competition based upon their knowledge of the resources base, the social-economic and institutional (including legal) conditions. The objective of serious gaming is to facilitate awareness raising, to analyze socio-economic conditions and institutional settings and to build trust between stakeholders (meanwhile it may be fun to be involved in such serious games). Nandalal and Simonovic (2003) developed a computer assisted negotiation model/software that can be used to facilitate multi-stakeholder discussions of water-related conflicts (so far TBAs are not included in the model but can be implemented relatively easily).

Serious games in water resources management can have different forms and purposes. In its simplest form, serious games are role-plays where the game participants take a certain role representing one type of stakeholder in a water resources setting. In such role games, participants are allowed to make decisions (like the increase in groundwater abstraction to meet domestic agricultural water demand) that are likely to affect other participants' options. The roles allow for negotiation and communication moments (mimicking real life) where the various stakeholders can discuss their diverse interests and try to come to more collective and optimal solutions. An example of such transboundary role-play is Calypso that is part of PCCP's and UNESCO-IHE's courses on Water Conflict and Resolution.

Serious games may use computer support that facilitates the process. In simple cases, the physical part of the role play setting (e.g., the transboundary aquifer system) is being represented by a computer-based groundwater flow model. The effects of a certain decision made by game participants can be put into the model and its consequences simulated on the fly. With current developments in computer technology and the computer entertainment industry, serious games exist that are fully placed in a virtual world and that can be played with multiple actors online on the internet. An example of such game is *Climate Quest*, an electronic game developed with support of UNESCO's PCCP. Its goal is to create awareness and to start a dialogue among youngsters about climate change and its consequences on the management of shared water resources (PCCP, 2010). In May 2010, IBM unveiled *CityOne*, a serious game for professionals to manage urban challenges like water management (IBM, 2010).

5. IGRAC'S TRAGEDY OF THE GROUNDWATER COMMONS

IGRAC developed a serious game called Tragedy of the Groundwater Commons. In this game, participants represent 10 countries sharing groundwater resources. Nine of these countries have an agricultural economy based on groundwater irrigation and one country's economy is based on inland fisheries in a groundwater dependent lake. The participants play multiple rounds in which each country decides how much land to cultivate and whether to fish or not. Groundwater levels decline as countries decide to irrigate more land. Fishing is only possible when the groundwater level has not declined below the lake bottom. A simple Excell-program calculates the groundwater levels in each country resulting from accumulated pumping. Furthermore, the program accounts for capital accumulation (positive and negative) in all countries. The countries' benefits result from their agricultural yields (function of amount of land under agricultural production). Costs predominantly consist of pumping costs, which is a function of the countries individual abstracted volumes of groundwater to meet its irrigation demand multiplied by the groundwater depth in their country during that round. The latter is partly caused by their neighboring countries and here is the typical transboundary externality. If no fish is produced during the game, all countries bear 'environmental' costs, as their diet is partly dependent on it.

Basically, this serious game addresses the tragedy of the commons dilemma translated into a TBA context. The game allows for cooperation and/or free-riding at multiple levels. Countries may invest in more efficient irrigation equipment resulting in less water demand. Investment costs bear on the countries that implement this irrigation technique while the positive consequences of less declined groundwater tables benefit neighbouring countries as well. The game allows for introduction a system of groundwater quota in order to regulate excessive groundwater abstraction. If sufficient countries support the regulation, countries exceeding the agreed groundwater abstraction quota are subjected to (negotiated) penalties. Enforcement of the regulation is only guaranteed when more than half of the countries agreed to support it. Implementation of the regulation imposes substantial costs that are equally shared by the supporting countries. The game allows for climate variability in the sense that at certain (unexpected) moments agricultural yields can decrease because of droughts.

The serious game has been played successfully in a number of settings with international students from Dutch universities. Feedback from participating students and their professors was very positive and revealed that learning by doing and experiencing greatly contributes to the students understanding of TBA management. We think this game has a large potential to be used in more professional settings, such as in ISARM projects and within River Basin Organizations which are often given the task to include transboundary groundwater as well.

The game could be improved in a number of ways. At this moment only one setting of hydrologeological (including meteorological), socio-economic and institutional conditions is simulated. The game could be developed further by 'installing' various settings depicting other transboundary aquifer situations. For this, the 6 archetypical TBA hydrogeological settings of Eckstein and Eckstein (2005) could be used. Players should be able to choose between various socio-economic settings (developed or developing economies and level of groundwater dependency of economies). From the institutional point of view, the game could be improved most. At this stage, game participants represent an entire country and it is assumed that the whole country acts as a homogeneous entity. Therefore, if a game participant decides to reduce groundwater abstraction, his whole country acts as if this happens. Obviously, this is not the case in reality. Whatever deal such a country representative makes during international negotiations, needs to be supported by the groundwater users within the country. In reality, the decisions-makers and top water resources managers need various policy instruments such as domestic regulations, monitoring and enforcement and various incentives to affect the domestic but likely heterogeneous group of groundwater users. The game might be improved by adding several layers of players representing various groups of stakeholders with diverse interests and influencing and by different levels of decision-making power. Possibly, part of the stakeholder groups could not be 'played' but simulated by using agent-based-modelling.

6. DISCUSSION

It is clear that the management of transboundary aquifers (TBA) must be seen in a wider context of country dependencies, increasing pressures, complexity, uncertainty and connectedness at various scales. For bringing ISARM to a next level, the adaptive water management approach should be fully adopted socio-economics and institutional issues taken into account more explicitly. The application pf approaches and tool such as hydro-economic modelling and serious gaming should become as standard in TBA management and in ISARM as hydrogeological surveying.

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