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Conceptualizing cooperation on Africa's transboundary groundwater resources

Waltina Scheumann / Elke Herrfahrdt-Pähle

Conceptualizing cooperation on Africa's transboundary groundwater resources

German Development Institute (DIE)

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Preface

The present volume is the outcome of a research project on "Transboundary Groundwater Resource Management in Africa". Like its forerunner, "Transboundary Water Resources Management in Africa" (Scheumann / Neubert 2006), it was carried out under the aegis of the German Federal Ministry of Economic Cooperation and Development (BMZ). Whereas the first study focused on rivers and lakes to the exclusion of groundwater resources in Africa, the second undertook to document and analyze transboundary efforts at cooperation in the management of transboundary groundwater resources in Africa.

Compared to the immense body of literature on cooperative management of international surface waters, studies which attempt to conceptualize cooperation in the management of transboundary aquifers are few and far between. As a consequence, the project described here was designed to contribute facts and ideas to the ongoing international discussion on transboundary groundwater management in Africa.

The major objectives of this BMZ-funded project may be defined as follows:

— To assess typical riparian constellations

— To identify specific cooperation problems

— To identify transboundary impacts deriving from national groundwater uses

— To identify cooperation mechanisms and discuss cooperation models

— To develop recommendations for German development cooperation.

The project components

— Conceptual notes

— Findings based on evidence from Africa

— Recommendations for German development cooperation

— A literature-based screening of the African transboundary aquifer systems

— Case studies, namely the Kilimanjaro Mountain Aquifer, the Lake Chad Basin Aquifer, the North-West Sahara Aquifer System, the Nubian Sandstone Aquifer System and the Stampriet Artesian Aquifer Basin

— An analytical discussion of "Institutional aspects of groundwater governance"

The project was conducted from January to October 2007 under the supervision of the German Development Institute (DIE), Bonn. Due to limited financial resources, all project components are the result of desk studies.

The team members

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Valuable support and input were provided not only by regional partners in Africa but also by the reviewers (Volkmar Hartje and Annika Kramer), Shammi Puri (ISARM), Alice Aureli (UNESCO-IHP), the BMZ and by various German agencies for development cooperation, including the Federal Institute for Geosciences and Natural Resources (BGR), the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), and the Kreditanstalt für Wiederaufbau (KfW).

Contents

Abbreviations

AfDB	African Development Bank
AFW	African Wildlife Foundation
AMCOW	African Ministers' Council on Water
AMO	Aquifer Management Organisations
ANBO	African Network of Basin Organisations
asl	above sea level
BCM	Billion cubic meters
BECC	Border Environment Cooperation Commission
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe / Federal Institute for Geo-sciences and Natural Resources
BMBF	Bundesministerium für Bildung und Forschung / German Federal Ministry of Education and Research
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung / German Federal Ministry of Economic Cooperation and Development
CAAC	Catchment Area Advisory Committee
CAR	Central African Republic
CDA	Coast Development Community
CEDARE	Center for Environment and Development in the Arab Region and Europe
CI	Continental Intercalaire
CIDA	Canadian International Development Agency
CILA	Comisión Internacional de Limites y Aguas
CNC	Costs of non-cooperation
CPI	Corruption Perception Index
CT	Complexe Terminal
DANIDA	Ministry of Foreign Affairs of Denmark, Technical Advisory Services
DED	Deutscher Entwicklungsdienst
DIE	Deutsches Institut für Entwicklungspolitik / German Development Institute
DRC	Democratic Republic of Congo
DWAF	Department of Water Affairs and Forestry (Namibia) (Republic South Africa)

EAC	East African Community
ESF	Environmentalists Sans Frontiers
EU	European Union
FAO	United Nations Food and Agriculture Organization
GAP	Guarani Aquifer Project
GAS	Guarani Aquifer System
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIWA	Global International Water Assessment
GNEB	Good Neighbour Environmental Board
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit GmbH
GWA	General Water Authority Libya
HCNE	High National Council for the Environment (Chad)
IBRD	International Bank for Reconstruction and Development
IBWC	International Border and Water Commission
ICCON	International Consortium for Cooperation on the Nile
IFAD	International Fund for Agriculture Development
IFPRI	International Food Policy Research Institute
IGARC	International Groundwater Resources Assessment Centre
IHP	International Hydrological Programme of UNESCO
InWent	Internationale Weiterbildung und Entwicklung gGmbH
ISARM	Internationally Shared Aquifer Resources Management
ISOHIS	Isotope Hydrology Information System
IUCN	International Union for the Conservation of Nature and Natural Resources
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
JMAS	Municipal de Agua y Saneamiento de Juarez
JPWC	Joint Permanent Water Commission
KfW	Kreditanstalt für Wiederaufbau
LCBC	Lake Chad Basin Commission
LVBC	Lake Victoria Basin Commission
MCM	Million cubic meters

MDG	Millennium Development Goals
MW	Megawatt
MWRI (Sudan)	Ministry of Water Resources and Irrigation (Sudan)
MWRI (Egypt)	Ministry of Water Resources and Irrigation (Egypt)
NAAEC	North American Agreement on Environmental Cooperation
NADB	North American Development Bank
NAFTA	North American Free Trade Agreement
NBI	Nile Basin Initiative
NEPAD	New Partnership for Africa's Development
NSAS	Nubian Sandstone Aquifer System
NWMP	National Water Master Plan (Botswana)
NWSAS	North-West Sahara Aquifer System
OAS	Organization of American States
ORASECOM	Orange-Senqu River Basin Commission
OSS	Observatory of the Sahara and the Sahel
PBWO	Pangani Basin Water Office
PNA	Post Nubian Aquifer
PWC	Permanent Water Commission
RBO	River Basin Organisation
SAB	Stampriet Artesian Basin
SADC	Southern African Development Community
SASS	Système Aquifère du Sahara Septentrional
SIDA	Swedish International Development Cooperation Agency
TDS	Total Dissolved Solids (mg/l)
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Program
UNDP/GEF	United Nations Development Program/Global Environment Facility
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USAID	United States Agency for International Development
WHYCOS	World Hydrological Cycle Observing System

WHYMAP	World-wide Hydrogeological Mapping and Assessment Programme
WMO	World Meteorological Organization
WRMA	Water Resources Management Authority
WUA	Water User Association
ZAMCOM	Zambezi Watercourse Commission

Conceptualizing cooperation on Africa's transboundary aquifer systems

Waltina Scheumann / Elke Herrfahrdt-Pähle

Introduction

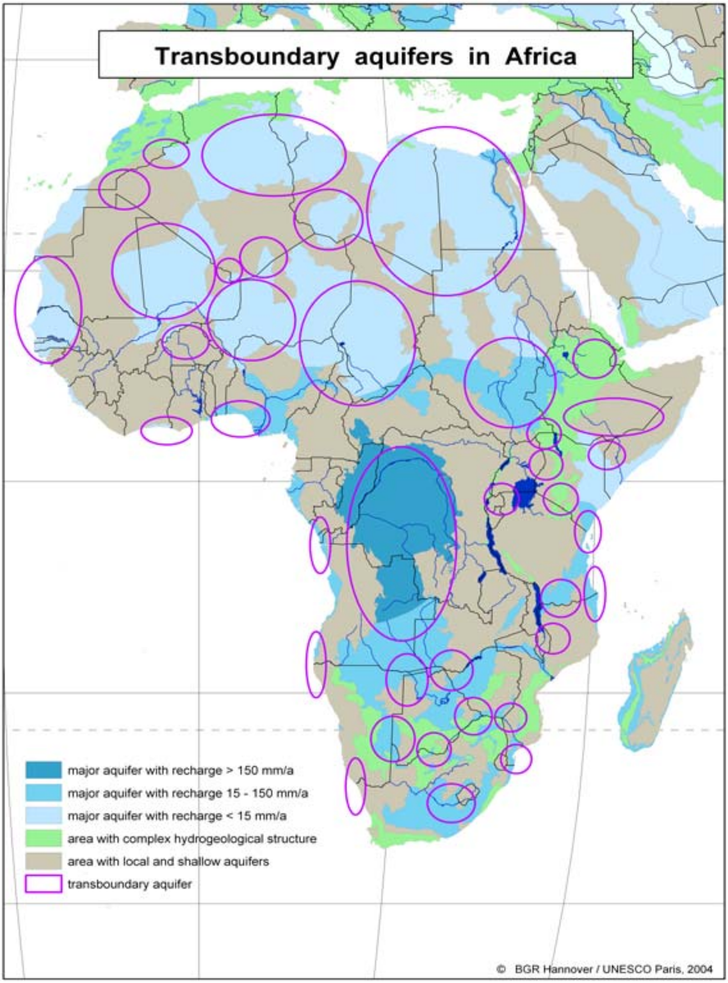
Waltina Scheumann / Elke Herrfahrdt-Pähle

The African continent is well endowed with groundwater resources which – besides the predominantly local and shallow aquifers – are stored in approximately 40 transboundary aquifer systems underlying the continent (cf. figure 1). The considerable amounts of water stored underground provide opportunities for the social and economic development of many African countries.

The relevance of groundwater in Africa is growing and is likely to increase in future for several reasons. Firstly, high population growth rates and population density in settlements where the urban poor live pose a challenge for achieving the water-related Millennium Development Goals (MDG) (i.e. reduce by half the proportion of people without access to safe drinking water and basic sanitation services by 2015). At present, less than half of Africa's population has access to basic water supply and sanitation services, whereby water services supplied to cities are better than those supplied to rural areas. The African Development Bank (AfDB) estimates that about 53 % of Africa's rural population has no access to safe drinking water, and about 57 % has no access to basic sanitation. Currently 14 African countries suffer from a chronic shortage of water, and this number will grow to 25 in 2025 (AfDB 2005, 2). As the demand for drinking water increases, surface water resources may no longer be adequate. Thus groundwater is of particular concern in this regard and needs to be protected from pollution.

Secondly, surface water resources are already under intensive use, particularly in the arid and semi-arid regions of the continent. Conjunctive use of surface water and groundwater is particularly relevant in arid and semi-arid regions where surface water resources are already being fully utilized or where allotments are contested. In these cases, conjunctive use of both sources may lessen tensions arising from limited surface water quantities.

Figure 1: Transboundary aquifers in Africa



Source: Struckmeier et al. (2006)

Thirdly, freshwater resources are geographically distributed unevenly over the continent and are characterized by a high seasonal hydrological variability which results in frequent floods and periods of drought (Dombrowsky / Grey 2002), thus jeopardising a secure and reliable water supply.

Fourthly, both the availability of water and hydrological variability are expected to become even more pronounced in future due to climatic change (IPCC 2007, 444–445). The number of countries which will face serious water availability problems is already increasing. Projections for water scarcity (500 m^3/capita/year and below) in African countries and water stress (below 1,700 m^3/capita/year) in the year 2025 are shown in Figure 2. It has been estimated that the percentage of Africans experiencing water scarcity or water stress will increase from 39 % at present to 76 % by the year 2025 (Ashton 2002). In sub-Saharan Africa, rainfall is expected to drop 10 % by the year 2050. This in turn may result in significantly less accessible surface water across 25 % of the African continent by the year 2100 (de Wit / Stankiewicz 2006, 1917).

These prognoses underline the increasing relevance of groundwater and emphasize the need for establishing a sustainable regime for its utilization today.

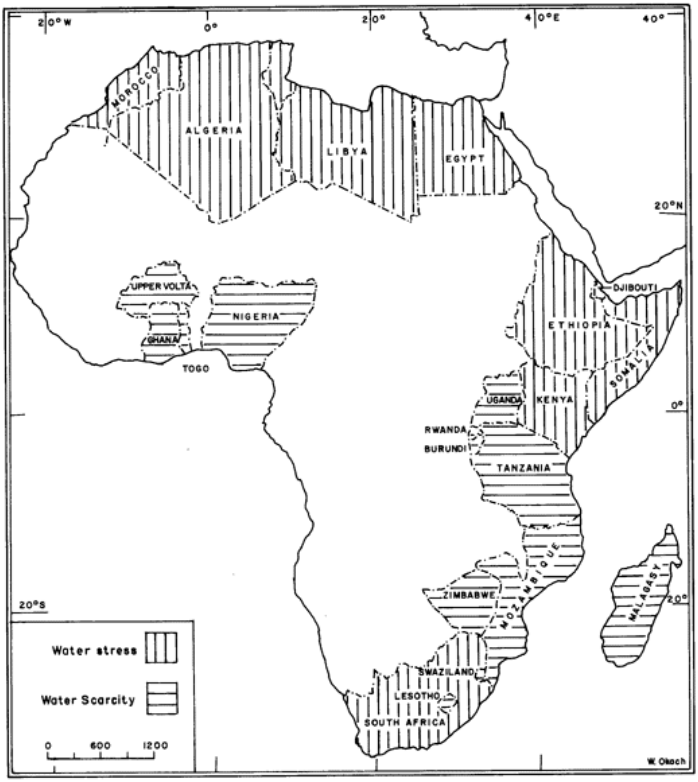
Groundwater has attributes which make it particularly appropriate for urban and rural water supplies, for small-scale irrigation, and for livestock economies (Colvin / Chimpimpi 2002; Shahin 2002):

— Although groundwater in some places is saline or contaminated by geogenic constituents like arsenic or fluorine, its natural quality as a rule is excellent. If groundwater is protected from anthropogenic pollution, especially from disease-causing microbes, it can often be consumed directly without treatment.

— It is naturally protected against evaporation (in the case of deep aquifers).

— Shallow aquifers can often be developed at low cost on a local scale for rural and dispersed communities.

Figure 2: Water stress and water scarcity in Africa in 2025



Source: IDRC (2007)

— Although the volumes stored are significant, their value stems more from the quality and reliability of supply over widely distributed areas than from the total volumes. During dry and drought periods, they provide an important buffer.

— The spatial distribution of aquifers extends over vast areas and – depending on depth and available technology – may permit access close to the area of need.

— In spite of the costs for drilling and pumping, the use of aquifers can reduce the need for costly, large-scale infrastructure investments. It can also preclude social and environmental costs associated with such investments, since groundwater does not require storage.

At present, groundwater resources play a major role in northern African countries by providing water for commercial agricultural irrigation on a large scale and for drinking water supplies. In sub-Saharan Africa, many mid-scale and mega cities as well as rural, livestock, and small-scale irrigation schemes depend on groundwater (Foster / Loucks 2006; Masiyandima / Giordano 2007). Nevertheless the large volumes of groundwater in sub-Saharan Africa are, as a rule, underdeveloped and underused (IWMI 2004), thus providing opportunities for economic development and social improvement.

When riparian countries increase their utilization of transboundary groundwater resources, transboundary effects can emerge either as a consequence of national extraction rates or as external effects, e.g. from agricultural production and/or leakage of untreated wastewaters into the water-bearing strata. Furthermore, if groundwater is linked to surface water bodies (rivers, lakes), negative transboundary effects may occur when pollutants and/or contaminants seep into the aquifer from surface waters (e.g. if untreated effluents discharge into rivers). Typical cases are thus water quantity and water quality problems (e.g. FAO 2003; Burke / Moench, 2000; Foster / Loucks 2006; UNEP et al. 2003; Foster et al. 2002).

Groundwater resources currently play a more limited role in agricultural irrigation in sub-Saharan Africa than in northern Africa (Masiyandima / Giordano 2007; GW-MATE 2006). The utilization of these resources for large-scale development is limited in sub-Saharan Africa by the hydrogeologic characteristics of groundwater-bearing formations: the yields of local aquifers are typically low, while the depth to groundwater in other cases is sometimes great, thus involving high pumping costs. The data provided by Masiyandima and Giordano indicate that

> *"around three quarters of the sub-Saharan Africa population lives in areas of poor groundwater availability, with 220 million people in low-yielding crystalline basement complex areas and about 110 million in areas of consolidated sediment. In these areas dwell most of the rural population, the socio-economic group often affected by problems of water access and who could potentially benefit from groundwater use".* (2007, 83–84)

Considering that many of Africa's groundwater resources are *transboundary* by nature and are stored in the yet estimated 40 transboundary aquifer systems, cross-boundary coordination, cooperation and management will become imperative, and this not only after effects spill over the border. Coordination and cooperation must aim to safeguard equitable and sustainable use of the respective resource. At present, transboundary groundwater resources in Africa are unilaterally used and managed, and few initiatives exist for coordinated activities.

The research and consultancy project presented here addresses the issue of cooperative management of transboundary aquifers in Africa by identifying typical riparian constellations and interstate cooperation problems on the basis of specific hydrogeological attributes of the aquifers. It is assumed that this will help in defining the incentive structures of the riparian countries for cooperation in the management of transboundary aquifers. Taking into account the peculiarities of transboundary aquifers and the stages of water cooperation in general, the present study discusses organizational modes and cooperation models, and presents, following Haddad and Feitelson (1998), a step-by-step approach to coordinated, joint endeavours on the part of aquifer riparians, with recommendations for German development cooperation in supporting this process.

The present volume is divided into three parts. Part A contains an analytical basis for scrutinizing transboundary groundwater resource management in Africa; it further presents findings and recommendations based not only on the results of the case studies but also on an intensive review of the available literature. Part B comprises the five case studies and the respective data sheets. In part C, a closer look is taken at experiences gained with transboundary and national groundwater governance in other parts of the world, with special emphasis on institutional settings.

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Part A: Analytical background and findings

Conceptualizing cooperation on Africa's transboundary aquifer systems

Waltina Scheumann,
with contributions from Elke Herrfahrdt-Pähle

Contents

Conceptualizing cooperation on Africa’s transboundary aquifer systems

Waltina Scheumann, with contributions from Elke Herrfahrdt-Pähle

1 Introduction

Compared to the immense body of literature conceptualizing cooperation on international rivers and the conflicts which may arise in this regard, similar studies of transboundary aquifers are rare (Feitelson 2003; 2006). The present conceptual notes discuss the major elements required in a concept for coordinated and cooperative management of Africa’s transboundary aquifers.

First, the characteristics of transboundary aquifers and their implications for cooperation and governance are described. Second, assuming that the geopolitical and hydrogeological features of transboundary aquifers structure the interrelationships of riparian countries and influence their cooperation, we take advantage of a useful classification (typology) developed by Eckstein and Eckstein (2005). Third, typical obstacles to cooperation are identified on the basis of these Eckstein types and in analogy with cooperative agreements for the management of international rivers. In the process, the differences between transboundary rivers and transboundary aquifer systems are taken into consideration. Fourth, additional factors that influence cooperation are discussed, taking the above-mentioned types as a starting point and in view of problems which affect the incentives of riparian countries to cooperate with one another. Finally, steps towards joint management are presented, and an attempt is made to identify the kind of organizational structure which is most likely to circumvent a “race to the pumphouse”.

2 Characteristics of transboundary aquifer systems

Transboundary aquifer systems display features which differ in some respects from those of international rivers and thus prohibit a direct transfer of experiences gained there. These differences are not absolute but rather in degree. The most prominent of them are:[1]

— The replenishment period of aquifers is long, and the provenance of groundwater generation is often unclear.

— Defining the boundaries of groundwater resources (the resource's domain) and the users' domain is a complicated and challenging issue which abounds with uncertainties. These uncertainties involve recharge areas, flow and discharge characteristics, interrelationships with surface water bodies, the fact that overexploitation and pollution is not immediately perceptible, the difficulties of riparian states in monitoring extraction rates, various sources of pollution, etc.

— Even when modern monitoring and modelling techniques are used to identify groundwater characteristics and boundary lines, it remains difficult to define the ownership of water resources (not only groundwater). This is all the more so inasmuch as groundwater dissipates beneath the surface irrespective of national boundaries (Matsumoto 2002).

— Large-scale hydraulic facilities are more common in surface water use than in groundwater use. In irrigated agriculture, groundwater use is more likely to reflect small to medium-scale, low-intensity investment decisions on the part of millions of individual groundwater users (exceptions to this are, for example, Libya's Great Man-Made River Project and Egypt's New Valley Project). In the case of urban and rural water supplies, extraction points may be either central or decentralized.

— As pointed out by Puri et al. (2005), a major difference between surface water and groundwater systems is that the former are dominated by flow whereas groundwater systems are dominated by storage. The effects of direct human intervention in river systems (e. g. extraction through interbasin transfers, large-scale irrigation schemes) may immediately emerge downstream.[2] In contrast, the impact of human activity on aquifers may become evident only at a considerable distance from the point of intervention, and with a considerable time lag, all of

1 Compiled from e. g. Feitelson (2006; 2003); Puri / El Naser (2003); Puri et al. (2005); Wandschneider / Barron (1993).

2 Effects may, of course, also occur in the long run as a result of e. g. deforestation or the draining of wetlands.

which make it difficult to predict this impact. Such transboundary events are hidden from view, creeping, and difficult to detect.

— Polluting substances may enter aquifer systems at either specific or diffuse and dispersed locations. In many cases, this can make it difficult to monitor them, to detect clear cause-and-effect patterns, and to assess the relative share of pollution from each source. Moreover, the cost of remedial treatment is high, and in some cases contamination can be irreversible.

— Pollution follows the direction of groundwater flow. However, it is difficult to identify this direction, and such efforts are complicated even more by the fact that pollution emerges only after a considerable amount of time and that the impact of groundwater extraction and pollution can emerge at a substantial distance from their sources.

These hydrogeological features have implications for transboundary groundwater governance. One striking implication is that hydrogeological features establish a physical interdependency between the riparian countries.[3] Activities in State A have actual or potential implications for State B. Problem-solving and sustainable resource use therefore demands coordinated action.

Externalities

Typically, it is difficult to trace the external effects of any one nation's local extraction and/or pollution activities. The complexity and time lag inherent in many aquifer flow regimes causes these regimes to become "decoupled" from the causes and effects of human intervention, both in terms of groundwater extraction and pollution. Although it is possible to trace pollution sources and paths of travel, this involves high costs (monitoring) and a sound basis of knowledge.

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3 This physical interdependency is not present in all aquifer systems labelled as transboundary according to the WHYMAP (Struckmeier et al. 2006). The Western African Coastal Aquifer System (No. 413 and 414), for instance, could be regarded as one hydrogeological formation. However, transboundary impacts will not show up from national uses because groundwater flows towards the Gulf. Overuse in one country has negative consequences in this respective country and not in its neighbour's. If all countries bordering the Gulf are threatened by sea water intrusion due to heavy pumping activities, they may share experiences on how to institutionalize strong national groundwater regimes. But problem-solving is not dependent on collective action.

Time lag and irreversibility

Once an aquifer is seriously polluted, it may be difficult, costly or even technically impossible to reverse or remedy this. In view of the time lag before such impacts on a groundwater resource become manifest, this calls for governance solutions of a precautionary nature.

Indivisibility

Unlike land, aquifers cannot physically be divided into pieces for ownership and use; rather, they are interconnected hydrological systems. While one state can contaminate by degrees, one cannot fence off part of an aquifer on a large scale[4] and allow only that part to be contaminated. Although approaches exist for defining pollution caps and assigning individual pollution rights, it may be difficult to implement these in the African context. This means that groundwater contamination in Africa has some qualities of a “yes-or-no”, “off-or-on” decision; that is, precautionary action appears to be the best solution (Wandschneider / Barron, 1993).

Information asymmetry

Groundwater management is also beset by asymmetrical information levels among the affected nations and within them (e. g. between the monitoring agencies and the polluters and/or extractors). The effort to monitor pollution and extraction in state A can cause transaction costs for state B. The same applies for the effort to monitor compliance with regulations at the national level.

Uncertainty and data needs

Reliable groundwater-related data and information is indispensable for informed decisions. In most African countries, however, only inadequate and inhomogeneous data is available on groundwater quantity and quality. National data collection and knowledge about the interrelationships between human activities and the extent and timescale of groundwater degradation is lacking. The pathways followed by contaminants to aquifers and from contaminant sources to potential receptors are often unknown.

4 However, protection zones around drinking water wells can exclude, or restrict, polluting sources.

Here too, management should be based on the precautionary principle, and decisions should be based on scientific knowledge.

Local regulation and control

Whether water uptake on the local level is centralized or decentralized is important for regulating groundwater usage and implementing management objectives on a multinational level. If usage is decentralized, it may be difficult to establish the kind of central monitoring system which is required if restrictions on national use are to be enforced (cf. Theesfeld in this volume).

3 How do geopolitical and hydrogeological factors influence cooperation?

On the basis of geopolitical and hydrogeological attributes, Eckstein and Eckstein (2005)[5] have developed a system for classifying the different types of riparian constellations associated with transboundary aquifer systems.[6] In doing so, their intention was that these types[7] may serve as

5 An initial approach to this issue was developed by Barberis in 1986. For their part, Eckstein and Eckstein (2005) discuss whether transboundary aquifers are subject to the UN Convention on the Law of Non-Navigational Uses of International Watercourses (the UN Water Convention) of 1997, and if not, the need to develop a separate convention for regulating joint groundwater use among riparian nations. Currently, draft articles for managing transboundary aquifers are being discussed; they would cover all groundwater and aquifer-related issues in a very general way.

6 After some study, we adopted the types of Eckstein and Eckstein as being the most appropriate to date. The authors of the present project originally intended to develop their own classification of typical riparian constellations. During the course of their research, however, it became clear that this was not feasible for several reasons. First, the considerable lack of data makes sound analysis and classification of riparian constellations impossible. Our continent-wide screening of 40 African transboundary aquifer systems based on a review of the literature, including relevant databases, failed to yield results. Second, and more importantly, the complexity of existing hydrogeological factors prohibited any such undertaking given the time and financial constraints of the project. Thirdly, other attributes such as the economic development and power of individual countries, along with their institutional structures, would also have required discussion. This in turn would have increased the diversity of cases to be studied, and would have complicated a categorization of typical riparian constellations.

paradigms for the application of international groundwater law. The attributes used to define each type are:

— The geographical location of one riparian state vis-à-vis the other.

— The location of the respective transboundary aquifer in relation to national border(s).

— Recharge, flow, and discharge of groundwater in relation to national border(s).

— Possible hydraulic links between the aquifers and rivers / lakes.

— Whether the aquifers are confined or not.

Based on these attributes, Eckstein and Eckstein have attempted to identify the transboundary implications of national groundwater resource usage associated with each type. In the hope of defining a real-world typology, the case studies presented here (cf. part B, case studies, in this volume) have taken the types of Eckstein and Eckstein as points of reference, have investigated whether they are useful in categorizing African aquifer systems, and have also studied whether they de facto mirror the respective settings and riparian constellations there (cf. findings of the case studies).

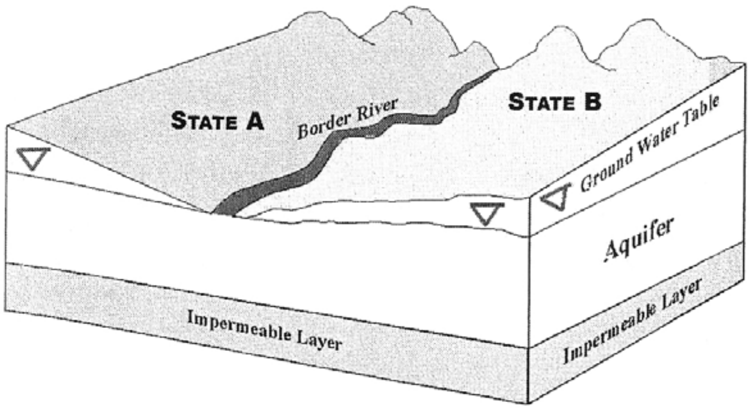
The six types of Eckstein and Eckstein are:

1. Riparian constellation: Type A

An unconfined aquifer, hydraulically linked with a river (either losing or gaining), both of which flow along an international border formed by the river. While the aquifer constitutes one body of water, the two related sections on either side of the border river have little or no direct effect on each other. Water flow is limited by the hydraulic gradient. Thus, any negative effect found in one section is unlikely to affect the other section. Exceptions, however, exist: e. g. to the extent that the river is gaining, groundwater will flow into the river, and negative effects will be introduced into and impact on the river.

7 Eckstein and Eckstein label them 'models'. We prefer the term 'types' in Max Weber's sense of *ideal types*, i. e. analytical categories. This distinguishes them from mathematical, hydrological models.

Figure 1: Riparian constellation: Type A

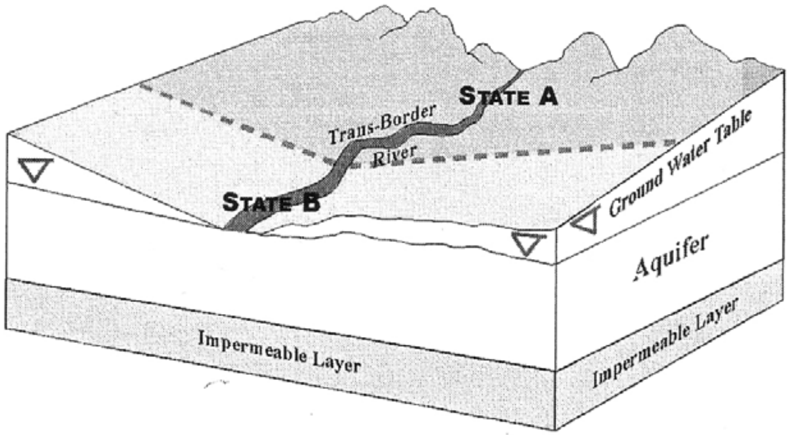


Source: Eckstein / Eckstein (2005)

2. Riparian constellation: Type B

An unconfined aquifer intersected by an international border and linked hydraulically with a river that is also intersected by the same international border. The political international border bisects both the river and the related aquifer. Generally, gradients explain the transboundary consequences. Water in the river and the related aquifer flows down-slope from State A to State B, therefore implying that most transboundary situations will result from pollution in State A transported to State B or from over-pumping in State A, which reduces the flow in State B. Nevertheless, excessive pumping in either state could have limited transboundary consequences.

Figure 2: Riparian constellation: Type B



Source: Eckstein / Eckstein (2005)

3. Riparian constellation: Type C

An unconfined aquifer flows across an international border and is hydraulically linked to a river that flows completely within the territory of one state. The transboundary implications of this model rely solely on the distribution of the hydraulic potential within the aquifer. The model shows a gaining river-aquifer relationship where groundwater recharged in State A flows into State B and into the gaining river. Depending on the proximity of uses in State B to the international border, transboundary consequences may also manifest themselves in the upslope State A.

Figure 3: Riparian constellation: Type C

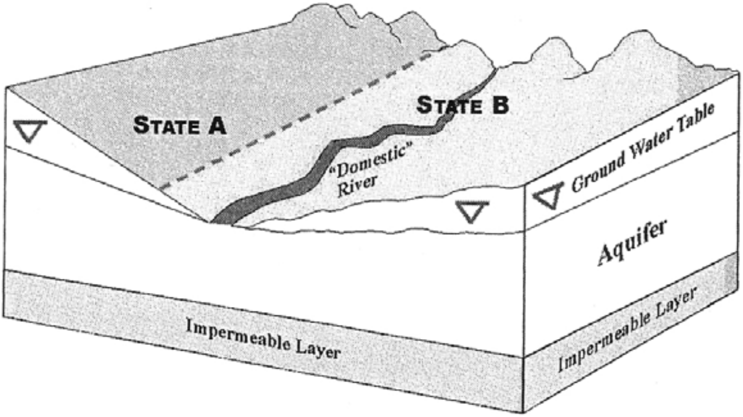
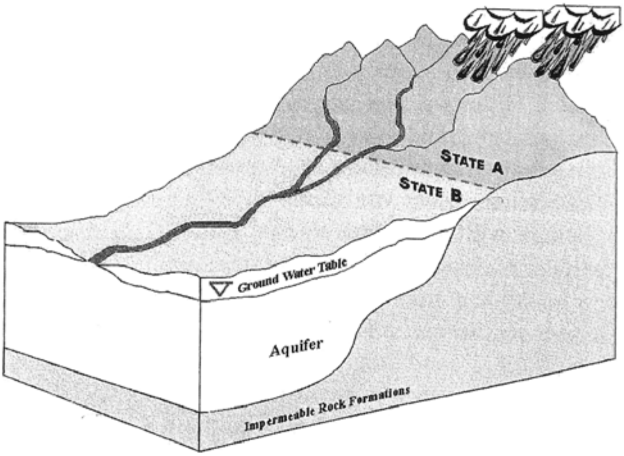


Figure 4: Riparian constellation: Type D



Source Fig. 3 + 4: Eckstein / Eckstein (2005)

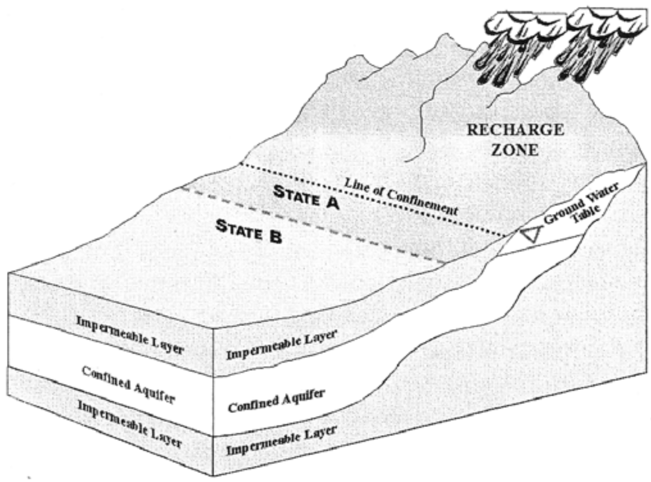
4. Riparian constellation: Type D

An unconfined aquifer that is completely within the territory of one state but is hydraulically linked to a river flowing across an international border (the aquifer is located in the 'downstream' state). The river is international, while the aquifer is geographically domestic. The transboundary implications are solely dependent on river volume and quality flowing from State A to State B, with State A having the singular opportunity and responsibility for ensuring the quantity and condition of water in the river.

5. Riparian constellation: Type E

A confined transboundary aquifer unconnected hydraulically with any surface body of water that traverses an international boundary or that is located completely in another state. This type of aquifer can clearly have transboundary consequences which are in large part a function of the rate of pumping. Any excessive pumping in one or both states could have serious implications for the part of the aquifer along the border of the two countries. Any negative characteristics found in the aquifer underneath one

Figure 5: Riparian constellation: Type E



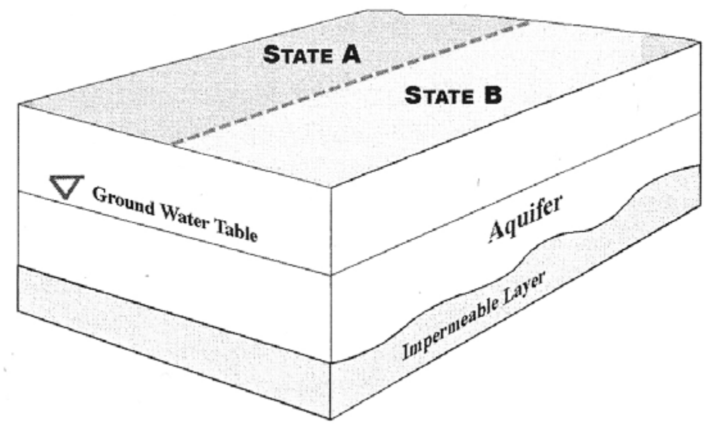
Source: Eckstein / Eckstein (2005)

of the states could be transported to the other as a result of either natural flow (from State A to State B), or a cone depression locally reversing the natural flow. State A could divert surface runoff from recharging the aquifer or undertake activities that pollute water in the recharge zone having international consequences.

6. Riparian constellation: Type F

This type covers all transboundary aquifers that are unrelated to any surface body of water and are disconnected from the hydrological cycle, and are thus devoid of any meaningful recharge (fossil). As there is neither a distinct recharge nor discharge zone, the water table is quasi-horizontal, and the water stagnant with little or no perceptible flow. The transboundary consequences are almost exclusively a function of pumping the aquifer in one or more of the overlying states. When a state commences groundwater pumping, it will create an ever-expanding cone of depression that will eventually encroach across the border. If the two countries employ competing wells on opposite sides of a border, the two cone depressions may overlap and coalesce. If states do not stop or reduce pumping, this aquifer eventually will be fully depleted.

Figure 6: Riparian constellation: Type F



Source: Eckstein / Eckstein (2005)

4 Cooperation problems: transboundary externalities and collective problems

Based on the above types and in analogy with the use of international rivers, the riparians of transboundary aquifers are likely to face typical cooperation problems where physical interdependencies exist. These transboundary problems may be unidirectional in character; others will be collective and reciprocal, and will involve symmetrical incentives for cooperation and similar interests on all sides (Klaphake / Scheumann 2006). As a starting point, we focus on these two types of problems with the assumption that these aspects will shape the incentives of riparian countries to cooperate with one another.

Unidirectional problems (transboundary externalities)

The most prominent example here is the upstream-downstream context in which downstream water pollution stems from upstream sources, or in which significant water diversion limits water availability and/or usability in the downstream countries ("downstream" here is defined by the direction of groundwater flow). Both can affect downstream aquatic ecosystems. One specific transboundary constellation occurs when the recharge area of an aquifer is located in one country while its flow and discharge area underlies a second riparian’s territory. In these instances, land use (e. g. deforestation) may have a negative effect on the aquifer’s recharge conditions. Too, if upstream reservoirs reduce a river’s flow, this may negatively affect the aquifer's recharge conditions. On the other hand, transboundary aspects may also be positive (for example when one country’s water extraction reduces waterlogging of soils and dampness in housing areas).

Collective problems

Collective problems occur if riparian states are mutually affected by difficulties in managing water quantity and quality. This may occur, for instance, if an aquifer is polluted as a result of one nations’ activities (infiltration of contaminants as a result of agriculture, or seepage of industrial and domestic effluents). Then, utilization may be restricted for e. g. urban water supply in the riparian countries. Again, if groundwater levels decline in all riparian countries because all are extracting water, all have a common interest in remedying this situation. And if wetlands that are a source of livelihood for all riparian societies dry up, the riparian countries have a common interest in reversing negative impacts.

Theoretically, transboundary externalities will be more difficult to solve than collective problems, because in general only one party will gain from cooperation, while the other will risk losing its advantages (unless arrangements are made to provide compensation). But even in the case of collective problems, it may be necessary to redistribute cooperation gains among the riparian countries in order to achieve cooperation (e. g. a "fair sharing" of costs). It is, after all, a fact that such advantages are more often than not unevenly distributed; this may impede joint action even if all parties would be better off in comparison with the initial situation.

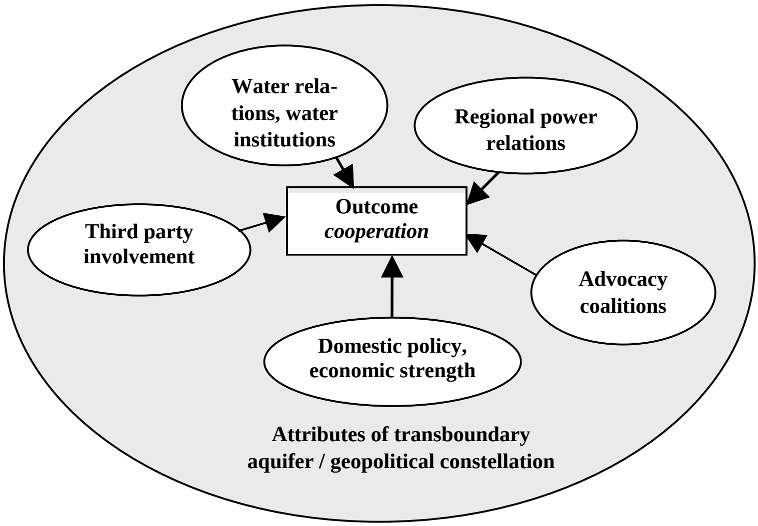
Identifying and delineating these two types of problems is no easy task: costly monitoring networks must be established, and standardized methods must be used to create sophisticated models of each aquifer's behaviour.

Many political recommendations have been worked out for implementing 'benefit-sharing' instead of 'water sharing' along transboundary rivers (cf. Sadoff / Grey 2002). These recommendations have their origins in the above-described conceptualization of riparian problems. Whether and to what extent the implementation of benefit-sharing mechanisms is realistic, feasible and preferable in view of the political difficulties involved has been the subject of much debate (cf. Klaphake 2006). It is assumed that the potential for developing benefit-sharing arrangements for the use of transboundary aquifers is more restricted than for rivers and may be more difficult to implement. Win-win situations, on the other hand, might include 1) the reduction of waterlogged agricultural land and dampness in housing areas by means of local extraction, and 2) agreements between riparians on joint investments (drilling, pumping) and the allocation of benefits.

5 Factors influencing cooperation

It is to be expected that cooperation and establishing regimes on transboundary aquifers will be strongly influenced, at least initially, by the very nature of the cooperation problem. The above-mentioned transboundary externalities, for example, are much harder to resolve than collective problems. Whether the riparian states arrive at cooperative outcomes in either case largely depends on a number of – not prioritized – factors (cf. figure 7) which have been found to be relevant for cooperation in the use of transboundary rivers. It can be assumed that they are valid for cooperation on transboundary aquifers as well.

Figure 7: Factors determining transboundary groundwater cooperation



Source: Authors' own compilations

National development strategies (e. g. expansion of irrigation agriculture) and economic strength (investment capability, technology) can fuel groundwater conflicts between nations. If riparian states are economically and socially dependent on a water resource, a "race to the pumphouse" is likely to take place in which nations hurry to develop groundwater resources before their neighbours do so. These nations perceive the non-use of such resources as a loss in favour of their neighbour state(s). A "tragedy of the commons" would be the result.

On the other hand, the incentives for such unilateral development of groundwater resources become less attractive, according to Feitelson (2003), when the costs of non-cooperation (CNC) are taken into account. These costs refer to water quality and quantity, and include direct costs such as those for increased pumping if water tables drop, treatment costs if water becomes saline and polluted, and the loss of benefits which might have been realized had the respective nation states cooperated with each other.

Feitelson assumes that the incentives for one state to cooperate with others will be low if the CNC for that state are also low. If, on the other hand, the CNC rise, the incentives to cooperate will also increase. In Feitelson's words, *"all parties sharing the aquifer need not perceive the CNC and transaction costs in the same way. It is possible that some parties are more heavily dependent on the aquifer or lie downstream and thus are more sensitive to pollution of the aquifer, and hence have higher CNC than parties that are less affected. In cases where there is substantial uncertainty regarding flows within the aquifer, and hence no party can be sure to what extent the burden of non-cooperation will fall upon it (…) we can expect the parties to perceive a similar CNC curve."* (2003, 149)

This argument assumes that cooperation among nation states is both reasonable and possible because, at least in the long term and under certain conditions, the payoffs of cooperation will exceed the gains from non-cooperation for all riparians. Following this line of thought, it may be argued that CNC need not motivate decision-makers simply because negative effects are politically not valued (if e. g. marginalized groups are affected, wetlands are dried up), or if CNC are perceived then not necessarily as transboundary effects.

One might also expect that cooperation is much more likely if the riparian countries have peaceful relations characterized by mutual trust and are economically and politically on a sound footing. International organizations and multilateral or bilateral donors may also be important as neutral and trustworthy parties for mediating conflicts and supporting the acquisition of information. This can drastically reduce the costs otherwise associated with long-lasting fact-finding activities and controversial negotiations.

Further aspects for consideration are the relative power distribution among the riparian countries, along with their economic and political disparities. While powerful (upstream) countries may generally be uninterested in cooperation, feeling that it will limit their freedom of action, powerful (downstream) states may support or even enforce the development of water regimes in order to secure their own water supply. Thus an unequal distribution of power among the riparians may hamper water cooperation but may also promote joint activities. This is all the more the case if the long-term strategic (water) interests of one riparian coincide with cooperation. Since major economic, political and military disparities exist among the African countries, and the strategic interests of regional powers like South Africa and Egypt strongly shape regional cooperation patterns on the continent, the respective power categories are highly relevant; this is generally acknowledged in the literature on water cooperation.

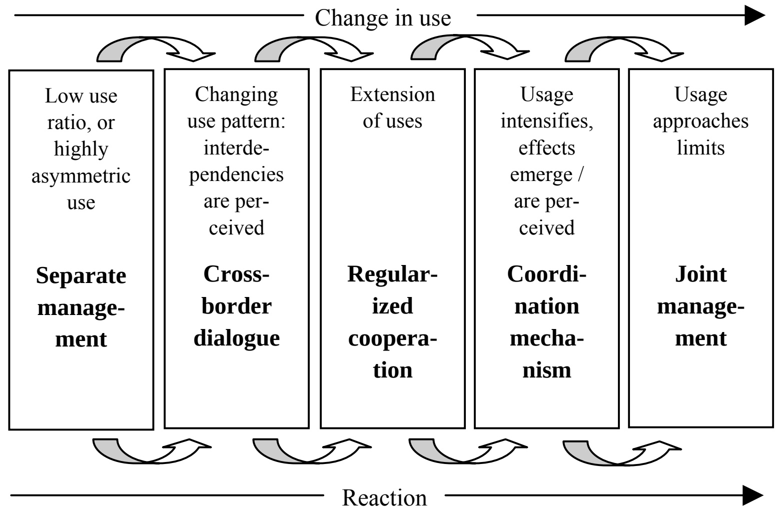
6 The path from individual national to institutionalized joint management

The need for a step-by-step approach

Individual management of transboundary groundwater by a nation may be justified if use rates are low and if there is no transboundary impact on either side. However, such management becomes problematic as soon as water use is highly asymmetric and if one nation attempts to establish a right of prior use (either de facto or formally). On the other hand, joint endeavours may develop if use patterns change and intensify, and if interdependencies show up and are politically perceived and acknowledged as "cross-border issues" (cf. figure 8).

A challenge which emerges in the early stages because of unclear benefits, is to get governments engaged in cross-border groundwater cooperation. This necessitates a coordination of cross-border data generation and exchange (cf. table 1). The dilemma is that action must be taken promptly

Figure 8: Model of a cooperation path



Source: Authors' own compilation

even when use ratios (and thus the incentives for cooperation) are modest. By the time the transboundary impact of unilateral use by one nation are recognized, it may be too late, too complicated, or simply too costly to engage in joint endeavours (Feitelson 2003; 2006; Wandschneider / Barron 1993). In this respect, third parties such as international organizations and advocacy groups may well have a role to play (cf. figure 8) which may increase and diversify with progressive cooperative linkages among the riparian countries.

The critical issues for African countries currently engaged in groundwater development are

— to institute national policy frameworks that may respond to actual and future challenges (cf. Theesfeld in this volume), and

— to implement transboundary consultation mechanisms for joint regulation prior to the emergence of negative transboundary impacts and the development of contested issues (water rights allocations etc.).

Table 1: Stages of transboundary groundwater cooperation	
Stage of cooperation	**Levels of increasing complexity**
Establishment of a cross-border forum to develop an information basis, to coordinate national research activities, and to establish a monitoring network	Less contentious
Geological surveys and exchange of information on national use patterns	Touches on strategic interests
Identification of sources of actual and potential threats to transboundary groundwater resources	Touches on strategic interests
Developing use scenarios, including a pre-assessment of transboundary impacts	Requires cost / benefit distribution
Decisions regarding common objectives and joint activities to be implemented on national levels	Touches on sovereignty; restrictions on use may conflict with property rights
Source: Authors' own compilation	

Coordination and consultation mechanisms

Recommendations for transboundary aquifer management organizations to be promoted in Africa can rely on neither a rich background of institutional experience nor on a body of academic research like that which is available for transboundary river and lake basin organizations.

If organizational decisions are based on biophysical boundaries, then one has to acknowledge that boundaries of transboundary aquifers extend, a priori, over (or under) the administrative boundaries of nations and the spheres of responsibility of the respective water administrations. Young describes this as follows: " *(…) the problem of fit deals with congruence or compatibility between ecosystems and institutional arrangements created to manage human activities affecting these systems*" (Young 2002, 20).

The establishment of a separate, appropriate organisation for aquifer management would be consequent; it would cover the resource domain and includes all riparian countries. Following this reasoning, it would be necessary to promote the establishment of aquifer management organizations even parallel to similar existing organizations for river and lake basin management. According to some proponents of the integrated water resources management approach, the establishment of such separate transboundary aquifer management organizations is in harmony with the fundamental idea and internationally accepted key principles in the sense that planning, coordination and management should be based on the natural boundaries of basins. This idea has great appeal because it combines planning and management with natural hydrogeological and geographical features. While existing incompatibilities between administrative and natural units have to be solved in any case, organizational development and design may too rely on other, equally important, factors (e.g. path dependency of organizational development, designation of responsibilities, the management issues to be addressed, capacities and skills) (cf. findings and recommendations).

In cases where transboundary aquifers are not linked to surface waters, separate aquifer management organizations are the only option. On the other hand, it might be possible to achieve integrated management of surface water and groundwater within a single organisation. This could help to defuse sources of friction between competing organisations while providing support for the coordination process.

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Findings of the case studies

Waltina Scheumann / Elke Herrfahrdt-Pähle

Contents

Findings of the case studies

Waltina Scheumann / Elke Herrfahrdt-Pähle

1 Typical riparian constellations based on the Eckstein types

Eckstein and Eckstein (2005) developed six *ideal types* in an effort to mirror the transboundary implications of national groundwater utilization when national borders cut across aquifer basins (cf. the chapter "Conceptualizing Cooperation" in this volume). In view of their idealized character, however, it is not surprising that these types (or constellations) do not always perfectly reflect real-world situations and that reservations exist concerning their use. When the types are applied to empirical cases in Africa, we observe the following:

First, in all but one case study presented here (cf. case studies, part B), the respective transboundary aquifer systems have more than two riparians. While this does not contradict the assumptions of Eckstein and Eckstein, it makes the task of tracing factors which cause transboundary problems and compensating for them more difficult.

Second, and more important: in some cases, more than one type of Eckstein and Eckstein is applicable (cf. table 1). For example, if one transboundary aquifer is composed of different water-bearing strata, the role of each riparian may change depending on which part of the aquifer it draws its groundwater from.

Third, the distinction between shallow and deep aquifers must be considered. Although the Eckstein types cover non-renewable fossil groundwater which is, as a rule, at great depths, they do not consider different scales at which transboundary impacts can occur. Jarvis describes this as follows: *"The megascale domain represents the regional through continental groundwater flow system which can extend over tens to hundreds of kilometres and depths ranging from 800 meters to three kilometres. At the macroscale, geomorphologic and hydrologic processes of catchments and watersheds define aquifer properties, the permeability architecture, and water circulation characteristics. The mesoscale domain incorporates hy-*

Table 1: Application of the ideal types of Eckstein and Eckstein

Transboundary aquifer system	**Type**	**Attributes**
Kilimanjaro Aquifer System	Types B, C	Groundwater gradients explain transboundary impacts, because water in the unconfined aquifer and rivers flow downslope from the recharge area in Tanzania to Kenya which consequently causes transboundary effects resulting from reduced recharge or overuse in upslope state.
Lake Chad Basin Aquifer	Types B, C, D, E, F	Hydraulic link to a transboundary lake with changing water levels and, as a result, changing riparian states. Three-layered aquifer system. The Upper Aquifer in the downstream states (Cameroon, Nigeria) is recharged from rivers in the upstream Central African Republic; however, downstream dams have changed the recharge conditions.
North-West Sahara Aquifer System	Type F	Recharge does not match extraction and is limited to unconfined areas (sub-layers are not recharged); flow is from the innercontinental regions of Libya and Algeria towards the Tunisian coast. Transboundary implications are exclusively a function of pumping.
Nubian Sandstone Aquifer System	Type F	Water flows but very slowly, and there is natural discharge of the aquifer. Nevertheless, transboundary implications are almost exclusively a function of pumping.

Table 1 continued		
Stampriet Artesian Aquifer Basin	Types B, E	The upper Kalahari Aquifer is unconfined, the lower Auob and Nossob Aquifers appear to be partially both confined and unconfined. Recharge is present in one country. The aquifers are hydraulically connected to rivers and are intersected by international borders. There is a water flow from one state to the other (in this case Namibia would be State A, Botswana and South Africa would be State B/State C).
Source: Case studies in this volume		

drodynamic controls, matter and energy fluxes, and human impacts. Human impacts by intensive exploitation (…) are important at this scale. The microscale domain represents short term events such as during the annual hydrologic cycle and at a spatial scale of the pore, fissure or channel.” (Jarvis 2007, 46)

Fourth, accurate boundary demarcation and delineation are of critical importance for determining which countries are riparians and which make use of groundwater or influence recharge. The case studies presented here show that much is still unknown in this regard (e. g. with respect to Nubian Sandstone, Stampriet, Lake Chad, Kilimanjaro). Even when riparian countries can be clearly identified, uncertainties exist concerning their location in relation to the entire aquifer system and the latter’s interaction with surface water bodies.

Table 2: National and transboundary impacts (observed and expected)

Transboundary aquifers **Intensity of national use**	**Local / national impact**	**Transboundary impact (actual, *potential*)**
Kilimanjaro Aquifer In Kenya and Tanzania not intensively developed	Rising groundwater levels in Amboseli Basin (high runoff due to overgrazing)	Reduced inflow into Lake Jipe affects ecosystem; shrinking forest belt affects recharge; *Kenya's plan to divert water from Lake Chala will likely have an impact on Tanzania*
Lake Chad Basin Aquifer High intensity in Chad, Nigeria; increasing in Niger	Declining groundwater levels, nitrate and faecal contaminants	*Likely* (decreasing recharge, increasing extraction), impact on flood plains and river base flows
North-West Sahara Aquifer High intensity in Algeria, followed by Tunisia and Libya	Declining groundwater levels, drying up of outlets in Tunisia	*Potential* impact on Libya of projects planned by Algeria; and on Tunisia and Algeria of projects planned by Libya
Nubian Sandstone Aquifer Very high intensity; most intensively used in Libya and Egypt	Declining groundwater levels in Egypt and Libya, pollution in Libya	Not reported, *likely* in Sudan
Stampriet Artesian Aquifer Intensively used in Namibia	Overuse is still contained within national boundaries (Namibia)	No information

Source: Case studies in this volume

Nevertheless, it should be emphasized that the six types of Eckstein and Eckstein have proven useful as a "mind map", i.e. as a guideline for preliminary assessment of constellations related to the transboundary aquifers under study. On the other hand, it is also apparent that transboundary aquifer systems resist generalized definitions and require precise, site-specific models that depict and mirror real riparian constellations.

2 Actual and *potential* cooperation problems

As mentioned in the previous chapter, the riparian countries of transboundary aquifers may face *unidirectional transboundary externalities* problems, and *collective problems* where the incentives for cooperation are symmetrical and interests are homogeneous on all sides. There is however, one variation of the above-mentioned unidirectional setting: a transboundary aquifer situation where the recharge area is located in one riparian state while discharge and outflow are located in a downstream riparian state (e. g. the Kilimanjaro Aquifer). Unlike *collective problems*, some countries face similar problems. In these instances, e.g. the West African coastal aquifers (cf. box 1); their transboundary dimension is somehow different if compared with the case studies (cf. part B).

Box 1: The West African coastal aquifers

The West African coastal aquifers are part of a vast structural unit (a sedimentary basin) that borders the Guinean Gulf and extends from the Ivory Coast, Ghana, Togo, Benin to Nigeria (Zuppi 2005). However, scholarly articles that mention separate cross-border formations, do not agree on the exact delineation of the sub-units. (e.g. Helstrup 2006; Agyekum 2004; Wright 1985)

In the densely populated coastal strips, groundwater is the major source for the large cities' water supply (e.g. Cotonou/Benin, Lomé/Togo) the quality of which is suitable for drinking purposes. Groundwater is used too, although to a limited extent, for agriculture. In some parts of the sedimentary basin, groundwater extraction has been significant, with drilling activities starting already in the 1950s, but intensifying after 1980s. Drinking water wells are not protected from local polluting sources of which seepage of untreated industrial and domestic waste water is the most important.

Due to high population growth rates in all coastal countries, and subsequently an increasing demand for freshwater supply for domestic, agricultural and industrial purposes, the countries bordering the Gulf may face a similar, regional problem: sea water intrusion which affects water quality and its usability. However, sea water intrusion as a consequence of intensive extractions has yet not been reported; increased EC levels in the Keta Basin of Ghana and Togo are not of modern origin (Helstrup 2006).

While the sedimentary basin stretches over the countries bordering the Guinean Gulf, impacts from national utilization (i.e. sea water intrusion) and pollution is limited to the national domains where groundwater is abstracted or polluted since the general flow direction of the aquifers moves from the North towards the Gulf. Excessive pumping in state A will eventually cause sea water intrusion in state A but not in state B.

Considering the regional importance of groundwater use and protection, a platform for debating common groundwater management issues along the Gulf and for discussing ways to tackle emerging issues may be a useful instrument.

Based on the literature reviewed here and in all but one case study (cf. table 2), signs of over-extraction and pollution have been observed in most cases at the local level within the respective countries. If negative transboundary impacts exist, they have not yet been perceived due to poor monitoring conditions and data availability (cf. table 3). However, they can be expected to develop sooner or later if utilization intensifies.

Water quality issues in the aquifers have been reported but are also only evident at the local level. It is clear that Africa's groundwater resources are locally threatened by microbiological and chemical contaminants stemming from on-site sanitation, solid waste dumpsites (including household waste pits), pollution of surface water, agricultural chemicals (fertilisers, herbicides and pesticides), petrol service stations (underground storage tanks) and mismanagement of well fields (Xu / Usher 2006). Nitrate pollution of groundwater has been reported in Botswana, Namibia, South Africa (Tredoux / Talma 2006), the Ivory Coast (Jourda et al. 2006), and Nigeria (Adelana 2006), Ghana (Duah 2006). In addition, Ghana suffers at different locations from excessive concentrations of iron, manganese, heavy metals and biological pollution. In Harare, Zimbabwe, diffuse pollution of urban groundwater has been investigated by Love et al. (2006). It appears that groundwater quality in large- and mid-sized African cities, where a significant share of the inhabitants are dependent on groundwater, shows serious signs of faecal contamination and elevated levels of nutrients (Cronin et al. 2006; Boukari et al. 2006).

Table 3: Synopsis of the case studies

	Nubian Sandstone Aquifer System	Northwest Sahara Aquifer System	Stampriet Artesian Aquifer System	Lake Chad Basin Aquifer System	Kilimanjaro Mountain Aquifer System
Riparian countries	Chad, Egypt, Libya, Sudan	Algeria, Libya, Tunisia	South Africa, Namibia, Botswana	Central African Republic, Chad, Cameroon, Niger, Nigeria	Kenya, Tanzania
Extension	2.2 mio km^2	1 mio km^2	No comprehensive data	2.434 mio km^2 (hydrological basin) 1.035 mio km^2 (conventional basin)	15,000 km^2
Storage	15,000 - 372,960 km^3	1,280 km^3	n.a.	170,000 – 350,000 km^3	n.a.
Surface water bodies	Nile, Lake Chad (uncertain)	None	Orange-Senqu river	Lake Chad, Chari, Longone, Komandougou –Yobe rivers	Pangani and Athi rivers, Jipe, Chala and Amboseli lakes
Importance of ground-water use	Very high, most intensively used in Libya and Egypt	High in Algeria, Tunisia and Libya; further plans in Libya and Algeria	Very high; intensive use in Namibia; possibly also used in small villages in Botswana	High in Chad and Nigeria (downstream), increasing importance for Niger	Not intensively developed

National / local effects	Declining water levels in Egypt, declining water levels and pollution in Libya	Declining water levels, drying up of outlets in Tunisia	Signs of overuse in Namibia	Declining water levels, nitrate and faecal contaminants	Rising water levels in Amboseli basin (high runoff due to overgrazing)
Trans-boundary impacts from ground-water use	Not yet clear, potential impacts from Egypt's plans on Sudan	Potential impacts on Tunisia from Algeria's plan, on Tunisia and Algeria from Libya's	No information (assumingly low demand in Bot-swana and South Africa due to low water quality)	No data, but likely due to decreasing recharge, increas-ing abstract-ions, impacts on flood-plains and river base flows	Reduced inflows into Lake Jipe affects ecosystem; Kenya's plans to divert water from Lake Chala; shrink-ing forest belt affects recharge
Trans-boundary ground-water cooperation	Joint Authority; NAS Study Project; Nubian Project; ISARM case study	Joint Research Project	SADC Protocol; SADC Regional Groundwater As-sessment; ORASECOM; ISARM case study	Lake Chad Basin Commission (Mas-ter Plan, Strategic Action Plan)	Greater Pangani Basin Cross-Border Dialogue
Development constraints	Financial con-straints (high drill-ing costs); political instability (Sudan, Chad)		Naturally occurring poor water quality in Botswana and South Africa	Technical and economic weakness (high extraction costs), political instability (Sudan, Chad)	Poorly maintained boreholes

Lack of data / information bases	Uncertainties relate to boundaries, inflow from Nile, link to Lake Chad, stored volumes, national uses in Sudan and Chad		Uncertainties relate to boundaries and national uses in Botswana and South Africa; recharge and sustainable abstraction rates in Namibia	Uncertainties relate to boundaries, connection to NSAS and Iullemeden Aquifer, volume stored, extraction rates and use pattern	Uncertainties relate to boundaries and flow directions
Assessment	Potential impacts; common interests, weak position of Chad and Sudan	Fossil water overused; uneven incentives to cooperate; no technical asymmetries	No impact, asymmetric and overuse in Namibia, low water quality in South Africa and Botswana	Potential impacts; common interests (deep aquifer) and uneven interests (upper aquifer)	Local conflicts; interrelation surface-groundwater; up-down stream constellation; safeguarding of recharge area

n.a. not available
JPWC Joint Permanent Water Commission
PWC Permanent Water Commission
* East African Community Protocol for Environment and Natural Resources Management

However, transboundary impacts are unlikely due to the locations of individual pollution sources and the hydrogeological characteristics of the aquifer systems.

Thus scholarly articles which address transboundary problems tend to refer to *potential* rather than *actual* threats (e. g. Turton et al. 2006; Jarvis et al. 2005). This means that the incentives for transboundary groundwater cooperation in many regions are still rather insignificant, since the cost of non-cooperation and inaction at the transboundary level has not (yet) been felt by the riparians or does not yet exist. Nevertheless, the absence of still unidentified negative transboundary effects does not preclude the possibility of their emergence. In this respect, it would be misleading to conclude that coordinated activities are unnecessary. On the contrary, on the positive side, the present stage of utilization of transboundary groundwater resources makes it possible to coordinate initiatives which centre in all cases on non-contested activities, namely on joint research (cf. chapter 4).

3 Incentives for and barriers to cooperation over Africa's transboundary aquifers

Given the present stage of resource utilization, groundwater mismanagement has not yet become critical enough to compel decision-makers to engage in joint endeavours (except in North Africa). At present, separate, unilateral national development and management is the predominant feature. However, some early forms of cooperation have developed regarding the North-West Sahara and the Nubian Sandstone aquifer systems, where groundwater utilization rates are high, dependency on non-renewable groundwater resources is extensive, and the negative impact of overuse is beginning to be felt. Use rates have risen sharply over the past decades, and it is planned to increase extraction rates even further.

The case studies presented in this volume indicated that transboundary impacts show up only in exceptional cases (cf. table 2 above). One may therefore conclude with Feitelson (cf. the chapter "Conceptualizing Cooperation") that the cost of non-cooperation has not yet been recognized, is not yet high enough to trigger cooperation, or is perceived differently by the various riparians (for example when utilization is highly asymmetric as in the Stampriet Artesian Aquifer). This lack of perception of the cost of non-cooperation thus constitutes a barrier to cooperation.

Furthermore, cooperation on the use of transboundary aquifers is hampered by insufficient knowledge and a poor understanding of aquifer behaviour (recharge areas, flows, pollution, etc.). Due to this knowledge gap, the riparians can not always be sure (1) whether their country form part of the groundwater basin, (2) whether they thus have a stake or an interest in transboundary groundwater cooperation, and (3) what exactly is at stake for their country, i.e. how high the costs of non-cooperation (or the benefits of cooperation respectively) will be. This uncertainty often prevents cooperation: the parties can determine neither the costs nor the benefits of cooperation and non-cooperation. Only in very obvious cases is it possible to measure such factors and to identify the costs of present overdrafting. The countries which have succeeded in doing so for their respective basins are naturally the forerunners of cooperative groundwater management in Africa. Tunisia is such a case: it is already experiencing the impact of overextraction and depends heavily on groundwater use. Realizing that non-cooperation will involve major costs down the road, it has pushed for the establishment of transboundary cooperation mechanisms and research initiatives.

Another important obstacle for cooperating over transboundary groundwater in the African context lies in the different social and economic conditions of the riparian countries (cf. Steyrer in this volume). Often the riparians find themselves at different development stages regarding economic development and technical and financial capacities. These differences result in an asymmetry of information, thus hampering cooperation.

On the other hand, incentives for cooperation also exist. There is evidence that comprehensive and consistent national water policies and good performance provide motivation for promoting cooperation in the use of transboundary groundwater. Tunisia again may serve as an example: it scores highest of all NWSAS riparians (as well as among the majority of countries sampled in this research) on the Corruption Perception Index, and it has a relatively well-functioning national water sector policy at its disposal. At the same time it actively supports cooperation in the use of transboundary groundwater.

It is thus clear that a functioning, reliable national groundwater governance system is a critical prerequisite for transboundary groundwater cooperation among African countries that are actively engaged in groundwater development. Such a governance system will include national policy and institutional frameworks that can facilitate sustainable groundwater utilization (cf. Theesfeld in this volume). Without a supportive and effective national groundwater governance system, it will be difficult at the least, if not impossible, to benefit from measures and mechanisms worked out via transboundary consultation. In the end, these can be effective only to the extent that they are implemented within the riparian countries.

4 Stages of cooperation and institutionalized forms

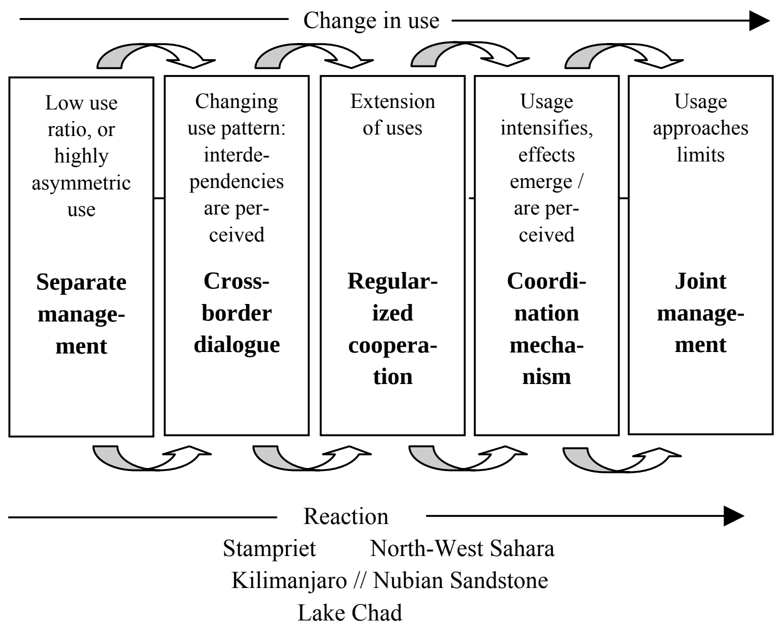
Compared to the successful, cooperative use of Africa's transboundary rivers and lakes, the record of cooperation in managing African transboundary aquifer systems and setting up institutions for doing so is poor. Matsumoto (2002) identified 13 treaties which deal with groundwater in Africa.[1] Where joint initiatives exist, they focus on gathering data, generating information, developing models of the aquifers and their attributes, assessing their use potential, and identifying vulnerable and/or potentially threatened regions. All are in a rather early stage of development, and in most cases are receiving support from regional (SADC), international (UNESCO / IHP) and multilateral organizations (e. g. the World Bank).

Box 2:	**Current forms of transboundary aquifer cooperation in the regions studied**
Aquifer committees / organizations Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System Joint Research Project North-West Sahara Aquifer System. **River / lake basin organizations with a wide-ranging mandate** Orange-Senqu River Basin Commission Lake Chad Basin Commission. A rather unspecific cross-border dialogue is developing in the Pangani Basin for the inclusion of groundwater resources in river management (Kilimanjaro Aquifer).	
Source:	Case studies in this volume

1 Matsumoto researched the Transboundary Freshwater Dispute Data Base (TFDD).

Based on the literature review and the case studies presented here, two different forms of cooperation and consultation can be distinguished (box 1): the first is a constellation in which riparian countries of a transboundary aquifer simultaneously share a transboundary river and/or lake. Jarvis mentions that *"14 out of 40 of the WHYMAP-listed transboundary aquifers in Africa fall within a river basin with some form of a freshwater agreement"*[2] (2007, 76). In a second constellation, a transboundary river or lake is absent, and the aquifer is in no way linked to transboundary surface water bodies. This requires the setup of an entity which exclusively focuses on transboundary groundwater management.

Figure 1: Case studies and the stages of cooperation



Source: Authors' own compilation

2 No specifications are given regarding boundaries, hydrogeophysical attributes etc.

To summarize: existing initiatives and efforts for cooperative management of transboundary aquifer systems in Africa, whether in the form of separate aquifer management organizations or as part of river/lake basin organizations, are all in a rather early stage of development (cf. figure 1).

4.1 Cooperation through a river or lake basin organisation

The mandates of the Lake Chad Basin Commission (LCBC) and the Orange-Senqu River Basin Commission (ORASECOM) extend beyond international rivers and/or lakes to include transboundary groundwater even when the boundaries of the transboundary river and/or lake do not coincide with the boundaries of the transboundary aquifer. However, these mandates do not necessarily include all riparian states of a transboundary aquifer system.

The Lake Chad Basin Commission

The member states of the Lake Chad Basin Commission are Chad, Cameroon, Niger, Nigeria, the Central African Republic, and (observer status only) Sudan. The Lake Chad Aquifer Basin extends in all likelihood to Algeria and Libya as well (cf. AMCOW / ANBO 2007, 35 ff.).

Based on the "Convention Relating to the Development of the Chad Basin", signed in 1964, the Lake Chad Basin Commission's mandate covers water and other natural resources, including groundwater. Almost no groundwater-related activities have been implemented during the last 20 years, although the LCBC Master Plan for the Development and Environmentally Sound Management of the Conventional Lake Chad Basin and the Strategic Action Plan acknowledge their importance. The LCBC member states can rely on an inventory of the basin's groundwater resources, but important information remains to be collected, updated and analyzed in order to guide decision-making. A lack of technical capacities hampers an assessment of the impact of planned projects on the aquifer. At present, a number of internationally supported projects are being implemented with the LCBC to develop its capacities for transboundary groundwater management (cf. Alker in this volume, Lake Chad Basin aquifer case study).

Since the Lake Chad Basin Commission has proactively taken over the task of managing groundwater resources, it would not make much sense to create any additional management body. Rather the LCBC might well emerge as the most appropriate platform for groundwater cooperation.

The Orange-Senqu River Basin Commission

Three of the four member states of the Orange-Senqu River Basin Commission are riparians of the Stampriet Artesian Aquifer Basin (SAB), namely Botswana, Namibia and South Africa. Lesotho, although not a riparian of the SAB, is a riparian of the Orange-Senqu river basin and as such is also a member of ORASECOM (AMCOW / ANBO 2007, 65 ff.).

The Commission's mandate covers water matters of common interest, and the Commission seems to be well aware of groundwater resources in the basin. ORASECOM is currently preparing an Integrated Water Resources Management (IWRM) Plan for the Orange Basin which includes an overview of groundwater resources. In a preparatory paper, ORASECOM has outlined the need for further investigation of shared aquifers. Moreover, it has presented a project portfolio to the European Union listing current cooperative activities and legislation of nations in Africa and giving priority to the need to conduct a study on the transboundary aquifers. The member state governments have instructed ORASECOM to conduct a joint study of the Molopo and Nossob watercourse systems. This may yield information on the Stampriet Aquifer as well, since it is connected to the lower Nossob River (cf. Alker in this volume, Stampriet Artesian Aquifer Case Study).

It stands to reason that ORASECOM is the most appropriate forum for dealing with the transboundary Stampriet Artesian Aquifer Basin. The riparian countries share extensive experience in transboundary water management which is conducive for implementing transboundary groundwater management if the need is felt. However, only low priority is currently being given to transboundary groundwater management in the SAB, since of all SAB riparians only Namibia has shown a significant interest in utilizing groundwater (asymmetric use pattern). Interesting in this regard is that the SAB has been chosen as one ISARM case study.

4.2 Consultation mechanisms in the absence of river or lake basin organisations

In the absence of transboundary river and/or lake and related river and/or lake basin organizations, new mechanisms have been set up for dealing with hydrogeological conditions. This holds true in particular for the North-West Sahara Aquifer System (NWSAS) and the Nubian Sandstone Aquifer System (NSAS).

The Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System

The Joint Authority for the Study and Development of the Nubian Sandstone Aquifer System was established by Libya and Egypt in 1982, with Sudan and Chad joining later. Its internal code defines its objectives and functions as follows:

- Collecting data, information, and study results for classification, analysis and linkups.
- Conducting complementary studies to determine the present state of the aquifer regarding quality and quantity.
- Preparation of plans for the development of water resources as well as proposing and implementing joint policies for the exploitation and use of water resources at national and regional levels.
- Managing the aquifer on a sound scientific basis.
- Cooperation in the areas of training and building up required capacities.
- Creating heightened awareness of the need for rational use of the Nubian Sandstone Aquifer's water.
- Studying the environmental impacts of water development.
- Organization of scientific workshops and dissemination of aquifer-related information.
- Strengthening ties with regional and international organizations of common interest (Salem 2007, 111).

The Joint Authority, which is more a committee than an "authority" in the true sense of the word, has a board of directors consisting of three members from each nation, along with an administrative secretariat and a managing director who is appointed by the board (Foster / Tuinhof / Garduno 2006, 54). The Authority is chaired by each member state on a rotating basis. The members come from the Ministry of Water Resources and Irrigation of Egypt, the Secretariat of Agriculture of the Libyan Arab Jamahiriya, the Ministry of Irrigation and Water Resources of Sudan, and the Ministry of Environment and Water in Chad. The Authority has held six meetings within its 25 years of existence, most of which were directed towards exchanging information and scientific data and following progress in managing the Nubian Sandstone Aquifer System Project (cf. Alker in this volume, Nubian Sandstone aquifer system case study).

The members of the Joint Authority signed two agreements in the year 2000 dealing with activities to be undertaken by each member nation of the Authority. The first concerned the monitoring and exchange of groundwater information within each nation, the second contained regulations for continuous monitoring of the aquifer and a sharing of data via an update of regional information systems. The agreements are perceived as first steps in establishing a permanent mechanism for regional cooperation (Puri 2001).

However, the challenge ahead will be to anchor this initiative on the national level and to develop transboundary cooperation further. To this end, the Nubian Project has recently been set up to prioritize transboundary threats and their causes, fill key information gaps, prepare a Strategic Action Programme, and establish a framework for its implementation.

A consultation mechanism for the North-West Sahara Aquifer System

A consultation mechanism for the North-West Sahara Aquifer System has been established that covers the boundaries of the transboundary aquifer and its riparian countries, namely Algeria, Tunisia, and Libya. The authorities of Algeria, Tunisia and Libya have agreed on the implementation of a joint research project under the supervision of the *Observatory of the Sahara and the Sahel* (OSS).[3] In 1998 the OSS obtained support from the

3 The OSS is an international organization whose mission is to serve as a tool for liaison and an international framework for partnership and consultation and to contribute to the exchange of information in combating desertification and attenuating the effects of drought. It is composed of African and non-African states along with sub-regional, United Nations, intergovernmental, and non-governmental organizations.

Swiss Agency for Development and Cooperation, the *International Fund for Agricultural Development* and the *UN Food and Agricultural Organization* for a first three-year study up to 2002 (Mahmou et al. 2006, 70).

The official wording of the project's objective was *"to coordinate, promote and facilitate rational management of the NWSAS water resources"* (Burchi / Mechlem, 2005, 7). The project identified three major tasks: 1) to improve overall knowledge concerning the basin's hydrogeology and to create a joint database, 2) to create a mathematical model of the basin in order to understand its dynamics and to be able to draw future predictions, and 3) to set up joint consultation mechanisms (Mahmou et al., 2006, 70). The latter objective has been implemented in the form of a *steering committee* composed of representatives of the national agencies in charge of water resources. This *steering committee* meets ordinarily once a year. In addition, extraordinary sessions can be held upon request. Apart from the *steering committee*, a so-called *coordination unit* directed by the OSS has been installed. Finally, an *ad hoc scientific committee* is in charge of organizing research activities. *"Each state bears the operating costs of its own focal point, while the functioning of the coordination unit is financed out of subventions and gifts granted to the OSS by the concerned states and cooperating countries."* (Burchi / Mechlem 2005, 7–8; cf. Alker in this volume, North-West Sahara aquifer system case study)

According to Puri *"the joint data collection projects underway [...] bear [...] evidence of the participating project countries' implied concurrence with, and acceptance of, at least one fundamental obligation of international water law [...] on shared water resources, namely, the obligation to exchange on a regular basis available data and information [...]. In addition, the behaviour of those same states could arguably bear testimony to the general obligation not to cause significant harm, insofar as the joint data collection projects they are currently engaged in have sprung from the perception that unilateral development could work harm across the border."* (Puri 2001, 22) However, it remains to be seen whether the riparians will strengthen their coordination, e. g. in the form of procedures for reporting on national water utilization rates, and will accelerate initiatives even to the point of formally sanctioned agreements.

4.3 Which type of organization is most appropriate?

In light of the foregoing description of the different paths taken by transboundary groundwater management cooperation in Africa, the question remains which type of cooperation best matches the requirements for sustainable and efficient groundwater management there. Basically, the organizational setups that have developed to date differ according to whether or not their sphere of responsibility exactly matches the respective domain of the groundwater resource, including related rivers and lakes, and includes all riparian countries.

The effort to establish separate transboundary aquifer management organizations conforms with the fundamental idea and internationally accepted key principle of Integrated Water Resources Management in so far as planning, coordination and management should be based on the natural boundaries of basins. As a consequence the establishment of aquifer management organizations could be seen as the best option even if river or lake basin organizations already exist, since in most cases the biophysical boundaries of aquifers match neither the administrative boundaries of nation states nor the mandates of existing water management organisations such as river or lake basin organisations.

However, the case studies presented here have revealed that many unknowns still remain. To recapitulate: the natural boundaries of transboundary aquifers are difficult to identify, and much uncertainty exists about their recharge, flow and discharge areas. Where groundwater resources are linked to surface water bodies, their hydraulic links are not always precisely known. When systems are multilayered, demarcation of the utilized portions may be even more complicated.

Any organization which attempts to coordinate and regulate transboundary water management must live with this situation and still be able to take action. This underscores the need for flexible mechanisms (of whatever form), since the fit of an organisation to the biophysical environment will almost never be perfect.

Since no tailor-made solution exists, decisions for either separate aquifer management organizations or for organizations with extended mandates regarding river and/or lake basins should be pragmatic: They should take into account the limited financial and human resources and management capacities of many African countries. The establishment of parallel aquifer management organisations could lead to competition for scarce resources (e. g. experts, funds and know-how) among the various river and lake basin organisations and aquifer organisations. This would likely weaken both types of organisations and prevent them from carrying out their functions properly. In view of the fact that the riparian countries of transboundary aquifer systems are usually riparians of river and lake basins as well and also members of the respective organizations for managing them (see table 4), decisions on management bodies must also take into account the available human resources. One crucial question is whether the riparian countries are prepared to set up new organizations.

These points are mentioned in order not to preclude other options. In fact, it might be more promising to integrate transboundary groundwater issues into river basin planning, coordination, and management and to make use of existing organizations[4] and the good relations they have developed (cf. table 4; BMZ 2006, 11). The integration of groundwater and surface water management might provide additional incentives for some riparians to engage in transboundary groundwater management, since the "pie" at stake would then be larger. Therefore it is advisable to build on developments in a basin, whether this involves a river, lake or groundwater basin organisation. River basin organizations can then extend their mandates and cooperate with the parties concerned as needed in the management of transboundary aquifers.

4 Interestingly, the European Water Framework Directive does not prescribe any one form for the institutionalization of river basin management.

Table 4: Multiple water relationships among riparians of transboundary aquifers

Transboundary aquifers with riparian countries	Water relations other than groundwater
Kilimanjaro Aquifer riparians: Kenya, Tanzania	East African Community: Protocol for Environment and Natural Resources / Strategic Environmental Assessment Nile Basin Initiative (plus Egypt, Sudan, Ethiopia, Eritrea, DRC, Uganda, Rwanda, Burundi) Lake Victoria Basin Commission (plus Uganda) Mara and Pangani River Basin (Kenya, Tanzania)
Lake Chad Basin Aquifer riparians: Chad, Cameroon, Niger, Nigeria, Central African Republic, Sudan	Niger Basin Authority (plus Guinea, Mali, Benin, Burkina Faso, Ivory Coast) Nigeria-Niger Joint Commission Chad-Cameroon Joint Commission
Nubian Sandstone Aquifer riparians: Egypt, Chad, Sudan, Libya	Nile Basin Initiative (plus Ethiopia, Eritrea, DRC, Uganda, Tanzania, Kenya, Rwanda, Burundi)
Stampriet Aquifer riparians: South Africa, Namibia, Botswana	Orange-Senqu River Basin Commission (plus Lesotho) Okavango Permanent Commission (plus Angola) Zambesi Watercourse Commission (plus Angola, Zambia, Zimbabwe, Malawi, Mozambique, Tanzania) Joint Permanent Water Commission (only Botswana, Namibia) Permanent Water Commission (only South Africa, Namibia) SADC Revised Protocol

Source: AMCOW / ANBO (2007); Case studies in this volume

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Recommendations for German development cooperation

Waltina Scheumann / Elke Herrfahrdt-Pähle / Insa Theesfeld

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Recommendations for German development cooperation

Waltina Scheumann / Elke Herrfahrdt-Pähle / Insa Theesfeld

1 Criteria for engaging in transboundary groundwater cooperation

Although limited in extent, German development cooperation is already playing a role in cooperative transboundary groundwater use and management in Africa. Whether this field will receive more attention (and funds) is subject to decisions which have yet to be made. Such decisions should be based, among other things, on the criteria given below:

- Hydrological and environmental factors: surface water availability is already limited or is likely to be so in future (climate change); that is, surface water resources are either already being fully utilized or are approaching full utilization.
- Socio-economic factors: conjunctive use of surface and groundwater has a high potential for reducing tension among the users of surface waters. It can reduce the need for large-scale infrastructure investments; it is important for urban and rural water supplies; small-scale irrigation and livestock economy can be promoted through the development of shallow aquifers; and groundwater resources can help in mitigating drought.
- Institutional factors: management organisations which already exist on the transboundary level or corresponding initiatives which have been set in motion within regional organisations.
- Also to be considered is whether German development cooperation is already involved in the water sector in countries which are riparians of a transboundary aquifer.

In accordance with the strategy of the German Federal Ministry for Economic Co-operation and Development (BMZ) regarding the use of non-renewable fossil groundwater resources, we again emphasize that the following conditions must be met in order for the BMZ to provide support in relation to the utilization of fossil groundwater resources: 1) no other water sources are available to meet the demand for drinking water, and 2) a significant, positive development impact can be expected from the utilization of the resource (BMZ 2006).

2 A step-by-step approach towards joint management

Cooperation should build on initiatives that already exist on the transboundary, river/lake basin or national level. German support should aim to promote these initiatives and to improve cooperation at its various stages.

The first stage consists mostly of data gathering, establishing a knowledge base, assessing national use patterns etc. This first stage of cooperation may also aim at establishing a uniformity of technical capacities and knowledge in the different countries (e.g. by lifting less-developed countries to a higher level, cf. Steyrer in this volume). Where riparian states utilize *transboundary* groundwater, and where this use may have an impact, it becomes important to exchange information, to standardize measuring techniques, to install monitoring networks etc. Even when use ratios are low, the riparian countries should consider setting up a reporting procedure for jointly monitoring development trends.

After this initial phase, further steps towards joint management of the resource may be possible. Useful for this are: an exchange of expertise, building up technical capacities, support for research activities, the provision of capital for project activities, and direct intervention, e.g. in the form of convening meetings, facilitation, mediation etc. (Mostert 2005). Donors can provide training and assistance with the harmonization of standards and can promote an exchange of information and expertise among African countries and between developing and developed countries. Table 1 below lists possible and important measures for each respective stage of cooperation.

As a general rule, the role of development cooperation should be to facilitate and consolidate existing efforts at each of the five stages of cooperation between riparian countries shown in the table 1. These stages can be defined and described as follows:

Table 1: Possible support measures at each stage of cooperation

Stages of cooperation / Measures	1st No cooperation	2nd Limited cooperation	3rd Regularized cooperation	4th Extended cooperation	5th Joint management
Research (e.g. development of use scenarios)	●	●	●	●	●
Facilitation through workshops, meetings etc.	●	●	●	●	●
Exchange of information	○	●	●	●	●
Exchange of expertise/knowledge transfer			●	●	●
Technical equipment (e.g. for measuring water quality/quantity)		○	○	●	●
Training (e.g. measuring techniques)		○	○	●	●
Harmonization of standards, measuring techniques etc.		○	○	●	●
Capacity building (groundwater management, organisational development etc.)	○	○	○	○	●

○ = Possible measure ● = Important measure
Source: Authors' own compilation

No cooperation (separate management)

At this stage, the role of development cooperation should focus on the facilitation of meetings on general topics between the relevant ministries and agencies, with the aim of establishing trust and promoting the political will to engage in transboundary groundwater cooperation. *"The riparian states must themselves want and promote transboundary water cooperation."* (BMZ 2006b, 11) Measures can be implemented to broaden the knowledge base through joint research; additional measures might include capacity building and the exchange of information.

Limited cooperation (cross-border dialogue)

At this very early stage of cooperation, development support can centre on generating information (hydrogeological, but social and economic too in order to understand who relies on and benefits from groundwater use) through research and supporting the exchange of available information. Joint seminars and workshops may be conducted to this end. The aim should be to intensify existing contacts through meetings which focus on issues of particular relevance or topics that are prerequisites to further cooperation (e.g. harmonisation of measurement techniques and standards). During this phase, emphasis should be given to the development of expertise and the reduction of gaps in knowledge between the relevant riparian states.

Regularized cooperation (data exchange, joint research)

This phase is characterized by the creation of transboundary groundwater platforms that aim at generating data, establishing a sound knowledge basis, and exchanging data. Similarly to the previous stage, the emphasis here should be to promote specific and targeted information exchange and to support joint research activities of the riparian countries. In addition, the establishment of discussion fora and platforms could be promoted to enhance the exchange not only of data but also of know-how and expertise, and to explore the possibilities for benefit-sharing arrangements.

Extended cooperation (coordination mechanisms)

After lines of communication have become established among the riparians, the role of development cooperation could be to consolidate the platforms for cooperative data exchange and to help develop reporting procedures for jointly monitoring development trends. Financial support and other types of assistance could be provided for the development of joint management plans, for training in technical expertise, for procuring technical equipment, and for harmonizing standards and measuring techniques. In order to set up the necessary organisational bodies there will most likely be a need to train personnel and staffs which will be in charge of groundwater management. Relevant expertise can come from countries that are more advanced in groundwater management and from members of river and/or lake basin organisations which are more advanced in the integration of groundwater issues. Development cooperation can also aim at facilitating knowledge transfer. This phase relies primarily upon available expertise and upon instruments for coordinating technical and financial development.

Joint management

The final stage of cooperation is joint management of transboundary groundwater resources. This implies the establishment of coordinating or joint management bodies whose mandates and authority would have to be defined by the member states. Given the current lack of qualified water management personnel in many African countries, this stage is characterized by a high demand for capacity building. Among other things, this involves setting up management institutions, working out organisational structuring, defining management techniques etc. Continuous application of the measures applied in previous stages is also preferable, since information exchange, joint research etc. are preconditions for functional joint management of the resource.

3 Strategic recommendations

Transboundary groundwater resources have the potential to promote economic development and the social wellbeing of Africa’s societies and population. Therefore German development cooperation should emphasise coordinated management for several reasons.

Firstly, coordinated management can promote economic growth and development in arid and semi-arid regions that are threatened by (surface) water scarcity. Sustainable use of these natural resources can substantially contribute to achieving the Millennium Development Goals, especially regarding poverty eradication (MDG 1) and access to safe drinking water and sanitation (MDG 7). Secondly, transboundary groundwater resources are already showing first signs of overdraft in some cases (reduced quality etc.). Coordinated action and sustainable use strategies can help to avoid future negative impacts and costs in the form of decreasing agricultural yields, high investments in the treatment of drinking water etc. Thirdly, both overuse and the neglect of groundwater resources have a major negative impact on the poor. Groundwater management should thus become an integrated part of national poverty reduction strategy plans. Fourthly, unilateral utilization of transboundary groundwater resources may lead to competition and friction unless conflict resolution is implemented.

Together with the fact that climate change is likely to alter surface water availability, and affect groundwater recharge, groundwater utilization becomes increasingly relevant. Unfortunately, a website-based survey of donor activities, another survey conducted by GTZ (2007) and a literature review have shown that transboundary groundwater cooperation is as yet neither a priority for riparian nations nor for donors in Africa.

In addition, the present study clearly revealed deficits in transboundary groundwater management with regard to available databases as well as institutional structures for coordinated management and governance at the transboundary level. Notwithstanding the uncertainties that exist with regard to groundwater resources, efforts should be directed towards institutionalized management. We suggest a two-pronged approach that aims at closing knowledge gaps while simultaneously proceeding with the establishment of institutions for sustainable water resource management.

Such an approach is of course ambitious. In particular, the process of institutional development must be highly flexible. New institutions for groundwater management, along with the related laws, regulations, cooperative agreements and organisations, must be able to react to new scientific evidence in order to adapt water management plans in accordance with hydrological findings.

Development cooperation should aim at advancing transboundary groundwater cooperation to the next higher stage of cooperation (cf. figure 1, 46). It should take place on both the transboundary level (i.e. direct collaboration with organisations already in place and facilitation of their development) and the national level (i.e. support for closing gaps in data and knowledge, and promoting the incorporation of groundwater issues into national water policies and other policy areas which are relevant for groundwater protection).

3.1 Recommendation one: Put the issue of sustainable transboundary aquifer management on the political agenda and coordinate donor activities

In general, German development cooperation should progressively intensify its support for transboundary aquifer management as a field of bilateral and multilateral development cooperation. Such management will have steadily increasing importance for the reduction of poverty, for economic development, and for the assurance of sustainable resource use.

In order to heighten awareness for these issues on the part of political decision-makers, German development cooperation can take advantage of existing multilevel beachheads which it has established for shaping and implementing groundwater management-related policies. The levels of possible intervention here range from the international (EU Water Initiative; UNESCO-ISARM, UNEP), the continental (AMCOW), the regional (e.g. SADC Groundwater Assessment Programme), the national, and down to river and lake basins (e.g. ORASECOM, LCBC) (BMZ 2006b, 11, 13). After all, the governance of global environmental resources is increasingly based on multilevel solutions which take effect simultaneously on the local, national, international and intermediate levels.

This will naturally make it necessary to deal with institutional diversity (Paavola 2007,94). German development cooperation should promote transboundary groundwater issues at all these different levels and should introduce the topic of transboundary groundwater management into its bilateral and multilateral policy dialogues. We especially recommend that German development cooperation use its already existing connections at transboundary and national levels. It should rely on existing technical expertise (BGR, GTZ, KfW, InWent, DED) and on individual national experience (e.g. in Namibia, Tanzania), and should also make use of its own expertise in policy advisory projects (GTZ support to e.g. SADC and ORASECOM). In particular, there is a need to assist by (1) helping to close information and data gaps, (2) building communication and coordination bodies, and (3) dealing with traditional national policies which are mainly based on the enforcement power of the state and to a lesser extant on voluntary cooperation.

As a means of further developing transboundary groundwater management, we recommend that groundwater protection be integrated into other areas of German development cooperation such as the promotion of land use planning, the protection of wetlands and biodiversity, water supply and sanitation services in settlements of the urban poor etc. as also suggested in the BMZ position paper on transboundary water cooperation (BMZ 2006b, 14).

German development cooperation should promote the coordination of bilateral or multilateral donor organizations dedicated to transboundary aquifer management. Among the donor organizations currently involved at the transboundary level are e.g. the IBRD (World Bank and GEF projects), UNDP, UNEP, AfDB, and France, Germany and Switzerland (GTZ 2007). At the same time, a number of bilateral and multilateral donor organizations are involved at the national level. African countries currently receiving support are e.g. Mozambique, Zambia, Ghana, DR Congo, Burkina Faso, Kenya, Tanzania, Morocco and Egypt. Some of the countries that receive support are riparians of transboundary aquifer systems, and as such the interlinkage between the national and transboundary level has to be considered.

The fields of activity which should be coordinated cover national groundwater assessment studies (already receiving support from SIDA, DANIDA, CIDA, GTZ), national groundwater management (supported by SIDA, DANIDA, JICA, GTZ), and the development of national integrated water resource management plans which also include groundwater (supported by Dutch Ministry of Foreign Affairs/DC, USAID, GTZ).

3.2 Recommendation two: Support existing regional river / lake basin and aquifer organisations and facilitate the establishment of transboundary consultation mechanisms

Individual, unilateral national development and management is currently the predominant feature of transboundary groundwater use. This may be justified if use ratios are low and if there is no transboundary impact. However, separate national management becomes problematic as soon as water use becomes highly asymmetric, since the countries involved seek to establish rights of prior use. If use patterns intensify and interdependencies show up, the critical issue is to put in place a transboundary consultation mechanism. International donors and German development cooperation may support step-by-step development of transboundary groundwater cooperation (cf. findings from the case studies). One important step might be the establishment of an institutional environment for participatory and bottom-up knowledge elicitation and exchange, and the establishment of arenas for conflict resolution and mediation (BMZ 2006b, 13). This includes horizontal and vertical consultation mechanisms among the stakeholders involved.

Since they lack the considerable body of experience and academic research available to transboundary river basin organisations, aquifer management organizations cannot rely on equally profound analyses for their recommendations. Nevertheless, the case studies presented here have made it clear that German development cooperation has in fact two options: first, to support the establishment of *aquifer management organizations* with jurisdiction over each respective resource domain and composed of members from all riparian countries. Second, to widen the mandates of *river / lake basin organizations* even when an aquifer's boundaries extend beyond those organizations' spheres of responsibility, and even if some of the riparians do not belong to the respective river and lake basin organizations.

In the absence of a transboundary surface water system, the first choice (and the only feasible one in this case) has been applied for the North-West Sahara and the Nubian Sandstone aquifer systems.

At first glance, it appears to make sense to support the establishment of separate *aquifer management organizations* parallel to existing river / lake basin organizations. Although this approach has great appeal because it suggests that planning, coordination and management can be carried out in harmony with hydrogeological boundaries, thus resolving the problem of fit (Young 1999; 2002), the findings of the case studies presented here and of earlier studies (Scheumann / Neubert 2006) lead us to reject it. Rather, the findings suggest an approach that builds on regional development. Major reasons for this are:

- In view of limited financial and human resources and management capacities in many African countries, the establishment of additional, separate organizations would overburden countries which are simultaneously riparians of transboundary aquifer systems and members of one or more river and lake basin organizations.
- Integrating transboundary groundwater management into *existing* river and lake basin organizations may well provide additional incentives for riparians to engage in joint endeavours, since this will increase the "water cake" at stake while reducing tensions due to the scarcity of surface water.
- A useful fund of mutual trust has already been created by existing forms of cooperation even if this trust is “only” in areas not directly linked to groundwater issues, such as river basin management or bilateral agreements on water issues.
- Last but not least, ground and surface waters are often linked in various ways. Thus management activities within the framework of a common organisation meet the basic premise of Integrated Water Resource Management (IWRM): to manage water in an integrated way.

Therefore it appears to be more promising to integrate transboundary groundwater management into existing river basin planning, coordination and management activities and to make use of existing organizations for this purpose. River / lake basin organizations may then cooperate with other involved parties as needed in case of common issues regarding transboundary aquifer systems. This could, for example, include the establishment of permanent working groups or groundwater management bodies within the respective river / lake basin organisation for discussing new developments, addressing emerging problems, exchanging information, and describing best practices.

True, this approach also has disadvantages. The boundaries of institutional jurisdiction for governance and management of the resource systems will not match the biophysical boundaries of these systems. Moreover, this solution will face administrative inertia due to the high transaction costs faced by civil servants when working out new procedures with extended responsibilities and implementing them properly (cf. Theesfeld in this volume).

On the other hand, this approach also has important advantages. In view of the lack of capacities and funds faced by many river and lake basin organizations, it is unlikely that additional groundwater management organizations will be able to live up to their tasks. And it might be possible to overcome the misfit of river / lake basin organisation if - during the course of time - additional units are created to include all groundwater riparians.

There is evidence that river / lake basin organizations are becoming increasingly aware of the role played by groundwater resources: cooperation over parts of the Kilimanjaro Mountain Aquifer between Kenya and Tanzania, for instance, is growing within the context of the Great Pangani Basin Cross-Border Dialogue. The IWRM plan for the Orange Basin includes a groundwater overview (Stampriet Artesian Aquifer); the Lake Chad Basin Commission has included groundwater resources in its project "Management of groundwater resources for sustainable development of Lake Chad Basin" (cf. case studies in this volume).

3.3 Recommendation three: Improve the knowledge base and build capacities for groundwater management

Good cooperation needs good information. In line with the BMZ position paper on transboundary water cooperation (BMZ 2006b, 13) German development cooperation should aim to support the establishment of a joint information basis for planning purposes: sound, unified, consistent information on water balances, on the interaction of aquifer and river / lake systems in relation to hydrological units, on the extent and nature of the respective aquifers, on recharge and discharge mechanisms, and the socio-economic dimension of groundwater use (who relies on, who benefits from). This information will be valuable for meeting the data requirements of each development phase (cf. Grossmann 2006, 198).

The present dearth of such information requires that joint investigation projects be carried out and that scientific cooperation be intensified in order to establish a sound basis of information. Scientific cooperation might be promoted by the German Ministry of Education and Research (BMBF). Possible research themes could be, e.g. research on affected aquifers, coastal aquifers and climate change, and how to develop flexible approaches and strategies for managing non-renewable groundwater resources. These efforts should be undertaken in close cooperation with researchers and research organizations in the partner countries in order to facilitate the translation of scientific evidence and results into policy processes in the relevant countries and regional water management organizations.

Capacity building for groundwater management can be supported at the level of regional river / lake basin organizations and national water administrations. Support can also be provided for training and twinning projects, and for long-term capacity-building programmes. For instance, the BMZ is currently funding a Master's Degree Program on "Integrated Water Resources Management" for students from Germany and Arabic countries which is being jointly implemented by the Fachhochschule of Cologne and the University of Jordan in Amman. A similar (regional) program could be developed for a larger number of African countries in cooperation with regional universities and research institutes.

Priority should be given to capacity building in African countries with relatively little expertise in groundwater management compared to their riparian neighbours. Development cooperation should aim at eliminating these differences in information, skills, knowledge etc. among the riparian countries and thus removing one of the barriers to transboundary groundwater cooperation.

3.4 Recommendation four: Assist in the development of flexible management approaches

A crucial question remains as to how transboundary aquifer management can be effectively incorporated into the mandates and functions of existing regional river / lake organizations. Currently, river and lake basin treaties in Africa cover groundwater resources only in a superficial and rather unspecified way. German development cooperation could help the respective organizations to add a "groundwater component" and to develop and strengthen their capacity to carry out the functions for which they have been designed. Some hints on how to proceed in this regard are given in the step-by-step approach already described (cf. findings from the case studies).

A high degree of factual uncertainty currently hinders the development of rules and specific regulations for transboundary aquifer management. There is widespread uncertainty about physical characteristics such as the natural boundaries of transboundary aquifers, their recharge, flow and discharge areas, their three-dimensional extension, their inhomogeneous geological formations, and their hydraulic links to surface water bodies. When they are multilayered, the demarcation of their utilized portions may be even more complicated. Their depth, their flow rates, and the related cause-effect patterns are important in designing rules and regulations for the joint utilization of regional groundwater resources, where individual and/or national water extraction rates must be monitored, pollution emission targets must be defined, and policies must be implemented.

According to the Rio Declaration of 1992, the existence of uncertainty is no excuse for neglecting to develop rules or for abstaining from management: "… lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." (cited in Matsumoto 2002, 33). Matsumoto makes reference to the negotiations over greenhouse gas emissions in the Framework Convention on Climate Change, and the Kyoto Protocol for setting emission reduction targets. In both cases, "flexible mechanisms" and a "process-oriented" approach have been used to address the issue of scientific uncertainty. The negotiating parties called for using "the best available scientific information and assessment on climate change and its impacts, as well as relevant technical, social and economic information." As a practical consequence, decision-makers can take action based on the "best available data and assessment tools on a given date" (cited in Matsumoto 2002). Thus the emphasis is on creating open and flexible mechanisms and rules.

On the other hand, uncertainty also has a positive side. It can also promote cooperation if the process of negotiating rules and regulations is designed so as to ensure flexibility in promoting the interests of all concerned and in revising rules and regulations when new scientific evidence requires this. Since cross-boundary cooperation and respective institutions evolve over time, as experience and confidence builds up, support must be tailored to the respective stage of cooperation when various functions and the goals pursued undergo change (cf. Feitelson / Haddad 1998, 229–230).

3.5 Recommendation five: Strengthen national groundwater governance

Transboundary aquifer management cannot be effective without a properly functioning system of national groundwater management and the harmonization of national water policies (BMZ 2006b, 13). To complement aquifer management on the regional level, national groundwater management in the riparian countries must be strengthened, integrated into water policies and ongoing water sector reforms, and implemented in policy areas relevant for groundwater protection. This involves, for instance, land use planning to protect and improve catchment functions, waste water management, and better agricultural practices in order to reduce sources of pollution. If German development cooperation is involved in other sectors than water, then it would be important to assess (as a component of environmental impact studies) whether the intervention planned will have a negative impact on groundwater resources.

Groundwater resources are currently being heavily exploited for large-scale commercial agriculture in Northern African countries and on a small- and medium scale in Sub-Saharan Africa. In Tanzania, for instance, the use of treadle pumps is spreading. Transboundary groundwater resources are considered relevant for irrigation in e.g. Botswana, Kenya, Nigeria, South Africa, Tanzania, Togo, Uganda, Zimbabwe and Zambia. However, information on actual national usage and on development plans is lacking. If state administrations and management are weak, nationwide monitoring of groundwater use and the establishment of licensing and registration systems become important and challenging issues. Besides groundwater legislation, additional items have a strong impact on national groundwater governance, as discussed by Theesfeld (in this volume). These items are, for instance, the need for voluntary compliance by water users, bureaucratic inertia in the form of administrative reluctance to implement policies involving substantial changes in procedures, economic instruments such as subsidies, taxes and the establishment of groundwater markets, and a commitment to participation on the part of groundwater users.

Delineation of groundwater protection zones and the implementation of appropriate land use restrictions around drinking water wells could facilitate the protection of certain catchment functions. German development cooperation could support such policy measures, for instance with regard to the Kilimanjaro forest belt, which has a high impact on water availability for the Amboseli ecosystem and consequently for the agricultural sector in Kenya.

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Part B: The African case studies

The African case studies

The case studies were selected in an attempt to represent a diversity of geopolitical and hydrogeological features. The major criteria for selection were:

- Hydrogeological diversity
- Actual or highly probable transboundary implications of national groundwater use with regard to quality and/or quantity
- The existence of transboundary cooperation mechanisms

Since the studies were conducted as desk studies, the availability and accessibility of data were indispensable criteria for selection. Based on a continent-wide screening of the 40 or so transboundary aquifer systems in Africa and a review of the literature, it was decided together with experts from the German BMZ, BGR, GTZ and KfW that the following aquifers meet these criteria:

1. The Kilimanjaro Mountain Aquifer: it is linked to surface water; the recharge area is located within one riparian state; cooperation is at a very early stage.

2. The Lake Chad Basin Aquifer: it is linked to surface water bodies, and the lake commission has been mandated to concern itself with transboundary groundwater.

3. The Northwest Sahara Aquifer System: non-renewable, fossil water (limited recharge), with high dependency on groundwater; only a cooperation mechanism for transboundary groundwater is in place.

4. The Nubian Sandstone Aquifer System: non-renewable, fossil water; high dependency on groundwater; an institutional structure is in place for information exchange and joint management.

5. The Stampriet Artesian Aquifer: linked to a transboundary river; a river basin commission could well serve as the coordination mechanism for transboundary groundwater.

The case studies are presented with a common outline:

- Characteristics of the aquifer
- Groundwater use patterns
- Transboundary impacts (actual or potential)
- Institutional arrangements for groundwater management and transboundary cooperation
- Prospects for transboundary cooperation, and recommendations for German development cooperation.

The Kilimanjaro Aquifer

A case study for the research project ”Transboundary groundwater management in Africa”

Malte Grossmann

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The Kilimanjaro Aquifer

Malte Grossmann

1 Introduction

The Kilimanjaro Aquifer, shared by Tanzania and Kenya, was selected for one of five illustrative case studies within the research project “Transboundary groundwater management in Africa” for the following reasons: first, Mount Kilimnajaro is a “water tower” in an area of high population density and rapid economic development, where surface water resources are drawing to a closure and the development of groundwater resources is becoming more important. Second, the Kilimanjaro Aquifer was chosen as an example for the groundwater conditions in the volcanic region of the Eastern African Rift as well as in associated basins. It further represents the typos of a mountain aquifer. At a first glance, not much written information is available about the Kilimanjaro Aquifer. This desktop case study therefore is an attempt to draw together available but dispersed information in order to paint a broad- brush picture and to identify potential issues for transboundary conflict and cooperation related to its management.

2 Characteristics of the aquifer

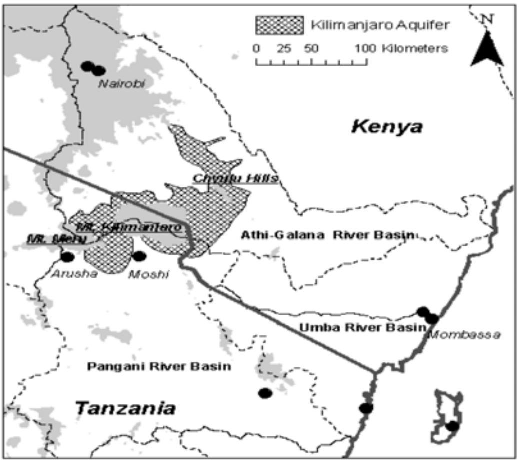
2.1 Extent, topography, and geology

The Kilimanjaro Aquifer is the general name given to various aquifers which have Mount Kilimanjaro at their centre. The present study is based on a delineation of the aquifer as proposed in the International Groundwater Resources Assessment Centre (IGARC) Database of transboundary aquifers of Southern Africa (IGRAC 2005). According to data and maps presented there, the Kilimanjaro Aquifer system has an area of about 15,000 km². Besides Mount Kilimanjaro, it includes aquifers emanating from the slopes of Mount Meru in Tanzania and the Chyulu Hills in Kenya.

Mount Kilimanjaro is the highest mountain in Africa, a huge strato volcano (ca. 60 x 90 km) composed of three peaks, the highest of which reaches an altitude of 5,859 m. Kilimanjaro is also Africa's highest free-standing mountain, looming some 5,000 m above an undulating plain which averages 1,000 m above sea level.

The aquifer as shown in figure 1 is delineated on the basis of geology and topography so as to include the volcanic pyroclastic and volcanic alluvium deposits found at the base of Mount Kilimanjaro and extending across the Kenyan-Tanzanian border. These deposits form basins which extend outward from the mountain and are limited by the surrounding precambrian basement rocks. Occurrence of groundwater in the surrounding basement plains is limited to faults, fractures and small parts of weathered zones and also to the bottom layers of wide alluvial valleys which are recharged by natural flood spreading.

Figure 1: Location of the Kilimanjaro Aquifer and major river basins



Source: Author, extent of aquifer based on IGRAC (2005)

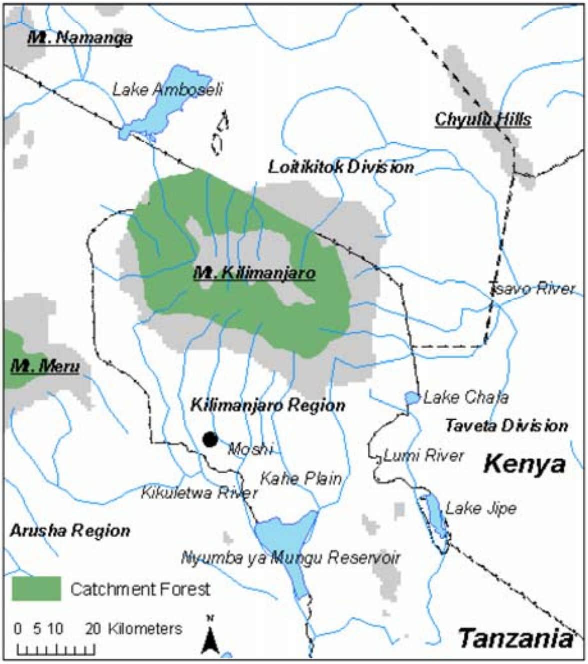
The basement rocks are an aquaclude for a large regional groundwater flow system emanating from Kilimanjaro. It extends into the volcanic alluvium at the base of the mountain and forms major aquifers. These basins are filled by alluvium deposits chiefly composed of sand, gravel and clay, along with calcerous deposits with some lava and pyroclastic volcanic rocks. The thickness of the alluvial deposits on the plains of the southern slopes (Kahe-Miwaleni Basin) is estimated to be roughly more than 130 m; it increases on the lower mountain slopes (Isozaki et al. 1977). The depth of the basement below the volcanic zone is not accurately known. The basement's configuration is difficult to estimate because of quartenary tectonics, of which there is evidence. The surrounding plains can be regarded as a depressional zone because of the loading of the mountain on the basement, whereby the rims are affected by faulting and flexuring (Meijerink et al. 1997). Water from regional groundwater flow systems within the volcano reaches the aquifers and high yielding springs at the base of the mountain in two ways: by diffuse flow and by concentrated flow.

According to Mpanda and Yanda (2001), three major geological features determine the formation of springs; in-fills of paleo-valleys, fractured rocks along fault zones, and lateral aquifers characterised by porous rocks or sedimentary materials. Aquifers of the first two types have a limited spatial extent, and springs emerge from them at isolated points. Lateral aquifers, on the other hand, are often extensive and are characterised by series of springs and swamps.

Meijerink et al. (1997) have proposed, for example, that upwelling water within the lower part of the Amboseli Basin on the northern slopes of the mountain flows concentrated in subterranean collectors, probably lava tunnels or fractured conduits, and emerges at the springs. In contrast, the groundwater system of the plains extends far into the lacustrine deposits of the basin, but flow rates are low.

The aquifer basins are limited to the south by precambrian basement mountains. To the west, the aquifer system is bounded by the eastern slopes of Mount Meru. Towards the north, the basin is bounded by basement rocks and the Chyulu Hills. These hills consist of a series of recent volcanic cones, some only a few hundred years old, with lava flows that extend down to the lower ground of the Amboseli Basin. Both Mount Meru and the Chyulu Hills, although included in the Kilimanjaro Aquifer (figure 2), form more or less separate aquifer systems (cf. Mailu 1994). No studies are known which investigate the Kilimanjaro Aquifer as a whole and confirm the extent of its perimeters, the direction of its groundwater flow and areas of confluence with other aquifers.

Figure 2: Area around Mount Kilimanjaro



Source: Author, extent of aquifer based on IGRAC (2005)

2.2 Rainfall, surface water basins and groundwater discharge from springs

Mount Kilimanjaro straddles the catchment boundaries of two major river basins and one internal drainage basin, all of which are shared by Kenya and Tanzania: the Pangani and the Athi River Basins and the Lake Amboseli Internal Drainage Basin. The Mount Kilimanjaro water catchment area is of critical importance for both Tanzania and Kenya. Its value stems from heavy annual rainfall and extensive forests. 96 % of the water flowing from the mountain originates from the forest belt alone (Rohr 2003). The following distinct agro-ecological zones can be identified: a lowland zone (< 900 m asl) with pastoralist livestock farming, a midland (900–1,800 m asl) maize-bean belt and a highland (1,200–1,800 m asl) home garden or coffee-banana belt; the montane forest belt extends above the home garden belt to around 2,800 m asl, above which the alpine zone begins (Soni 2005).

The natural forests of Mount Kilimanjaro receive ca. 2,093.5 million m³/a of water, of which 73 % comes from rainfall and 27 % from fog interception (Agrawala et al. 2003). The forest dampens the air, leading to a permanent high humidity of the air above the forest belt. This results in cloudiness and rain showers even during the dry seasons. Evapotranspiration would be much higher (due to higher temperatures) without this permanent cloud cover above the forest, and rain showers during the dry season would be absent. It is estimated that the condensing capacity of montane forests on the mountain add up to 10 %–25 % of the total annual rainfall. These mechanisms enhance the forest's value as a water reservoir which stabilises the seasonal flow patterns of the emanating rivers.

Annual rainfall on the southern slopes is high and reaches a maximum of 3,000 mm at 2,100 m asl in the forest belt. Annual mean rainfall is 400–900 mm in the lowland plains, 1,000–1,200 mm in the midlands, and 1,200–2,000 mm in the home garden belt. The south and southeastern slopes form the main upper catchment of the Pangani River, one of Tanzania's largest rivers, which drains into the Indian Ocean near Tanga. It has a total length of 432 km, and drains a basin area of 43,650 km². It provides water to the hydropower plants of Nyumba ya Mungu (8 Megawatt [MW]), Hale (17 MW) and Pangani Falls (66 MW), which generate some 20 % of Tanzania's total electricity output. The river also supplies several large-scale irrigation schemes. Mount Kilimanjaro is estimated to provide 60 % of the inflow to the Nyumba ya Mungu Dam and 55 % of the Pangani River's total surface water (Rohr 2003).

The Pangani River has two main tributaries: the Ruvu which rises on the southeastern slopes of Kilimanjaro, and the Kikuletwa, which rises on Mount Meru and the southwestern slopes of Kilimanjaro. At their confluence lies the Nyumab ya Mungu Dam, whose inflow is estimated to be around 35–43 m³/s. Springs arising on the lower slopes of the mountain contribute as much as 20 m³/s, that is around 50 %, to the Nyumab ya Mungu inflow. The two largest springs are Chemka Springs in the Kikuletwa catchment and Miwaleni Springs in the Ruvu catchment. Total flow at Chemka Springs has been estimated at 10 m³/s with very small variations throughout the year (Rohr / Ngana / Killingtveit 2002). The springs at Miwaleni also have a nearly constant flow of 3–4 m³/s. Taken together with a number of smaller springs, total flow is 20 m³/s (Rohr 2003). This sustains river flows in the dry season when rainfall contribution diminishes.

The Ruvu River originates from Lake Jipe, a shallow lake between Kilimanjaro and the Pare Mountains. The lake is shared by Tanzania and Kenya. In the Kenyan section of the Pangani River Basin, the Lumi River drains the southeastern slopes of Mount Kilimanjaro and is the main source of water to Lake Jipe. The headwaters of the river are on the southeastern slopes of Mount Kilimanjaro in Tanzania. Surface runoff from Mount Kilimanjaro forms small tributaries to the Lumi River. These tributaries remain dry most of the year, and the perennial flow of the Lumi River is maintained by a system of high-yield springs when the river reaches the Kenyan side of the border. The largest of these springs is Njoro Kubwa, with a discharge of ca. 4 m³/s. Before emptying into Lake Jipe, which has a surface area of approximately 28 km², the Lumi River enters an alluvial flood plain which gradually merges into a large swamp whose area is estimated at more than 45 km². There is a strong possibility of other springs discharging underground into the northeast corner of Lake Jipe (Ndetei 2005).

A second lake on the Kenyan-Tanzanian border is Lake Chala. Lake Chala lies in a small volcanic crater above the Lumi River. It has no surface inflow or outflow, but is believed to be connected underground with the surrounding springs.

The northern slopes on the leeward side of the mountain receive much less annual rainfall. Annual rainfall is around 800–1,000 mm. Although this greater aridity is manifest in a sparser network of valleys, the northwestern slopes form a catchment for the Tsavo River, a tributary of the Athi-Galana River. The Athi-Galana River, the second-longest river in Kenya, has a total length of 390 km and drains a basin area of 70,000 km². The river rises as the Athi River and enters the Indian Ocean as the Galana River. Apart from numerous small feeders of the upper Athi River, practically the only tributary is the Tsavo River, emanating from the northeast slopes of Kilimanjaro and the Chyulu Hills. The main permanent water sources in the foothills are springs, the largest of which are the Kisioki, Olchoro, and Nolturesh Springs. Kisioki and Olchoro feed the Rombo River. Noolturesh Springs are the source of the Noolturesch River, which flows north towards the Chyulu Hills. The Chyulu Hills in turn are a major recharge area for several springs emerging at their foot and feeding into the Tsavo and Athi Rivers. One of the largest of these springs is Mzima Springs, which discharges 6 m³/s.

The internal drainage basin of Lake Amboseli to the northwest also depends on water from Kilimanjaro. Mean annual rainfall here is as low as 300 mm. Lake Amboseli (140 km²) is seasonal and receives its surface water supply from the River Namanga, which flows in a west-to-east direction. The Amboseli Basin also receives both surface runoff and groundwater from Mount Kilimanjaro. Groundwater levels below the lake are much higher then those to the west of the lake, indicating a subsurface flow of saline water from the lake into the alluvial deposits of Namanga. Thus ephemeral surface water and a continuous flow of groundwater move in opposite directions in this part of the aquifer (Meijerink et al. 1997). Underground water seepage in the basin maintains a series of freshwater marshes, swamps and springs on the eastern shores of the lake. In addition, there are also seasonal wetlands which fill with water during the long wet season. Scarcity of permanent water is the salient feature of the Amboseli ecosystem's surface hydrology. There are no perennial rivers in the ecosystem, only numerous seasonal streams that flow for short periods during the rains. River flows in the north and northeast portion of the ecosystem are highly seasonal. There is no surface runoff from the Chyulu Hills: rainfall soaks into the porous volcanic soils almost on impact. There are also no permanent streams coming from the Kilimanjaro slopes or the catchment of Namanga Hill to the west.

2.3 Groundwater hydrology, recharge and yield

It has long been assumed that most recharge of the springs comes from Kilimanjaro, but the recharge area and its mechanisms are not very well known. Several studies (URT 1977; Itzoki 1977; Perzyna 1994; NORPLAN 1995; Meijerink et al. 1997; Rohr, 2003) have attempted to understand hydrological processes in the area better by calculating a water balance that includes both recharge and discharge areas.

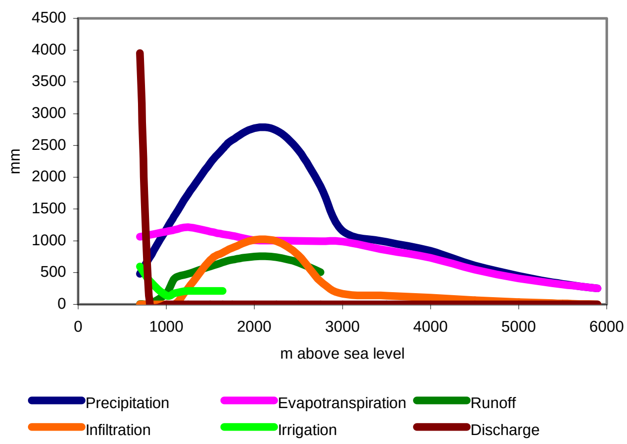
Rohr / Killingtveit (Rohr 2003; Rohr / Killingtveit 2003) attempted to make a water balance for part of the Kikuletwa Basin on the southwestern slopes of Kilimanjaro and to develop a hydrological model for predicting the effects of changes in land and water use. The role of springs and their contribution to river flow was considered of central importance. Since it is not possible to determine groundwater recharge directly, it was necessary to measure precipitation, evaporation and river flow and to determine infiltration and groundwater recharge as the rest component in the water balance.

Such measurements are complicated by the fact that all hydrological processes vary widely with changes in elevation. Results of these water balance calculations are given in figure 3. Water balance models show that surface runoff occurs mainly from the forest zone, with high precipitation and up to an altitude of ca. 2,750 m asl. Above this elevation, all precipitation either evaporates or infiltrates and recharges the groundwater. Maximum groundwater recharge was found at an altitude of 2,000 m, where more than 1,000 mm/year infiltrates and recharges the regional groundwater storage system. In comparison, groundwater recharge is negligible above 5,000 m and is also insignificant below 1,100 m. Most groundwater recharge therefore seems to occur in the forest zone between 1,500 m asl and 3,000 m asl. Contrary to common belief, the snow cap's contribution is absolutely insignificant, and the amount of precipitation here is so small that most of it evaporates.

Using this data, a model for the recharge of the entire Kikuletwa Basin was set up. The computed average groundwater recharge for the upstream area of 1,780 km^2 was found to be 15.6 m^3/s, or 492 million m^3/year.

Meijerink & van Wijngaarden (1997) studied the groundwater hydrology of the Amboseli basin. The two major spring zones there sustain some 20 km^2 of swamps and 16 km^2 of wet grasslands. A 7.5 m rise in the groundwater table since the 1960s and the recent expansion of one of the swamps has been a cause of concern to the management of Amboseli National Park because of changes induced in the vegetation (dying woodland) and potentially negative effects on tourism. A water balance model and 2-dimensional groundwater flow models were used in an attempt to assess possible changes in recharge to the basin. On this basis, it was concluded that the total groundwater catchment area upstream of the swamps is approximately 750 km². On the basis of evapotranspiration of the permanently wet swamp areas, a maximum recharge of 60 million m³ was calculated, i.e. about 14 % of total annual rainfall. The results showed that the recharge zone starts roughly above 1,450 m asl. Using long-term climate data, the authors concluded that spring flows are governed by rainfall patterns on the northwestern slopes of Kilimanjaro, where little change in land use has taken place. The rise in groundwater may have two additional causes: more runoff may reach the lake due to overgrazing in large parts of the Namanga catchment, and longer periods of inundation may have

Figure 3: Groundwater recharge and water balance along an altitudinal gradient on the southern slopes of Kilimanjaro



P = Precipitation, E = Evapotranspiration, R = Runoff, I = Infiltration, IR = Irrigation, D = Discharge

Source: Rohr (2003)

caused the groundwater level to rise. Tectonic movements may also play a role.

In an earlier study, Isozaki et al. (1977) studied the hydrogeology of the central southern slopes of Kilimanjaro in the so-called Kahe-Miwaleni groundwater basin. This study was conducted as part of a feasibility study for the development of irrigation in this area, which is variously also referred to as the Kahe Plains or the Lower Moshi Plains. This is the most intensively used aquifer within the Kilimanjaro Aquifer system. One of the major groundwater abstractors is the Tanzanian Planting Corporation (TPC) whose sugar cane plantation covers ca. 16 million m^3/year. The aquifer includes major springs at Miwaleni, which have a discharge of 120 million m^3/year and feed into the Ruvu tributary of Pangani River. The area has a basin structure and is filled by alluvium deposits. It is surrounded by faults or precambrian basement rocks. A geological map of this section of the aquifer was shown above in Figure 3. Recharge of the catchment, which is approximately 350 km^2, was estimated on the basis of a water balance approach to be 300 million m^3/year. Of this, 120 million m^3/a are discharged at Miwaleni Springs and 16 million m^3/year were abstracted by TPC. It was concluded that abstactions in the order of another 50 million m^3/a could be developed, taking hydrogeological restrictions into account.

Lake Chala lies in a small volcanic crater on Mount Kilimanjaro's south-eastern slopes. It is between 85 and 90 m deep, has a surface area of 3.5 km^2, and contains between 300–350 million m^3 of water (Payne 1970). The feasibility of using water from Lake Chala for expansion of the Taveta Irrigation Scheme in Kenya was considered in 1962. In this context, Payne (1970) conducted isotope investigations to study the relationship of the lake to the springs in the area and the turnover time of the lake water. Over the five-year study period, mean annual subsurface inflow and outflow were estimated to be 12.5 million m^3 and 8.2 million m^3 respectively. The study also attempted to clarify the relation of Lake Chala to the springs feeding the Lumi River. It was concluded that none of the springs derive a major part of their discharge from Lake Chala (6 % at most). It was postulated that there might be an outflow to Little Lumi Spring above a certain lake water level.

The alluvium deposits of the Kahe Miwaleni Basin, chiefly composed of sand, gravel, clay and calcerous deposits, are high-yielding aquifers. The

22 boreholes analysed by Isozaki et al. (1977) had yields ranging between 100–765 m^3/h. Besides the Kahe Miwaleni Basin, the Sanya Plains on the southwest are reported to have boreholes with yields of 10 m^3/h to 50 m^3/h. Msindai (2004) has reported on a hydrogeological evaluation of groundwater resources in the Kilimanjaro Region. The methods used included an evaluation of topographical and geological maps, satellite imagery, and an analysis of data from 142 boreholes. With respect to these boreholes, data was available on well locations, drilling depths, water strikes, static water levels, yields, drawdown, and water chemistry. The results showed that the Kilimanjaro Region can be zoned into three hydro-geological areas: volcanic, metamorphic, and unconsolidated sediments characterised by three porosities: channel, joint/saprolite, and interstitial. The highest-yielding boreholes (500 m^3/h) were found in the sediments at the base of Kilimanjaro and in the Kahe-Miwaleni Plains. Average yields are lower, as is shown in table 1.

Boreholes in the Taveta Division have been drilled into the volcanic aquifer system, which is characterized by a high groundwater potential due to high permeability of the pyroclastic formations and storage at the volcanic/basement interface (ESF 2005). These boreholes have been drilled to depths of 15–68 m below the surface. Water is found at levels between 13–61 m, with water rest levels between 13–35 m and yields of 10–23.79 m^3/h. Groundwater tables in some areas are to be found at very shallow depths of 0.5–2 m below surface. This is also the range at which most shallow wells exist and is prevalent where calcareous ruffaceous grits underlie the area. The formation is porous from the surface down to about 10–20 m below the surface, and shallow ground water is stored within this range. Below about 20 m, the calcareous formation becomes impervious, thus preventing percolation of the water into deeper aquifers.

Groundwater is also an important water source on the plains on the northern slopes in Loitokitok Division. It is available from springs, shallow wells and boreholes. Most of the wells are in dry river beds. The depth of shallow wells varies between 3–30 m. The average depth of the boreholes is 80 m, but water has sometimes been found only at a depth of 250 m (Rutten 2005).

Table 1:	**Groundwater parameters for water resource planning for the Kilimanjaro region**			
	Mean static water level (m)	**Mean yield (m^3/h)**	**Mean drawdown (m)**	**Recom-mended drilling depth (m)**
Volcanic	42	15	9	50–60
Metamorphic	33	10	13	65–85
Sediments	12	28	10	10–25
Source: Msindai (2004)				

3 Groundwater use patterns

3.1 Administrative units, population, and land use

The Kilimanjaro Aquifer not only cuts across the national border: it also spans several regions and districts. Mount Kilimanjaro itself is within the Kilimanjaro Region, which consists of six administrative districts, four of which are within the Kilimanjaro Aquifer. The aquifer covers approximately the following administrative divisions: the urban centre of Moshi (Moshi Urban) and Moshi Rural on the southern slopes, Hai District on the western slopes and Rombo District on the eastern slopes. Towards the west on the slopes of Mount Meru is the urban centre of Arusha, which is the second largest city in Tanzania, and northward towards the Kenyan border lie parts of the Monduli and the Arumeru District, both within Arusha Region. On the Kenyan side, the area is in the Loitokitok Division of Kajiado District and in the Taveta Division of Taita District.

Population in the basin is approximately 2.05 million. Population growth rates are currently estimated at 4.0 % in Arusha Region and 1.6 % in Kilimanjaro Region. The population growth rate in Taita-Taveta in Kenya is estimated at 1.7 %. It is widely held that there is much migration within the basin from the overpopulated highland areas to the lowlands as people move in search of land (Lein 2002). Nevertheless, the overall population increase over the past 14 years (since the 1988 census) has been greater in highland than lowland areas of the basin.

Settlement patterns reflect uneven environmental conditions in the area. Around 90 % of the population lives in the highland areas. This settlement concentration yields population densities of up to 900 people per square km on Mount Kilimanjaro (IUCN 2003). In contrast, the dry lowland area exhibits substantially lower population densities. Historically, the economies of the basins have reflected the divergent environmental conditions. The lowland plains support pastoralists, while the higher areas on Mount Kilimanjaro support agriculturalists. With the advent of European colonialism, great swaths of land were transformed for plantation farming, mainly coffee, sugar cane, and sisal. Most of the land in the Kenyan part of the aquifer is semiarid and unsuitable for rain-fed agriculture.

A major expansion of agriculture to the lowlands has occurred over the past 50 years (Soni 2005). This expansion has created a new and distinct group of farmers who have settled in the dry lowlands previously considered unsuitable for permanent settlement due to insufficient rainfall. At the same time, pastoralists have also begun crop farming. Due to the marginality of the lowland farmland's water supply, these farmers are highly vulnerable (Soni 2005). However, population pressure has not only resulted in expansion but also in agricultural intensification and diversification. Basically, therefore, water issues within the Kilimanjaro Aquifer are related to population density and to two key input factors of the farming systems: land and water.

3.2 Groundwater use in the Kilimanjaro region in the Pangani Basin, Tanzania

Quantification of groundwater use in Tanzania is not easy due to lack of data (Mtao 2002). However, some efforts have recently been made to systematically assess groundwater resources in the Pangani River Basin as part of a World Bank-funded river basin management project. An initial groundwater assessment was finalised for Pangani Basin. In addition, a preliminary design for a groundwater monitoring network was drawn up, and geophysical surveys were conducted in two zones of the Kilimanjaro Aquifer (Lower Moshi and Sanya Plains) to locate suitable groundwater monitoring boreholes. Boreholes for monitoring were to be drilled and equipped with data loggers (Rumambo 2002).[1]

According to an evaluation by the Tanzanian Department of Water Resources, there are over 5,000 recorded deep boreholes drilled both as exploratory and production wells throughout Tanzania (Kongola 1999 cited in Mtao 2002). 325 boreholes are recorded within Pangani River Basin. In contrast to other basins in the country, there is significant potential for groundwater resource development in the Pangani Basin. For the Kilimanjaro Region, a total of 287 groundwater extraction points (boreholes and shallow wells) have been identified (Luhumbika 1999 quoted in Rohr 2003). The rate of new boreholes being drilled in Kilimanjaro Region is given as 2 in 2001, 4 in 2002, and 5 in 2005 (URT 2005).[2]

All surface and groundwater extraction in the Pangani River Basin is based on water rights. The Pangani Basin Water Office (PBWO) issues these water rights and maintains a register of all water rights and amounts abstracted. According to this data, about 95 % of the water abstracted in the Pangani River Basin comes from surface water, while the remainder is taken from groundwater resources. 88 % of groundwater use in the Pangani River Basin is for irrigation, 4 % for industry, and 8 % for domestic water supply (Turpie 2005).

The single largest agricultural extractor of groundwater in the Kilimanjaro aquifer system is the Tanzanian Planting Corporation, whose land covers some 17,000 ha, of which ca. 5,000–7,000 ha are under sugar cane, in the Kahe-Miwaleni Basin. Ongoing expansion will result in another 1,200 ha being planted in the Kahe area. Irrigation is a prerequisite for sugar cane cultivation. For the area presently being exploited, the sugar estate derives its water from the Weruweru River via two irrigation canals and from ten boreholes, the latter supplying about 20 % of its requirements. The new area at Kahe will obtain its water from the Miwaleni Springs. Irrigation boreholes supply about 1,700 litres/sec, rivers supply 3,600 litres/sec, and

1 No further information was available for this study concerning both the status of this monitoring programme and that of a European Union and World Bank-funded project of the Water Resources Division entitled "Ground Water Resources Development and Management". The latter project has the aim of creating a hydrogeological map and a groundwater database for planning purposes in Tanzania.

2 These may be only minimum estimates.

Miwaleni Spring supplies 1,700 litres/sec. Sugar cane is irrigated with about 50–70 m^3/ha/day of water, amounting to an estimated total of about 12,000–17,000m^3/ha/year. The Pangani Basin Water Office receives 12.8 million Tanzanian shillings (ca. 12,800 U$) per year for this water (Turpie 2005).

Most water supply schemes in the area rely on springs and surface water sources, while groundwater contribution varies. Moshi urban area has a population of about 145,000. Its urban water facility supplies a total of about 50,000 people with 26,000 m^3 per day (including leakages). This includes commercial and industrial use. This water is supplied from three springs and nine boreholes.

The municipality of Arusha, with 282,000 inhabitants, is located on the slopes of Mount Meru, one of the further recharge areas at the perimeter of the Kilimanjaro aquifer system. Arusha is supplied by groundwater from 13 boreholes into the unconfined Arusha aquifer and by several springs. Overall groundwater abstraction is estimated to be 32,000 m^3/day in the dry season and 44,000 m^3/day during the wet season (Ong'or / Long-can 2007).

The Kilimanjaro region has 402 rural villages, of which 249 are serviced via water schemes. More than 90 % of these schemes rely on springs and river water sources (United Republic of Tanzania 1998). In Moshi Rural District, there are a total of 67 water sources, of which 53 are springs, and feed 30 water schemes that provide gravity-fed piped water. These 53 springs, most of which are surrounded by forest, are protected by the District Council and the local communities. The existing schemes supply 58 % of the rural population. The other 42 % of the population that do not benefit from these supply schemes are mostly found in the lower plains. They rely on shallow wells for water or take water from traditional furrows. In addition, 17 boreholes have been drilled in the lower areas. In Hai District, water is tapped from springs and rivers and flows by gravity, dropping by about 850 m. Most of the sources are located within Kilimanjaro Forest Reserve. Pumping from boreholes is considered as being too expensive an alternative in this district.

3.3 Groundwater use in Loitokitok Division in the Athi River Basin, Kenya

Water is a major limiting factor for cultivation and livestock in the Loitokitok Division and the Amboseli Ecosystem. The demand for water in Kajiado District, of which Loitokitok is a division, is growing rapidly and is estimated to be around 223,000 m³ daily, with some 31,000 m³ for livestock, 8,000 m³ for wildlife, 15,000 m³ for human consumption, and 170,000 m³ for irrigation. Boreholes, natural wells, and springs have a daily maximum potential of 180,000m³, resulting in a daily shortfall of 40,000 m³ (Rutten 2005).

For the Masai pastoralists who inhabit this area, this lack of water is primarily a problem for their herds. The availability of water near the dry season grazing areas is of crucial importance for livestock. During the wet season, the animals (both cattle and wildlife) spread out to make use of new grass and available surface water. But in the dry season they gather near swamps and springs on the slopes of Mount Kilimanjaro and Lake Amboseli.

Early conservation efforts for Amboseli Ecosystem recognised that the Massai herders would either have to have access to reliable water points away from the Park's edge or to the swamps within the Park if the core of today's Amboseli National Park and Biosphere Reserve were to be sustained. In the 1970s, donor-funded efforts to drill boreholes at strategic points well outside the National Park were only partly successful because the boreholes were not subsequently maintained.

Groundwater is an important water source in Loitikiotok Division. The Kenyan Ministry of Water Development's Borehole Register shows that from 1927–1988 a total of 60 boreholes were drilled in the Loitokitok Division, of which only 36 % were still operational in 1988 (Rutten 2005). The rise in borehole numbers since 1970 stems mainly from the fact that Kjiado loosened its status as a “closed” district for settlement at the end of the 1960s. Since 2004, efforts have been made to rehabilitate all community-owned boreholes in a bid to solve some of the water-related health problems in the District.

Irrigation activities in Loitokitok were initiated in the 1950’s. However, it was only with the advent of land adjudication and privatisation in the

1970s that the irrigated land area expanded significantly and cultivation was directed toward commercial purposes. Today Loitokitok Division has 11 group irrigation schemes with a total area of 1,256 ha under irrigation. The irrigation water comes mainly from springs and from swamps which are fed by groundwater. Overutilisation of water resources has led to implement of water rationing regimes. The amount of water from the springs is not adequate to sustain current levels of use in some areas, such as Namalok and the Kimana swamps, and some cultivated fields have been abandoned. The construction of shallow wells has risen explosively: 1,505 wells were counted in 1988. After a project was carried out to fund improvements in traditional well building, the number of shallow wells in Kajiado rose to more than 3000 by the late 1990s, and water drawn from these new sources has boosted small-scale irrigation (Rutten 2005).

Water availability in the Loitokitok Division has also been reduced because of two pipelines which take water directly from the springs at Noolturesch on the slopes of Kilimanjaro. In 1956 a 100 km-long pipeline was built to take water to the Nairobi Mombasa railway line. A second, 262 km-long pipeline, was built in 1992 and was immediately dubbed a white elephant because of its extremely high extraction rates. The main spring source provides some 200 litres/s; however, the Noolturesch pipeline alone takes some 168 litres/s and the old railway pipeline takes 17 litres/s, so that the source is overused. At present the towns of Kajiado, Machakos and Athi are supplied (Rutten 2005).

A further major pipeline takes water from Mzima Springs at the base of Chyulu Hills to Mombasa, ca. 250 km away. The present water demand for Mombasa City and the Coastal Region is 230,000 m³/day for a population of 1.6 million. The total supply to Mombasa and the coastal region from various sources is 124,000 m³/day – a shortfall of 100 000 m³/day. Mombasa's sources of water are essentially surface and groundwater-based. Water from the Mzima Springs provides 35,000 m³/day, or roughly 35 % of the coastal area's drinking water supply.

3.4 Groundwater use in Taveta Division in the Pangani Basin, Kenya

The Kenyan part of the Lake Jipe catchment includes parts of Tsavo West National Park, 43,500 km² of sisal estate, and 19,600 ha of public land set aside for the Lake Jipe Settlement Scheme. Taveta Division is a water-deficient area and is ecologically in the category of arid and semiarid land. Its water supply comes from both surface and groundwater sources. Efforts have been made to sink boreholes and shallow wells, but due to the different levels of groundwater, some are very deep and in effect yield either too little water or water which is saline. In fact, only the boreholes near riverbeds yield enough water of drinking quality. Private companies (sisal estates, hotels), and some ranches and individuals use boreholes and shallow wells as their major source of water. In general, many of these water sources have been abandoned or have gone dry due to operation and maintenance problems (ESF 2005). The main water supply for irrigation is from the springs feeding the Lumi River.

Currently it is estimated that 3,500 ha are under irrigation in Taveta Division (Huggins 2002). The Division can be divided into two sections. The southern section towards Lake Jipe has a high water table and is swampy in places. The area is mainly fed by many small springs, and poor drainage is an obstacle to agricultural production. The northern section toward Loitokitok, on the other hand, is drier. Because of water availability and salinisation problems, there was a demise of several irrigation schemes. On the other side, many other schemes have been expanded. In addition, there are a significant number of farmers in the area who irrigate private plots with water pumped from shallow wells. Many of them use pipe systems but are reportedly switching to open furrow systems. The last water availability assessment study for Taveta was undertaken in 1993. At that time, 31 irrigation schemes were either proposed or had actually been implemented. The assessment concluded that of these 31 schemes, only 5 would have an adequate supply of water, while 16 would experience water shortages even in average years. Water availability is therefore a key factor limiting the expansion of irrigation (Huggins 2002).

4 Transboundary implications

4.1 Conflict over extraction: the Lake Chala and Lake Jipe hotspot

Local transboundary conflicts have emerged over groundwater extraction in the Lumi River Basin, which feeds Lake Jipe, and the Rau River, which in turn feeds the Pangani River. Two lakes in this area are crossed by the international border: Lake Jipe and Lake Chala. These lakes feature prominently in the irrigation and water planning of Kenya's Taveta District, which is located mainly in the downstream section of the aquifer but in the upstream section of the emanating rivers.

The idea of irrigating the land around Taveta for farming dates as far back as 1931, when irrigation schemes were proposed with the dual aim of putting the spring water of Njoro Kubwa into productive use and draining local swamps by diverting dry season flows. These plans had a detrimental effect on the Lake Jipe ecosystem due to a reduction of water inflow (Ndetei 2005; ESF 2005). Several projects are currently addressing this issue with the overall goal of recharging the (rapidly drying) Lake Jipe and improving the livelihood of the adjacent communities while also enhancing conservation of an important transboundary wetland ecosystem in Kenya and Tanzania. Under the leadership of the East African Wildlife Society and with financing from United Nations Development Program/Global Environment Facility (UNDP/GEF), the waters and biodiversity of the Lake Jipe region are to be conserved by desilting the bed of the Lumi River, blocking current diversion channels, restoring Njoro Springs, and promoting improved irrigation and fishing methods. The “Greater Pangani Basin Cross-border Dialogue” in Kenya and Tanzania, which will be described in greater detail below, aims at the development of an integrated management plan for Lake Jipe, Lake Chala and the Umba River and the promotion of transboundary dialogue in this regard.

Lake Jipe is neighboured to the west by Lake Chala. Lake Chala is fed by groundwater and has no surface outflow. The feasibility of using water from Lake Chala for expansion of the Taveta Irrigation Scheme in Kenya was already considered in 1962 (Payne 1970). The lake's water quality is good, and is therefore also regarded as a further source of supply for Kenya’s coastal urban centres (IUCN 2003). The lake's elevated position means that its water could be conveyed by gravity. Future extraction rates of 7 million m^3/year have been projected. More recently, the Njoro Kubwa Canal Project has been suggested as a means of transporting water by pipeline from Lake Chala to the lower zones for irrigation.

This has led to disagreement between Tanzania and Kenya (Guardian, 2006-04-25). According to the then Tanzanian Minister for Infrastructure Development, who is also a Member of Parliament for Rombo, Tanzania is comfortable neither with the proposal to pipe water from Lake Chala nor with other projects to develop groundwater resources in the lake's vicinity, since they would have detrimental effects on river flow into Lake Jipe and on the groundwater system connected with Lake Chala. The issue has been taken up by the National Assembly of Tanzania, but further action is pending.

The development of a consultation, joint planning and conflict resolution mechanism related to water use in general and including groundwater abstraction with cross border impacts is thus a relevant issue for transboundary cooperation between Tanzania and Kenya to be addressed

4.2 Conjunctive development of groundwater and surface water resources

All river basins which are connected to the Kilimanjaro Aquifer are characterised by water shortages. Water resources in the Pangani River Basin have become scarce and appear to be over-apportioned, to the extent that not all urban and rural water requirements are being met. This has led to a deficit in water available in the basin as demonstrated by the water balance of inflows into and outflows from the Nyumba ya Mungu Reservoir, showing a deficit of 2.2 m^3/sec. Uncoordinated planning, inadequate water resource data, and inefficient water use have resulted in conflicts among different water using sectors. These conflicts are bound to increase in future if management practices remain the same and demand for water rises (Turpie et al. 2005). The same problem applies to the Athi River basin in Kenya, which has pronounced water deficits in the coastal areas.

Groundwater resources in all these basins have not been very intensively developed to date. Thus the current need for restrictive groundwater resources management is limited to various local hotspots. However, effective planning and sustainable implementation of groundwater development is of general concern (Giordano 2005). Precise information on utilisable groundwater resources is required. Because of hydrological interrelationships, new water sources can only partially be used to supplement surface water extraction. Water resource planning thus needs sound and unified information on the water balance and interactions of aquifer and river systems according to hydrological units (Puri 2001). Establishing such a joint information basis for planning and monitoring purposes is a second potential issue for transboundary cooperation.

4.3 Groundwater recharge and catchment forest conservation

As already described, the forests of Kilimanjaro constitute the major groundwater recharge zone. This zone is located entirely in Tanzania. Changes in recharge are thus bound to have a transboundary impact on discharge zones in Kenya.

A comparison of two satellite images from 1976 and 2000, along with an aerial survey from 2001 (Lamprechts et al. 2001), reveals the enormous changes which have taken place in the forest zone of Kilimanjaro. The upper forest line has retreated several hundred meters downward, mainly due to frequent forest fires (Hemp 2005). This has caused a loss of 13,000 ha of forest. Since fog and cloud interception by the forests plays a key role in water regulation, the replacement of the fog-intercepting forest belt by low-lying shrubs has already seriously affected runoff and recharge. It is estimated that water runoff has dropped by 58.4 million m^3/a since 1976 (Agrawal et al. 2003). In addition, large tracts of indigenous forests on the northwestern and northern slopes have been converted into tree plantations with fast-growing species. On the northwestern slopes, the expansion of forest plantations has reduced the indigenous forest belt to a width of less then one kilometre. Most of the clear-cut areas have not been replanted, even though this is required by rotation management. Additionally, trees are disappearing at the lower forest edge due to the demand for land, timber and wood for fuel. Fortunately, encroachment is contained to some extent by the fact that the remaining forest is under protection as part of the Kilimanjaro Forest Reserve and National Park. Nevertheless, that part of Kilimanjaro's forest in the so-called "half mile strip" intended for community forestry at the edge of this forest reserve shrank by 4,100 ha between 1952 and 1982.

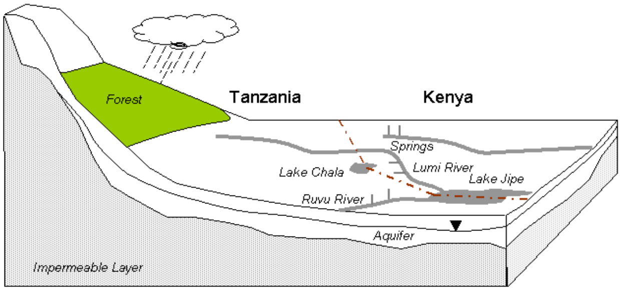
In summary, recent surveys have shown that the forest belt has shrunk on both its upper and lower borders. This has a negative effect on surface water runoff and groundwater recharge, and therefore a heavy impact on water availability for the Amboseli ecosystem and for agricultural livelihoods in the Loitokitok area in Kenya. A third issue for cross-border cooperation is therefore the development of cross-border mechanisms to share the burdens of maintaining or improving the catchment functions of the Kilimanjaro forests.

4.4 Analysis of the cooperation problem

It is clear from the description of the hydrogeology, that the so called Kilimanjaro Aquifer is at least partially a transboundary aquifer system. The aquifers are unconfined, and virtually all recharge occurs in Tanzania on the forested higher slopes of Kilimanjaro. The water flows underground from recharge areas in Tanzania into Kenya, where it emerges as springs. The aquifers are also hydraulically linked to rivers which (a) flow across the border from Tanzania to Kenya or (b) emanate from springs on the Kenyan side of the border. There is therefore a clear upstream-downstream constellation. It follows that extraction, pollution and recharge in Tanzania influence groundwater availability in Kenya. An additional complication in the Lake Chala area is that each of the two countries is both upstream and downstream at various locations: the upstream groundwater recharge area is in Tanzania, which is also the downstream riparian of rivers which are fed by midstream groundwater discharge in Kenya. Thus Kenya is partly in the position of an upstream user. In addition, Lake Chala straddles the international border and is a surface water body that is fed solely by groundwater (cf. figure 4).

Eckstein and Eckstein (2005, compare also Scheumann and Herrfahrdt-Pähle in this volume) have developed six conceptual types of transboundary aquifer constellations as paradigms for the application of international law relating to groundwater. The types show the potential transboundary implications of groundwater use of two riparian countries sharing a single aquifer. The Kilimanjaro Aquifer essentially ressembles their Types B and C, which describe unconfined aquifers intersected by an international border and linked hydraulically by a transboundary (Type B) or domestic

Figure 4: Schematic model of the transboundary constellation of the Kilimanjaro Aquifer in the Lake Chala Basin



Source: Author

(Type C) river. In these two types, gradients explain the transboundary consequences in that water from the aquifer and the river flows downslope from one country to the other, so that transboundary effects can result from reduced recharge, overuse, or pollution in the upslope state. Depending on the proximity of users to the border between the two countries, transboundary consequences may also affect the upslope state.

5 Institutional arrangements for groundwater management and transboundary cooperation

5.1 Institutional arrangements in Tanzania

The regulatory and institutional framework for water resources management is provided for under The Water Utilisation Act of 1974. The Act sets conditions for the use of water and provides for a Principal Water Officer who is to be responsible for setting policy and allocating water rights at the national level. For designated water drainage basins with established Basin Water Offices, the responsibilities are under a Basin Water Officer. Tanzania has adopted a National Water Policy (URT 2002) which has led to the development of a comprehensive framework for water resource development and management, as documented in the National Water Resources Strategy (URT 2006). This National Water Policy has not yet been incorporated into legislation, since all legislation in this regard is currently being revised. Changes in organisational setups have already taken place. While water resources management is retained as core government function and is being devolved to operating levels at basin and catchment scale, water supply, after being separated from water resources management functions, is operated by autonomous to semi-autonomous water supply and sewerage authorities under respective boards. Groundwater development is now being carried out by the private sector, while the government is providing incentives for promoting such development.

The Pangani Basin Water Office (PBWO), established in 1991, administers the Tanzanian part of the Pangani River Basin. The PBWO reports to the Pangani Basin Water Board (PBWB), which consists of ten members appointed by the Minister for Water and Livestock Development. The board members are presently drawn from institutions that represent the government, the private sector, and non-governmental organisations. The Pangani Basin Water Office is the board's secretariat. The PBWO's primary activities relate to the allocation of water rights, pollution monitoring and control, and the supervision of both surface water and groundwater resources. This has been broadened by the National Water Policy (2002) to include coordination and planning, conflict resolution, and cooperation with other sectors and stakeholders. The PBWO is also expected to deal with technical transboundary issues within the basin. The PBWO has an advisory role, and the Water Officer, who directs the PBWO, is not bound by its advice. The Office has very little regulatory, sanctioning, or executive power. In fact, there are no administrative levels below the PBWO. Under its current institutional setup, the PBWO has an informal agreement with the Regional Administrations' Regional Hydrological Officers. The PBWO encourages the formation of water user associations; typically, water can be used for irrigation only after applications for this have been approved by a WUA. The WUAs are also expected to collect fees from water users.

5.2 Institutional arrangements in Kenya

The Kenyan section of the Pangani and Athi River Basins is managed by three government authorities. These are the Coast Development Authority, the Tana and Athi River Development Authority, and the Water Resources Management Authority for the Athi River Basin. The two development authorities were established as state corporations to coordinate integrated regional development, including the development of water resources. In addition to the development authorities, the Athi River Water Resources Management Authority was recently established following a water sector reform.

The new Water Act of 2002 established a new institutional framework for water resources management. The primary public sector institution is the Water Resources Management Authority, which has responsibility for the management of Kenya’s water resources. Through regional offices in six river basins, the WRMA will monitor water resources and administer water resource regulation, e.g. permits for water extraction and discharge. Sectoral coordination and participation in decision-making will be achieved through Catchment Area Advisory Committees (CAAC) which will be established in each of the six river basins to advise the WRMA.

At the local level, Water Resources User Associations (WRUA) will be established to ensure that water users participate in the decision-making process concerning management of water resources in sub-catchment areas. The WRUAs will have an important role in preventing conflicts over water and ensuring that improved management will benefit all segments of the society.

In a transitional phase, the River Development Authorities will remain in place, and the present Water Resources Authorities, Local Water Authorities, and Water Apportionment Board will continue to function until their functions are transferred to the new WRMA.

5.3 Transboundary cooperation on water issues

Kenya and Tanzania have concluded a number of agreements related to water use and transboundary cooperation in the management of natural resources. Although no special institution for joint management is in place regarding the Kilimanjaro Aquifer, there is an ongoing cross- border dialogue which touches on groundwater issues.

The two countries are members of the East African Community (EAC). The governments of Kenya and Tanzania have recognized their mutual dependency on shared natural resources and the need for equitable cooperation to mange them, when they agreed to the establishment of the East African Community. In order to further the aims of the treaty which established that Community, the partner states recently drew up a Protocol for Environment and Natural Resources Management. In order to implement cooperative management of shared water resources, the partner states and the EAC must begin to establish cross-border management mechanisms as authorized by Article 13 of the Protocol. In 2005 the EAC established further guidelines for strategic environmental assessments of shared ecosystems in East Africa. These strategic environmental assessments are to be used proactively to identify opportunities and constraints that the environment places on development.

Transboundary cooperation also features in the national water policies of Kenya and Tanzania. The principles of equitable and reasonable use are to guide cooperative approaches in the management of shared water resources. For example, the official Tanzanian strategy for transboundary waters is to establish in collaboration with riparian states mechanisms for acquiring and exchange of transboundary water resources related data and to foster regional cooperation to develop a framework for the management and utilisation of transboundary water resources were there is a specific need for such cooperation.

Several initiatives exist for the management of transboundary waters in the region, including three UNDP/GEF-supported lake basin management projects, along with the Nile Basin Initiative (NBI) and various Southern African Development Community (SADC)-supported programmes. Despite difficulties involved in building consensus among the riparian nations on cooperative management of shared water bodies, Tanzania and Kenya have taken major steps towards joint management of many of their shared lakes and rivers. One consequence of this was the establishment of the Lake Victoria Basin Commission (LVBC).

Within the Lake Victoria Basin, an initiative is also under way to address water shortage and management issues in the Mara River Basin. The Mara River is shared by Kenya and Tanzania. It runs through the Masai Mara Game Reserve on the Kenyan side and the Serengeti National Park on the Tanzanian side, both of which have global conservation significance and are of great economic importance. The initiative involves a wide range of stakeholders, including local communities, decision-makers, and water users and managers and aims to develop an integral, cross-border water resource management strategy. An interim Regional Mara River Water Users' Secretariat has been formed to lead the formation of a transboundary Water Users Association in Kenya and Tanzania. It is intended to develop a transboundary agreement and management mechanism.

Of special relevance to the Kilimanjaro Aquifer is the cross-border dialogue between Kenya and Tanzania concerning the Pangani Basin. This stems from efforts to conserve Lake Jipe, which suffers from receding water levels. In Kenya, the Coast Development Authority (CDA) has the mandate to coordinate developments in the Pangani Basin. In 1993 the CDA was given the task of working with a similarly mandated Tanzanian counterpart to develop a comprehensive management plan for the Kenyan part of the basin. In 1994 the CDA and Pangani Basin Water Office (PBWO) decided to carry out a joint assessment of the water requirements of the Lake Jipe catchment. This assessment was completed in 1996. In 1999 a joint planning workshop was carried out to facilitate the development of mechanisms for collaborative management. In a second workshop held in 2004, the management of the Lake Chala, Lake Jipe and the Umba River catchments were prioritised for joint action. The resulting initiative under the name of "Greater Pangani Basin Cross-border Dialogue" is jointly managed by the PBWO and the CDA with support from Deutsche

Gesellschaft für Technische Zusammenarbeit (GTZ) and InWent. The initiative aims to develop an integrated management plan and to promote the dialogue regarding Lake Jipe, Lake Chala, and the Umba River. Although the issues affecting water management for Lake Chala, Lake Jipe and the Lumi River are primarily related to surface water, they are also related to groundwater flows, as already shown. It was proposed that the PBWO and the CDA should facilitate the dialogue process, with each acting as a focal point within its respective country. In a series of consultations between CDA and PBWO, key documents and information were identified and exchanged. Proposals were made for possible milestones, including an official agreement and the establishment of a coordinating secretariat. The dialogue process is currently continuing.

Some other cross-border initiatives for transboundary management of natural resources in the Kilimanjaro area do not focus primarily on water. One such initiative is the East Africa Cross-Border Biodiversity Project which is funded by UNDP/GEF (Rodgers 2002) and focuses on catchment forests. Another is the Kilimanjaro Heartland's initiative of the African Wildlife Foundation (AWF 2002) which focuses on the Amboseli Ecosystem.

6 Prospects for transboundary cooperation

Both the establishment of the East African Community and the ongoing water sector reform processes in the two countries are provide for a conducive setting for transboundary cooperation. Experience in the management of transboundary water resources is being gathered within the framework of several initiatives. As the Kilimanjaro Aquifer is to a large extent within the responsibility of the authorities involved in the "Greater Pangani Basin Dialogue" and working contacts are established and experiences with transboundary water management are being made, it can be regarded as probable that formal and informal collaboration on groundwater issues will be intensified, as soon as the need becomes more pressing. Experience gained from other initiatives in the region indicates that the best way to ensure transboundary management of water resources is to engage all riparian nations at both the national and regional levels while also focusing on issues affecting the livelihoods of local residents.

To date, groundwater extraction is a conflicting issue only in the context of the local water management problems in the Lake Chala and Lake Jipe basins. This is to some extent being addressed by the Greater Pangani Basin Dialogue. This dialogue has not yet acquired the status of a formalised transboundary management mechanism or agreement. As the water sector reforms proceed, transboundary water user associations and catchment committees may become an option. These are currently being pioneered in the Mara River Basin. Both water user associations and catchment commitees are elements of both the Kenyan and Tanzanian institutional setup,. A formalised mechanism of consultation for planning and for the resolution of conflicts may also be helpful in addressing general water water resource problems, including groundwater. There seems to be no need at present for a specific groundwater cooperation mechanism, since this can be dealt with in the context of water resource management in general.

As the surface water resources are drawing to a closure, groundwater development will become more important. Since groundwater and surface water flows are interlinked, the conjunctive management of groundwater and surface water will need to be given more attention. The prerequisites for an assessment of available groundwater resources will be a unified and consistent body of knowledge regarding the extent and nature of the aquifers, their recharge and discharge mechanisms, use rates, and the interrelationships with river flows and lake water levels (Puri 2001). Reliable data is crucial for cooperation in developing the Kilimanjaro Aquifer, and building up this body of data is in itself an important issue for transboundary cooperation.

A further issue for transboundary cooperation is to develop a cross-border strategy for maintaining the catchment function of Kilimanjaro's forests, which are the recharge areas for aquifers on the lower slopes and in the surrounding plains. Dwindling water resources in the Pangani River Basin are partly attributed to catchment forest degradation. The conservation of catchment forests is high on the political agendas in both Tanzania and Kenya. Different approaches to build more direct linkages between water use and the protection of catchment areas are being discussed. For example, even though the Tanzanian Water Act does not provide for catchment protection fees, the new water policy proposes that such a fee should be put in place (Turpie 2005). In the same line, it was proposed in the Pangani River Management Plan (NORPLAN 1995), that the Pangani Basin Water should contribute financially to forest management from funds from the collected water user fees. This payment would vary with the "delivery" of base flows of adequate quantity and quality from the catchments forests, and would thus create an incentive for the custodians of catchment forests to protect and manage these forest areas accordingly. Such, or any other suitable mechanism for the protection of catchment functions across a national boundary could, for example, be implemented in the context of transboundary water user associations and catchment committees.

Box 1: German development cooperation projects related to the Kilimanjaro Aquifer

- Kreditanstalt für Wiederaufbau (KfW) is funding three water supply projects in Tanzania's Kilimanjaro Region: urban water supply in Arusha and Moshi, rural water supply in Hai District, and rural water supply in East Kilimanjaro.
- Internationale Weiterbildung und Entwicklung (Inwent) & GTZ are supporting the "Greater Pangani Basin" Cross-border Dialogue on water resources management.
- GTZ is providing support to the Tanzanian and Kenyan Water Sector Reform Programme.
- Deutscher Entwicklungsdienst (DED) has started cooperation with the Global Environmental Facility (UNDP/GEF) Small Grants Programme in Kenya by assisting the programme with technical advisors. Projects related to the restoration of Lake Jipe are being supervised.

Source: Author

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The Lake Chad Basin Aquifer System

A case study for the research project
"Transboundary groundwater management in Africa"

Marianne Alker

Preface

I wish to thank Dr. Segun Adelana (Department of Earth Sciences (Groundwater Group), University of the Western Cape, South Africa) for his valuable input as well as Dr. Sara Vassolo (BGR), Dr. Klaus Schelkes (BGR), Dr. Ralf Klingbeil (BGR), Dr. Wilhelm Struckmeier (BGR) and Klaus Jacobi (AHT Group AG Consultant to the GTZ / Lake Chad Basin Commission Project) for sharing their knowledge of the Lake Chad Basin with me.

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1 Introduction

The Lake Chad Basin Aquifer System was chosen as one of five illustrative studies for the research project "Transboundary Groundwater Management in Africa" for two reasons: First, groundwater dependency has been increasing along with a growing freshwater shortage in the basin.[3] Second, an intergovernmental (i.e. transboundary) institution, the Lake Chad Basin Commission (LCBC) assumes responsibilities for regional cooperation over transboundary aquifers, since it is in charge of the management of all water resources in the basin.

Despite the urgent need for integrated water management which makes Lake Chad a prominent case within the international scientific and practitioner water community, only limited, basic information on its aquifer system seems to exist. Most of the numerous publications contain variations of the following generalized statement: *"… groundwater is considered to be abundant, which does not mean that it is always easy to exploit"* (compare LCBC / WMO 2005, 11; Adenle 2002; UNEP 2004, 50). In summary, knowledge of the underlying aquifers and the hydrodynamics of groundwater flow in the Lake Chad Basin as a whole are still rather limited.

Nevertheless, the present research study gives a brief overview of the major characteristics of the aquifer system, use patterns in the riparian countries, the incentives for and barriers to cooperation, and an analysis of achievements so far and challenges ahead for interriparian cooperation. Finally, the study will present some initial considerations concerning strategic options for German development cooperation.

3 The GIWA ranked freshwater shortages as the most important concern in the basin and the source of many other development concerns (UNEP 2004).

2 Characteristics of the Lake Chad Basin Aquifers

This chapter provides information on general geographic, climatic and hydrological conditions in the Lake Chad Basin. It then elaborates in greater detail on groundwater quantity and quality as well as on recharge to and discharge from the aquifers.

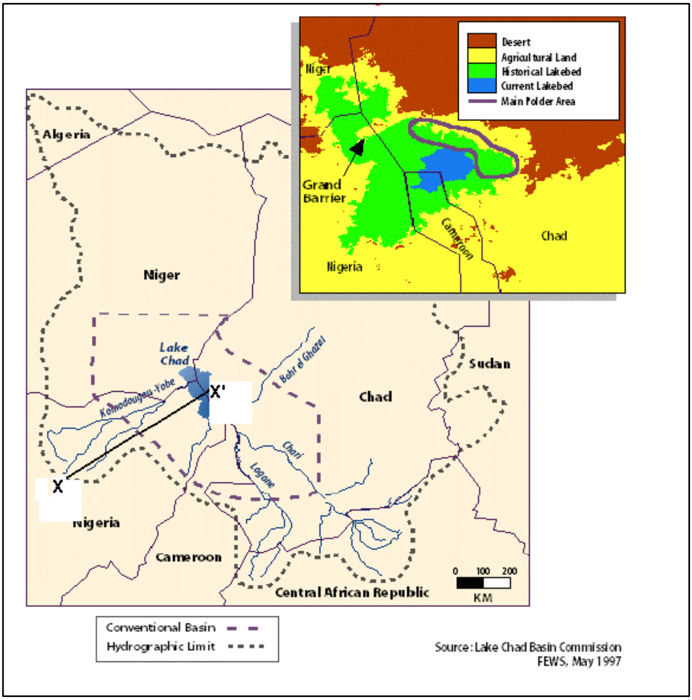
Box 1: The Lake Chad Basin subsystems
The Chari-Logone subsystem The Chari-Logone subsystem covers an area of approximately 650,000 km². The Chari River has a length of 1,400 km. Riparians of the subsystem are Chad, Cameroon, the Central African Republic, and Nigeria. The Waza-Logone floodplains are situated in the sub-basin. **The Yedseram and Ngadda subsystem** The Yedseram and Ngadda Rivers originate in northern Cameroon and lose most of their water in flood plains and swamps, so that the rivers do not maintain a flow of water into Lake Chad. The Alau dam is southeast of Maiduguri (Nigeria). Riparians of this subsystem are Cameroon and Nigeria. **The Komadugu-Yobe subsystem** The Komadugu-Yobe subsystem covers an area of 148,000 km² but contributes only 2.5 % of total riverine inflow into Lake Chad. The Komadugu-Yobe River constitutes the border between Niger and Nigeria over its final 160 km and is the only perennial river flowing into the northern pool of Lake Chad. The tributaries of the river system and the upstream area are located on Nigerian territory. The Hadejian-Nguru wetlands are part of the basin in Nigeria. The wetlands extend over an area of approx. 6,000 km². The dry parts of the floodplains in particular provide a variety of resources for the population and regarding biodiversity. The Hadejia River is controlled by three large dams. Due to impoundment at these reservoirs and siltation and blockage by invasive weeds, the river has not been able to establish a natural regime through the downstream Yobe River in Nigeria and Niger for 20 years.

Box 1 continued
Water requirements in the Hadejia River Basin already exceed available water resources at times (Bdilaya et al. 1999 cited in UNEP 2004, 55). An IUCN study estimated that potential water requirements (not taking into account evaporation losses) are at least 2.6 times greater than the mean available surface water resources. The impact on groundwater resources is not mentioned (GEF n.Y., 13). In the Jama'are and Yobe River Basins, available water resources presently meet requirements. However, the realization of planned projects could result in water requirements of 1.8 times more than the water resources available in a mean year for the Jama'are River Basin (Bdilaya et al. 1999 cited in GEF n.Y., 13). Again, the impact in terms of loss of potential recharge and withdrawal from storage has not yet been addressed. The amount and rate of extraction from agricultural tube-wells due to public and individual agricultural development in the fadama areas is increasing, thus reducing inflows and aquifer recharge (GEF n. Y., 13–14). **Lake Fitri** Lake Fitri is located in Chad. The surface area is 300 km². The sahelian lake is fed by inflow from seasonal rivers and rainfall. Unlike Lake Chad, Lake Fitri has not been negatively affected by significant hydrological changes. **North of Lake Chad** Riparians of the large dry area of the Lake Chad Basin are Chad and part of Algeria. There are virtually no surface flows from the north into the lake. **East of Lake Chad** The eastern part of the basin is on Sudanese territory. Here the seasonal wadis Wadi Kaya and Wadi Azum flow into the Chari River. The alluvial aquifers of these wadis have the potential to provide about 0.08 km^3/a of excellent quality freshwater.
Source: UNEP 2004, 21–23

2.1 Geographical characteristics and climatic zones

The Lake Chad Drainage Basin, covering 2,434,000 km² or an estimated 8 % of total African land surface (UNEP 2004, 13), is shared by the following countries: Chad (45.5 %), Niger (28 %), the Central African Republic (CAR) (9 %), Nigeria (7 %), Algeria (4 %), Sudan (4 %), Cameroon (2 %) and Libya (0.5 %). With more than half of their respective territories in the Lake Chad Basin, Chad and Niger are the riparian countries with the largest territorial share. However, three quarters of the lake's water come from the CAR (which does not border the lake) and from Cameroon (which shares only a small part of it) (Wirkus / Böge, 2006, 64).

Figure 1: Drainage and Conventional Basin of Lake Chad



Source: Lake Chad Basin Commission 1997, taken from Adelana 2006.

The geographical limits of the Lake Chad Basin are constituted by the so-called Conventional Basin, founded under the Fort Lamy Convention in 1964. This Conventional Basin is considerably smaller than the drainage basin of Lake Chad. The Conventional Basin was extended in 1994 to include the upstream part of the Komadugu-Yobe River Basin (compare box 1). After 2000, when Sudan was granted membership in the LCBC, the Conventional Basin area increased from 966,955 km² to 1,035,000 km², effectively covering the hydrologically active part of the drainage basin. The northern part of the lake is hyper-arid and therefore not usually connected hydraulically with the lake (Odada et al. 2006; UNEP 2004, 38).

The major rivers in the Lake Chad Basin are the Chari and Longone which account for 90 % of Lake Chad´s inflow in the south, and the Komadougou-Yobe river system, which drains into the lake in the northwest (see box 1).

Five climatic zones[4] can be identified in the Lake Chad Basin: The southern edge of the basin on Cameroon's and CAR's territory belongs to the humid zone, followed by the dry sub-humid zone on CAR's and Chad's territory. Small areas with humid and sub-humid climatic conditions in the northwestern part of the basin lie within Nigeria. The central part of the basin on Nigerian, Chad and Niger territory is semiarid. Further north, the basin's climatic conditions become arid and even hyperarid in Niger and Chad, i.e. in the upper northern part of the basin. Precipitation varies from 1,400 mm/year in the south to 10 mm/year in the northern area of Lake Chad. Annual potential evaporation is estimated at 2,000 mm/a in the south and 3,000 mm/year in the Sahara Zone (GEF n.Y., 10).

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4 The climatic zones are differentiated according to the UNEP/GRID and UEA/CRU Global Humidity Index (Deichmann / Eklundh 1991 in UNEP 2004, 17) based on a ratio of annual precipitation and potential evapotranspiration (P/PET): hyperarid zone where P/PET < 0.05, arid zone where 0.05 <= P/PET < 0.2, semiarid zone where 0.2 <= P/PET < 0.5, dry sub-humid zone where 0.5 <= P/PET < 0.6;5 Humid zone where 0.65 <= P/PET.S.

2.2 Groundwater occurence

The Lake Chad Basin was formed during the Cretaceous Period at the end of the Mesozoic[5] by the opening of the large Doba and Bousso troughs along the pan-African trends (NE and NW) and following the deposition of sequences of sediments (Continental Interclaire, Continental Hamdien, Continental Terminal, Lower Pliocene and Quaternary Sequences) (Oguntola 2002, 203). These sediments are the main water-bearing strata in the basin.

The basin communicates with other large basins such as the Niger River Basin in the west, the Murzuk Basin in the north, and the Benue River Basin in the southwest. The degree of interconnection with these basins is, however, still not clearly known (Zektser / Everett 2004, 224).

So far, the volume of exploitable water in the basin is difficult to estimate, and the relationship between the lake, the rivers, and the aquifers has been neither clearly defined nor quantified (UNESCO 2005, 6). Foster et al. (2006) estimate the exploitable reservoirs of fossil groundwater in the Lake Chad Basin at between 170,000 and 350,000 MCM,[6] of which 250 MCM/a are currently being abstracted.

The Global International Water Assessment (GIWA) and Adelana (2006) differentiate between three major aquifers in the Lake Chad Basin, i.e. the Upper, the Middle and the Lower Aquifer.[7]

The Upper Aquifer

The Upper Aquifer consists of two overlying water-bearing strata: the first is the Phreatic[8] Aquifer, contained within quaternary sand or clayey sand deposits. This comparatively extended aquifer system is located at depths of a few meters to 50 m. Mineralization is low, and the water is suitable

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5 Mesozoic is an era of geological history comprising the interval between Permian and Tertiary, i.e. 245–65 million years ago (Merriam-Webster 1998).

6 MCM means $106m^3$. For large aquifers km^3 are also frequently used, equivalent to $109m^3$.

7 Odada (2006), however, describes only two major aquifer systems in the Lake Chad Basin as defined by Olivry 1996 namely the Phreatic and the Pliocene Aquifer (UNEP 2004; Adelana 2006).

8 Phreatic: relating to, or being groundwater (Merriam-Webster 1998).

for domestic consumption and livestock watering (Olivry 1996 in Odada 2006). However, nitrate concentrations up to 300mg/l, attributable to agriculture or faecal contamination (Oguntola 2002, 204), are also found. The Phreatic Aquifer is hydrologically connected to Lake Chad (UNEP 2004, 15). It is tapped for domestic use in rural and urban communities through dug wells and boreholes (Odada 2006).

Second, there is the confined and often artesian[9] Pliocene[10] Aquifer, which is found at depths of 250 to 400 m. Water from the Pliocene Aquifer is used mainly in Nigeria and the extreme north of Cameroon, where many boreholes constructed in the 1960s constantly drain the aquifer (Odada 2006, 80). Between 1999 and 2000, a sharp decline in artesian pressure appeared in the basin (Oguntola 2002, 204), possibly due to overpumping. This water is more mineralized, with total dissolved solids (TDS) up to 700 mg/l.

It is not likely that the Phreatic Aquifer and the Pliocene Aquifers are hydraulically connected (Odada 2006). Consequently, the Pliocene Aquifer would not be connected to Lake Chad and only replenished to a very limited extent. However, information is limited (UNESCO 2005, 6). This second part of the upper aquifer separates the Upper from the following Middle Aquifer (UNEP 2004).

The Middle Aquifer

The Continental Terminal, Continental Hamadien, and Continental Interclaire are generally artesian aquifers at greater depths and have not been well studied up to the present. Only the Continental Terminal Formations, or Middle Aquifer, are more developed and understood. The Middle Aquifer is comprised of alternating sandstone and clay 450–620 m from the surface; it extends from Niger and Nigeria into Cameroon and Chad

9 Artesian water is confined in an aquifer between impermeable beds and is under pressure, like water in a pipe. When a well or fracture intersects the aquifer, water rises in the opening, producing a flowing well or an artesian spring (Hamblin / Christiansen 1995).

10 Pliocene: a geological epoch in the period of Tertiary; 5 million years ago (Merriam-Webster 1998).

(UNEP 2004). It outcrops in the south of Chad,[11] and the water is mineralized to a degree that allows it to be used as drinking water (TDS less than 200 mg/l).

The assessment of the International Hydrological Program (IHP) differentiates in more detail between two parts of this aquifer: a northern part underlying an area of 130,000 km² at depths of 80–100 m, and a southern part covering an area of 160,000 km² at an average depths of 350 m (Zektser / Everett 2004, 225). Although the water quality is suitable for use as drinking water, the costs of abstraction are considerable (UNEP 2004). Therefore the northern part of the aquifer is only slightly developed and is essentially used for domestic and livestock demands and not for irrigation (UNEP 2004, Zektser / Everett 2004; 224). The aquifer supplies important urban centers like the city of Maiduguri in Nigeria, where it is heavily exploited (UNESCO 2005, 6; Zektser / Everett 2004, 224).

The Lower Aquifer

The Continental Hamadien and the Continental Interclaire are considered to contain fossil, highly mineralized water. This Lower Aquifer consists of sediments deposited in the Cretaceous period. No further information is available on this aquifer (UNEP 2004).

2.3 Recharge and discharge

The Upper Aquifer is recharged from rainfall, tributaries to the lake, the lake itself, and wetlands in the basin (Oguntola 2002, 204). Isotopic evidence suggests that groundwater in the Middle and the Lower Aquifers is 20,000 or more years old and is not replenished by modern recharge (Edmunds et al. 1998 and 1999 cited in British Geological Survey 2003, 3). Additionally, the Lake Chad Basin Aquifer System is believed to have an important inflow from the neighboring Iullemeden transboundary aquifer in the west (GEF n.Y., 11).

Recharge from rainfall of the aquifers in the Lake Chad Basin are reported to be below 5 %/year. The amount of recharge from the rivers depends on

11 UNESCO (2005, 6) assumes that the Continental Terminal is recharged in the area south of Chad and Cameroon (Koros area).

discharge from the major rivers in Cameroon, CAR, the southern part of Chad, and upstream areas on Nigerian territory.

Isiorho et al. (1996) (cited in UNEP 2004, 18) showed that 18 to 32 % of the total recharge of the groundwater system is accounted for by the lake itself. It is assumed that most of the water percolates into the shallow Upper Aquifer/Phreatic Aquifer underlying the lake. There have been no studies yet that document the recharge of the deeper aquifers through the lake bed. The findings of Isiorho et al. (1996) indicate that the available amount of groundwater in the Upper Aquifer is quite extensive. On the basis of data from the southwestern and southern part of the basin in Nigeria, they estimated a recharge of $10^{10}m^3$/year (cited in Adenle 2002), whereas annual recharge in Niger is much lower, and sustainable use rates are consequently much lower as well (Adenle 2002).

However, groundwater recharge from the lake, the wetlands, and the rivers has decreased in recent years. Present drought conditions,[12] combined with the impact of management decisions in the upstream areas, have led to a decrease of river inflow volumes by 47 % since the late 1960s. Including rainfall, total input into Lake Chad has thereby dropped by 50 % (Odada 2006, 82).

Recharge from but also discharge into the rivers and lakes occurs depending on the geographical location. The aquifer system discharges into the Chari River and Lake Chad. Direct evapotranspiration is found in the west and northwestern parts of Lake Chad. 86 % of the natural discharge through seepage, of which 42 % evaporates, is needed to meet ecological water demands in the ecosystem of the lake and wetlands. Recharge and discharge become interrupted when the water tables in the aquifers decrease, resulting in a disruption of the hydrological cycle (GEF n.Y., 11). The aquifers' seepage discharge to the land and surface water ecosystems is critical for the control of land degradation and desertification (GEF n.Y., 8).

12 The Lake Chad Basin has been experiencing severe droughts during the 1970s and 80s.

2.4 Groundwater quality

Although groundwater quality within the aquifer varies, it is of high quality on the average, with some decline from south to north. Total dissolved solids are high in the Pliocene aquifer. This can cause a risk of salinization of agricultural land. Investigations of water quality in the Upper, the Middle and the Lower Aquifer in the Maiduguri area (Nigeria) have found considerably high concentrations of fluoride. Although some high concentrations of other trace elements (barium, boron, chronium, nickel, molybdenum, lead and uranium) were found in Nigeria, these appear in only a small number of samples (British Geological Survey 2003, 6–8).

3 Groundwater use patterns

Groundwater dependency and abstraction rates have been increasing, along with a growing freshwater shortage in the basin.[13] The lake has shrunk by 90 % since the middle of the 20th century, and water flow in the tributaries has declined due to a combination of drier climate and overexploitation. At the same time, the demand for water has increased due to population growth, and as surface water resources decline the population relies more and more on groundwater. UNEP (2004, 55) states that groundwater extraction has increased in the Lake Chad Basin; this is, however, not reflected in the figures given in the AQUASTAT data base.

The general picture is one of overexploitation of groundwater resources as groundwater levels decline. However, the Global International Water Assessment states that moderate changes in the water table are the result of reduced recharge and increased sinking of boreholes[14] (UNEP 2004).

Depending on climatic conditions, the riparian states show different water dependency rates: Niger's is almost 90 % (compare box 3), Chad's 65 %, Nigeria's 23 %, Cameroon's 4.4 %, and the CAR's 2.4 %. One shortcoming of this aggregate list is that it fails to reflect the different water dependency rates of the drier and more humid Nigerian States. Since most of the

13 The GIWA ranked freshwater shortages as the most important concern in the basin and the source of many other development concerns (UNEP 2004).

14 For the Logonge-Chari region UNESCO measured a water level decline of 2.5 m in 20 years, mainly due to drought (UNESCO 2005, 3).

Lake Chad Basin's population is Nigerian, this therefore fails to reflect the high dependency on water in this most densely populated part of the basin, where on the average 50 % of the demand for drinking water and agricultural production is met by groundwater (BGR n.Y., 4).

Box 2: Key facts on socioeconomic development in the basin
The 20 million people in the Lake Chad (conventional) Basin live in some of the poorest countries of the world.[a] This is reflected by a number of indices: most members of the Lake Chad Basin Commission rank in the UNDP category of "low human development" (Sudan 141st, Cameroon 144th, Nigeria 159th, Chad 171st, CAR 172nd, and Niger 177th (of 177))[b]. Settlements in the Lake Chad Basin show poverty indices above the already high national averages in Niger, Cameroon and Nigeria. Access to safe drinking water is limited, ranging for the year 2000 from 26 % in Chad to 56 % of the rural population of Niger (figures from the World Bank in UNEP 2004, 37). The majority of water users in the rural areas obtain water using traditional methods. Sanitary conditions are very poor in the region (for further details see UNEP 2004, 37 and FAO Country Profiles for Niger, Chad, Sudan and Nigeria 2005).
a Only Libya and Algeria in the northern part of the basin have a higher average per capita GDP. b The Human Development Index considers a long and healthy life, knowledge and a decent standard of living (measured in life expec tancy, alphabetisation rate of adults, schooling rates in primary, sec ondary and tertiary schools and income taking into account the pur chasing power parity) (UNDP 2006, 323).

The most important activity for over 60 % of the basin's population is agricultural production, of which 95 % is traditional and rain-fed.[15] Between 1983 and 1994, the demand for irrigation water grew by 200 %, leading to overexploitation of water resources which were already under

15 Modern and traditional methods are applied only in the case of irrigated rice (Odada 2006).

stress due to severe droughts (UNDP 2006, 267). Groundwater is used increasingly for irrigation, especially of marginal farmland. This is of particular concern, since irrigation efficiency is low. Furthermore, growing groundwater use for dry-season irrigation of seasonal grazing grounds has intensified, affecting access to land and water between and among farmers and pastoralists (Adelana personal communication 2007).

Box 3: Water dependency in Niger

The case of Niger impressively illustrates the adverse conditions for agricultural production and therefore food security and human development in the drier part of the basin: whereas Niger is dependent on the one hand for 90 % of its water from external sources, it can exploit only 15 % of its total available resources due to economic, technical, environmental and geopolitical limitations. 90 % of its population lives along the border with Nigeria, where rainfall patterns are favorable for agricultural production and agropastoralism (FAO Country Profile: Niger 2005). Here, however, the water available in the bordering river has decreased due to development projects in upstream areas of Nigeria. Additionally, Niger has lost access to Lake Chad since 2004 because of shrinkage of the lake's surface. At the same time, the population is growing at an estimated 3 %/year (UNDP 2006).

Table 1 shows the share of groundwater used for human consumption, agricultural production and animal supply as well as for industrial purposes in Niger and Chad. The figures clearly show the limited importance of industrial use of groundwater in the two countries; this can be assumed to be representative for the other riparian countries too.

Table 1: Sectoral groundwater use in Chad and Niger

	Chad	Niger
Industrial use	0 %	4 %
Agricultural use	79 %	39 %
Domestic use	21 %	58 %

Source: Data sheets, Part B in this volume

4 Transboundary impact

The following section discusses the transboundary impacts deriving from national groundwater use and analyses the cooperation problem over the Lake Chad Basin's groundwater.

4.1 Manifest and potential transboundary impact

In summary, the declining groundwater tables appear to reflect a manifest transboundary impact. Although the scale of this impact is not known today, it may well increase in future due to high population growth rates and climatic change.

However, neither precise information on the full extent of this impact nor estimates concerning its future development are available. While it is certain that dependency on groundwater is growing, scientific knowledge of the groundwater system is still limited[16] (BGR n.Y., 4). However, even in the absence of comprehensive data and scientific demonstration, the existence of such an impact is very likely (Vassolo, personal communication 20.3.2007).

Two causal chains for a transboundary effect on groundwater quantity have to be considered here: first, a reduction in quantity due to decreased recharge of the (Upper) Aquifer, and second the reduction of available groundwater due to increased extraction.

The reduced recharge to the aquifers is due to climatic and anthropogenic factors which have had a basin-wide, transboundary impact. Among the climatic factors are the severe droughts of the 1980s and climatic changes with reduced, highly variable precipitation, increased temperatures, and evaporation. Among the primary anthropogenic factors for reduced recharge were dam projects at the main tributaries to Lake Chad, the Hadejia River, the Komadogu-Yobe River System and the Logone River. These dams, constructed at the end of the 1970s, not only had a negative impact on agricultural production for downstream farmers (reduced yields of 33 % for cotton and 75 % for rice in the last two decades), but also reduced the rivers' input into Lake Chad and the surrounding wetlands,

16 An exception in this regard is Nigeria, where information and know-how about groundwater use and management are more developed (BGR n.Y., 4).

leading in the end to the shrinkage of Lake Chad[17] (UNDP 2006). The causal chain of negative effects of these upstream water development projects extends through the hydrological cycle to the (Upper) Aquifer and thus has a basin-wide impact.

The second development occurred contemporaneously and was also basin-wide: groundwater was increasingly extracted for human, agricultural and pastoral purposes (Thieme et al., in preparation, cited in UNEP 2004, 51). Groundwater extraction increased as the population adapted to drought. The droughts of the 1980s, for example, triggered a mass drilling of 537 wash boreholes (Isiorho et al. 2000, cited in UNEP 2004, 51). Improved well-drilling techniques and pumping technologies, along with the recent expansion of the basic infrastructure (e.g. electrical power plants) and social services in rural areas of Cameroon and Nigeria, have resulted in an ever-increasing exploitation of groundwater. Nevertheless, the majority of the newly drilled boreholes did not fulfill technical requirements and disregarded hydrogeological conditions. Most are uncapped and free-flowing, thereby contributing to inefficient use and high water losses. The result is generally a sharp decline in artesian pressure, e.g. 4.5 m/year measured at a Nigerian waterpoint (UNEP 2004, 51), and an uncontrolled loss of artesian water estimated at 28 MCM/year (Adelana, personal communication 2007).

In summary, both reduced recharge and increased extraction have led to a decline in water tables with a basin-wide impact.[18] Wells have had to be deepened in order to reach groundwater in lower strata, resulting in longer and costlier pumping, which in turn has negative consequences for the poor above all (UNEP 2004, 50–51) in the form of limited access to water and sanitation, with predictable consequences regarding health, food production, and school attendance. Many families eventually migrated, and

17 The example of N'guigmi east of Niamey impressively illustrates the shrinkage of the lake: formerly a lakeside town, it is now 100 km from the lake's shores (Adelana 2006).

18 The combination of the two developments is illustrated by the town of Maiduguri in Nigeria (Adenle 2002). In the Maiduguri urban area, the groundwater table dropped several tens of meters due to over-pumping. Root causes for this phenomenon were the increased urban water demand and the simultaneous reduction in recharge from flooding over the Sambissa wetlands due to construction of the Alau Dam upstream from Maiduguri (UNEP 2004, 51). Interesting in this case is the transboundary impact of actions in the upstream and downstream Nigerian states in the Lake Chad Basin.

water-related conflicts arose among different user groups and riparian countries. In the end, although not yet quantified, the social costs of water mismanagement in the basin are considered to be very high (GEF n.Y., 12).

Continuing population growth (around 2.5 % in the riparian countries) and the trend to rapid urbanization (UNEP 2004, 29–30) have also led to increased groundwater demand, especially on the densely populated shores of Lake Chad, thus aggravating the situation. Moreover, it is assumed that water demands for human consumption and especially for groundwater-irrigated agriculture (to ensure a secure food supply) are certain to increase in future (UNEP 2004, 55).

The interrelationships between groundwater quantity and biodiversity are another complex issue for analysis: declining groundwater tables affect biodiversity basin-wide, since groundwater is hydrologically connected to the extensive, ecologically valuable floodplains[19] in the basin. These wetlands are supported by discharge from the Upper Aquifer. A declining water table apparently hinders the regulatory capacity of the groundwater system for the wetlands ecosystem, especially during periods of extended drought. At the same time, the wetlands are important recharge areas because of seasonal inundation by the rivers. When they receive less water from the rivers, recharge to the Upper Aquifer is reduced.[20] In summary, reduced inundation due to reduced discharge from the aquifers and reduced inundation from the rivers not only causes a loss of biodiversity (breeding grounds for fish and other wildlife) but also a reduction in (traditional) agricultural production and of grazing grounds for semi-nomadic herders.

Transboundary impacts on groundwater quality are not considered a major problem in the literature. For example, because industrial production is low, chemical pollution of water is not thought to be severe. Exact data, however, is lacking. Although agrochemicals can be washed into the water in regions where rice and cotton is grown, regulation and control in the

19 The LCBC signed a Memorandum of Understanding with the Bureau of the Convention on Wetlands (Ramsar Convention) which states the special value of the wetlands in the Lake Chad Basin and the need to protect them.

20 Reduced aquifer recharge is reported for the Hadejia-Nguru Nigeria and the Yaérés floodplains in Cameroon (LCBC 1998 cited in UNEP 2004, 50).

region are weak in this regard. It is certain, however, that microbiological pollution is a problem in the densely populated areas where industrial and domestic wastes as well as sewage are directly discharged (UNEP 2004, 73).

Apart from the general implications of population growth, two further factors may heavily impact in future on the Lake Chad Basin Aquifer System. The first is the Inter Basin Transfer Scheme planned by the members of the Lake Chad Basin Commission for transfer from the Congo. This project could have a positive impact on groundwater dependency (and demand) while also increasing groundwater availability in the case of the Upper Aquifer. At present, The Inter Basin Transfer Scheme remains in a conceptual stage, and feasibility studies will not start until all member states have submitted their ideas (UNEP 2004, 99–100). However, this scheme could have a negative effect as well, including potential threats to biodiversity and negative social effects in relation to the salinization of agricultural soil due to improper irrigation management, pollution of groundwater from increased agrochemicals used, and microbiological pollution of groundwater due to improper waste and sewage discharge in growing towns and villages.

Secondly, an impact on the aquifer system can also be expected from the development of the oil industry of Chad. Today the basin is less industrialized than the rest of the region, but it is expected to become more industrialized with the commencements of oil exploration in Chad (Odada 2006, 78). This can lead to increasing urbanization, mining activities in the CAR, and large-scale agricultural development projects like the Cari-Logone Integrated Rural Development Project. These developments could lead to a further loss of wetlands and lakes. Oil spills and related hazards might cause contamination of the waterbodies, including the aquifers, and thus deplete biodiversity.

4.2 Cooperation problems

Based on the findings presented in the previous chapter, a more detailed analysis now follows of the cooperation problem in the Lake Chad Basin. On the basis of this, together with the results of an institutional analysis (see Chapters 5 and 5.2), the barriers to and driving forces behind transboundary groundwater management in Lake Chad Basin will be discussed in the final chapter (see Chapter 6).

Eckstein and Eckstein (2005) developed six types as paradigms for the application of international law governing groundwater. The types show potential transboundary implications of groundwater use in a very stylized fashion for two riparian countries which share one aquifer. An attempt will be made here to determine whether one or more of these types applies to the situation in the Lake Chad Basin and if it/they can help to demonstrate the transboundary implications of groundwater use. To this end, three analytical steps will be taken:

First, it can be stated that none of the six types apply to the Lake Chad Basin because more than two riparian countries and not merely one but three overlying aquifers are presented in the basin. Furthermore, the hydraulically linked surface watercourse is not a river, as in types A, B, C and D of Eckstein and Eckstein, but a transboundary lake. Moreover, the setting is complicated by the general shrinkage of Lake Chad and its varying water levels, so that the lake is sometimes shared by riparian countries and at other times not.

In a second step, the types could be applied to sub-basins and the underlying shared aquifers. Taking this approach the types would not reflect the complex constellation in the whole Lake Chad Basin. They therefore do not permit a better understanding of cooperation problems in the Lake Chad Basin.

Thirdly, the types are applied to the different aquifers, assuming that these are not hydraulically linked to each other:

— The Upper (Phreatic) Aquifer would probably best be described by Type B. To what extent and in which direction an upstream-downstream relation exists depends on the hydraulic gradient.

  Type C applies partially, where the lake (= linked surface water body) is on the territory of one state, but the underlying aquifer is shared. The potential transboundary impact depends on the distribution of the hydraulic potential within the aquifer, the topography, and precipitation. Multidirectional impacts are possible.

  Type D applies to the Central African Republic, where rivers originate which replenish the aquifers in the downstream states. In this case the Central African Republic occupies an upstream position.

Cameroon and Nigeria also play a role in this respect, since large dams on their territories presumably changed the recharge conditions of the upper aquifer.

— Type E and F apply for the Pliocene Aquifer, the Middle (Continental Terminal) and the Lower Aquifer (Continental Interclaire, Continental Hamedien), since these are confined aquifers that are not hydraulically linked to any surface water body. In the case of Type E, transboundary impacts are possible due to excessive pumping in one of the states. Apart from that, Type E foresees an occurrence of recharge mostly in one state. Consequently, transboundary implications can arise when surface runoff is diverted or when water is polluted. The middle and the lower aquifer would fit Type F, since they contain fossil water. In this case, transboundary impacts are only a function of pumping.

To summarize: in the case of the Lower Aquifer, the riparian countries face collective problems and share common interests. The level of incentives for cooperation might vary depending on climatic conditions and the water dependency of each riparian state.

— Downstream Nigeria may have a strong incentive for cooperation inasmuch as its water demand is high and surface water availability has been considerably reduced by water development projects in upstream Nigerian states. In contrast to the other riparian countries, groundwater extraction from all aquifers, including the lower one, is technically and financially feasible in Nigeria, giving it a clear advantage in groundwater development.

— Cameroon presumably has little incentive for cooperation since it shares only wetlands in the Lake Chad Basin and does not depend on exploitation of the lower aquifers. The groundwater resources of Lake Chad which are accessible on Cameroon territory add less than 4 % to the nation's groundwater resources (FAO Country Profile Cameroon 2005).

— Since the north of Chad is sparsely populated, and exploitation of the Lower Aquifer will probably be hindered by technical and financial limitations, the incentive for Chad to cooperate can be assumed to be moderate to low. This assessment is based on the assumption that the political priority given by Chad to this sparsely populated area will be relatively low.

— Niger is very dry and depends heavily on access to groundwater (compare Box 3). No information is available on exploitation of the aquifers in Niger. From the viewpoint of groundwater dependency, it may be assumed that Niger has a strong incentive for cooperation. This is confirmed by the fact that Niger faces technical and economic constraints in groundwater development. A further decrease of the groundwater table would therefore have negative consequences there.

— The Central African Republic is presumably independent of groundwater resources and therefore presumably has little incentive to cooperate due to its own interests in groundwater development.

In the case of the Upper (Phreatic) Aquifer, upstream-downstream externalities seem to dominate the situation. Although this may not necessarily be true of the entire aquifer, because information on the complexity of the groundwater flow system is not available at the moment. Generally speaking however, Niger, the north of Chad and the downstream areas of Nigeria clearly hold a downstream position, whereas Cameroon, the south of Chad and the Nigerian states in the upstream areas are in upstream positions. The latter are in a position to dictate how most of the recharge water will be used. This may also be true of the middle aquifer.

5 Institutional arrangements for groundwater management and transboundary cooperation

The following is an analysis of national water policies and national institutional set-ups with reference to groundwater management, along with a summary description of multilateral, bilateral and trilateral institutional arrangements for transboundary cooperation concerning groundwater in the Lake Chad Basin. Achievements thus far and challenges ahead for transboundary groundwater management by these institutions will then be discussed.

5.1 National institutional arrangements

The riparian countries, all of which are members of the Lake Chad Basin Commission (LCBC), have opted for a state-led policy of development and natural resources control rather than for a delegation of increased responsibility to multilateral institutions for natural resource management such as the LCBC (Odada 2006). At the same time, rankings of these countries based on, for example, the Bertelsmann Transformation Index[21] or the Failed States Index,[22] support the assumption that their institutional capacities are limited and thus limit successful (water) governance.

The most recent institutional developments in Nigeria, Niger, Chad, Cameroon and the CAR have consisted of formulating national water resource policies and working out environmental plans focused on sustainable management, development, and use of natural resources. These plans include reversing land and water degradation, combating desertification, and adapting to climate changes. The countries have recently adopted modern water law legislation and institutional mechanisms for water administration (GEF n. Y., 6). Presumably, however, implementation of these policies, plans, laws and institutional reforms, especially at the local level, are still limited.

In 2004, the GIWA (UNEP 2004) assessed a number of legal and governance challenges for Integrated Water Resource Management in the Lake Chad Basin:

First, it cannot be assessed whether the responsibilities of the different member state ministries are now more clearly defined and no longer overlap or conflict, as was reported in the past of Chad and Nigeria. Furthermore, it remains open whether mechanisms for stakeholder participation, especially at the national levels, are now integrated and actively supported (Wirkus / Böge 2006, 74; UNEP 2004, 86). A third question is whether current environmental plans foresee water resource environmental planning and improved water efficiency management (UNEP 2004, 95). In this regard, it is also unclear whether regulations to encourage economization

21 The Bertelsmann Transformation Index (BTI) is a global ranking that analyzes and evaluates development and transformation processes in 119 countries. The Bertelsmann Transformation Index provides the international public and political actors with a comprehensive view of the status of democracy and market economy as well as the quality of political management in each of these countries. The riparian states rank as follows: Nigeria: 67, Niger: 68, Cameroon: 89, Chad: 97, CAR: 108, Sudan: 110.

22 The index is compiled using the Fund for Peace's internationally recognized Conflict Assessment System Tool (CAST). It assesses violent internal conflicts and measures the impact of mitigating strategies. In addition to rating national indicators for sources of conflict, it offers techniques for assessing the capacities of core state institutions and for analyzing trends in national instability (http://www.fundforpeace.org/programs/fsi/fsindex.php).

of water are in place and how water tariffs for production purposes are designed (UNEP 2004, 94).

In addition, some of the countries have recently established domestic policies on groundwater management with a focus on groundwater development and use and with only limited attention to the ecological role of groundwater. No information is available concerning the role of customary rights to groundwater; these have led to conflicts in national water policies in the past and presumably still coexistence with modern laws (UNEP 2004, 92).[23]

Nigeria, for example, restricts the use of deep groundwater for drinking water and has updated its Groundwater Map into a GIS-based information system. In Chad, where groundwater levels have declined due to drought and climate change, supplies from simple wells were restricted. While Chad's groundwater resources are in general only dimly understood, the national administration has responded with a National Water Resources Strategy to introduce state-of-the-art technology for affordable extraction of groundwater from aquifers (GEF n.Y., 6). This document contains not only a detailed analysis of the available information on Chad's water resources and use but also well-defined description of projects for future development, together with cost estimates. To what extent this document has already begun to serve as a basis for water development policy cannot be judged at the moment (HCNC et al. 2003).

Although water policies and legislation may have improved recently, harmonizing the water legislation and water policies of the individual member countries is one of the major challenges ahead for IWRM in the Lake Chad Basin (Wirkus / Böge 2006, 69).

In this regard, UNEP emphasises that the riparian countries still lack coherent water allocation laws to provide for (sub-) basin-wide IWRM.[24] Without such a legal framework, (transboundary) IWRM is hindered.

23 Reports concerning Nigeria indicate that customary rights to groundwater had the force of law before Decree 101 came into force in 1993. These customary rights permitted anyone to make use of water where available for his personal needs and for his livestock and agriculture. This inadequately regulated the use of interstate water and prevented effective management of the growing demand for water resources (Bdilaya 1999 cited in UNEP 2004, 92).

24 For the different subbasins see box 1.

Achieving equitable agreement, however, will be a difficult political process. Politically stronger nations like Cameroon and Nigeria may insist that their water demands are met, while water authorities and stakeholders of irrigation projects may not cooperate because they will fear losing out on water resource rights (UNEP 2004, 110).

Concerning implementation of policies, the capacities of the riparian countries to promote compliance and to enforce agreement are either very limited (Chad, Cameroon, CAR, Niger), or legal provisions are not published and one can therefore not rely on these (Nigeria).

In summary: the riparian countries of Lake Chad are engaged in developing an adequate legal framework and establishing an institutional environment for IWRM. To what extent these steps are focussed on regional cooperation and explicitly include groundwater-related aspects cannot be judged in detail on the basis of the available information. It can, however, be assumed that groundwater is increasingly being taken into account as dependency on this water source grows.

5.2 Institutions for transboundary cooperation

The riparian countries of Lake Chad have created a multitude of bilateral and multilateral institutions for transboundary water management. The functions and functionality of these institutions, however, vary and are in some cases very limited. In this context, the Lake Chad Basin Commission (LCBC), as the most important regional institution, will be discussed in somewhat more detail.

Generally, regional institutions such as the LCBC, the river basin commissions, and other bilateral commissions, are enhancing riparian cooperation for sustainable management of transboundary (ground)water. They also provide mechanisms for conflict prevention and resolution and dispute settlement (Adelana personal communication 2007) in view of the fact that the Lake Chad Basin in the past has experienced (violent) conflicts over natural resources.[25]

25 Whereas the scope of this paper does not allow for a detailed analysis of the root causes and the conflict settlement mechanisms in place, Wirkus / Böge describe a variety of conflicts over water in the basin, most of them upstream-downstream conflicts at the tributaries, and conflicts over the borderlines at Lake Chad (Wirkus / Böge 2005, 54–66).

5.2.1 The Lake Chad Basin Commission

Based on the "Convention Relating to the Development of the Chad Basin" signed in 1964 at Fort Lamy, the LCBC attempts to regulate the transboundary management of natural resources. Cameroon, Niger, Nigeria, Chad and the Central African Republic are members of the LCBC.[26] In 2000, Sudan was granted membership, but has not yet ratified the convention.

The LCBC is responsible for:

— Regulating and controlling the utilization of water and other natural resources in the basin.

— Initiating, promoting and coordinating natural resource development projects and research within the area.

— Examining complaints and promoting the settlement of disputes, thereby fostering regional cooperation (Odada 2006, 79; UNEP 2004, 38).

Because groundwater is recognized as part of the basin's water resources, the LCBC is also in charge of regulating and controlling transboundary groundwater. Consequently, the LCBC's organizational structure foresees the hiring of a hydrogeologist (see Figure 4). Interesting for the purpose of this paper is the fact that this hydrogeologist position was vacant for some years.[27] This reflects the rather limited implementation of groundwater-related activities in the LCBC until now (personal communication with GTZ/AHT and BGR, 3/20/2007).

Although the riparian countries continue to lack adequate strategies for enhancing transboundary aquifer management (Adelana 2006, 1), the importance of groundwater in the region has been recognized by the LCBC. This is reflected for example in the LCBC's Master Plan for the Development and Environmentally Sound Management of the Conventional Lake Chad Basin and the Strategic Action Plan (SAP).

In addition, Odada (2006) describes conflicts connected with the failure of the big irrigation projects and migration caused by freshwater shortage (Odada 2006, 82– 83).

26 For a more detailed description and analyses of the Lake Chad Basin Commission see Wirkus / Böge 2005, Odada 2006, Adelana 2006, UNDP 2006, UNEP 2004, WWF 2003.

27 The position was filled in June 2007 by Mr. Saleh, a Chadian hydrogeologist.

The LCBC member states can count on an inventory of the basin's groundwater resources. Nevertheless, important information concerning the aquifer system in the Lake Chad Basin remains to be collected, updated and analyzed on the basis of a model of aquifer dynamics. The results will serve as basis of decision making on transboundary groundwater management strategies.

Since 1990, the LCBC has had a yearly budget of 1 million US$, 50 % of which is used for operational and 40 % for development activities. The budget is provided by the member countries as follows: Nigeria (52 %), Cameroon (20 %), Chad (11 %), Niger (7 %), CAR (4 %) (Odada 2006, 79). Not all of the member states, however, comply with their financial duties, presumably due to a lack of both funds and political will. Consequently the LCBC has to deal with a constant shortage of funds.

Limited political will and severe financial constraints make the LCBC a relatively weak institution; cooperation between the riparian states has been inadequate, and common agreements are rarely complied with (UNDP 2006, 267; Wirkus / Böge 2005, 67–75). As a result of this institutional weakness and the lack of ability to enforce policies and promote compliance with agreements, the LCBC has often been bypassed despite the fact that the problems at issue fall under its mandate (2002 cited in UNEP 2004, 86).

The LCBC's members have committed themselves to prior notification of each other in case of problems and to the avoidance of negative effects on the quality and quantity of water resources of the other riparian states. The Fort Lamy Convention upholds the sovereign rights of each member state to water resources in the basin and forbids unilateral exploitation, especially when this has a negative impact on other states. Water projects can be planned in the member states only if the LCBC is consulted first.

An important legal weakness of the Fort Lamy Convention, however, is that the LCBC is without veto powers, thus hindering basin-wide management (UNEP 2004, 85). Because the rule of *prior notification* is not equivalent to *prior agreement,* member nations do not necessarily need the agreement of the other members before carrying out projects which alter the regional watercourses. In the past, this has led to the implementation of various dam and irrigation projects which have a negative impact on downstream riparian countries.

Another major gap in the Fort Lamy Convention is the lack of any water allocation rule. Explicit groundwater issues have not yet been addressed adequately. The convention therefore does not provide a regulatory framework for (ground-) water allocation. This major legal gap hinders effective transboundary groundwater management (UNEP 2004, 85). The FAO has assisted the LCBC in elaborating common regulations, but no final report has been issued nor has any of the countries ratified a water allocation agreement (Odada 2006, 83). UNEP reports that the draft prepared by FAO does not stipulate groundwater issues (UNEP 2004, 84).

One of the most important bottlenecks for strategy development as well as implementation of activities is the lack of mechanisms for coordinating the rights of stakeholders and for regulating (groundwater-related) activities at different levels (local, provincial, national, sub-basin and on the regional and interstate level). This includes the creation of greater awareness among stakeholders who are not involved at all or only to a limited extent through institutionalized participation. Improving the possibilities of participation and consultation may foster compliance and increase awareness of groundwater-related problems in the region (Odada 2006, 90) Coordination and participation are therefore indispensable for successful groundwater management.

Moreover, the LCBC is hampered in the area of transboundary groundwater management by a lack of technical means for assessing the impact of planned projects on the aquifer system (BGR n.Y., 4). In this regard, building up capacities for joint monitoring and information sharing plays an important role. In a first step, models of all aquifers layers are needed, along with maps of aquifer units indicating the direction of flow and showing links and interactions. This would create a better understanding of the aquifer system in the Lake Chad Basin. Together with joint monitoring systems, such research and mutual learning will allow for more precise identification of cross effects and will thereby provide a basis for transboundary groundwater management.[28]

28 Moreover, integrated assessments would allow an evaluation of the impact of future changes on the water environment. In particular, the successful integration of socio-economic scenarios into spatial land use models could enable an assessment and quantification of indirect effects which result from changing patterns of urbanization, flooding and cropping (Adelana personnel communication 2007; BGR n.Y., 4).

A number of internationally supported projects have been put into operation in cooperation with the LCBC in order to develop the latter's capacities for transboundary groundwater management. Details on these projects are summarized in box 4.

Box 4: Donor involvement for improving groundwater management in the Lake Chad Basin

International donors and NGO-supported projects are being implemented in the Lake Chad Basin. The main objectives of this are to strengthen the Lake Chad Basin Commission and to contribute to a sustainable development of the Basin's resources. Only a few initiatives focus directly on groundwater.

The largest project in the region is the GEF "Reversal of Land and Water Degradation Trends in the Lake Chad Basin". With the support of this project, the Strategic Action Programme was adapted in 1998. It is being implemented by UNDP and the World Bank. The aim of this project is to set up coordinated, integrated and sustainable management of the Lake Chad Basin's international waters and other natural resources. At the same time it aims to reverse the trend towards degradation of soil and water resources of the Lake Chad Basin (Wirkus / Böge 2006, 70). In its support for the LCBC, the project is also integrating groundwater issues. In this regard a proposal has been made to advance the current understanding of transboundary groundwater resources in the Basin, to explore the possibilities of conjunctive use, and to develop a capacity for sustainable aquifer management at different levels (Adelana 2006; GEF n. Y.).

Germany is cooperating with the LCBC in the project "Sustainable Water Management at Lake Chad", for one part of which the GTZ has been responsible since 2005. This is aimed at strengthening the LCBC in the establishment of a regional GIS-based knowledge management system for effective management of the Basin. The project therefore supports the establishment of technical capacities for monitoring and sharing data. A Water Resources Information System will be established that will serve as an effective decision-making tool for the sustainable management of the water resources of the Lake Chad Basin. Until now this project has focused on surface water resources; it will be supplemented by a BGR component on groundwater that will start in May 2007.

Box 4 continued
This second component will aim at fostering the integration of groundwater-related information in the Water Resources Information System. The BGR therefore mainly helps in the development of regional professionals at the national level and within the structure of the LCBC (BGR n.Y.). A project proposal of the World Meteorological Organization (WMO) exists for a sub-regional component of the World Hydrological Cycle Observing System (WHYCOS) for the Lake Chad Basin. Many of the proposed activities are already part of the GTZ/BGR project, and close cooperation is planned (WMO 2005). From 1992 to 1993, the French Cooperation financed the project "Monitoring and Management of Groundwater Resources in the Lake Chad Basin" to provide the LCBC with a groundwater resource management model. Although the funds available sufficed only for development of a premodel, the project provided recommendations for groundwater resources in the Lake Chad Basin and also identified gaps in knowledge (UNEP 2004, 39).

Despite the fact that riparian cooperation through the LCBC is generally assessed as limited due to a lack of political will and severe capacity constraints, more positive developments have recently been reported: the LCBC takes an active part in the international dialogue on transboundary water management and has been able to speak with a unified voice on interstate concerns, for example at the World Water Forum (Adelana, personal communication 2007). Also, positive experiences from cooperation with the World Bank and UNDP in implementing the GEF project (see box 4) have helped to establish the principles of IWRM in the LCBC. The growing importance which member states give to the LCBC is shown by the fact that they send qualified persons who in turn perceive working for the LCBC as very positive for their career (BGR n.Y., 9–10).

5.2.2 Agreements regarding Lake Chad subbasins

The Nigeria-Niger Joint Commission

In 1998 the Federal Republic of Nigeria and the Republic of Niger signed an agreement concerning the equitable sharing and the development, conservation and use of their common water resources through formation of the Nigeria-Niger Joint Commission (Adenle 2002, 178). The agreement extends to the following shared basins: the Maggia/Lamido River Basin, the Gada/Goulbi of Maradi River Basin, the Tagwa/El Fadama River Basin and the lower section of the Komadougou-Yobe River Basin.

Interestingly, groundwater contributing to the flow of surface water is explicitly included in the agreement, thus recognizing the hydraulic link between surface and ground water. Article 9 elaborates on the types of groundwater resources which are subject to joint management, namely those that are part of the shared river basin and those that lie in whole or in part within the shared river basins and are bisected by the common frontier between the contracting parties (Adenle 2002, 179, 181).

The Commission meets regularly. Given the fact that only the shared part of the 160 km-long border is a subject of discussion by the Commission, since everything upstream in Nigeria is not included, the principles of IWRM cannot be applied (UNEP 2004, 91). Part of the river basins is covered by the Nigeria-Niger Joint Commission; since the lower Komadougou-Yobe River Basin forms a sub-basin of Lake Chad, it is therefore also subject to the LCBC.

The Chad-Cameroon Joint Commission

Cameroon and Chad reached the Moundou Accord in August 1970. The Accord covers water abstraction rates from the Logone River for agricultural production. The Chad-Cameroon Joint Commission was created subsequently, but until today has neither enforced nor monitored abstraction rates. This weak commission is essentially inactive, and no permanent secretariat is in place (UNEP 2004, 85). It is presumably neither mandated for the regulation of groundwater abstraction nor involved in any groundwater-related management.

Finally, the Cameroon-Nigeria-Mixed Commission was created outside the LCBC in 2002 in order to resolve border-related conflicts between Cameroon and Nigeria.

5.2.3 Other interriparian agreements

The Niger Basin Authority, and cooperation regarding the Iullemenden Aquifer

Cameroon, Chad, Nigeria and Niger have also joined forces with Benin, Burkina Faso, Ivory Coast, Guinea and Mali for development and management of the Niger River basin and established the Niger Basin Authority in 1964 (WWC 2006, 71). The NBA can already count on a legal and institutional framework and operational objectives and has formulated a Sustainable Development Action Plan. The NBA has adapted a pragmatic, consensus-building approach for developing a common vision for joint use and development of the basin's resources. The next step will be a joint action programme (WWC 2006, 48).

Nigeria and Niger also cooperate with Mali over the use of the Iullemeden Aquifer System, which partly underlies the Niger Basin. As no clear legal framework for cooperation exists yet, the three riparian countries are supported by international donors (mainly UNDP / GEF) in their steps towards transboundary management of the Iullemeden Aquifer System (Dodo 2006, 1–2).

6 Prospects for transboundary cooperation, and recommendations for German development cooperation

Conclusions and recommendations

Scientific knowledge about the groundwater system is still too limited to allow for a comprehensive assessment of the Lake Chad Basin Aquifer System. Nor is it yet possible to quantify or precisely describe transboundary impacts[29] (BGR n.Y., 4).

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29 An exception in this respect is Nigeria, where information and know-how about groundwater use and management are more developed (BGR n.Y., 4).

The present study is based on both the available literature and on communication with experts from the BGR, the advisors to the LCBC from AHT/GTZ and on valuable input received from Dr. Segun Adelana, Department of Earth Sciences (Groundwater Group), University of the Western Cape, South Africa.

Transboundary impacts and resulting conclusions for transboundary cooperation

Freshwater shortage presents the greatest challenge to the management of water resources in the Lake Chad Basin. Thus the limitation of water resources, with its clearly negative impact on human development at the regional level, is the driving force behind efforts at cooperation. Although no comprehensive data exists on the basis of which such an impact can be scientifically proven, the existence of transboundary effects on groundwater availability in the Basin is very likely (Vassolo, personal communication 20.3.2007). In view of expected population growth and diminishing surface water resources, conflicting groundwater interests will almost certainly continue to cause tension.

At the national level, the riparian countries are engaged in developing an adequate legal framework and an institutional environment for IWRM. To what extent these steps are focussed on regional cooperation and explicitly include groundwater-related aspects cannot currently be judged in detail on the basis of available information. It can, however, be assumed that groundwater is increasingly being taken into account as dependency on this water source grows and the basin orientation of national water policies improves.

The countries sharing the Lake Chad Basin have created the Lake Chad Basin Commission (LCBC) with headquarters in N'djamena (Chad). The LCBC is coordinating information and the sharing of risks, is facilitating the pooling of technical and financial resources, and is thereby reducing the burden on individual countries. The LCBC also aims to integrate economic development programmes.

The management of the basin's groundwater resources is recognised as one responsibility of the LCBC. However, major obstacles for sustainable groundwater management remain: improving the legal framework, providing for cooperation mechanisms and building capacities at the different levels, and improving the groundwater-related database and models.

Barriers for undertaking further steps towards joint management may be posed by resistance to the formulation of a basin-wide water allocation rule, generally severe capacity constraints in the member states, and above all political instability in the region. However, a growing political will of the member states to cooperate within the LCBC is noticeable, and evidence of improved commitment by member states to their financial obligations (Odada 2006, 87) gives reason to hope that the crucial barrier for cooperation, i.e. a lack of political will, will be lowered.

Role of external actors and resulting recommendations for German development cooperation

External development agencies have played an important role in supporting regional cooperation through the LCBC. In this respect, German development cooperation is involved part in various bilateral and multilateral activities in the Lake Chad Basin. At the regional level, German development cooperation is supporting the LCBC bilaterally (i.e. both the GTZ and the BGR) as well as multilaterally through the GEF/UNDP/World Bank and in the form of EU development cooperation and the European Water Initiative.

The present analysis underscores the assessment that the regional level is the proper institutional point of entry for German development cooperation. Thereofore, we recommend the continuation of support for the LCBC in its endeavours to develop transboundary groundwater management through bilateral and multilateral cooperation.

Furthermore, groundwater-related issues should be actively included in the mainstream of all future German development cooperation activities in the region. These include the effort to reduce poverty, to make progress regarding the MDGs, and as a result to improve conservation of the Ramsar Site Lake Chad Basin.

Additionally, German development cooperation might well increase its support at the regional level for AMCOW, since the Lake Chad Aquifer System is a priority area for the African Water Facility. Finally, German development cooperation should intensify its engagement in the African-EU strategic partnership on water affairs and sanitation.

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The Stampriet Artesian Aquifer Basin

A case study for the research project ”Transboundary groundwater management in Africa”

Marianne Alker

Preface

I would like to thank Mr. Piet Heyns (Heyns International Water Consultancy, formerly Under Secretary and Head of the Department of Water Affairs and Forestry Namibia) for contributing all technical information on the Namibian part of the Stampriet Artesian Basin and for his valuable input into the present study; furthermore, many thanks to Dr. Gideon Tredoux (DTEC/CSIR South Africa) and Dr. W. Struckmeier (BGR) for sharing their knowledge with me.

After the work on this desk studie was already acomplished I learnt during the World Water Week in Stockholm, that the riparian countries of the Stampriet Artesian Basin / Western Kalahari Karoo Aquifer agreed upon a joint assessment of this shared aquifer. The fact that research cannot keep pace with the political developments in this case raises hopes for future successful transboundary cooperation over groundwater in this arid part of the world.

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1 Introduction

The Stampriet Artesian[30] Basin (SAB),[31] which is shared by Namibia, Botswana and South Africa, was selected for one of five illustrative studies within the research project "Transboundary Groundwater Management in Africa" for the following reasons: First, the presence of fresh water is of special value in the very arid environment at the border between Namibia, Botswana and South Africa, where brackish and saline groundwater is frequent. Second, the SAB lies within the Orange River Basin, where a river basin commission exists. This means that an institution for transboundary cooperation concerning shared water resources is already in place and could also serve for joint management of the shared groundwaters. Third, the SAB has been well studied, at least on the Namibian side,[32] and thus provides a basis for analysis.

2 General characteristics of the Stampriet Artesian Basin

The name "Stampriet Artesian Basin" refers to a transboundary groundwater system that has been identified and investigated thus far only in Namibia (Christelis / Struckmeier 2001), where it encompasses the Nossob and Auob sandstones of the Ecca subgroup in the Karoo and Kalahari Sequences. Although no studies have yet been undertaken to investigate the basin as a whole and to confirm the extent of its eastern perimeter (Tredoux

30 Artesian water is confined in an aquifer between impermeable beds and is under pressure, like water in a pipe. When a well or fracture intersects the aquifer, water rises in the opening, producing a flowing well or an artesian spring (Hamblin / Christiansen 1995).

31 The basin was named after the town of Stampriet that was established by missionaries who saw a potential for using free-flowing groundwater from the Auob aquifer for gardening purposes.

32 The Internationally Shared Aquifer Resources Management (ISARM) Programme has also chosen the SAB under the name "Kalahari / Karoo Multi-Layered Aquifer" for a case study. This study has not yet been commenced. The present paper draws upon the problem analysis presented in Puri (2001).

email 3.4.2007), it is assumed that the aquifers extend into parts of Botswana and to a lesser extent into South Africa.

2.1 Geographical characteristics

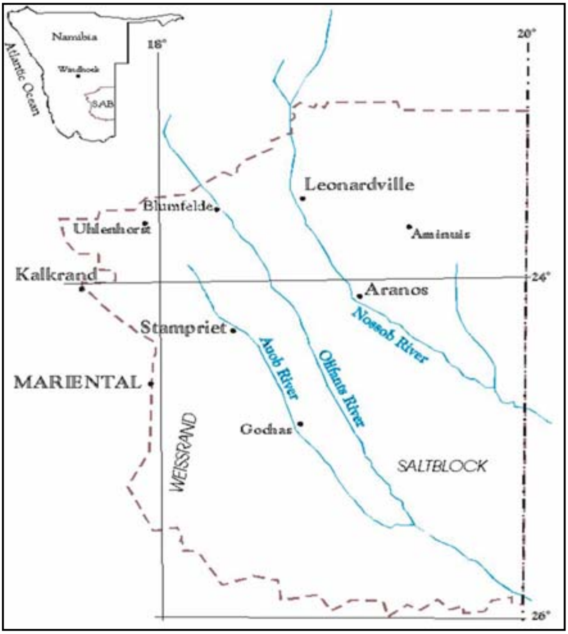
The SAB lies within the Orange River Basin and covers 7.1 % of its total area in Southern Africa (DWAF [Namibia] 2000; Christelis / Struckmeier 2001).

The boundaries of the SAB are well known in Namibia. The northern boundary is visible in the form of sub-outcrops of Karoo strata. In the northwest, the boundary follows an arbitrary margin that delineates where sandstone with artesian groundwater may still be encountered under the Kalkrand Basalt. In the west, the boundary is formed by the escarpment of the Weissrand Plateau above Nama Group sediments along the watershed between the Orange River Basins's Fish River sub-catchment to the west and Auob River sub-catchment to the east. In the south, the boundary of the SAB runs along a line south of which no artesian conditions exist. On the east, the basin stretches into Botswana and South Africa across the Namibian border, which runs along the 20° east longitude line.

In Namibia, the SAB covers an area of about 71,000 km², or about 8.6 % of the country's total surface area (cf. fig. 1). The north of the basin is characterized by a transition from quartzite ridges in the far north to monotonous flat plains of sand and calcrete in the northeast. On the western edge of the basin, the Weissrand, a surface limestone plateau, rises about 80 m above the Fish River plain and is predominantly covered by calcrete and dune sand. A dune field comprising stationary, longitudinal dunes roughly follows the upper part of the Auob River in a NNW-SSE direction and continues eastward toward and across the border with Botswana. The dunes are 10 to 15 m high. It is assumed that these linear dunes were formed during the last glacial period when a persistent high pressure cell circulated over the subcontinent, resulting in strong, dry windstorms.

As mentioned above, little is known about the southeastern, eastern and northeastern boundaries of the SAB.[33] Puri have estimated that the basin

33 A geological map of Botswana demarcates the Nossob Basin from the Namibian border at about 21.5 ° east (ORASECOM 2007, 32), and it is known that the Ecca sandstone is found in large areas of Botswana's part of the Orange River Basin (ORASECOM 2007,

Figure 1: Location of the Stampriet Artesian Basin in Namibia

Source: DWAF (Namibia) / JICA (2000)

occupies 70,000 km² within the territory of Botswana, but no such estimates exist for the SAB in South Africa (Puri 2001, 54–55).

Interestingly, available data indicate that 90 % of the SAB's aquifers lie within Namibia. The contrast between this and the figures presented by Puri suggests that the terms "Stampriet Artesian Basin" (used in Namibia) and "Kalahari/Karoo Multi-layer Aquifer" (used by the Internationally Shared Aquifer Resources Management [ISARM] Programme) are not necessarily congruent.

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35). The only information found for the South African side is that the main known productive aquifers are along the Molopo and Nossob Rivers (ORASECOM 2007, 39).

A surface drainage system runs from the northwest to the southeast across the basin. The Auob, Olifants and Nossob Rivers are ephemeral watercourses that are part of the larger Orange River Basin in Southern Africa. These rivers flow only when above-average rainfall occurs, but they are endoreic within the Orange River Basin. This means that their runoff never reaches the Orange River but rather dissipates into the Kalahari Desert about 130 km to the north of the Orange River in South Africa.

Mean annual rainfall across the basin varies between 120 mm (Stampriet) and 240 mm (Leonardsville). It is highly variable and therefore cannot be reflected accurately in a figure for average precipitation. Rarely, extreme rainfall can even reach 500 mm. The mean annual potential evaporation varies between 3,000 mm in the north and 3,500 mm in the south.

The northwestern part of the SAB in Namibia lies at an elevation of 1,350 m above mean sea level; this drops 500 m over a distance of 400 km to 850 m ase in the southwest.

The landscape of the SAB is characterized by two distinct biomes. A tree and shrub savanna occurs in the north and southeast, while dwarf shrubland of the Nama Karoo covers the west and southwest of the SAB. The valleys between the dunes of the Kalahari sandveld may be up to several hundred metres wide and are covered with grass and acacia trees (mostly Camelthorn). The grass and pods from the Camelthorn trees form the basis of the biomass on which extensive stock farming activities in the area rely. The presence of the trees indicates shallow groundwater.

The density and quality of the vegetation depend on seasonal rainfall conditions. The carrying capacity is in the range of 12 to 15 hectares per large stock unit[34] (ha/LSU) in the Kalahari sandveld and 18 to 24 ha/LSU in the Nama Karoo biome.

The Kalahari sandveld is covered by (windblown) ferralic arenosols which have a high content of iron and aluminium oxides, resulting in the red colour of the sand. In the northwest and southwest areas, petric calcisols predominate. These soils have the potential to be fertile, but have a solid layer at shallow depth and contain accumulations of calcium carbonate. In the Stampriet area there are fertile eutric leptosols (caused by erosion) and

34 A large stock unit is one head of cattle; this is considered equivalent to five small stock units such as goats and sheep.

fluvisols (flood deposits) with a low base saturation. Irrigation is common on these soils.

2.2 Information about the Stampriet Artesian Basin

2.2.1 Studies carried out in Namibia

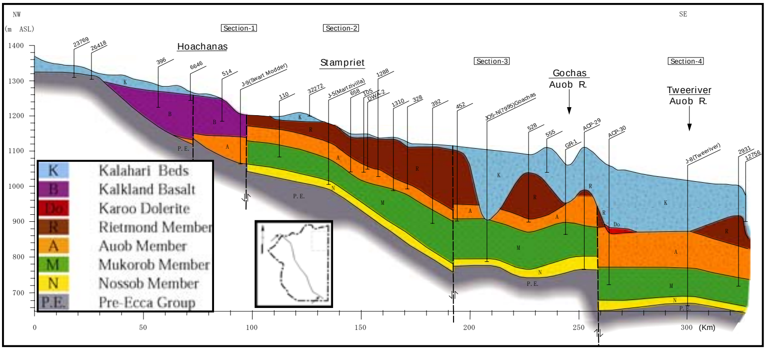
The geology, hydrology and hydrogeology of the Stampriet Artesian Basin are relatively well known because of well-documented meteorological data and borehole information. The first results of hydrogeological investigations were published by Range (1915). After World War One, the Irrigation Department of the newly created South West Administration undertook an extensive drilling program with the aim of finding water for the development of new stock farms in previously undeveloped areas. This process was repeated after World War Two.

The quality of groundwater in the basin has also been investigated. In 1965, the Committee for Water Research of the South West Africa Administration employed the Council for Scientific and Industrial Research in South Africa to investigate the quality of the groundwater in an area west of the town of Kalkrand. This led to the Water Quality Map Project, which included a hydrochemical analysis of more than 30,000 water samples from boreholes, wells and springs across Namibia between 1969 and 1981. Four maps showing total concentrations of dissolved solids, sulphate, nitrate and fluoride in the groundwater of Namibia were prepared, and a similar map is available for the SAB.

In the 1980s, further work was done in the north and northwestern parts of the SAB by the Geohydrology Division of the Namibian Department of Water Affairs (DWAF [Namibia]). A major improvement in aquifer management resulted from the collection of extraction data, which led to a better understanding of the impact of extraction on recharge and the implications of this for sustainable use.

The last round of investigation started at the turn of the present century, when the Japanese Government, through the Japanese International Cooperation Agency (JICA), provided funds for a hydrogeological investigation of the so-called Southeast Kalahari Basin (JICA 2002). The aim of this was to develop an integrated Groundwater Management Plan. This work provided a better conceptual model of the basin, as reflected in Figure 2.

Figure 2: Geological Cross-Section of the Stampriet Artesian Basin



Source: DWAF (Namibia) / JICA (2000)

At the same time, the International Atomic Energy Agency funded an isotope-based study project to investigate the recharge of the aquifers in the SAB.

2.2.2 Studies carried out in Botswana

No integrated investigation of the SAB on the Botswana side has been undertaken. The main problem for studies in this regard is that lithological units have different names in the two countries and that the terms used to describe stratigraphy have also been amended from time to time (Tredoux email 3.4.2007).

Nevertheless, some information from local studies does exist. The Department of Water Affairs for Botswana has undertaken studies in the areas of Matsheng and Kang-Phuduhudu, tapping Ecca Sandstone Aquifers that may lie within the SAB or be connected with it. This latest investigation of the deep Ecca aquifer of the Kalahari in southwestern Botswana concluded that the high-yield Ecca aquifer horizons contain highly saline groundwater which is unsuitable for agricultural purposes (Cheney et al. 2006, 311).

Other investigations currently being carried out in Botswana are the Groundwater Recharge Estimation Study, implemented by the University of Botswana and the Botswana government's Department for Geoscience in association with the University of the Netherlands, and the ongoing Kalahari Research Program of the International Institute of Aerospace Survey and Earth Science (ORASECOM 2007, 39-40). In Botswana, data on groundwater levels and extraction are being collected by the Department of Water Affairs and the Department of Geoscience. Unfortunately, the information gathered by these two departments is not mutually complementary and is also unsatisfactory in terms of quality and quantity (ORASECOM 2007, 39–45).

2.2.3 Studies carried out in South Africa

Generally, little is known about groundwater in the Orange Basin in South Africa (ORASECOM 2007, 104). Although South Africa is currently undertaking some groundwater resource assessment activities, no specific information for the SAB there is available. DWAF (South Africa) and the Water Research Commission (WRC) have prepared a number of groundwater maps (e.g. the Groundwater Harvest Potential Maps) which provide quantitative information on sustainable rates of groundwater extraction. The maps are prepared by the Department of Water Affairs and Forestry's Directorate of Geohydrology (http://www.dwaf.gov.za/Geohydrology/Maps /harvpot.asp).

2.3 Hydrogeological features

2.3.1 Groundwater occurrence

It is assumed that groundwater occurs in all three riparian countries in the upper Kalahari Group and in the underlying Karoo Sequences. The three main aquifers in the SAB in Namibia are in the Kalahari Beds, the Auob Sandstone and the Nossob Sandstone. The average thickness of the Kalahari Aquifer is 100 m, that of the Auob 80 m, and that of the Nossob 25 m (JICA 2002). In the southeastern part of the Namibian SAB, the Kalahari sediments are considerably thicker, reaching about 250 m in the ‘Pre-Kalahari Valley’.

The Auob Sandstone Aquifer and the Nossob Sandstone Aquifer lie in the Ecca Group of the lower Karoo Sequence and are separated by shale layers of the Mukorob Member, which is overlaid by Rietmond Shale and Sandstone. The Auob and Nossob Aquifers are confined and free flowing in the Auob Valley from Stampriet and further downstream, as well as in the Nossob Valley around Leonardville. Water levels elsewhere in boreholes in the artesian aquifers are subartesian. Several springs are located in the eastern outcrop of the Kalkrand Basalt in the northwest. Groundwater also occurs in the Kalahari layers across the basin and in the Prince Albert Formation of the Karoo Sequence.

As stated earlier, little is known about groundwater occurrence on the Botswana and South African side. For Botswana the most significant water-bearing layers are believed to be in the Lebung and Ecca Group (within the Karoo Supergroup). The Ecca Group is divided into two formations: the lower Kobe Formation and the Otshe Formation. The Otshe Formation is equivalent to the Auob Sandstone in Namibia. A conglomerate at the base of the Kobe Formation is classified as the Nossob Sandstone in Namibia and also occurs in Botswana (ORASECOM 2007, 28). Groundwater stored in the Kalahari Group is an important water source for settlements in southwestern Botswana (ORASECOM 2007, 35–36).

In South Africa, the aquifer in the Kalahari Group is known to be the most productive. Additionally, the underlying bedrock Karoo Sediments may contain important waterbearing strata. This, however, has not yet been investigated in detail for the whole region (Puri 2001, 52).

Estimates of groundwater storage volumes exist for the different aquifers in Namibia. It is estimated that the total quantity of water stored in the SAB's aquifers is 357 BCM, of which 120 BCM (33.6 %) is thought to be present in the Kalahari Aquifer, 180 BCM (50.4 %) in the Auob, and 57 BCM (16,0 %) in the Nossob.

These estimates, shown here in Table 1, assume an average porosity of 5 % of the Auob and Nossob Sandstones. However, this assumption has been called into question by various experts who believe that the actual figure is lower (A. Margane, personal communication 2007). The total stored volume in that case would also be smaller. Data available for the Namibian SAB therefore reflects uncertainties while at the same time showing gaps where further investigation is required.

Villages in southwestern Botswana's Matsheng area extract their water mainly from the shallow Kalahari Group, whose thickness ranges from 8

Table 1: Namibian aquifer data (unavailable for Botswana and South Africa)			
Aquifer	**Average depth (m)**	**Stored volume BCM**	**Percentage of total (%)**
Kalahari	0-250	120	33.6
Auob	0-150	180	50.4
Nossob	0-60	57	16.0
Total	-	357	100.0
Source: JICA (2002)			

to 108 m, and from the Lebung Group, which ranges from 17 to 120 m in thickness (Cheney et al. 2007, 303–04).

2.3.2 Geological origins and implications for water quality

Sedimentary succession in the SAB was basically created by a river system that enters Namibia at a point about 20°E and 24°S and flows in a southwesterly direction. This river system cuts deeply into the Karoo Sequence, which rests on the Kamtsas Formation in the north and northwest and on the Nama Group of rocks in the remainder of the basin. The Karoo Formations dip about 3 degrees to the southeast, and groundwater flow generally follows that direction. Sediments that created the sandstone layers were transported from higher-lying mountains in the northeast and were deposited in a deltaic environment in the basin. The subsequently deposited Kalahari layers are relatively thin along their northern and western boundaries, with calcrete and dune sand at the surface; in the southeast, however, the layers may be up to 150 m thick and are about 250 m thick in the pre-Kalahari River.

Groundwater quality deteriorates in a south-southeasterly direction[35] because the Kalahari in the central parts of the basin consists mainly of fine sand, silt and clayey deposits which have accumulated mineral salts due to

35 The quality of artesian water in the upper part of the basin is in the order of 1,000 to 2,000 mg dissolved solids/l, but this deteriorates to more than 5,000 mg dissolved solids/l in the southeastern parts of the basin.

low rainfall and runoff as well as high evaporation. The confining layer of the Auob Aquifer has also been largely carried away in the southeastern parts of the pre-Kalahari River, resulting in saline groundwater. In fact, the southeastern area of the SAB is referred to as the “Salt Block” because of the brackish to saline water in the Kalahari, Auob and Nossob Aquifers.

Regarding the border region between Namibia and Botswana, it is assumed that groundwater with good quality is found for 100-150 km into Botswana. The water is characterized by a relatively high sodium bicarbonate content, but salinity is low enough in most of the area to make it suitable for livestock consumption (and generally also for human consumption). Nevertheless, it is not necessarily usable for irrigation (Tredoux email 3.4.2007). Recent investigation of the Ecca aquifer in the Matsheng area of Botswana has shown that the water stored there is too saline for human or animal use.

Nitrates present in large areas of the SAB also limit groundwater use. Most of these nitrates are of natural origin. They extend to the artesian part of the aquifers via the overlying Kalahari Beds. Nitrate concentrations within artesian aquifers are naturally lower due to the presence of coal and carbonaceous shale (Tredoux email from 4.4.2007; WRC 2005).

South Africa's groundwater quality has been investigated for the Lower Orange Water Management Area.[36] It is very poor near the borders with Namibia and Botswana (Western Highveld), where the highest concentration of groundwater nutrients is found with a median of 15.1/mg/l in 2003. This value is above the threshold for human consumption (DTEC/CSIR 2004, 11).

2.3.3 Groundwater recharge

Most aquifer recharge is thought to occur on Namibian territory (Puri 2001, 52). Recent studies in Namibia have provided more details on recharge from surface runoff into the different aquifer layers. Estimates based on these studies are that recharge to the artesian aquifers in normal rainfall years is relatively low but that considerable recharge may occur during wet years, i.e. about once every fifty years. Recharge to all aquifers

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36 The Lower Orange Water Management Area contains 13 groundwater regions (DTEC/CSIR 2004, 11).

in the basin during years with average rainfall is estimated at 105 MCM/year, or 0.5 % of rainfall (JICA 2002). However, recharge in wet years may be as much as 3 %, or around 1.5 BCM.

A recent study has led to a better understanding of these recharge mechanisms (JICA 2002). According to this study, small, shallow depressions caused by calcrete dissolution become karstic sinkholes where local runoff concentrates and sinks into permeable layers or structures below. In addition, fractures are also a major source of groundwater recharge. These geological features exist in the west, northwest and southwest of the basin. It has been confirmed that water tables begin to rise in artesian aquifers some 50 km from these recharge areas a few weeks after heavy rainfall has occurred. In addition, isotopic evaporation of the water in these artesian aquifers is very low or nonexistent.

In contrast to this, the water in the Kalahari layers in the central part of the basin has a very definite isotopic evaporation signal, indicating that a substantial proportion of rainfall evaporates and consequently does not recharge the aquifer.

2.3.4 Groundwater extraction in Namibia

A hydrocensus conducted as part of the most recent study[37] covered 1,269 commercial farms and collected information at boreholes (including wells and springs). It was found that of a total number of 6,280 boreholes in the SAB, 4,915 are currently in use, of which 3,915 tap the Kalahari Aquifer and 1,000 the artesian aquifers.

Extraction from the Kalahari Aquifer is estimated to be 9.8 MCM/year. This comprises about 65 % of all water extracted in the SAB in Namibia. Of the 1,000 boreholes drilled into artesian aquifers, 200 (20 %) yield artesian flow while 800 (80 %) tap subartesian water levels. 4.97 MCM/year are extracted from the Nossob Aquifer and only 0.2 BCM/year from the Nossob Aquifer (see table 2).

The depth of the boreholes ranges from 250 to 380 m. The age of the water is less than 40,000 years, and the water temperature is around 30 °C.

37 See DWAF (Namibia) / JICA (2000).

The artesian pressure is normally around 11 m, but drops in some places to between 5 and 6 m. Different factors may be responsible for this phenomenon: overextraction from the artesian aquifers, leakage into the upper aquifers, or a possible compression of confined layers, thus reducing storage capacity.

Table 2: Extraction data for Namibia

Aquifer	Stored volume (BCM)	Extraction (MCM/year)	Percentage of total (%)
Kalahari	120	9.80	65.50
Auob	180	4.97	33.20
Nossob	57	0.20	1.30
Total	357	14.97	100.00

Source: DWAF (Namibia) / JICA (2000)

3 Groundwater use patterns

The following is an attempt to shed light on patterns of groundwater use in the three countries which share the SAB's aquifers. All countries are highly dependent on groundwater resources, since climatic conditions are arid and surface water is unavailable during most of the year, especially at the joint borders.

3.1 Groundwater use patterns in Namibia

Approximately 35,000 people live in the SAB in Namibia. They extract groundwater from aquifers in the SAB for their domestic water supply, their livestock production, and for irrigation. Almost no groundwater is used for industrial purposes (see table 3).

Groundwater for domestic purposes in larger towns in the area is extracted from the Auob Aquifer. Only the town of Koës in the south uses water from the Nossob Aquifer. The subartesian aquifers at Aminuis have maintained their yields over many years, but other boreholes in the same aquifer have lower yields. At Leonardville, over-extraction has caused a large local drop in the water table, but at Aranos in the northwest the aquifer continues to supply sufficient water of good quality (although fine sand entering the boreholes causes operational problems). The town of Gochas formerly obtained water from the Auob Aquifer, but this groundwater gradually became contaminated with salt water from the overlying 150-m-thick Kalahari Aquifer, and it proved necessary to move the boreholes to a more suitable well field some 10 km to the north.

The great majority of the local population is dependent on farming for its livelihood. Groundwater is supplied to about 2,000 commercial farms in the SAB; these have now diversified from the production primarily of karakul pelts to stock farming with cattle, sheep, goat and ostriches. Groundwater is also used by 160 farms for irrigation, and the total area under irrigation is about 550 ha (all information by Piet Heynes).

The extension of the national electricity supply network to this area has increased the economic viability of irrigation farming, and further expansion will be limited only by the availability of water. It can be assumed that a major challenge for stakeholders in the area will be to determine the ecological and social sustainability of available water.

Table 3: Water consumption in the Stampriet Artesian Basin in Namibia

Sector	Consumption (MCM/year)	Percentage of total (%)
Domestic	2.37	15.80
Stock	5.70	38.10
Irrigation	6.90	46.10
Total	14.97	100.00

Source: DWAF (Namibia) / JICA (2000)

Almost no groundwater is used for industrial production. Although it is known that high-quality coal deposits are present, there is as yet no mining activity.[38] The small service industries in the towns are not major water consumers. The value of economic activities in the basin is estimated at roughly 1.33 million US$/a (N$1.0 billion/year, 1 US$ = 7.5 N$).

A study carried out by the DWAF (Namibia) and JICA in 2000 came to the conclusion that present groundwater extraction exceeds recharge in SAB, and that the groundwater supply is therefore unsustainable at present extraction rates. However, the assumptions used by this study to create a model of the water balance and for deriving rates of water use and sustainable extraction were not fully agreed upon by all stakeholders in Namibia. Consequently, monitoring has been further improved in order to keep track of these quantities and, if necessary, to arrive at results on the basis of which reasonable allocation decisions can be made.

Changes in groundwater availability on the Namibian side due to overuse make the question of future development of the aquifer a complicated and politically sensitive issue. Both the supply of potable water and the economic activities of the population in the basin depend on groundwater. What is certain is that artesian pressure on the Namibian side has decreased in some places from 11 m to 5 or 6 m in other places. Three possibilities have been advanced for this: over-extraction from the artesian aquifers, major leakage into the upper aquifers, and/or a compression of the confined layers which may have reduced storage capacity. Stakeholders in Namibia have reacted to these changes with further improvements in groundwater management in order to avoid further losses. Moreover, groundwater monitoring has been intensified in order to acquire reliable data as a basis for development decisions.

38 An investigation by the Coal Commission has shown that the coal deposits probably cannot be mined profitably, especially in view of the depth and the artesian water environment.

3.2 Groundwater use patterns in Botswana

Population density is low in Botswana's Molopo Basin, that part of Botswana into which the SAB extends. This is particularly true of the Kgalgadi District next to the Namibian border (ORASECOM 2007, 13–14). Extraction from the SAB in Botswana is therefore estimated to be limited. Groundwater is the only available water source most of the time in this region. It is drunk by game and is used for stock watering, human consumption, agriculture, and tourism.

Current plans to develop commercial ranching in the Kgalagadi District would overstrain the available supply of fresh groundwater (Cheney et al. 2006). Moreover, recent studies of the hydrogeological potential of the Kalahari's deep Ecca Aquifer in southwestern Botswana have shown that groundwater in the high-yield Ecca Aquifer is suitable neither for human nor for animal consumption due to its high salinity.

One third of the Kgalagadi District is in the Kgalagadi Transfrontier National Park, where water is used for tourism and by wild animals. The park is shared by Botswana and South Africa and unites the Kalahari Gemsbok National Park in South Africa with the Gemsbok National Park in Botswana. It can be assumed that further development of tourism in the region will (modestly) increase water demand.

3.3 Groundwater use patterns in South Africa

In South Africa, the Kgalagadi Transfrontier National Park is part of the Gordonia District in Northern Cape Province. The area belongs to the Lower Orange Water Management Area. The DWAF (South Africa) has underscored the importance of careful groundwater utilisation in this water management area, since groundwater is the only source of water in many parts of the WMA. However, groundwater availability and quality is low in the northern, sparsely populated parts of the bordering Namibia and Botswana[39] (DTEC/CSIR 2004, 15).

39 Since the borders of the SAB have not yet been clearly identified, it should be noted that the Molopo groundwater region can count on a much higher availability of groundwater (Molopo: 31 MCM/year, Lower Orange – Orange Sub-Water Management Area: 9 MCM/year) (DTEC/CSIR 2004, 15).

Both surface and groundwater extraction facilities in the area are so fully developed and utilised that no significant potential for further development exists (DWAF [South Africa] s. a.). In particular, aquifers in the Karoo sediments have only limited potential for further development because, apart from their water quality, their permeability and storativity is low. Consequently, it would be possible to derive significant further quantities of water only through a high number of boreholes (ORASECOM 2007, 108).

4 Transboundary implications

The following chapter elaborates on transboundry impacts in the SAB and analyses the cooperation problem which is mainly characterized by highly asymmetric development of the groundwater resources in the SAB.

Although accurate information on the extent and composition of the hydrogeological environment is almost entirely limited to the Namibian side, it is certain that aquifers in the SAB there continue further southeastwards into Namibia's neighbouring countries. The SAB must therefore be regarded as a transboundary aquifer system. Thus, transboundary impacts can occur.

At the time of writing, no information was available that point towards manifest negative transboundary impact from this use. Nor is information available which might indicate a reduction of extractable volumes on the part of downstream riparians due to (over-)use in the (Namibian) upstream area. Nor is the decline in water quality along the groundwater flow from northwest to southeast caused by groundwater use in the upstream riparian area; it is assumingly due to natural processes which limit the usable volume of groundwater (information from DWAR).

Therefore, even if Botswana and South Africa were to aim at further development of the SAB's aquifers in their territories, the low quality of the water in these aquifers and their respective hydrogeological conditions would probably limit possibilities for usage. However, an accurate assessment of transboundary implications will be possible only after the boundaries and interrelationships of the aquifer basin as a whole become known.

The transboundary cooperation problem at the SAB is characterized by two facts: First, demand and use by the riparian countries is asymmetrical, as the previous chapter has shown. Although three countries share the groundwater basin, only Namibia makes significant uses of its groundwater. This is presumably due to the more favorable natural conditions, i.e. groundwater occurrence and quality, on the Namibian side.

Secondly, transboundary cooperation in use of SAB groundwater must take into account the upstream-downstream constellation between Namibia as the upstream riparian and Botswana and South Africa downstream. This can be illustrated by using the types of Eckstein and Eckstein already described (Eckstein / Eckstein 2005). As mentioned, these six types were developed as paradigms for the application of international law in relation to groundwater. They show the potential implications of transboundary groundwater by two riparian countries which share one aquifer.

Although three countries share the SAB, and in spite of the fact that little is known about the aquifers underlying Botswana and South Africa, the Eckstein Models B and E seem to apply best to the situation in the SAB the upper Kalahari Aquifer is unconfined, the lower Auob and Nossob Aquifers appear to be partially both confined and unconfined, and recharge is present in one country. The aquifers are hydraulically connected to rivers and are intersected by international borders, and there is a water flow from one state to the other (in this case Namibia would be State A, Botswana and South Africa would be State B/State C).

Following this analysis South Africa and Botswana are likely to be only moderately interested in using the SAB's groundwater because of its poor quality and because population density in the border regions is low. For their part, Namibian farmers, who are in an upstream position, will likewise have only a limited interest in cooperating with their neighbours for fear that this might limit their use of groundwater from the SAB, on which they are very dependent.

Apart from the transboundary groundwater cooperation problems, groundwater management problems exist within Namibia (compare 3.1), and conflicts between Namibia and Botswana over available surface water have occurred. Future water-related conflicts could also arise due to dam building projects and to growing water demands on all sides as a result of population growth and climatic changes.[40]

5 Institutional arrangements for groundwater management and transboundary cooperation

The following is a brief overview of national and interriparian institutional arrangements for groundwater management in the SAB. A detailed analysis of these arrangements, including water legislation and policies, would far exceed the scope of this paper and is therefore not given here.

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40 Conflicts between Namibia and Botswana over available surface water runoff are reported stemming from a number of dams that have been built in the upper reaches of the Auob and the Nossob rivers in Namibia. The downstream impacts of these dams have been regarded as negligible by Namibia. The reason for this approach is firstly the fact that the flow in the Oanob River, which is a tributary of the Auob River, is basically blocked off by sand dunes and the runoff would therefore not have been available to augment flow further downstream in the Auob. The effect of the Oanob Dam at Rehoboth in Namibia on the flow Oanob River and indirectly in the Auob River could therefore be regarded as negligible. Secondly, the same argument applies to the Otjivero Dam at Omitara on the White Nossob River and the Daan Viljoen Dam at Gobabis on the Black Nossob River. The Otjivero Dam commands a relatively small portion of the total catchment and the Daan Viljoen Dam has a very small basin that can only impound a small portion of the runoff. Downstream of the confluence of these two tributaries the river is known as the Nossob River.

It is also known that the farmers along the Nossob river construct low cost embankments comprising the *situ* river alluvium, about 1,000 mm high, across the river to retard the flow during runoff events in order to give the water time to recharge the alluvium in the river bed with groundwater for future extraction. These embankments are normally washed away during a runoff event. However, this practice raised concern by Botswana because it is perceived that there is a reduction in the surface runoff in the Nossob River where it forms the border between Botswana and South Africa in the Kgalagadi Transfrontier National Park (Information from DWAF [Namibia]).

A conflict has also arisen because farmers along the Nossob river regularly construct low-cost embankments of *in situ* river alluvium about 1 m high across the river to retard its runoff in order to recharge the alluvium in the river bed with groundwater for future extraction. These embankments normally wash away during runoff. This has caused concern in Botswana that surface runoff may be reduced in the Nossob River between Botswana and South Africa in the Kgalagadi Transfrontier National Park (Information from DWAF [Namibia]).

5.1 National institutional arrangements

5.1.1 Institutional arrangements in Namibia

The Department of Water Affairs and Forestry for Namibia (DWAF [Namibia]) within the Namibian Ministry of Agriculture, Water and Forestry has a Geohydrology Division which is responsible for all water resource development projects in the country, including irrigation planning and development.

Groundwater extraction in Namibia is controlled through a permit system. After Namibia came under South African administration in 1921, the Artesian Water Control Proclamation (Proclamation 49, 1921) for the control of drilling activities in artesian aquifers in the country was issued in 1921 in order to ensure correct drilling techniques and prevent leakage from the confined artesian aquifers into the surrounding unconfined aquifers.

A licence had to be obtained before any drilling work was carried out, and all boreholes had to be licensed for purposes of supervision. This Proclamation was followed by two more in 1949 and 1950 in an attempt to improve the control over the drilling and extraction of water. In 1955, the existing laws governing use of artesian water were consolidated in the Water Ordinance No 35 of 1955, and the SAB was formally declared a Subterranean Water Control Area. The Ordinance also required that information about the actual quantity of water extracted must be provided by the permit holder. After the Articles of the South African Water Act of 1956 (Act No 54 of 1956) were made applicable in Namibia, Regulation R1278 was promulgated to regulate the sustainable use and management of artesian water sources, including those of the SAB.

At present, existing laws and regulations are enforced in the form of cooperation with water users. Groundwater management is controlled by means of both the permit system and the activities of local water user committees.

User participation is institutionalized in Namibia through Basin Management Committees. These organizations are created for surface water basins. In view of concerns on the part of both local water users and the government about possible overextraction of water in the SAB in Namibia, an aquifer management committee, the so-called Stampriet Basin Water

Committee, was formed to assist the Department of Water Affairs and Forestry in monitoring water utilization in the basin.

The Department consults with the Committee about new applications for water development, and the Committee provides information about the extraction of water, the management of water resources, the illegal drilling of boreholes, leakage of boreholes, and any wasteful use of water. The Department also monitors water levels and gives technical advice to the drilling industry about the development of boreholes under artesian conditions. The technical capacity of the Committee is limited, however, by the fact that its members are mostly farmers who have not been trained in water-related disciplines.

5.1.2 Institutional arrangements in Botswana

A number of institutions are responsible for water management in Botswana, including the Department of Water Affairs (DWA), the Department of Geological Surveys, and the Water Utilities Corporation in the Ministry of Minerals, Energy and Water Affairs, which is responsible for national water policy. The Water Utilities Cooperation is responsible for supplying water to all urban and mining centres. The Ministry of Agriculture supervises water provision to livestock and agriculture. In the rural areas, district councils under the supervision of the Ministry of Local Government, Lands and Housing oversee the supply of water to rural villages (FAO Country Profile Botswana).

This organizational setup has been criticised as lacking a clear and simple structure for water administration and for poor performance as a result (Swatuk / Kgomotso 2006, 4).

In Botswana, the National Water Master Plan being revised with the aim of providing an analysis of development potential of all available water resources. Given Botswana's high dependency on groundwater, this is of special concern: the Botswana Government currently estimates that groundwater supplies will be exhausted by the year 2020 due to increasing demand (NWMP 1992, cited in Swatuk / Kgomotso 2006, 3). Options currently under consideration are infrastructure developments such as dam construction, more boreholes, intrabasin and inter-basin transfer schemes, and technological intervention for better detection and utilisation of groundwater resources (Swatuk / Rahm 2004; Allan 2003 both cited in Swatuk / Kgomotso 2006, 3).

Against this background, Botswana has recognized the use of internationally shared water supplies (border rivers and perhaps transboundary aquifers) as a very important challenge for the future. It has therefore established an International Water Unit within the Ministry of Natural Resources to provide technical support for the management of shared river basins (Kranz / Interwies / Vidaurre 2005, 4, 5).

In the area of the SAB, however, no user-based organisation or institutionalized participation mechanism are known in Botswana. At most, an institutionalised mechanism of participation for the Okavango region has been mentioned by Swatuk and Kgomotso, who also describe a countrywide Community-Based Natural Resources Management Program; both rely on stakeholder participation (Swatuk / Kgomotso 2006, 3). It can therefore be assumed that at least a few user participation mechanisms do exist, at least formally, in the Botswanian part of the SAB.

5.1.3 Institutional arrangements in South Africa

In South Africa, the Water Act of 1998 specifies that all water use, with the exception of reasonable domestic use, home garden use, and stock water requirements, must be licensed. The issue of shared water basins is also integrated into this act (compare Heyns 2005, 60).[41] The Geohydrology Division in South Africa's Department of Water Affairs and Forestry (DWAF [South Africa]) is in charge of for groundwater-related issues in that country. The DWAF (South Africa) monitors surface and groundwater resources, supports the formulation of national water strategy, and is responsible for implementation of the Water Act. For its part, the Water Research Commission is responsible for most of the research conducted on the various aspects of water use in South Africa.

The Water Act divides South Africa into 19 Water Management Areas. It provides for a phased establishment of catchment management agencies which will gradually take over water resource management functions currently performed by the DWAF (South Africa). These catchment mana-

41 For an assessment of South African Water Policy see for example Turton et al. (2003).

gement agencies will be responsible for planning, implementing and managing water resources and will also coordinate all water-related activities and ensure public participation in water management (Mvula Trust 2005).

Where water user associations and catchment management agencies have not yet been finalized or are still being set up, the DWAF (South Africa) will continue to carry out these functions. Establishment of a catchment management agency for the Lower Orange WMA has only low priority, and it will therefore be years before this catchment management agency can take over the tasks of DWAF (South Africa) in this area (Herrfahrdt-Pähle, personal communication 2007).[42]

5.2 Interriparian agreements on water

Numerous bilateral and multilateral agreements exist concerning water use among the riparian countries. For the SAB, however, no special institution for joint management is in place, and consequently no formal interriparian cooperation in use of the SAB exists. Due to the fact that the riparian countries already cooperate in the form of numerous agencies and therefore share close contact and experiences regarding transboundary water management, formal and operational collaboration on groundwater issues will probably intensify as the need becomes more pressing. Since the SAB lies within the Orange River Basin, the River Basin Commission would be the most likely candidate in that case to assume responsibility for transboundary groundwater management.

5.2.1 Bilateral agreements

In 1992, the governments of Botswana and Namibia established a Joint Permanent Water Commission (JPWC) to deal with water matters of common interest (i.e. the Okavango River, various transboundary groundwater sources, and the Kwando-Linyanti-Chobe System (Heyns 2005, 71). According to Turton et al., this agreement is the only known international

42 Turton et al. discuss successful cooperation between the Water User Associations and the DWAF (South Africa) for managing the transboundary Pomfret-Vergelegen Dolomitic Aquifer, which is shared by South Africa and Botswana (Turton et al. 2006b, 377–384).

agreement in the SADC region that includes groundwater systems (WRC 2007, 25).

South Africa and Namibia established a Permanent Water Commission (PWC) in 1992, particularly in order to deal with issues involving management of the Lower Orange River along the common border between the two countries. The Commission's responsibilities were also to extend to ephemeral rivers along the boundaries of the Walvis Bay enclave in Namibia, which was South African territory until 1994. Although management of internationally shared groundwater sources was not specifically mentioned at that time, both States implicitly understood that it falls within the Commission's area of jurisdiction (information from DWAF [Namibia]).

5.2.2 Multilateral agreements

As members of the Southern African Development Community (SADC), all riparian countries of the SAB support the SADC Protocol on Shared Water Resources. They are also members of various other river basin commissions. The SADC has given increasing attention to groundwater issues in recent years (box 1).

The riparian countries of the SAB also share the Orange River Basin with Lesotho. In November 2000, they established the Orange-Senqu River Basin Commission (ORASECOM) in order to deal with water matters of common interest[43] and agreed to share information on a regular basis. In order to improve joint efforts to protect the basin, the parties also agreed to notify each other of any activities affecting the river system which might have a negative impact on the other riparians.

ORASECOM is intended to be a mediatory as well as an advisory body to the members. It conducts feasibility studies and can, in case of disputes or disapproval, transfer the issues in question to the political level, where the SADC's dispute settlement mechanisms come into play (Wirkus / Böge 2006). ORASECOM is funded both by the water ministries of the member states and by international donors. Together with other international donors, Germany is providing support for the development of ORASECOM.

43 Botswana and Namibia also cooperate in the Permanent Okavango River Basin Water Commission (OKACOM) and the Zambezi Watercourse Commission (ZAMCOM).

The institutional structure of ORASECOM was modified in 2005[44] to provide a small secretariat in South Africa and a Technical Task Team for the management of ORASECOM projects.

Currently, ORASECOM has put together a groundwater overview as a prelude to the development of the Integrated Water Resources Management (IWRM) Plan for the Orange Basin (see ORASECOM 2007). This clearly shows the importance of groundwater issues for ORASECOM. Another hint in this direction is, for example, the fact that in 2004 ORASECOM presented a project portfolio to the EU in which numerous legislative issues and studies of transboundary aquifers were listed as priorities (Heyns 2004, 9, in Wirkus / Böge 2005). The need for further investigation of the shared aquifers was again underscored in the preparatory paper for the IWRM plan concerning groundwater (ORASECOM 2007).

It should also be noted that the member governments instructed ORASECOM at its inception to conduct a joint study of the Molopo and Nossob watercourse system. Terms of reference for a formal study have already been drafted, and donor interest has been mobilized to fund the project. Since the lower Nossob River may lie within the SAB, an inventory of water resources in the study area will probably also yield information on the SAB.

Since ORASECOM's head offices are manned by only a small staff, the capacities of ORASECOM for transboundary groundwater management in the SAB depend heavily on the capacities of the member states themselves, i.e. on their political willingness to cooperate in use of the SAB.

44 The importance and strategic interests of all riparian countries in the Orange-Senqu-Basin are analysed in Wirkus / Böge (2006) and Kranz / Interwies / Vidaurre (2005).

Box 1: Groundwater in the SADC

All riparian countries of the SAB are members of the SADC and are therefore committed to support the SADC Protocol on Shared Water Resources (a revised version of which came into force in 2003). This Protocol defines watercourses in accordance with the UN Convention on Use of International Watercourses, which are defined in that Convention as systems in which surface and ground waters flow into a common terminus. The SADC Protocol lays down principles for the coordinated, cooperative and equitable use of water by the riparian countries. It takes issues of social development and environmental protection into account, and mandates an exchange of information among the riparian states about plans and projects pertaining to shared water resources. The SADC protocol provides for the development of joint management mechanisms (e.g. at the river basin level) and supports the IWRM concept, which implicitly includes groundwater.

Given the importance of transboundary aquifers in the SADC region, experts have called for an SADC agreement that specifically focuses on groundwater. To this end, accurate groundwater maps, groundwater classification in terms of hydrogeological characteristics and future demands, and adequate management regimes are deemed necessary (Turton et al. 2006, 3).

The Regional Strategic Action Plan for IWRM of 1998 includes a Regional Groundwater Management Program as one of 31 strategic projects. This Groundwater Management Program for the SADC Region aims at promoting sustainable use of water resources by assessing groundwater and groundwater management programs, integrating groundwater issues into regional water resource development programmes, and linking up national and regional initiatives in this respect.

The SADC has established a Sub-Committee for Hydrogeology in which each member state is represented. This committee supervises and guides national hydrogeological projects of regional magnitude. The Sub-Committee has undertaken an analysis of groundwater management in the Member Countries and has prepared a Regional Code of Good Practice for Groundwater Development. Joint management of river basins and their underlying groundwater resources is encouraged by the Sub-Committee in order to ensure efficient use of the RBO's institutional and personnel capacities.

Box 1 continued
International donors are active in the groundwater sector of the SADC. With support from United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Kingdom has provided grants, and International Groundwater Resources Assessment Centre (IGRAC), a web-based database for information on transboundary aquifers in Southern Africa, has been developed to facilitate information sharing and joint transboundary groundwater management. Nevertheless water experts from the region agree that information on the transboundary implications of groundwater use in the region is lacking in many cases and mostly concerns only one riparian country. Difficulties in reaching a regional consensus on groundwater information requirements reflect the lack of a functioning regional monitoring network (WRC 2007, 24). The World Bank, the Global Environment Facility (GEF) and the Swedish International Development Cooperation Agency (SIDA) are currently supporting a SADC Drought Management Project. One of the project's objectives is the establishment of a regional Groundwater Institute of Southern Africa (GISA). Moreover, the German and French governments are funding hydro-geological mapping activities as part of this international project (WRC 2007, 24).

6 Prospects for transboundary cooperation and recommendations for German development cooperation

Access to information and conclusions

Namibia can rely on detailed information concerning the SAB. (This information has kindly also been made available to the author of the present study by Piet Heyns).

Only limited information is available concerning aquifers in Botswana and South Africa, presumably because precise data on SAB aquifers underlying the two countries is still lacking. It would certainly be worthwhile to investigate these aquifers in more detail as part of a full-scale investigation of groundwater occurrence in the SAB. Among other benefits, this would permit an investigation of potential downstream impacts in the basin.

The fact that the SAB has not yet been fully investigated in the very groundwater-dependent countries of Botswana and South Africa suggests that these two riparian countries have limited interest in making use of the SAB.

Transboundary implications and conclusions for transboundary cooperation

Aquifers in the SAB are heavily used in Namibia, where water occurrence and water quality are favourable. However, there are also signs of overuse of the aquifers in the SAB there. In Botswana and South Africa, on the other hand, groundwater use in the area assumed to lie within the SAB, that is, in the triangle between the three countries and near the border between Botswana and Namibia, is rather limited. This seems to be due to the rather poor quality of the groundwater, which in Botswana and South Africa is apparently similar to the low water quality of Namibia's so-called “Salt-Block”. Both population density and demand in these areas of Botswana and South Africa are low.

The cooperation problem in the SAB shows two characteristics: First, a highly asymmetric demand and development of the groundwater in the three riparian countries, with Namibia as the only significant user the aquifers, and second, an upstream-downstream constellation between the upstream-user Namibia and the downstream riparians Botswana and South Africa.

However, from the information available rather similarly low incentives for cooperation can be concluded for Namibia as the upstream, main user of the groundwater and Botswana and South Africa with low water quality and/or limited groundwater occurence in the area. As for the South African side no possible further development of the groundwater resources in the (Lower) Orange Basin is stated, the interst to specificall cooperate over the SAB might also be limited. But, further information on potential transboundary impacts might modify this preliminary conclusion and reveal driving forces for cooperation.

Institutions already in place have created a promising environment for the riparian countries of the SAB to expand their cooperation (e.g. for carrying out joint studies on the hydrogeological environment of the aquifers) if needed:

— National institutions and policies for groundwater management are in place in all three riparian countries. This provides a basis for transboundary cooperation. In Namibia, where the SAB is used most, groundwater management is carried out in close cooperation with water users in order to ensure ecological and socially sustainable groundwater management.

— Botswana, Namibia and South Africa have all ratified the United Nations Convention on the law of non-Navigational Uses of International Watercourses, and all three states are party to the Protocol on Shared Watercourses drafted in accordance with the Treaty that established the SADC.

— In view of existing bilateral and multilateral water institutions (e.g. the JPWC, the Pricewaterhouse Coopers, and ORASECOM), there seems to be a considerable degree of understanding and mutual trust on both the technical and political levels between the basin states.

— Since no mechanism exists for transboundary consultation on the part of local authorities, the Water Committee in Namibia, and other riparian institutions, ORASECOM is destined to play a key role in supporting transboundary groundwater investigations and studies and in monitoring initiatives in the SAB. ORASECOM is aware of the importance of this role for basinwide groundwater management and is integrating its tasks into the development of the Orange Basin IWRM Plan.

— The capacity of ORASECOM to carry out projects for transboundary groundwater management in the SAB will depend on the personnel and financial capacities made available by the member states; this in turn will depend on the priorities of the member states. At present, the riparian countries appear to assign only low priority to transboundary groundwater management of the SAB.

Role of external factors and recommendations for German development cooperation

External factors play a role mainly in the development of technical capacities and advisory services for water policies at national and regional levels and in providing support for hydrogeological and socio-economic investigations.

In this regard, German development cooperation can be applied effectively at both the national and regional levels:

— At the regional level, German DC should support the riparian countries through the ISARM initiative in a basin-wide groundwater investigation in order to clarify potential transboundary implications and to find possibilities for the improvement of groundwater use and development in the riparian countries. In the process, German development cooperation can contribute to the SADC Regional Groundwater Assessment Project, which lists development of the Karoo aquifers as one of 10 high-priority projects. In this regard, German expertise could be brought in by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

— At the regional level, German DC should support transboundary groundwater management as a task of ORASECOM. Currently, German DC is already bilaterally supporting ORASECOM by supporting the SADC water management as implemented through Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). Here, a "groundwater component" could be added.

— At the national level, only Namibia has found signs of overuse of the SAB aquifers. Support for ecologically and socially sustainable groundwater management should therefore be provided by German DC. Water, however, is not a priority of German development cooperation in the three riparian countries. In Namibia, on the other hand, water-related activities are being carried out in the priority areas of environmental policy, conservation and sustainable use of natural resources.

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The North-West Sahara Aquifer System

A case study for the research project "Transboundary groundwater management in Africa"

Oscar Schmidt

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The North-West Sahara Aquifer System

Oscar Schmidt

1 Introduction

The paper at hand represents one of five illustrative studies within the research project “Transboundary groundwater management in Africa”. The project aims to assess typical riparian constellations based on the aquifer systems’ hydrogeological attributes. Secondly, it is the aim to identify specific cooperation problems which evolve out of these hydrogeological attributes and prevalent use patterns. Last but not least, the project aims to identify transboundary impacts deriving from groundwater uses and to develop policy recommendations. The huge groundwater reservoir of the *North-West Sahara Aquifer System* (NWSAS) is being shared by three North African countries. Across the globe, many countries are well experienced and often also well organized in terms of inter-riparian cooperation on transboundary river basins. In addition, research in this field has led to considerable knowledge. Accordingly, many institutional regimes and organizations have been established to successfully manage international rivers. It can be assumed that these experiences and the already existing cooperation mechanisms may serve as a basis to govern transboundary groundwater resources as well. However, although the NWSAS displays a range of characteristics which may represent many other similar settings in arid, water scarce regions, it does not feature a transboundary river basin as well. Correspondingly, no joint experiences and organizations exist upon which the riparian countries could build their efforts for cooperation. Especially for this latter reason an analysis of the NWSAS can be of particular interest for policy makers and researchers.

Section 2, will provide an analysis of the hydrogeological characteristics of the NWSAS. *Section 3* then discusses a range of socio-economic and water-related features of the respective riparian states Algeria, Tunisia and Libya. *Section 4* will go further into detail on the countries´ specific water resources and their national use patterns. As a follow up, *Section 5* discusses national and transboundary impacts that derive from current and future exploitation patterns. *Section 6* provides a short description of the actual inter-riparian agreements and consultation mechanisms that have been implemented up to this date. In *Section 7* the paper finally concludes with the identification of prospects for transboundary cooperation and recommendations for the German development cooperation.

2 Characteristics of the aquifer

The *North-West Sahara Aquifer System* often referred to as the *Système Aquifère du Sahara Septentrional* (SASS) is one of two major North African transboundary groundwater basins. Approximately half the size of the *Nubian Sandstone Aquifer System*, it is predicted to cover around 1 million km^2 and reaching a scale of 1,800 km from east to west and 900 km from north to south (Besbes et al. 2004, 163). As a result, the aquifer system spreads under large areas of Algeria and Tunisia and also parts of Libya. Its exploitable water reserves have been calculated at 1,280 km^3 (Struckmeier / Richts 2006). The present water stock is characterized as being of average quality with a high vulnerability towards salinization (Besbes et al. 2004, 163). Being located in one of the driest regions on the planet, these huge resources have been recognized to be of great importance to the socio-economic development of its riparian countries. In order to fully assess the aquifer system´s potential for groundwater provision it is necessary to highlight and understand its hydrogeological characteristics.

The NWSAS can be categorized as a multi-layered system of aquifers which embodies a huge stock of non-renewable, fossil water. It displays a mostly porous and fissured / fractured structure (Struckmeier / Richts 2006). The geological structure determines the aquifer's recharge infiltration rate and the velocity of groundwater flows in time and space. Among its different layers, two have to be distinguished as being of major size and importance. The so called *Continental Intercalaire* (CI) is located on the lower level. It has a thickness of many hundreds of meters and is found in depths ranging from around 400 up to 2,000 meters below ground. According to Besbes et al. (2004) the CI contains a set of layers with very differing lithology, comprising mainly continental sandstone in alternation with marine limestones and clay formations (see also Zekster / Everett 2004). The second of the two layers is the so called *Complexe Terminal* (CT). The CT is located on the upper level of the aquifer system. It designates limestones and continental, sandy and clayish formations, dating from the Upper Cretaceous to the Miocene and Pliocene (Besbes et al.

2004, 165). Additionally shallow phreatic aquifers of local importance occur. Especially at the basin boundaries connections between them and the deeper aquifers occur. In former times the CI and the CT were assumed to be disconnected from each other. However, in the course of research findings which have been obtained through the inter-riparian *NWSAS-Project*, this was proven wrong (Besbes et al. 2004, 69).

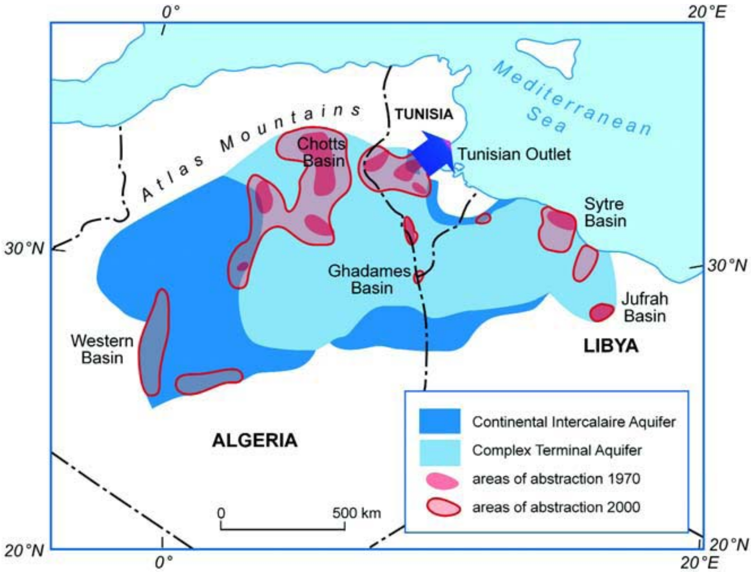
Eckstein and Eckstein (2003) have developed six different types which were intended to serve as paradigms to apply international law to the case of transboundary groundwater basins. Among these types, the author identifies the so called types *F* as fitting to the hydrogeological characteristics of the NWSAS. At this instance the type may as well serve as an illustrative basis to discuss some of the facts which will be presented in this paper. *Figure 1* provides a schematic visualization of the respective model.

The authors describe transboundary aquifers like the NWSAS as *"unrelated to any surface body of water, disconnected from the hydrological cycle, and thus devoid of any meaningful recharge. There is neither a distinct recharge nor discharge zone, the water table is quasi-horizontal, and the water stagnant with no perceptible flow. The transboundary consequences are therefore almost exclusively a function of pumping the aquifer in one or more of the overlying states. When a state commences groundwater pumping, it will create an ever-expanding cone of depression that will eventually encroach across the border. If the two countries employ competing wells on opposite sides of a border, the two cone depressions may overlap and coalesce. If states do not stop pumping, this aquifer eventually will be fully depleted."* (Eckstein / Eckstein 2003, 247). The description of *transboundary consequences* highlights the strong interdependency between specific hydrogeological features and impacts from human activities. This interdependency is apparently of great importance, because a comprehensive understanding of it can be seen as a prerequisite for any successful transboundary cooperation policy. It is important to note, that *type F* is a simplification. Due to a number of reasons which will be highlighted in the following this type does not fit accurately to the NWSAS. Accordingly, the description of *transboundary consequences* (see above) could therefore be inaccurate and misleading as well. On the contrary, one might also argue this inaccuracy to be negligible or at least of little importance, due to spatial and temporal reasons. In either case it seems to be sensible to at least address the respective mismatches.

The first, most obvious inaccuracy of course lies in the fact that it is not two but three states which actually share the resource. This does not necessarily contradict the assumptions on possible transboundary consequences as given above. Still, with a growing number of actors the task of tracing those causing a problem and compensating those directly affected by it will eventually become increasingly difficult. Further criticism has to address differences concerning the hydrogeological characteristics of the NWSAS and the respective type. Unlike Eckstein and Eckstein, other sources state that the aquifer system is in fact recharged by an annual average of 1 billion m^3 (Bied-Charreton 2002; Besbes et al. 2004; Mamou et al. 2006). The present recharge stems to a major extent from the *Saharan Atlas* in Algeria and the *Dahar* and the *Dj. Nefoussa* in Tunisia and Libya (Bied-Charreton 2002; Besbes et al. 2004; Mamou et al. 2006). Struckmeier et al. (2006) have calculated the annual recharge in proportion to the aquifer system's spatial extension to be less than 15 mm/year. A full turnover of the present water stock will therefore never occur within human time dimensions. Hence, recharge to the NWSAS might be regarded as inconsequently small in relation to the system's overall storage capacity and the water pressures deriving from the arid climate zone in which it is located (Eckstein / Eckstein 2003, 247). Accordingly, this groundwater unit has been classified as "non-renewable". The water which can be mined today is also to a large extent "fossil" since it was generated from rainfalls during the several humid phases of the pluvial times in the Pleistocene and the early Holocene (Edmunds / Wright 1979; Edmunds et al. 2003; ERESS 1972). However, the annual recharge cannot be left out of consideration. But it is necessary to recognize that recharge is limited to the unconfined areas of the NWSAS. Because of the complex structure of NWSAS geological sub-basins exist without any recharge. The current annual exploitation of the NWSAS ranges from 2.2 to 2.5 billion m^3 (Foster / Margat / Droubi 2006; Mamou et al. 2006). The classification "devoid of any recharge" would therefore be misleading.

Furthermore, research has highlighted some important flow patterns within the aquifer system. This fact contradicts the second assumption by Eckstein and Eckstein that the NWSAS is a rather stagnant water body, which is *disconnected* from the hydrological cycle. The underground flow patterns as shown by Pallas and Margat (2004) indicate an overall movement towards Tunisia. *Figure 1* provides a sketch of the NWSAS and its groundwater flow dynamics. Even though this visualization is rather simplified, it does indicate the trend of an overall flow from the inner-continental regions of Libya and Algeria towards the Tunisian coast [arrows].

Figure 1: Groundwater flow dynamics in the North-West Sahara Aquifer System



Source: Mamou et al. (2006, 69)

Groundwater flows at velocities between 1 meter per day and 1 meter per year. In the latter case it would take recharge water which entered the NWSAS on its western border, nearly 2 million years to reach its eastern border and 900 years to travel from the south to the north albeit any existing hydraulic connectivity on this course. Even at a speed of 1 m/day, these flows should therefore not be overestimated in their role of compensating exploitation efforts in place (Eckstein / Eckstein 2003, 218).

Regardless of the mismatches which have been discussed above, researchers have agreed on the NWSAS to be *non-renewable* and *fossil* as well as in its central compound *unrelated* to any surface body of water. As Eckstein and Eckstein have highlighted in their description of *type F*, these characteristics will inescapably lead to the total depletion of the resource, such that it will not be available for future use (Foster / Margat / Droubi 2006, 14). In reference to the exploitation of other non-renewables such as crude oil and gas, water extraction from a non-renewable aquifer is called *mining*. In the case of a transboundary aquifer system, groundwater mining activities are imposed by special conditions and constraints (Foster / Margat / Droubi 2006, 19). In this context, Eckstein and Eckstein (2003) state, that *"groundwater does not respect any political borders"* (see above). Apart from the international political scale to which this discourse mainly applies, groundwater mining also imposes great challenges on the national scale. Speaking in economic terms it is therefore a *common pool resource* which neither features the characteristics of a *private good,* nor those of a *public good*. It is impossible to exclude non-authorized actors from its use, it is rival and its exploitation may impose negative external effects on third parties. Foster et al. (2006) argue that *"groundwater resources become available for exploitation through technical advances and economic improvements which interact to make possible the mining of groundwater from an aquifer"* (Foster / Margat / Droubi 2006, 20).

3 The riparian states and their water resources

In regard to the earlier statement by Foster / Margat / Droubi (2006) it is sensible to take a closer look at the riparian countries from a socio-economic point of view in order to assess the actual and the possible future development of the transboundary aquifer. In the case of strong differences between the riparians` socio-economic capabilities it is possible that an asymmetry of utilization may occur. The characteristics as applied above would then in fact change towards virtual excludability with even higher external costs for third parties.

3.1 Algeria

With approximately 60 % to 69 % of the total surface Algeria occupies the biggest share of the NWSAS (Bied-Charreton 2002; Besbes et al. 2004; Mamou et al. 2006). Apart from its inter-riparian relations in the NWSAS the country shares five additional transboundary aquifers with other neighboring states (Struckmeier / Richts 2006). It is assumed that this fact influences the country's behavior as a transboundary riparian, because the concern and motivation for international cooperation is expected to be higher in countries sharing several transboundary aquifers (Appelgren 2006).

With a population of 32.5 million and a current Gross Domestic Product (GDP) of around 102 billion US$, Algeria is the biggest economy among the three riparians (devdata.worldbank.org 2007). In terms of GDP per capita the three riparians do not differ to a considerable extent. Anyway, it may be questioned though, whether this latter factor is of any significance for the exploitation dynamics. Other than in the case of many major sub-Saharan transboundary aquifers, none of the three riparians are classified as a "failed state" (foreignpolicy.com 2007). In line with the hypotheses stated above, the index would therefore possibly indicate the presence of a low level of negotiation skills and management performance in an inter-riparian setting. Algeria is ranked 84th in the *Corruption Perception Index* (CPI) of 2006 which is provided by *Transparency International* (transparency.org 2007). The CPI ranks countries according to their perceived levels of corruption (descending). The higher the ranking the lesser a country is perceived of suffering from severe corruption.

Compared to the other two riparians, Algeria holds access to the biggest amount of renewable surface water in proportion to its total water resources. In figures dating from the year 1990 renewable surface water makes up for around 50 % of the overall current water supply of the country. Renewable groundwater is estimated at around 40 %, whereas non-renewable groundwater makes up only about 9 % of the total supply (OSS 2004). Accordingly, Algeria is classified as having "a predominance of internal, renewable reserves without any downstream reserve constraints" (OSS 2004). These figures maybe misleading that Algeria is quite well-sustained in terms of renewable water resources. Moreover, in comparison to countries which are blessed with high annual precipitation the total amount of renewable water accessible to the country is with about 11.6 km^3/year to be considered as extremely low (fao.aquastat 2007). Hence, the per capita demand ranges at only approximately 188 m^3/year. Compared to a consumption of about 3,000 m^3 per year and capita in the United States this amount is of course incredibly low (OSS 2004). Apart from its limited stock in renewable water Algeria holds a great reserve of exploitable non-renewable groundwater. This share is estimated at 1,500 km^3 (OSS 2004, 27). Note that the estimations presented here and in the following include non-renewable resources not only from the NWSAS but also from other groundwater basins to which the country has access. In terms of external in- and outflows Algeria receives only about 0.2 km^3/a water from its neighbor Morocco. While 0.1 km^3 flows at an annual average from Algeria into Tunisia (OSS 2004, 13).

3.2 Tunisia

With approximately 8 % to 10 % Tunisia occupies the smallest share of the NWSAS's total surface area (Bied-Charreton 2002; Besbes et al. 2004; Mamou et al. 2006). The country has no access to any additional transboundary aquifers. Tunisia has a population of 10.1 million and a current GDP of around 28.7 billion US dollars (devdata.worldbank.org 2007). It is ranked 51st in the *Corruption Perception Index* (2006) which is the best score in comparison to the other two riparian neighbors (transparency.org 2007).

Tunisia displays a similar distribution of its water supply to that of its neighbor Algeria. Renewable surface water makes up for 40 % of the overall current water supply of the country. Renewable groundwater is estimated at around 50 %, whereas non-renewable groundwater makes up for 10 % of the total supply (OSS 2004). Accordingly, Tunisia is as well classified as having *"a predominance of internal, renewable reserves"*. It also is being classified as *"not suffering from any downstream reserve constraints"* (OSS 2004). The total amount of renewable water accessible to the country is only about 4.6 km^3/a (fao.aquastat.org 2007). In terms of per capita demands Tunisia currently ranges at 248 m^3/a (OSS 2004). Tunisia holds even a bigger reserve of exploitable non-renewable groundwater than its neighbor Algeria. Respective estimations lie at 1,700 km^3 (OSS 2004, 27). The country receives 0.1 km^3 inflow from Algeria annually. No water leaves the country to neighboring states (OSS 2004, 13).

3.3 Libya

Libya occupies around 23 % of the total surface area of the NWSAS (Bied-Charreton, 2002; Besbes et al. 2004; Mamou et al. 2006). Libya shares two additional transboundary aquifers with its neighboring countries, of which the *Nubian Sandstone Aquifer System* shared among Libya, Chad, Egypt and Sudan is the most important for Libya´s groundwater consumption. With only 5.8 million inhabitants Libya is smallest in population numbers compared to the other two riparians. The current GDP is with 38.8 billion US$ comparatively high. In terms of corruption Libya is ranked 105th (transparency.org 2007). This ranking is highest in comparison to Algeria and Tunisia. Hence it could be of interest to analyze whether authorities and actors in Libya's national water sector perform less effective in terms of resource allocation and management than those in Algeria and Tunisia. And whether this also led or leads to problems on the scale of international management efforts.

Libya displays a distribution of its water supply which is completely different to those of its riparian neighbors. Renewable surface water makes up for only about 3 % of the overall current water supply of the country. Renewable groundwater is estimated at around 7 %, whereas non-renewable groundwater makes up for 77 % of the total supply. Other than Algeria and Tunisia, Libya is already engaged in re-use of wastewater and desalination to a considerable extent (OSS 2004). Accordingly, Libya is classified as having a predominance of internal, non-renewable resources (OSS 2004). It is the only country to be classified that way in the whole community of the OSS countries. The total amount of renewable water accessible to the country is only 0.6 km^3/year (fao.aquastat 2007). In terms of the per capita demand Libya ranges at an extremely high rate of ~809 m^3/year (OSS 2004). Libya holds the greatest reserve of exploitable non-renewable groundwater. Its current reserves are estimated at 4,000 km^3 (OSS 2004, 27). The country has no in- and outflow exchanges with its neighbors. Therefore it is relying fully on its non-renewable resources (OSS 2004, 13). *Table 1* summarizes the figures that were given with regard to the national distribution of water supplies within the riparian countries. The table originally served as a summary of water sources in the *Maghreb* region.

Table 1: Water resources in the riparian countries

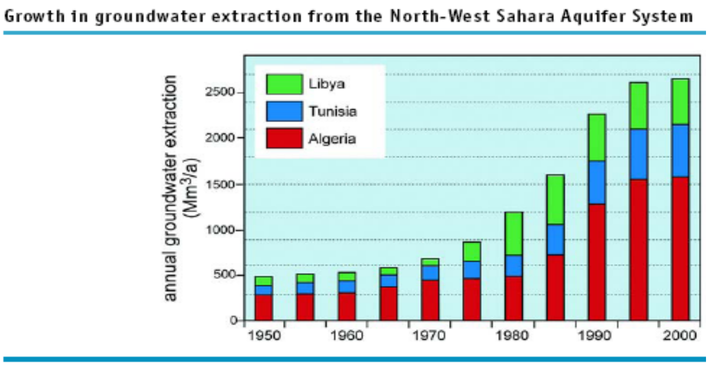
Country	Surface water (%)	Ground-water (%)	Total (%)	Exploitation of non-renewable groundwater resources (%)	Use of treated waste water and drainage water (%)	Desalination of seawater and brackish water (%)
Algeria	50	40	90	9	0	1
Libya	3	17	20	77	1.5	1.5
Tunisia	40	50	90	8	1.5	0.004

Source: OSS (2004, 41)

4 Groundwater use patterns

The total annual extraction from the NWSAS ranges currently at 2.2 to 2.5 billion m^3. Driven by all three riparian states, this rate has been increasing

Figure 2: Growth in groundwater extraction from the North-West Sahara Aquifer System



Source: Mamou et al. (2006, 69)

continuously in the course of the twentieth century. Figure 2 by Mamou et al. (2006) displays the increase of groundwater extraction from 1950 up to the year 2000.

Predictions for the future assume this trend to prevail. As the aquifer system is classified as “non-renewable” a full depletion of the resources will occur inescapably. However, it is the actual extraction rates which decide on the point in time when this will happen. *Section 5* will show that this scenario is still not the most pressing, since major problems related to over-exploitation occur a long time before depletion.

At date the NWSAS is exploited through a total of 8,800 water points (Mamou et al. 2006, 70). Other authors estimate a slightly smaller number of ~7,000 points (Besbes et al. 2004, 163). Analogous with the growth of the riparians populations and the growth of the regional economies it is estimated that the exploitation of the NWSAS will grow even further. In fact, Algeria and Libya are presently planning to increase their shares, and Tunisia plans to stabilize its extraction at its current rate. In this regard, Algeria has presented a so called “weak scenario” of raising its extraction amounts. This scenario opts for an increase from currently 42 m^3/s to 104 m^3/s. A second, “strong scenario” opts for an increase to even 143 m^3/s. Libya is planning to exploit additional 90 km^3/year in order to feed its *Great Man Made River Project*. Tunisia is the only riparian to choose for a stabilization by the means of optimizing its water utilization and by increasing its water treatment efforts (Mamou et al. 2006, 70).

The 8,800 water points as mentioned above can be subdivided into two major parts, of which 3,500 are situated in the *Continental Intercalaire* and another 5,300 are situated in the *Complex Terminal*. Algeria operates 6,500, while 1,200 lie in Tunisia and another 1,100 are being operated in Libya (Mamou et al. 2006, 68). As can be learned from Figure 3 and from the distribution of water points, Algeria exploits the biggest share of NWSAS resources ranging at around 1.3 billion m^3/year. Tunisia currently exploits 0.55 billion m^3/year and Libya accounts for the smallest share with 0.33 billion m^3/year. In 1999, Libya has mobilized 3,014 million m^3 of its non-renewable groundwater. This represented 95 % of the countries total water demand. In spite of having nearly 25 million more inhabitants, Algeria at the same time only generated 1,680 million m^3 from non-renewable groundwater. This amount accounted for 54 % of Algeria's total water demand. And finally Tunisia exploited a share of 59 %, 460 million m^3

respectively, of its total water demands out of non-renewable groundwater resources (Foster et al. 2006, 19). These figures seem to correspond with the figures on the national distribution of water resources that have been highlighted above. In addition, they indicate how dependent the three riparians, and especially Libya, are already at this stage on their shared transboundary resources.

How are these resources utilized among the different states? There are three major sectors of water consumption. These are *domestic* use, *industrial* use and most important *agricultural irrigation*. The numbers which will be presented in the following describe proportions which are being extracted from the total water resources available in the respective countries. This may include non-renewable and renewable resources, as well as national and transboundary groundwater or surface water. Numbers which comprehensively highlight the role only of groundwater and especially that of the NWSAS are apparently not available. However, keeping in mind the countries' general dependency on non-renewable groundwater, this resource can be suggested to account for an important share. Numbers for Algerian water uses range from 25 % to 46 % for the domestic sector, 5 % to 15 % for the industrial sector and a "lions share" of 49 % to 60 % for the irrigation sector. Tunisian numbers range from 10 % to 13 % for the domestic sector, 1 % to 4 % for the industry and 86 % for irrigation purposes. Libyan numbers at last indicate a domestic use of 9 %, an industrial use of 1.5 % to 4 % and a huge amount of 87 % to 90 % for the agricultural sector. The figures presented above stem from estimations by OSS (2004) and by the United Nations (UNEP) database (geodata.grid.unep.ch 2007).

It has been shown that all three riparians are heavily engaged in the irrigation sector. The utilized water comes to a great extent from non-renewable groundwater resources. Especially Libya to relies nearly completely on resources that will be depleted at some stage. Notwithstanding this situation Libya has the highest per capita water demand among the three riparians. Estimations on the development of Libya´s future demands indicate a growth up to 9 $km^3/a \sim 19$ km^3/a (OSS 2004). The *North-West Sahara Aquifer System Project* which is operated jointly by the three riparians has estimated severe impacts to be deriving from these future exploitation plans. These impacts correspond with the assumptions on *transboundary consequences* as given earlier by Eckstein and Eckstein as well as by Foster et al. (see *Section 2*). In this regard Mamou et al. (2006) report that calculations indicate Algeria's strong policy to lead to draw downs of up to 400 meters within the Algerian Sahara lower part and up to 300 meters on Tunisian territory. Libya´s policy will eventually lead to draw downs of 100 meters on its own and 50 meters on both of its neighbors´ territories (Mamou et al. 2006, 71). The three riparian countries are on very similar levels in terms of their technological, economic and social development. Especially in the water sector all three countries are highly engaged and experienced. Even though the exploitation rates differ, all three riparians seem to make full use of their access to the shared resource. The differences in extraction rates are most likely linked to the spatial shares which are open to the respective state. Hence asymmetries in the utilization of the aquifer system do not necessarily cause a situation of exclusion as it has been assumed. This factor may be significant for the inter-riparian negotiations on the management of the shared resource.

5 National and transboundary impacts

The following section discusses a range of impacts that derive or may derive in future from the extraction patterns which have been presented.

Problems that have occurred in the NWSAS up to now, are to a major extent linked to diminishing "water quantities". Whereas on a theoretical basis the non-renewable character of the resource was discussed to be leading to a full depletion. It is not very likely, that this scenario will occur in the near future. A simplified calculation that relates the total present groundwater stock of the NWSAS to the predicted use patterns indicates that the resource will last for another 400 to 500 years. Moreover the downsides of over-exploitation occur much earlier and differently from a situation where humans have no water left at all. In this regard Burke and Moench (2000) state that *"there will be major social, economic and environmental impacts long before the sustainability of the groundwater resource base is threatened in any quantitative sense"*. (Burke / Moench 2000, 60). According to Besbes et al. (2004) first signs of degradation have been observed in the NWSAS. The authors report a *"very important decline of [water table] levels, [which is] risking to entail irreversible salinization of groundwater in the near future. Most affected will be the Complex Terminal in the algero-tunisian Chotts region and the gulf of*

Syrte" (Besbes et al. 2004, 162). Table 2 shows the decline of major spring flows in Tunisia (namely the Djerid and Nefzaoua Springs) in the course of increased exploitation efforts between 1900 and 1985.

Table 2: Groundwater resource development in the North-West Sahara Aquifer System

Groundwater balance items	**Groundwater exploitation (million m³/year)** 1900	2000
Traditional galleries extraction	353	142
Artesian & pumped water well extraction	114	2,460
Total aquifer extraction	467	2,602
Estimated average recharge*	372	363
Difference derived from aquifer storage	95	2,239

* recharge often increases in time with falling groundwater level but in this case it reduced due to changes in land use and surface water regime.

Source: Foster / Margat / Droubi (2006, 20) modified

In line with recent exploitation policies, Mamou et al. (2006) predict further excessive draw downs in pumped wells, as well as excessive interferences of such draw downs among the riparian countries. And finally the drying up of the Tunisian outlet. These changes will eventually lead to a range of secondary effects on the national and international scale. Such effects correspond with Burke and Moench's (2000) assumptions. A direct national follow up to a decreasing water stock is that costs for extraction will explode. As groundwater mining is already very technology and cost intensive a further draw down will of course only worsen the situation. In addition, it can be stated that with an increase of salinization through different sources like irrigation backflow, upcoming of deep saline groundwater or seawater intrusion, the costs for remediation will explode as well. At some point the costs of exploitation may therefore become prohibitive.

Keeping in mind the regional dependency on fossil groundwater this may evolve into a “vicious circle”.

On the inter-riparian level the overall reduction of water quantities will naturally lead to an increase of water pressure and competition. Since the three riparians do not have a history of conflict in general (HIICR 2006, 53), and since they are already performing joint research and negotiations on the NWSAS, there is good prospect for advanced cooperation.

There are no actual reports which indicate a significant level of pollution within the NWSAS. A reason to this might lie in the hydrogeological characteristics of the aquifer system. Because of its enormous size and its pattern of very slow groundwater flows it is very likely that pollutants retain for extremely long periods within the system. The point in time at which effects of past pollution activities become observable may be far in the future. It has been shown that all three riparian countries use most of their water for agricultural irrigation. Together with the water for irrigation farmers tend to apply herbicides, pesticides and fertilizers. These substances enter the groundwater system as non-point pollutants which are very difficult to be monitored and regulated. As irrigation has been increasing throughout the past century and will prevail to increase, it can be argued that these activities are a “time bomb” type of threat to the system.

6 Institutional arrangements for groundwater management and transboundary cooperation

On the national scale groundwater-related issues are generally governed through the respective water authorities. This holds true for all three riparian states. In Algeria it is the *Agence National de Ressources Hydrauliques* (ANRH), in Tunisia groundwater is governed by the *Direction Général des Ressources en Eau* (DGRE) and in Libya the *General Water Authority* (GWA) takes charge (Bied-Charreton 2002, 2).

6.1 National arrangements

In recent years all three riparians have performed reforms of their respective water sectors. These reforms were mainly targeted to cope with low efficiencies of water management performance (World Bank 2000). In line with their reforms the three states have adopted the idea of *Integrated*

Water Resources Management (IWRM) into their national water policies. Throughout the process of reform, especially Algeria and Tunisia have been strongly supported by international donors both financially and on an organizational basis. The Tunisian *Water Sector Review*, which was launched in 1999, has been co-financed by the German *Kreditanstalt für Wiederaufbau*, the *International Bank for Reconstruction and Development*, the *African Development Bank* and the *Japan Bank for International Cooperation*. The water sector reform led to the creation of the *Letter of Sector Development Policy*, which serves as a long term strategy of IWRM in the country. The *Letter of Sector Development Policy* includes means for the improvement of technical capacities to manage, register and monitor groundwater both qualitatively and quantitatively. Algeria's water sector reform has been supported financially by the *World Bank*, the *European Investment Bank*, and the *German Government*. These external investments focused primarily on infrastructure for wastewater treatment and other water quality issues in order to protect and preserve the country´s water bodies. Accordingly, national groundwater basins are since being tested every three month (World Bank 2003). Libya has performed its reforms alongside the *Mediterranean Component of the EU Water Initiative* which is financed by the *European Union* and several institutions of the *United Nations*. Like in the case of Tunisia and Algeria, reforms in Libya have also focused on the implementation of IWRM. Apart from this short overview on some of the recent developments in national water resource management, it is not sensible to go further into detail on particular national governance structures. However, this short introduction may be interpreted as an indicator for a strong influence of international donors on the respective national water policies.

How do these national policies affect cooperation and governance issues on the inter-riparian scale? According to Puri *"none of the internal groundwater laws and institutions of the sharing countries, can provide rules of governance acceptable to all"* (Puri 2001, 21). Furthermore there is *"a complete lack of an international legislative framework or well defined property rights"* concerning transboundary groundwater basins that could be referred to instead (Puri 2001, 26). In the case of the NWSAS there is no transboundary river basin or lake linked. Correspondingly, no joint experiences and organizations exist to which the riparian countries could link their efforts for cooperation. Up to this date no formal agreement that deals with the distribution and exploitation of the shared

NWSAS resource has been found. In spite of this, there have been some efforts to establish mechanisms of cooperation.

6.2 Transboundary arrangements

Puri argue that *"as draw-down externalities become more and more apparent at national and international level it is important to go beyond simple national water balance considerations and address complete transboundary systems"* (Puri 2001, 26). According to Mamou et al. there has been a growing awareness among the three NWSAS riparian states regarding this development. The authors further state that this finally led the authorities of Algeria, Tunisia and Libya to agree on the implementation of a joint research project under the supervision of the *Observatory of the Sahara and the Sahel* (OSS). In 1998 the OSS obtained support from the *Swiss Agency for Development and Cooperation*, the *International Fund for Agricultural Development* and the *UN Food and Agricultural Organization* for a first three-year study up until 2002 (Mamou et al. 2006, 70). The official wording of the project's objective was *"to coordinate, promote and facilitate the rational management of the NWSAS water resources"* (Burchi / Mechlem 2005, 7). The project identified three major tasks. The first task was to improve the overall knowledge concerning the basins hydro-geology and to operate a joint database. Secondly, it was aimed to create a mathematical model of the basin in order to understand current dynamics and to be able to withdraw future predictions. And last but not least the project served to introduce a joint consultation mechanism (Mamou et al. 2006, 70). The consultation mechanism has been implemented in the form of a *steering committee* composed of representatives of the national agencies in charge of water resources. Ever since, the *steering committee* meets in ordinary sessions on a yearly basis. In addition, extraordinary sessions can be held up on request. Apart from the *steering committee* a so called *coordination unit* which is directed by the OSS has been installed. And finally a *ad hoc scientific committee* takes charge of the organization of practical research. *"Each state bears the operating costs of its own focal point. While the functioning of the* coordination unit *is financed out of subventions and gifts granted to the OSS by the concerned states and cooperating countries."* (Burchi / Mechlem 2005, 7–8)

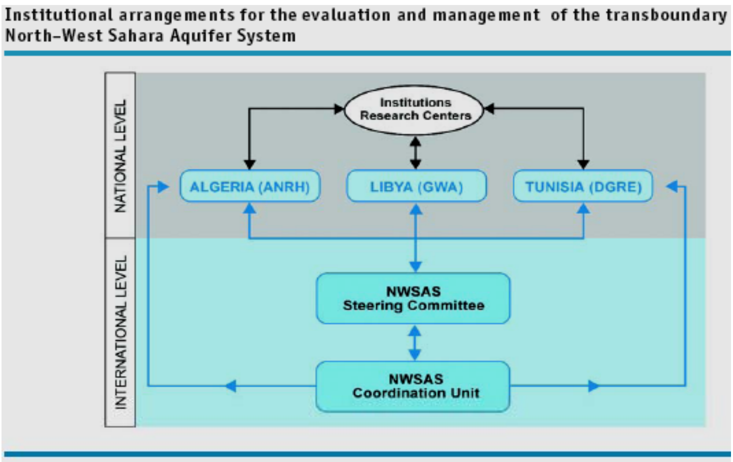
Figure 3 provides a schematic visualization of the consultation organs and their national and international interactions.

How should this research project be judged in the face of the necessity to reach a formal agreement that deals with the distribution and exploitation of the NWSAS? According to Puri (2001)

> *"the joint data collection projects underway [..] bears [..] evidence of the participating project countries' implied concurrence with, and acceptance of, at least one fundamental obligation of international water law [..] on shared water resources, namely, the obligation to exchange on a regular basis available data and information [..]. In addition, the behavior of those same states could arguably bear testimony to the general obligation not to cause significant harm, insofar as the joint data collection projects they are currently engaged in have sprung from the perception that unilateral development could work harm across the border."* (Puri 2001, 22).

Out of the development up to this date, it should not be taken for granted that the riparians will reach a formally sanctioned agreement on their ex-

Figure 3: Institutional arrangements for the evaluation and management of the transboundary North-West Sahara Aquifer System



Source: Mamou et al. (2006, 73)

ploitation rights and performance. Still, the institutionalization of sharing data and experience serves as a basis for transparency. Once installed, this basis will eventually lead to more consciousness and more vigilance concerning national and inter-riparian issues.

What are the incentives to engage in transboundary cooperation accordingly? In order to clarify this question, a distinction between direct incentives and indirect incentives will be made. Direct incentives are here seen as pressures which instantly evolve from transboundary consequences. That is from exploitation activities which negatively affect transboundary neighbours. It is self-evident that the greater incentive to seek cooperation lies with the riparian who suffers from the actions of his neighbour and not vice versa. Direct incentives can be identified quite easily for example by referring to the predictions that were made by the *NWSAS-Project*, as well as by referring to the discussion by Eckstein and Eckstein and Foster et al. (see *Section 2*). Accordingly, Algeria has a *direct* incentive to seek cooperation with Libya, because Libya's exploitation efforts will harm Algeria as well. Tunisia has a strong *direct* incentive to seek cooperation with both of its neighbours, because their respective exploitation efforts will both also harm Tunisia's resource use. Tunisia's use will affect neither of its neighbours. Accordingly, Tunisia could be compared with a downstream state in a transboundary river setting which is at mercy of its upstream neighbours. Libya alone has no *direct* incentive to seek cooperation with its neighbours, because neither of which will negatively affect Libya's use. An explanation based on *direct* incentives alone would contradict the idea of a growing "awareness" among the riparians to be the reason for cooperation. *Indirect* incentives could have many reasons either of political, economic or socio-cultural nature. Such incentives could include regional or international political pressure and relations. Political pressure and demands addressed by regional or international donors or simply moral obligations. Given the limited information it is therefore much more difficult to comprehensively identify such incentives. However, *indirect* incentives should not be left out of consideration. This holds true especially when it becomes visible that even countries which do not have any *direct* incentives to cooperate still engage. In the case of the NWSAS this can be observed for Libya. Even though the country does not have to fear negative impacts from its neighbours' use Libya does cooperate in the joint *NWSAS-Project*. Both, the *NWSAS-Project* as well as the respective national reforms were strongly subsidized by international donors. Taking this fact into consideration, it could be argued that the riparian countries have started engaging in transboundary negotiations only because of international obligations rather than because of moral obligations or a growing risk awareness. Not least since the implementation of the internationally favoured IWRM approach demands a *basin-wide* resource management, this interpretation might comprise some truth. Assumingly there will be a difference between cooperation mechanisms which were established because of *direct* inter-riparian incentives to others which have been established only to meet external demands.

7 Prospects for transboundary cooperation and recommendations for German development cooperation

The cooperative structures which have evolved in the course of the *NWSAS-Project* are not legally binding. Therefore future efforts should be made on a clarification whether a legal frame is feasible and politically volitional at all. If so, and at least for the Tunisian and the Algerian side this seems to be rational, further analysis should identify and address incentives for each side which are independent from international obligations. *German development cooperation* may act as a mediator in answering the respective problems. Furthermore support in creating legal structures which meet the individual demands of the three riparians should be provided. The experiences which have been gathered alongside with the management of transboundary river basins either in Europe or in other regions should be offered accordingly. In this regard it can be of special value to highlight legal solutions for upstream/downstream problems. Since German institutions like the *Kreditanstalt für Wiederaufbau* and the *German Government* have been involved in water sector reforms in all three riparian countries *German development cooperation* should make use of the relations and experiences in place. For two reasons, the *NWSAS-Project* should be regarded to as a promising basis for these efforts. On the one hand the joint definition of the aquifer system´s hydrogeological characteristics will minimize disputes which are related to borders, quantities and qualities. In addition transparency concerning the NWSAS exploitation will support an atmosphere of trust. A second reason lies in the considerable structures of negotiation which have been set up by the project.

8 Conclusion

The *NWSAS* is a multi-layered system of aquifers which embody a huge stock of non-renewable, fossil water with diverse quality. Its exploitable water reserves have been calculated at ~1,280 km^3. Currently theses reserves are being extracted at an annual rate of 2.2 to 2.5 billion m^3/year. It is planned to increase these rates further in the future. Especially since the respective riparians are heavily dependent on this resource. All three riparian states show a similar level of socio-economic development. They are equally engaged in the utilization of the shared resource, and they are using most of their water for irrigation purposes. Threats to the aquifer have been identified to refer mostly to issues which relate to diminishing *water quantities*. It was shown that these threats will not lie in a total depletion. Moreover, threats lie in the occurrence of major social, economic and environmental impacts long before the sustainability of the resource base is threatened in any quantitative sense. As a follow up, the costs for the exploitation of the resource may become prohibitive. Research findings have shown that Libya will not face any of such transboundary consequences from the activities of its neighbours though. Until today Algeria, Tunisia and Libya have not reached any formally sanctioned legal agreement on the utilization of their shared resource. This situation reflects a lack of international laws on the utilization of transboundary groundwater basins. In addition there is no experience or organisation concerning transboundary surface water management. In spite of this, the three countries have been engaging in a joint research project to produce a common understanding of their resource. The project is monitored by the *Observatory of the Sahara and the Sahel* (OSS). Data is being exchanged regularly and a consultation mechanism has been implemented. The project does not necessarily lead to a future formally sanctioned agreement between the riparian states. Still it was argued that it will serve as a basis of transparency which creates more consciousness and more vigilance concerning national and inter-riparian issues. In all three countries, international donors play a crucial role both in the case of national water reforms as well as in the *NWSAS-Project*. It is therefore unclear whether the incentives to cooperate lie in a growing awareness among the riparians for their neighbors' vulnerability and in a common notion of acting within interdependencies or whether cooperation simply tries to meet obligations by international donors.

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The Nubian Sandstone Aquifer System

A case study for the research project
"Transboundary groundwater management in africa"

Marianne Alker

Preface

I would like to thank Dr. Klaus Schelkes (BGR), Dr. Ralf Klingbeil (BGR), Dr. A. Margane (BGR) and Dr. Ahmed Sefelnsar (University of Halle, Germany) for their valuable comments and for sharing their knowledge of the Nubian Sandstone Aquifer System with me.

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The Nubian Sandstone Aquifer System

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1 Introduction

The study described here was one of five carried out for the research project "transboundary groundwater management in Africa". The Nubian Sandstone Aquifer System (NSAS) was selected for the study because it is one of the largest and most important transboundary aquifer systems in Northern Africa, where dependency on groundwater is high and the management of shared groundwater is an important, politically sensitive issue with social, economic and national security dimensions. This is so much the case that the riparian countries have already set up an institutional structure for information exchange and joint management of the NSAS.

The findings presented here are the result of a literary research study and can therefore give only a limited insight into the complex modelling activities currently being carried out in the NSAS region. However, they make it possible to draw conclusions concerning strategic options for German development cooperation.

This paper describes the major characteristics of the aquifer and its use patterns in the riparian countries and analyzes the incentives for transboundary cooperation in managing the NSAS. The paper then depicts steps already taken by the riparian countries for interriparian cooperation regarding the aquifer and ends by analyzing the challenges ahead. Finally, it formulates conclusions and recommendations.

2 Characteristics of the Nubian Sandstone Aquifer System

Although the NSAS has been the subject of numerous studies, scientific knowledge of this aquifer system is still limited. There exist for it no precise estimates of such characteristic values as the total volume of water stored, the rate of groundwater flow, and total annual extraction from it (A. Margane, personal communication 2007). Estimates of the total amount of groundwater stored, for example, vary from 15,000 km³ (Ambroggi 1966,

24) and 135,000 km³ (Gossel / Ebraheem / Wyick 2004, 711) to as much as 457,550 km³ (CEDARE 2002, cited in: Bakhbakhi 2006, 80).

The present study is based on figures taken from the Centre for Environment and Development in the Arab Region and Europe (CEDARE) (CEDARE 2002, cited in: Bakhbakhi 2006). At the same time, this study also attempted to determine where uncertainties and contradicting results of other studies have to be taken into consideration. Generally, the lack of area-wide data concerning geological structures, porosity, and the various thicknesses of water-bearing strata throughout the basin have led to a relatively high level of uncertainty.

The NSAS is shared by Libya, Egypt, Sudan and Chad and covers approximately 2.2 million km², of which 235,000 km^2 are in Chad (11 %), 828,000 km^2 in Egypt (38 %), 760,000 km^2 (34 %) in Libya, and 376,000 km^2 in Sudan (17 %) (CEDARE 2002 cited in: Bakhbakhi 2006, 75; Abu-Zeid s. a., 2).

The aquifer can be divided into two major parts one below the other, including different sub-systems divided by uplifts. The older, more extended and more important Nubian Sandstone Aquifer (NSA) underlies the Post-Nubian Aquifer. Whereas the NSA covers the whole area of the NSAS, the Post Nubian Aquifer (PNA) is located only in the north.[46] It is separated from the Post-Nubian Aquifer by low permeability layers[47] but is hydraulically connected to it in the form of upward leakage.

South of a line running between the 22nd and 29th parallels, the NSA is unconfined. In the northern part, it is confined and overlaid by the PNA (compare figure 1) (Margat 1995, cited by A. Margane in a personal communication 2007; Bakhbakhi 2006, 75; Salem / Pallas 2002, 19).

46 Bakhbakhi (2006), for instance, applies different terms: instead of NAS he prefers the term "Nubian Aquifer System", instead of Nubian Aquifer System "Nubian Sandstone Aquifer System" and instead of Post-Nubian Aquifer "Post Nubian System". To differentiate between the whole system and the individual aquifer layers and in order to take geological conditions correctly into account we have chosen the terminology used by BGR and Sefelnasr / Gossel / Wycisk (2007).

47 These low-permeability layers are of Mesozoic-Cenozoic origin (Salem / Pallas 2002, 19).

The NSA consists of continental (mainly sandstone) Palaeozoic[48] and Mesozoic[49] deposits. The system is formed by different interconnected aquifers within the geological formations (Salem / Pallas 2002, 19).[50] The most important sub-basins are the western Kufra Basin and the eastern Dahkla Basin.[51] Whereas the different uplifts subdivide the aquifer system and thereby shape it, the two main basins do not seem to be divided by such an uplift (Wycik 1993, cited in Gossel / Ebraheem / Wycik 2004, 699).

The northernmost boundary of the NSA is the Mediterranean Sea, with a northwestern boundary set by a stable freshwater and saltwater interface (Gossel / Ebraheem / Wycisk 2004, 700). The NSA is bounded in the north-east by the Suez Canal, towards the Red Sea in the east by a mountain range, and in the southeast by the Nile. The western border is a groundwater divide extending from the Tibesti Mountains in the south northwards along the 19° Meridian (Bakhbakhi 2006, 75). The definition of the western border, however, is based on models created by Thorweihe and Hrinl (1996, cited by A. Margane, personal communication 2007) and others, so that the Nubian Sandstone Aquifer possibly extends even farther to the west. Likewise, a definition of the southern boundaries towards the Lake Chad Basin is still subject to further investigation. Therefore, a flow of groundwater between the NSA and the Lake Chad Basin cannot be ruled out at this point of time.

Within these boundaries, the NSAS reaches a maximum depth of 4,500 m. The hydraulic head ranges from 570 m above sea level west of Darfur to –78 m in the Qatar depression (Sefelnasr / Gossel / Wycisk 2007). CEDARE estimates the total volume of freshwater stored in the NSA to be 373,000 km³, of which 41.5 % are under Egyptian territory, 36.6 % in Libya, 12.8 % in Chad, and the remaining 9 % in Sudan (CEDARE 2002 cited in: Bakhbakhi 2006, 76). Other authors, however, arrive at much

48 Palaeozoic: an era of geological history 570–244 million years ago; in this era the earliest fish, corals, plants, insects and reptiles developed (Merriam-Webster 1998).

49 Mesozoic: an era of geological history comprising the interval between Permian and Tertiary; 245–65 million years ago, the era of dinosaurs, earliest birds, mammals and flowers (Merriam-Webster 1998).

50 For a detailed description of the geological history of the basin consult Zektser / Everett (2004, 219–20).

51 For further details about the different uplifts separating the sub-basins consult Gossel / Ebraheem / Wycik (2004, 699–700).

lower estimates (Gossel / Ebraheem / Wycisk 2004; Ambroggi 1966), as already explained above.[52]

Water quality in the aquifer system varies from excellent in the southern part, with 500 ppm total dissolved solids (TDS), to hypersaline in the northern part. The saline part of the aquifer lies in its confined part in the north, mainly under Libyan territory.

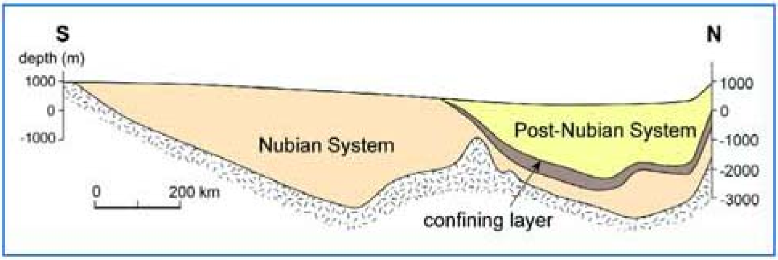
The PNA underlies parts of Libya in Post-Eocene[53] continental deposits (mainly sandstone) and parts of Egypt in carbonate rocks. It is bounded by no-flow boundaries to the south and is hydraulically linked to the NSA by upward leakage. Apart from that it shares the same borders as the NSA. The total volume of groundwater (average formation bulk porosity of 10 %) in storage is more than 84,600 km³ (CEDARE 2002, cited in Bakhbakhi 2006, 78–80). A depression at latitude 30° N is marked by several salt pans (*sabkhas*).[54] Taking this line as a boundary, stored capacity is estimated to be 72,767.17 km³, 54 % of which is under Libyan and 46 % under Egyptian territory (CEDARE 2002 cited in: Bakhbakhi 2006, 78). Here too, however, and for the reasons already outlined, a high level of uncertainty applies.

52 It is unclear how the thickness of water-bearing strata has been estimated by Bakhbakhi. Since geological structures are not well known everywhere in the basin, the possibility of error is high when mean thickness values are used. In addition, Bakhbakhi's assumption of 20 % porosity everywhere in the basin is probably too high. Lithology will vary, and other authors have assumed a porosity of 1 to 10 % for their models (A. Margane email communication 2007).

53 Eocene: epoch in geologic time in the period of Tertiary. The Eocene was about 58 to 38 million years ago (Merriam-Webster 1998).

54 Sabkha is an Arabic name for a salt pan ordinarily found near sand dunes. These relatively flat and very saline areas of sand or silt form just above the water table, where the sand is cemented together by evaporite salts from seasonal ponds (http://www.nps.gov/archive/grsa/resources/curriculum/glossary.htm).

Figure 1: The Nubian Sandstone Aquifer and the Post-Nubian Aquifer



Source: Bakhbakhi (2006, 76)

Since recharge is very low and the contained water is fossil water, the NSAS is regarded as a non-renewable groundwater resource.[55] Major recharge of the aquifer system took place in the last pluvial period of the late Quaternary. Radiocarbon dating has indicated that the bulk mass of groundwater in the NSAS dates from 100,000 to 1,000,000 years ago and up to 2 million years ago in the deeper zones (Himida 1969 cited in Zektser / Everett 2004, 221). Presently, there is inflow into the NSAS due to seepage from the Nile, since water levels in Lake Nasser have risen (Gossel / Ebraheem / Wycisk 2004, 712).[56]

55 This is based on the definition of Foster et al. that a *"non-renewable groundwater resource is a resource available for extraction of necessity over a finite period of time, from the reserves of an aquifer which has a very low current rate of average annual renewal but a large storage capacity"* (Foster / Loucks 2006, 14). However, *"to speak synonymously about 'fossil groundwater' and 'non-renewable groundwater resources' is misleading, since there are many aquifer systems containing large volumes of fossil (usually Holocene) groundwater which, if extracted, is replaced (or renewed) by more modern recharge"* (Foster / Loucks 2006, 17).

56 The interactions between Lake Nasser and the NSAS are currently being investigated by Sefelnasr / Gossel / Wycik (2007).

Groundwater in the NSAS generally flows from north to south. However, regional flow across the system is very small compared to that within the subsystems (Zektser / Everett 2004, 221).[57]

Climatically, the major part of the basin is hyperarid.[58] Due to current climatic conditions, there is a slow discharge of the aquifer system (Salem / Pallas 2001, 41) because natural groundwater flow transports the water into a large and deep evaporation area between Ajdabyia (Libya) and Cairo (Egypt). This implies a slow but permanently progressing depletion of stored groundwater (Salem / Pallas 2002, 19). Natural discharge to the Qases and the Qatara depression is due to their location (Qatara depression: -50m below sea level) (A. Margane, comment per email 2007). No estimates of the amount of water discharged are currently available.

3 National groundwater use patterns

An attempt will now be made to shed light on patterns of use of groundwater from the NSAS in the four countries which share the aquifer and, with the help of background information, to assess the significance of the NSAS for each riparian country.

Because water stored in the NSAS is regarded as non-renewable, its extraction will inevitably lead to its eventual depletion. The agricultural and water demands of a growing population in the riparian countries as well as economic growth in the region have already led to a rapid increase in demand over the last three decades, and it can be assumed that this trend will continue (Bakhbakhi 2006, 75).[59]

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57 *"Based on estimates of the hydraulic parameters (gradient 3x10-4, hydraulic conductivity 10-5m/sec, and effective porosity 10 %), groundwater flow velocity has been estimated at 1m/yr. Thus the groundwater needs about one million years to pass through the system from recharge areas in the southern boundaries to the Qattara discharge area."* (Zektser / Everett 2004, 221).

58 This is reflected by the following figures: average precipitation in Kharga und Dakhla: 0.3mm/a, east-central Libya <25mm/a, Ennedi Mountains in Chad 200mm/a, and in the Tibesti Mountains 100mm/a (Zektser / Everett 2004, 221).

59 Bakhbakhi presents figures showing that groundwater extraction grew by a factor of 10 from 1970 to 2000. Whereas extraction in 1970 from the NSA was about 3.5 MCM/a and app. 1 MCM/a from the PNA, extraction rates grew to around 21 MCM/a for the NSA and 16 MCM/a for the PSA in the year 2000 (CEDARE 2002 cited in: Bakhbakhi 2006, 78).

Large-scale groundwater development projects are currently being carried out in Libya and Egypt. Any assessment of the effects of these projects will depend on estimates of the total amount of freshwater stored in the aquifer system and on assumptions concerning the interrelationships between different parts of the aquifer system. Scientists agree that the NSAS has been under unstable conditions since the beginning of economic development in Egypt and Libya (Gossel / Ebraheem / Wycisk 2004, 699). It remains unclear what impact this will have. The University of Halle, Germany, is currently constructing models for calculating the impact of Egyptian and Libyan groundwater development projects and is outlining different management scenarios (Sefelnasr / Gossel / Wycisk 2007).

Based on the more optimistic estimates of CEDARE, present extraction per year represents only 0.01 % of the estimated total recoverable freshwater volume stored in the NSAS (Salem / Pallas 2002, 10; compare table 1). As discussed above, however, questions remain open about the reliability of these estimates.

Table 1: Recoverable volumes and present extraction from the NSAS

	Nubian Sandstone Aquifer		**Post-Nubian Aquifer**						
	Area (km^2)	Volume in storage (km^3)	Area (km^2)	Volume in storage (km^3)	Volume of freshwater in storage (km^3)[a]	Total recov-erable groundwater volume (km^3)[b]	Present extraction from Post-NSAS (km^3)	Present extraction from NSAS (km^3)	**Total present extraction from NSAS (km^3)**
Egypt	815,670	154,720	494,040	35,867	190,587	5,367	0.306	0.200	0.506
Libya	754,088	136,550	426,480	48,746	185,296	4,850	0.264	0.567	0.831
Chad	232,980	47,810	-	-	47,810	1,630	-	0.000	0.000
Sudan	373,100	33,880	-	-	33,880	2,610	-	0.833[c]	0.833
TOTAL	**2,175,838**	**372,960**	**920,520**	**84,613**	**457,573**	**14,457**	**0.570**	**1.600**	**2.170**

Source: Bakhbakhi (2006, 80)

a Assuming a storativity of 10-4 for the confined part of the aquifer and a 7x10-2 for the unconfined part.

b Assuming a maximum water decline of 100 m in the unconfined aquifer areas and 200 m in the confined aquifer areas.

c Most of this water is extracted in the Nile Nubian Basin (833 ucm) which is not considered to be part of the Nubian Basin.

The figures given in Table 1 indicate that only a very small share of the groundwater stored is actually used. When adding up the extracted amounts it is assumed that the extracation is evenly distributed in space which is in reality not the fact. Consequently, extraction will more likely become uneconomic as it is concentrated and thereby leading to increasing pumping lifts in these spots.

3.1 Groundwater use patterns in Libya

More than 80 % of Libya's population (approximately 5 million people) live in the northern plains, particularly in the costal strip, where the soil is suitable for producing a variety of agricultural products. Population density in this area reaches 120 persons/km², whereas in the central and southern part the ratio is only 1 person/km² (Salem 2007, 106). This shows that the areas of greatest water demand and greatest availability of high quality groundwater are not congruent.

Libya meets 95 % of its water requirements mostly from non-renewable groundwater.[60] Groundwater accounts for 98.72 % of the water used in irrigated agriculture, which produces more than 60 % of the country's crops (FAO Country Profile). This underscores Libya's dependence on non-renewable groundwater resources.

Development of the NSAS in Libya, where the subsystems are named Kufra in the north and Sarir in the south, started in the late 1960s. The groundwater is extracted through wells from a few meters to more than 1,000 m in depth (Salem 2007, 107). The water is used for human applications, agricultural production (especially for major irrigation projects in Kufra and Sarir), and for oil production. The Great Man-Made River Project (GMRP) (see box 1) also extracts water from the NSAS and uses it to a great extent for urban supply.

The NSAS on Libyan territory has been studied intensively. Libya can therefore rely on information on its hydraulic properties and on flow directions in the aquifer system. Monitoring of aquifer behaviour through a

60 Exact figures range from 68 % of non-renewable groundwater (although not exclusively from the NAS [data from Foster / Loucks 2006, 19]) and 78 % (Salem 1997, 107) to 87 % (FAO 2005c).

piezometric[61] network of more than 150 wells has made it possible to develop mathematical models on the basis of which future scenarios can be analyzed (Salem 2007, 109).

The FAO country profile indicates some negative developments for the shallow, non-renewable aquifers in the south of the country. Severe pollution and a significant water table decline have been reported due to inadequate sanitation and excessive pumping (FAO 2005c).

Box 1: The Great Man-Made River Project of Libya

The primary objective of the GMRP is to achieve a secure supply of food and a stable supply of water for domestic consumption. Libya's most densely populated region in the north is inadequately supplied with water. The situation has worsened since saltwater intrusion following a water table decline induced by over-pumping made water in the coastal aquifers unsuitable for human consumption. The Great Manmade River Project is designed to transport eventually 2.3 BCM of fossil water from the south of Libya to the north.

The project consists of five phases, of which Phases I and II are currently being implemented. In Phase I, two well fields in the As Sarir - Al Kufrah Basins of the NSAS have been selected as a source of 730 ucm of water per year to the coastal areas from Binghazi to Sirt. The first well field is located in the Sarir area and currently produces 94 ucm of water per year. This is 25–30 % of its capacity. The second well field is located near the village of Tazirbu, some 200 km south of the Sarir well field, and is currently under development. In Phase II, several well fields in the Jabal Hasawna area will transport some 910 ucm of water per year to the Jifarah plain around Tripoli.

Altogether, the first wells already in operation produce about 140 ucm of water per year. The GMRP is designed mainly to serve irrigated agriculture, but up to now the water has been used almost exclusively for domestic and industrial purposes in the major cities of the country.

The total amount of water required to ensure basic food self-sufficiency and to meet the domestic water requirements of the 12 million Libyans in the year 2025 is estimated to range between 10.5 and 16.4 bcm/year, compared to 4.3 bcm/year at present. When the GMRP is fully operational, and assuming that present groundwater production equipment will be in service until 2025, the total amount of water available for all uses will be approximately 6.5 BCM/a and will thus barely cover 50 % of total water requirements (p. 5). According to the FAO, the GMRP will permit distribution of only 2.0 BCM/year (p. 9).

Source: FAO (2005c)

61 The piezometer is an instrument for measuring pressure changes in a material subjected to hydrostatic pressure (Merriam-Websters 1998). A piezometric survey measures groundwater levels.

3.2 Groundwater use patterns in Egypt

Egypt's water dependency ratio, which is defined as the percentage of renewable water resources originating outside the country, is at 97 %. The most important water source for Egypt is the Nile; Egypt meets only 7 % of its water demand from groundwater (Foster / Loucks 2006, 19). Of this, only 1.2 %[62] is fossil groundwater from the NSAS[63] (FAO 2005b). The FAO Aquastat country profile (2005) does not provide figures how this amount is split among domestic, industrial and agricultural uses.

Most of the groundwater presently extracted is used for agriculture. In Egypt, private farms located in the old traditional oases of the New Valley[64] are the major users of water from the NSAS (Bakhbakhi 2006, 78). However, large irrigation schemes are under development in the south-western part of the country at Al Qweinat, in the vicinity of traditional irrigation systems in the New Valley. In 2003 4,200 ha were already under irrigation, and it is planned to increase this area (Salem / Pallas 2002, 20; Salem 2007, 107; FAO 2005b). When fully developed, the New Valley Project[65] will extract 540 MCM from the Dakhla sub-basin (Al-Eryani / Appelgren / Foster 2006, 32).

Exploitation of groundwater has been growing in the last 40 years in Egypt, resulting in a groundwater table decline of 60 m in the oases. All free-flowing wells and springs have been replaced by deep wells (Bakhbakhi 2006, 78).[66]

Since the availability of water is a limiting factor for agricultural production, the use of saline groundwater for agriculture and the concomitant

62 1.2 % is equivalent to 825 106m³/year (FAO 2005b).

63 82 % of the groundwater used is seepage water extracted from the Nile Basin, 1.2 % comes from the NAS and 1.3 % is extracted from shallow aquifers in Sinai and on the northwest coast (FAO 2005b).

64 The New Valley is a sequence of oases receiving water through discharge from the aquifer system. New Valley is also the name of the Egyptian governorate in this region.

65 The New Valley Project has created a new river valley by pumping water from Lake Nasser 310 km to the Paris Oasis. The water is used for agricultural production along the whole stretch (http://lexicorient.com/e.o/nw_valley.htm).

66 Murakami (1995) gives figures according to which yields declined by 40 % after a few deep wells had been drilled in the 1950s in the Kharga and Daklha Oases.

change in agricultural practices and crops is currently being discussed as a potential way to increase water supply (IWMI 2004).[67]

3.3 Groundwater use patterns in Chad

The northern part of Chad has a very dry climate and is only sparsely populated (0.2 capita/km²; FAO Country Profile Chad). The figures published by the CEDARE do not indicate the amount of extraction from the NSAS on Chadian territory (Bakhbakhi 2006, 79), nor is the NSAS mentioned in the FAO Aquastat Country Profile Chad (2005a). Nevertheless, it can be assumed that Chad is extracting water from the NSAS to such a limited extent that this is not monitored and is not thought to have any transboundary implications.[68]

In general, future overexploitation of the NSAS by Chad seems unlikely, since groundwater requirements in the Sahara zone of Chad amount to only 0.14 % of potential groundwater resources in that part of the country. By the year 2020 this figure is expected to rise to only 0.25 %, and it is estimated that the level of extraction from the NSAS will be only 0.07 MCM/year in 2000. Moreover, groundwater use faces severe technical and economical constraints in Chad, and no irrigation projects are currently planned (HCNE et al. 2003, 113, 66, 115).

On the other hand, the Integrated Plan for Chad's Water Development and Management assesses conditions for the exploitation of groundwater stored in the NSAS in Chad as favourable. However, information on the characteristics of groundwater use in the area of the NSAS is considered insufficient (HCNE et al. 2003, 111–112).

3.4 Groundwater use patterns in Sudan

The NSAS area in the north of Sudan receives an average annual rainfall of only 25 mm. As a consequence, the area is sparsely populated and is

67 In Egypt, only 3 % of the country is under cultivation, and 97 % of all inhabitants live near the Nile, resulting in a population density of 1,165 persons/km² in the Nile basin (FAO 2005b).

68 This view is also shared by A. Sefelnsar from the University of Halle (personal communication 4/2007).

used by nomadic and semi-nomadic herders for extensive animal production. The FAO Aquastat country profile for Sudan (2005d) indicated that groundwater use is confined mainly to domestic purposes. Only 4 % of the irrigated area is supplied by groundwater, and this is probably not extracted from the NSAS, since the irrigated area is confined to the southern part of the country (FAO 2005d).

Two groundwater basins, the Nile Nubian Basin and the Sahara Nubian Basin, are found in northern Sudan. Figures reported by CEDARE indicate that Sudan extracts most of its groundwater from the Nile Nubian Basin, which is recharged by the Nile as well as by the underflow of the Blue Nile (Omer 2002, 974). The Nile Nubian Basin is not considered to be part of the NSAS. Nevertheless, extraction from both the Nile Nubian Basin and the Sahara Nubian Basin are included in the figures by CEDARE. No explanation could be obtained why the abstraction figures from the NSAS for Sudan include both groundwater basins (compare table 1).

Research by the University of Halle, Germany, has identified the Selima oasis (probably in the Nile Nubian Basin) and the Naqiya oasis (probably within the Sahara Nubian Basin) as water-stressed areas. For this reason, Sudan's groundwater development activities at these oases are included in the University's models of transboundary impacts in the NSAS (Sefelnasr / Gossel / Wycisk 2007). In summary, although Sudan is using and developing the NSAS, it remains impossible at present to assess the extent of these activities and their transboundary impact, if any.

4 Transboundary implications

The following section discusses the transboundary impacts deriving from national groundwater use and provides an analysis of the cooperation problem over the NSAS. In the process, the NSAS will be regarded as a transboundary resource with asymmetric use patterns in which upstream-downstream constellations do not play a role. Two riparian countries, namely Egypt and Libya, are apparently exploiting the aquifer more intensively than the southern riparians Sudan and Chad. Although no transboundary impact of this between Egypt and Libya has been reported, negative impacts on Sudan are likely. No information is available concerning Chad in this regard.

4.1 Pressures deriving from national use patterns

Although extraction in relation to the volume stored in the NSAS might be low, signs of over-extraction have been described. The Great Man-Made River Project, for example, has led to reduced water levels in Libya´s Kufra sub-basin and has dried up lakes linked to oases. Water levels also declined in Egypt's Kharga Oasis by 60 m from 1960 to 1998. In the north of Chad, groundwater level declines have led to a migration of the rural population (online: http://www-naweb.iaea.org/napc/ih/Nubian/IHS_Nubian _irrational_extraction.html). However, no information has been found to indicate that this is a transboundary impact of Libya's groundwater development.

Population growth in the riparian countries is certain to increase water demand and will contribute further to already existing over-extraction of groundwater from the NSAS.

4.2 Cooperation problems

The types developed by Eckstein and Eckstein will be used here to develop a conceptual understanding of the NSAS. These six types were developed as paradigms for the application of international law to groundwater use. The types show the potential transboundary implications of groundwater use in the hypothetical situation of two riparian countries sharing one aquifer (Eckstein / Eckstein 2005).

The Eckstein-Eckstein types depict only situations involving two riparian countries and thus do not perfectly reflect the situation of the NSAS with its four riparian countries. Nevertheless, type F (cf. page 25) can be applied to the NSAS. As in this model, the NSAS is unrelated to any surface water bodies, is recharged only to a negligible extent, and thus contains mainly fossil water. Some characteristics of the NSAS are not contained in the type: water in the NSAS is not stagnant but flows very slowly, and natural discharge exists (see Chapter 2).

Nevertheless, the transboundary implications shown in the type can also be applied to the NSAS since they are almost exclusively a function of pumping.

The assumption that transboundary implications are exclusively a function of pumping is corroborated by Salem and Pallas, who describe the (expected) negative transboundary impact on water quantity. Although the authors do not expect mutual transboundary impacts to ensue from development projects currently planned in Libya and Egypt, a negative impact on Sudan is considered possible. For example, intensified groundwater pumping in the southeastern part of Egypt could cause a cone of depression extending 50–70 km beyond the Sudanese-Egyptian border (Salem / Pallas 2002, 20).

This assumption is currently being tested in a research project by the University of Halle, Germany, which integrates the transboundary implications of major aquifer development projects in Egypt and Libya into models based on current and planned extraction rates. While the results have not yet been published, preliminary findings indicate that development projects in the southeastern part of Egypt are likely to have a transboundary impact on the Kufra area (communication with A. Sefelnasr, University of Halle). Based on planned extraction rates, it is estimated that water levels will eventually sink below economically viable groundwater depths (Sefelnasr / Gossel / Wycisk 2007).

Furthermore, increased groundwater pumping in the Siwa Oasis (Egypt) and the development of the well field in Libya's Jaghubub will eventually threaten water quality due to the intrusion of salt water in the deeper, confined part of the NSAS (Salem / Pallas 2002, 10). It remains unclear, however, whether this projected decline in water quality will also affect neighbouring countries to the south.

When studied in light of the Eckstein-Eckstein types (2005) and evidence from the region itself, the NSAS shows no upstream-downstream constellation. It can therefore be assumed that common interests and incentives for cooperation do indeed prevail. Nevertheless, development of the NSAS seems to be asymmetrically distributed between Egypt and Libya, which heavily exploit the NSAS on the one hand, and Sudan and Chad on the other. This may have a bearing on the incentives for cooperation among the riparian states.

4.3 Need for cooperation

The literature reflects different points of view concerning the need for cooperation. Al-Eryani / Appelgren / Foster (2006) have summarized various assessments of the transboundary impact of water extraction and the resulting need for socio-political cooperation in using the NSAS. Given the rather long time frame (50–100 years) in which water will probably continue to be available from the NSAS, the authors conclude that the most important objective in management of the NSAS is to optimize social developments induced by groundwater use. On this basis, the authors underscore the need for socio-political cooperation among the riparian countries.

Other authors already cited in the present study believe that the amounts of water needed even for the great development projects in Egypt and Libya are so small in comparison to the stored volume that any future transboundary impact will be small (Khouri 1999, in: Al-Eryani / Appelgren / Foster 2006, 31–32). These authors therefore see only a limited need for socio-political cooperation in the form of regular data exchange (Attia 1999, in: Al-Eryani / Appelgren / Foster 2006, 31–32). Others, on the other hand, emphasize the nature of the NSAS as a common pool resource and point to the need for an integrative approach, taking the entire system into account, as opposed only to its parts, i.e. the sub-basins (Alghariani 1999, in: Al-Eryani / Appelgren / Foster 2006, 31–32). This again points to a need for intensified cooperation among the riparian countries.

In summary, socio-political cooperation through joint management of the NSAS appears necessary as a means of optimizing social development, since the riparians are very dependent on the NSAS and negative transboundary impacts cannot be ruled out. This is even more so inasmuch as development of the NSAS and its resulting, potentially negative transboundary impact are asymmetrically distributed between the northern and southern riparians. Cooperation is therefore needed to take this impact into account, to manage it, and to harmonize the differing interests.

5 Institutional arrangements for groundwater management and transboundary cooperation

The following is an overview of national water policies and national institutional setups for groundwater management in the NSAS area. Multilateral, bilateral and trilateral arrangements for transboundary cooperation concerning the NSAS will be briefly described, and an analysis will be given of achievements to date and challenges lying ahead for transboundary groundwater management through these institutional arrangements.

5.1 National institutions

5.1.1 Institutions in Egypt

In November 1999, Egypt created a department for the management of freshwater and non-fresh groundwater resources within the Ministry of Water Resources and Irrigation (MWRI), thus delegating the responsibility for groundwater management clearly to a single agency. The department has the following tasks:

— Keeping track of present groundwater development and management

— Conducting campaigns to increase public awareness of the need for groundwater protection

— Dealing with legislative aspects for the licensing of wells and pollution control

— Investigating appropriate technologies for groundwater management, rain water harvesting. and the conservation of flash flood water

— Finding ways to augment the supply of fresh groundwater (IWMI 2004, 3).

With the support of the *German Development Cooperation agency (in German: GTZ)*, a "Vision and Strategy on Institutional Reform" has been developed and agreed upon within the MWRI. Currently, a consultative process with various ministries and with both regional and local representatives aims at a general agreement on this strategy for reform before it is presented to the cabinet (online: http://www.gtz.de/en/ weltweit/maghreb-naher-osten/1477.htm).

Groundwater in Egypt is owned by the nation and managed by the MWRI. As far as groundwater rights are concerned, two different systems coincide in Egypt. The licensing system, which ensures water rights relating to wells, applies to most users in the country, including non-traditional users in the desert. On the other hand, a system of traditional rules clearly allocates ownership of groundwater at oases and in wadis (IWMI 2004, 4). Irrigation schemes worked out by the NSAS will be subject to the licensing system, whereas traditional agriculture at the oases will be governed by the traditional system.

The MWRI has presented a Water Resources Policies and Strategies Plan (WRPSP) for the period from 1997 to 2017. This strategy aims at integrating all water-related ministerial policies and strategies (i.e. for agriculture, industry, domestic use etc.) into a single, comprehensive framework document. It provides for 5-year national plans. The WRPSP is aimed at (1) the management and development of existing resources in terms of quantity, (2) control of all sources of pollution and serious hazards, and (3) the development of new water resources through close cooperation with the upper riparian countries of the Nile Basin.[69] In Egypt, a national groundwater monitoring system dating back to the 1960s exists to monitor groundwater levels and to estimate potential and future recharge. Moreover, a system which uses data from 250 wells to monitor the quality of groundwater has been in place since 1997. Apart from all this, well inventories are updated every 3–5 years for licensing purposes (IWMI 2004, 34).

The Research Institute for Groundwater is the focal point of groundwater management organization, and its director acts as national coordinator of the internationally supported Regional Nubian Sandstone Aquifer System Study Project (Abu Zeid s. a., 5).

Available information indicates that Egypt has implemented a fairly consistent body of policies, legislation and strategies for management planning, monitoring, and assessment. However, the GTZ believes that Egyptian water management structures are still so highly centralized that effective fulfillment of their tasks is hindered.

For the same reason, the GTZ also concludes that Egypt is struggling to cope with its water-related challenges. German-Egyptian cooperation therefore seeks to promote further reforms in the Egyptian water sector in order to achieve greater efficiency. Decentralisation, establishment of regionally integrated water basin management, delegation of functions and

69 A number of sophisticated tools such as models, databases, Geographic Information System (GIS) and Decision Support Systems are already in use to provide input for the Management Plan. Researchers from the National water Research Centre, in cooperation with the Italian Centre for River Restoration, have developed a dynamic model for integrated evaluation of management alternatives (Nardini / Fahmy 2005).

authority to water use organisations, cost recovery from water users, and the strengthening of ministerial authority in the exercise of regulatory and monitoring functions are priority areas of such bilateral development co-operation within the Egyptian water sector (online: http://www.gtz.de/en/weltweit/maghreb-naher-osten/1477.htm).

However, the available information does not yet permit a realistic assessment of the actual state of groundwater governance in Egypt in terms of user participation and water-related governmental authority at decentralized levels.

5.1.2 Institutions in Libya

In Libya, the General Water Authority (GWA), established in 1972 is responsible for all water resource assessment and monitoring. This institution is organized into six General Directorates: Planning; Follow-up and Statistics; Water Resources; Dams, Irrigation and Drainage; Soils; and Finance and Administration. The GWA supervises all irrigation and drainage projects in Libya and carries out research aimed at improving the irrigation network. It is also concerned with data storage and the development of water resources (e.g. linkups with GIS).

The Secretariat of Agriculture and Animal Wealth is responsible for the development of irrigated agriculture and the implementation of major irrigation projects. The Secretariat has appointed the General Water Authority as the focal institution and its director as the national coordinator in Libya of the internationally supported Regional Nubian Sandstone Aquifer System Study Project (Abu-Zeid s. a., 5).

For the Great Man-Made River Project, a special authority, the "The Great Man-Made River Water Utilization Authority", was created, which is supervising the whole project up to final water use in irrigation. The Secretariat of Municipalities is responsible for water supply to urban settlements.

In conclusion, the main characteristics of the institutional set up in Libya are the relatively strong capacities for strategic planning and especially engineering in the country. User participation and decentralisation, however, are evidently not very much developed. At present, for example, no water fees are imposed on of irrigation water; rather, irrigated agriculture is subsidized, and water-saving practices are not politically encouraged.

5.1.3 Institutions in Sudan

In Sudan**,** the Ministry of Irrigation and Water Resources (MIWR) is the federal body responsible for all water affairs. The Directorate of Groundwater and Wadis is responsible for all groundwater issues as well as those concerning non-nilotic streams and valleys. This Directorate is also the national focal point for coordination of the internationally supported Regional Nubian Sandstone Aquifer System Study Project (Abu-Zeid s. a., 5).

The responsibilities of the MIWR in Sudan are:

- Planning, management, development, and allocation of water to various users throughout the country
- International and regional cooperation concerning shared water resources
- Planning, designing, executing, operating and maintaining the various irrigation schemes
- Control of water extraction
- Construction of new irrigation works
- Operation and maintenance of all large-scale irrigation structures and drinking water facilities
- Provision of means for hydropower generation and protection of the water-related environment (FAO s. a.).

Current groundwater legislation, however, assigns responsibilities to various ministries and government agencies with little integration of their mandates. Moreover, water management institutions have been in a state of flux for years (study by the IFPRI 2006, 30).

According to the 1998 Constitution, all surface and subterranean resources, including water, are a public good whose utilization must be regulated and managed by the Federal Government (IFPRI 2006, 20). Initially, this regulation was introduced as part of the Water Resources Act of 1995.

Sudan is a federal republic, and each of its states has its own state legislative assembly, with complete administrative and fiscal autonomy (FAO s. a.). The State Water Corporation Act of 1996 regulated the management of water resources at the state level by *de facto* delegating responsibility to the State Ministries of Engineering Affairs. In accordance with this Act, state water corporations were set up. These entities are responsible for setting policies, planning the use and development of water infrastructures, setting tariffs, and generally for all management initiatives concerning groundwater. Despite the fact that no clear distinction is made between state and interstate water, in practice the State Water Corporations' jurisdiction also extends to water inasmuch as it is formally regarded as national property (IFPRI 2006, 21).

Other overlaps also exist and hinder effective water resources management. For example, the authority of the State Water Corporations often overlaps with that of municipalities and provinces. Whereas the Local Government Act of 2002 empowered municipalities to manage local water resources, laws and agreements concerning the use and protection of local water resources also exist at the regional level. Responsibilities are also sometimes duplicated at the national level, e.g. between the Higher Council for Environmental and Natural Resources and the National Council for Water Resources (IFPRI 2006, 20–21).[70]

A new National Water Policy formulated in 2000 aims at improving water governance. However, this policy has not yet been implemented, with the result that efficient coordination among the different agencies responsible for water management and greater involvement of the stakeholders are still not in place. Especially in the case of groundwater, local and state-level agencies and bodies do not sufficiently consult with groundwater authorities and specialists in their decision-making processes. Moreover, groundwater authorities are not permitted to monitor drilling activities of the petroleum industry or to enforce pertinent regulations.

Although some policy and legislative steps have been taken on the federal and state levels, water governance and the water-related legislative framework remain on the whole weak in Sudan. Furthermore, existing legislation has generally undermined or openly delegitimized the authority of

70 The case study published by the IFPRI (2006) gives a very interesting analysis of natural resource governance in Sudan.

traditional institutions for the management of natural resources and the resolution of conflicts over natural resources. Given the fact that the new institutions are weak, often overlap, and are not easily accessible to the local population, the regulatory gap created by the delegitimization of traditional institutions can easily result in an escalation of use conflicts over natural resources within the country (IFPRI 2006, 21–22).

5.1.4 Institutions in Chad

The Ministry of Environment and Water in Chad is responsible for groundwater resource planning. The Directorate of Hydraulics is responsible for hydrogeological issues and also provides data on available water resources and water use for rural water supply and livestock. It is also the institution with primary responsibility for the Regional Nubian Sandstone Aquifer System Study Project in Chad (Abu-Zeid s. a., 5). The General Directorate of Rural Works and Agricultural Hydraulics is in charge of irrigation and drainage from surface and groundwater sources and agricultural water use in general (AHT Group for GTZ / LCBC 2006).

A national Water Code has been in place in Chad since 1999, but is only weakly implemented. The Water Code defines all water resources in Chad as communal property, the exploitation of which is subject to declaration or authorisation under modern laws and must also comply with customary laws (FAO 2005a; HCNE et al. 2003, 73–74). United Nations Environment Programme (UNEP) assesses the capacities and the legislative framework for groundwater management in Chad as rather limited: equitable use of groundwater is not adequately governed by national law. Legal instruments and the authority to ensure compliance and enforce agreements are lacking (UNEP 2004).[71]

Moreover, the responsibilities of the different ministries are not clearly defined; the jurisdictions of the ministries often overlap and are sometimes conflicting (UNEP / Fortnam / Oguntela 2004, 86, 94, 99). The situation in Chad, one of the poorest countries in the world with a very low index of human development, is further worsened by adverse conditions in the

71 For more details on laws and regulations governing the water sector see HCNE et al. 2003, 73–75.

country such as domestic and cross-border armed conflicts (for example in the Lake Chad region).

Nevertheless, Chad drafted with support of United Nations Department of Economic and Social Affairs (UNDESA) and UNDP an Integrated Plan for Chad's Water Development and Management in 2003. In order to organize implementation and funding of the plan, institutional strengthening of the Ministry of Water and a cooperation mechanism between the supervising administration and stakeholders is needed. With the drafting of the Integrated Plan, an intersectoral consultative mechanism was set up and institutionalized in Chad for water governance (HCNE et al. 2003, 151). As capacities for planning and implementation are assessed to be a limiting factor, a planning and monitoring unit has been set up in the Directorate of Hydraulics (HCNE et al. 2003, 151).

The Integrated Plan covers groundwater-related activities for development of the Nubian Sandstone Aquifer (see chapter 4 for the Integrated Plan), namely the development of capacities and the sharing of know-how in relation to the CEDARE project (see Chapter 5.2 below) (HCNE et al. 2003, 198).

5.2 Institutions for transboundary cooperation

The chapter provides an overview of international institutions which have been established for transboundary groundwater management. Multilateral agreements are summarized, and the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer is analyzed in detail.

5.2.1 Cooperation over the NSAS

All riparian countries of the NSAS are members of the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer.[72] This Joint Authority was created by Libya and Egypt in 1982, and Sudan and Chad became members at a later point in time. The objectives and functions of the Commission have been declared as follows:

72 Note: The term Nubian Sandstone Aquifer is equivalent to the term Nubian Aquifer System used in this paper.

— Collecting data, information and study results for classification, analysis and linkups
— Conducting complementary studies to determine the present state of the aquifer regarding quality and quantity
— Preparation of plans for the development of water resources as well as proposing and implementing joint policies for the exploitation and use of water resources at national and regional levels
— Managing the aquifer on a sound scientific basis
— Cooperation in the areas of training and capacity building
— Awareness raising for rational use of the Nubian Sandstone Aquifer's water
— Studying the environmental impact of water development
— Organizing scientific workshops, disseminating aquifer-related information, and strengthening ties to regional and international organizations with common interests (Salem 2007, 111).

The Authority's board of directors consists of three members from each member country, an administrative secretariat, and a managing director appointed by the board (Nanni et al. 2006, 55–56). The Authority is chaired by each member country on a rotational basis. The board members are appointed from the Ministry of Water Resources and Irrigation in Egypt, the Secretariat of Agriculture of the Libyan Arab Jamahiriya, the Ministry of Irrigation and Water Resources in Sudan, and the Ministry of Environment and Water in Chad (Abu-Zeid s. a., 3).

Financial resources for the Authority are allocated annually. The budget for 2005 was 400,000 US$ (IAEA / UNDP / GEF 2006, 6.1), all of which was contributed by Libya (IAEA / UNDP / GEF 2006, 6.5). The board should meet twice a year and makes its decisions by a majority vote. However, only eight meetings have been held up to now, most of which were devoted to an exchange of information and scientific data and a review of work in progress in the Nubian Sandstone Aquifer System Study Project. This project is a primary responsibility of the Joint Authority, and it remains to be seen what role the Joint Authority will play in other projects in the future (compare also IAEA / UNDP / GEF 2006, 6.5).

The first phase of the Nubian Sandstone Aquifer System Study Project started in 1994. The project is carried out by CEDARE. This first phase was financed by the International Fund for Agricultural Development (IFAD), the second by the Islamic Development Bank (Salem 2007, 112; Abu-Zeid s. a., 2).

The project has two main objectives: 1) formulation of a regional strategy for utilizing of the NSAS, and 2) developing the capacity of national institutions to monitor and manage groundwater reserves in the riparian countries (WWC 2006, 76).[73]

Concerning the first objective, three major steps have been taken so far. First, the Joint Authority has sought to establish an adequate institutional setup for the formulation of a regional strategy. In line with this, the Joint Authority for Study and Development already mentioned above was revitalized and expanded to include Chad (in 1999), and other supportive regional and national institutions were also created.[74]

Secondly, studies to provide accurate technical information about the NSAS were carried out. These included the acquisition of data on ca. 2,100 wells, a GIS system with regional, hydro-geological and water quality maps, a mathematical model, simulation of different scenarios of exploitation, draft agreements by the National Coordinators on a protocol for information-sharing, and development of a website (WWC 2006, 76, compare also FAO s. a.). All information thus gained is stored in the Nubian Aquifer Regional Information System (NARIS) (see box 2).

73 In CEDARE (s. a.) a third objective was cited for the first project phase: “Assist the rural poor in accessing the resources needed to better their lives” (s. a., 5). Other publications do not refer explicitly to this objective. The socio-economic study described above might well be included under this objective.

74 A Regional Program Steering Committee 30 was also formed by the members of the Joint Authority to manage its work plan and budget (WWC 2006, 76). Another body formed was the Regional Technical Review Committee, consisting of representatives from Egypt, Libya, Sudan, Chad, CEDARE, IFAD, IDB, UNESCO, ACSAD, OSS, and the Technical University of Berlin (Abu-Zeid s. a., 5). With support from the Project, national focal point institutions were appointed in the member countries, and offices of the Joint Authority were opened in each country (Abu-Zeid s. a., 5, 2).

Box 2: Databases of the NSAS
The Nubian Aquifer Regional Information System (NARIS) contains data on water location characteristics, groundwater levels, water quality, water extraction, and stratigraphic and hydraulic parameters. Additionally, it includes a bibliographic database on earlier studies and research findings. It is linked to a geographical information system. NARIS is used to prepare input parameters for aquifer models as a means of simulating scenarios for different approaches to development of the NSAS. NARIS is stored on a server operated by CEDARE in Egypt. This server is accessible only to members of the Joint Authority. However, the application and maintenance of NARIS is also subject to severe limitations: difficulties in renewing software licences in Sudan and Egypt and technical limitations in Chad. Furthermore, the IAEA / UNDP / GEF project has identified major gaps in NARIS. A second NSAS database is the Isotope Hydrology Information System (ISOHIS), which focuses on isotopes and related data. It is operated by the IAEA. However, this database too appears to have significant gaps. One of the first meetings of the project partners of the new IAEA / UNDP / GEF Nubian Project recommended that close links be established between ISOHIS and NARIS in order to make them compatible and more accessible to the riparian countries and other institutions.
Source: Abu-Zeid s. a., 6 / Grossmann (2006, 211–212); IAEA / UNDP / GEF (2006 6.0); IAEA / UNEP / GEF (2007, 33)

A third objective concerns socio-economic development in the region as a whole. Recommendations for future socio-economic development were elaborated, and a system of regional indicators was developed in order to balance the groundwater needs of the population and available groundwater resources on the basis of a comprehensive assessment (WWC 2006, 76). This was carried out in the second phase of the project up to 2002 (Abu-Zeid s. a., 2). Abu-Zeid, who has described decisive factors for socio-economic development in the NSAS in detail, has shown that the topics relevant for cooperation concerning the NSAS go beyond hydrogeological and technical aspects. However, it remains unclear whether and how these issues are being taken into consideration in national policies and cooperation concerning use and development of the NSAS, since detailed information from the concerned member states is lacking.

With respect to the second objective mentioned above, namely the development of technical capacities, an assessment of needs has been carried out, hardware and software have been purchased, and training courses in key areas have been carried out by the national institutions in the four riparian countries (WWC 2006, 76).[75]

The member parties of the Joint Authority signed two agreements in 2000: The first governs the supervision and exchange of groundwater information concerning the NSAS. The members agreed to continue studying the NSAS, to share information gained by regional projects, and to incorporate this into a regional information system (details below). The second agreement governs continuous monitoring of the aquifer and data sharing by updating the regional information system.[76] These two agreements establish a continuous mechanism of regional cooperation (Abu-Zeid s. a., 2, 8).

As this makes clear, the Joint Authority is primarily an investigation and information exchange group which is not actually in charge of management decisions. However, its objectives include joint groundwater management, and its modelling activities do provide information for decision makers.

The major challenge ahead for the Joint Authority (JA) will be to promote a transition from transboundary cooperation in information sharing to joint management. Recently, A "Nubian Project" was started with this as its goal. Partners in the project include UNDP / GEF / International Atomic Energy Agency (IAEA), United Nations Educational, Scientific and Cultural Organization (UNESCO), the Joint Authority itself, and the four NSAS countries. The project's long-term goal is to establish a rational and equitable system of management of the NSAS for sustainable socio-economic development and the protection of biodiversity and land resources. The project's four immediate objectives are: 1) to identify priority transboundary threats and root causes; 2) to fill key gaps; 3) to prepare a Strategic Action Programme (SAP); and 4) to establish a framework for SAP implementation (online: http://www-naweb.iaea.org/ napc/ih/Nubian/IHS_ nubian.html).

75 Training was given in the application of mathematical models, the use of databases, the GIS, and the use of advanced monitoring equipment (Salem 2007, 112).

76 It is planned to provide updates of the Regional Information System in a database which is accessible through the Internet. This, however, has not yet implemented due to a lack of funds (Abu-Zeid s.a., 8).

5.2.2 Other agreements concerning transboundary water resources in the region

Apart from cooperation regarding the NSAS as a whole, the two NSAS riparian countries of Egypt and Sudan also cooperate in the Nile Basin Initiative, which has distinct objectives of its own and an individual regional scope.

The Nile Waters Agreement, signed between Egypt and Sudan in 1959, established regulations for each country's share of the Nile. Joint transboundary Nile management received new impulses during the 1990s, especially in 1998, when all riparian countries of the Nile, namely Tanzania, Burundi, Rwanda, Democratic Republic of the Congo (DRC), Uganda, Kenya, Ethiopia and Eritrea (the latter with observer status only) created a "Regional Partnership for Sustainable Development and Management of the Nile Waters". On the basis of this Partnership, the Nile Basin Initiative (NBI) was launched in 1999. The objective of the NBI is "*to achieve sustainable socio-economic development through the equitable utilization of and benefit from the common Nile Basin water resources*" (FAO 2005b). A strategic program containing a number of joint projects was developed within the NBI (Grossmann 2006, 207).

In contrast to practices concerning the NSAS, information sharing and steps towards joint management of the Nile appear to be hampered by limited political will due to strategic reasons in this upstream-downstream constellations (Grossmann 2006, 207). In particular, problems seem to appear between Sudan and Egypt.

It may therefore be asked whether the agreements reached above all between Sudan and Egypt concerning the use of the Nile have an influence on their negotiations concerning the use of the NSAS and vice versa. Two basic facts have to be kept in mind: First, Sudan is in the upstream position of the Nile and second, groundwater development projects in Egypt near the border with Sudan are likely to have a negative impact on groundwater availability in Sudan. For these reasons it can be assumed that any evaluation of water cooperation between Egypt and Sudan must take both NBI and NSAS cooperation into account.

In general terms, the respective responsibilities of the NBI and the Joint Authority, along with their respective memberships, coincide only in certain areas. However, inasmuch as both organizations are of great importance for water policy and security in their riparian countries, both could almost certainly benefit from the experience gained by countries which are members of each.

In addition to the NBI, other institutions also exist for transboundary water cooperation in the region. Libya, for example, also cooperates with Tunisia and Algeria over the North-West Sahara Aquifer. Chad is a member country of the Lake Chad Basin Commission.[77]

6 Prospects for transboundary cooperation, and recommendation for German development cooperation

Access to information and conclusions

The present study is based on the available literature and on communication with experts from the BGR and the University of Halle, Germany. Attempts to obtain the assistance of representatives from CEDARE were unsuccessful.

Although, information on the NSAS was accessible from the literature, recent detailed information on transboundary implications was not available. The available data show high variability and could therefore lead to differing conclusion.

The new IAEA / UNDP / GEF Project currently being conducted by the riparian countries is aimed at identifying and filling these data gaps. During the project's Technical Meeting held in Vienna in April 2007, a baseline of technical knowledge concerning the NSAS was established (IAEA / UNDP / GEF 2007) on the basis of which a Transboundary Diagnostics Analysis will be undertaken. The technical information gained in this way will serve as a basis for negotiations on transboundary groundwater management.

77 Transboundary groundwater management for the Lake Chad Basin and the North-West Saharan Aquifer are discussed elsewhere in this volume in two separate case studies.

Transboundary impacts and conclusions for transboundary cooperation

Since estimates of groundwater quantities stored in the aquifer system and theoretically available for use vary substantially, different authors have presented different conclusions regarding current and planed groundwater development projects in the region. Briefly, it appears that Egypt's groundwater development projects are likely to have a negative impact on Sudan. Whether this will also be the case for Libya is still subject to investigation. A drop in the level of groundwater tables at centres of extraction in Libya and Egypt has been reported.

The main impetus for cooperation over the use of the NSAS derives from prevailing common interests and similar incentives among the riparian states. This was underlined above by an analysis of the Eckstein-Eckstein types, which showed that the NSAS is a common pool resource without considerable upstream-downstream constellations.

In general, cooperation concerning the use of the NSAS is a strategic choice for the riparian countries in order to prevent international conflicts over socio-economic and environmental objectives and to secure access to water. This is naturally of enormous importance in this waterscarce region. Thus, cooperation in the use of the NSAS can be described as an issue of national security.

While the incentives for cooperation are similar, they are not equally strong for each riparian state: in each case, the capacity to pursue national interests differs substantially in practice depending on economic and political power and stability. This results in asymmetrical use and development of the NSAS. Among the riparian countries, Chad and Sudan seem to be in a weaker negotiating position since their groundwater extraction is limited by both technical and economic factors as well as by political stability.

The riparian countries have created a promising institutional environment for mutual cooperation in use of the NSAS. They have institutionalized this cooperation through the Joint Authority and other related interriparian and national organizational bodies. This process has been strongly supported by the CEDARE / IFAD / IDB project. Since the NSAS is one of ten transboundary water basins selected by African Ministers' Council on Water (AMCOW) within the framework of New Partnership for Africa's Development (NEPAD) to receive support from the African Water Facility, further activities in joint monitoring and evaluation as well as strategic development can be expected.

Main aspects of the interriparian cooperation at the moment are investigation, joint modeling and information sharing. In this regard, the major challenge appears to lie in improving the interface between monitoring and decision-making in order to react to changes within the system and to arrive at decisions based on reliable monitoring results. Analysis shows that the topics discussed among the riparian countries go beyond hydrogeological and technical issues to include the socio-economic dimensions of groundwater use in the region.[78] This provides a clue to the possible direction of future development of the institutions for cooperation in use of the NSAS, i.e. from data-sharing to joint management. However, the extent to which these issues are actually reflected in national policy making and in the cooperation process can at this stage not be fully assessed.

Barriers for undertaking further steps towards joint management by delegating more power to the Joint Authority can, however, be assumed to exist. Since access to the NSAS is a matter of national security, especially for Egypt and Libya, decisions concerning groundwater development projects are politically highly sensitive. This may not only create incentives for cooperation but also hinder them: that is, the countries involved may well refrain from transferring this kind of decision to an institution for transboundary cooperation.

The Joint Authority is an important part of Africa's institutional architecture for transboundary water management. While it may not yet have the authority to implement management decisions, it remains a successful forum for information collection and exchange.

Since transboundary cooperation concerning groundwater resources in the region is still in its infancy compared to cooperative use of surface water resources, the endeavours of Egypt, Chad, Sudan and Libya to jointly agree on the use of transboundary non-renewable groundwater may well

78 Given the fact that Chad and Sudan in particular are economically underdeveloped countries, the socioeconomic impact of groundwater development may be important for the reduction of rural poverty there.

yield an example of good practices for other countries. The challenge ahead is to move from developing the information sharing to cooperation in the form of joint management. This, in fact, is the goal of the recently initiated "Nubian Project".

External actors and recommendations for German development cooperation

Concerning the potential for cooperation between the NBI and the Joint Authority and its subordinate bodies, it is important to remember that the NBI and the Joint Authority are two separate institutions whose responsibilities are not identical. The importance of studying both therefore lies more in lessons to be learned regarding bilateral cooperation between Sudan and Egypt in both areas in spite of their different objectives.

External development support has played an important role in reviving the cooperation process in 1998 and technically and financially promoting it. In addition, research seems to be playing an increasingly important role for information gathering and the creation of models of use of the NSAS.

The following considerations can be derived from the preceding analysis for German development cooperation:

Most importantly, a general decision needs to be made as to whether German development cooperation should actively support the development of non-renewable groundwater resources. The current BMZ Sector Concept for Water states that support for deriving drinking water from non-renewable groundwater resources should be considered only if a) there is no other water source available to meet the demand for drinking water, and b) if a highly significant positive development impact can be expected from such intervention. It is indispensable, however, that all alternatives be carefully evaluated as a means of improving the water balance in the long run.[79]

79 See BMZ (2006, 17): *"In water catchment areas with a strained or negative water balance, the drinking water supply can only be safeguarded – if no water is to be diverted away from agriculture – through the temporary or permanent overexploitation of groundwater or from rivers and, in extreme cases, the utilisation of fossil groundwater. in such situations, the need to ensure a basic supply of water services to poor population groups must be brought into line with the need for environmental sustainability. in*

Applying this framework to the case of the NSAS, the following conclusions can be drawn:

— In actual fact, the population depends completely on the NSAS for its water supply, since no alternative water sources are available. Support for the drinking water supply should therefore be an option for German development cooperation within the framework of the Water Sector Concept. However, any measure must focus on improving the drinking water supply of marginalized people.

— Egypt and Libya are using the NSAS to augment irrigated agriculture in the Sahara Desert. Support for these activities would not conform to the Water Sector Concept. Nevertheless, support for greater water use efficiency and for the introduction (or further development) of water-saving practices (like wastewater use in agriculture) could be an interesting option for German development cooperation.

Apart from implications involving the non-renewable nature of groundwater resources in the region, the dimension of conflict prevention must also be taken into account. For this reason, support for the establishment of institutions and for the development of strategies in the riparian countries for successful cooperation in use of the NSAS could well be considered as a potential area of support for German development cooperation.

In this regard, German development cooperation may have effective entry points at both the national and regional levels.

The national level: since the riparian countries are relatively advanced regarding their information-sharing mechanisms, the focus could be put on developing national capacities for groundwater management. This is especially true in the case of Chad and Sudan, which appear considerably less advanced in terms of capacities for groundwater management in comparison to Libya and Egypt. However, since only Egypt is currently a partner country for bilateral German development cooperation, options at the national level are at the moment limited to this country.

In response to its tremendous population growth, Egypt is currently attempting to develop other parts of the country for agricultural production and human settlement. Here, the NSAS's non-renewable groundwater

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the long term, social justice can only be achieved on the basis of ecologically sustainable resource management."

plays a rather small role in comparison to that of the River Nile. Consequently, it would appear far more important for the reduction of (rural) poverty in Egypt to provide support for improving water governance in general and for increasing the efficiency of agricultural production while making the best use of available water resources. For these reasons it seems advisable that German development cooperation should concentrate on these issues in its development cooperation with Egypt rather than on bilateral support in relation to the NSAS.

The regional level: the Joint Authority and its subordinate bodies could provide institutional entrypoints for providing advisory services. The creation of mechanisms for resolving conflicts and compensating for negative impacts seems to be an important starting point in this regard. However, the riparian countries' political will to introduce such steps remains difficult to assess.

Information from the new IAEA / UNDP / GEF project, however, has shown that the Joint Authority is perceived by some of the riparians as being an institutional body of the IFAD project rather than an independent regional institution. The possibility of channelling support through the Joint Authority will therefore depend in future on strengthening the authority of existing institutions, on building up technical capacities, and on improved dialogue on the national and regional (= Joint Authority) levels in order to eventually change the role of this institution and the riparians countries' perception of it.

Germany is already contributing support at the regional level through its multilateral development cooperation. In view of the facts already presented, the present study recommends that these activities continue to receive support.

Finally, and again on *the regional level*, German development cooperation should intensify its cooperation with the African Water Facility for transboundary water management (AMCOW), since the NSAS is one of the priority areas for AMCOW. Support for AMCOW could therefore be extended to the improvement of capacities for implementing activities already planned for the NSAS.

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Data screening of the African case studies

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1 Categories and indicators for the data sheets

Five basic categories were used in the *Data Sheets* in order to structure information on transboundary aquifer systems in Africa. The information, collected from databases and from various publications, was grouped as follows:

Category 1: Aquifer information

The information in this category concerns the type of aquifer system, the riparian countries, the extension of each aquifer and its storage capacity, whether it is renewable or non-renewable (incl. the rate of recharge if renewable).

Comment: The figures found for storage capacity and annual recharge rates differed tremendously from one source to another.

Category 2: Information about riparian countries

This category contains information about the respective riparian countries, including their economic strength vis-à-vis each other (Gross Domestic Product, GDP) and their foreign relations (source: Heidelberg Institute for International Conflict Research, Annual Conflict Barometer). It also includes indicators of the riparian states' economic and social stability (Failed States Ranking) and their levels of corruption (Corruption Perception Index).

We expected that combining the GDP with these indicators would make it possible to draw tentative conclusions about a riparian state's ability to develop water resources, to provide water services, and to cooperate with other riparian states.

Failed States Ranking: these rankings are based on 12 political, economic, military and social indicators of instability. The higher the number, the greater the instability. Rankings from 1 to 20 thus identify a "critical" status, rankings from 21 to 40 an "in danger" status, and rankings from 41 to 60 a "borderline" status.

Corruption Perception Index: The CPI ranks more than 150 countries by their perceived levels of corruption (in descending order). The higher the ranking, the less a country is perceived to suffer from severe corruption. All African states are among the most corrupt two thirds of countries ranked by this index.

Category 3: Groundwater use in riparian countries

The third type of information concerns groundwater availability and sectoral use in the riparian countries (with special attention to irrigated agriculture, the major sector of use in Northern African countries). The aim here was to qualitatively assess whether the respective resource is being underutilized or overused and whether asymmetrical use is observable among the countries which share the respective aquifer system.

Comment: Most databases and literature consulted refer to national scenarios rather than to transboundary aquifers. Figures on groundwater use per sector are available for only a few countries, and figures given on water withdrawal for irrigation as a percentage of total renewable water resources do not differentiate between surface and groundwater. No reliable, comprehensive statistics on groundwater use are known, and there is very little information on which to base an estimate of current groundwater use, particularly in irrigated agriculture.

Category 4: Water relations

This category contains information on the riparian states' water relations in general and on transboundary aquifers in particular. It lists all formalized types of cooperation (e.g. treaties, memoranda of understanding) and names organizational units set up for any kind of joint activity, and, if available, the joint activities undertaken.

Category 5: Assessment

Last but not least, hydrogeophysical attributes and riparian constellations are described, and a qualitative assessment of the obstacles to cooperation is given, including an evaluation of the actual or potential transboundary impact of unilateral (national) use of groundwater resources and the current stage of cooperation.

2 Data sheets for the transboundary aquifer systems of the case studies

Data sheet 1: Volcanic Aquifer System (Kilimanjaro)

Category 1: Aquifer information	
Riparian countries	Kenya, Tanzania
Extension (km^2)	15,000 km^2
Type of aquifer	Fissured / fractured
Groundwater recharge	Medium (15–150 mm/year)
Renewable: Non-renewable	Yes
Storage in km^3	not available
Category 2: Information about riparian countries	
Population (in million / growth rate per annum)	Kenya: 32.4 / 2.5 Tanzania: 37.6 / 1.8
GDP in billions of US$ / per capita per year	Kenya: 18.0 / 530 Tanzania: 12.1 / 340
Failed States Ranking / score (Foreign Policy)	Kenya: 25 / 92.7 Tanzania: 31 / 91.0
Corruption Perception Index 2006 (Transparency International)	Kenya: 142 Tanzania: 93
Geopolitical conflicts	None

Category 3: Groundwater use in riparian countries	
Total groundwater availability (renewable) per country (km^3/a)	Kenya: 3.0 Tanzania: 30.0
Water dependency ratio (%)	Kenya: 33.1 Tanzania: 9.9
Groundwater use per sector as % of total groundwater resources (incl. non-renewable resources)	Kenya (no data) Tanzania (no data)
Water withdrawal (irrigation) as % of total renewable water resources	Kenya: 3 Tanzania: 2
Category 4: Transboundary water relations	
Interriparian water agreements	Convention for the Establishment of the Lake Victoria Fisheries Organization, Kisumu, 30 June 1994. Agreement to initiate a program to strengthen regional coordination in management of resources of Lake Victoria, 5 August 1994. Revised Protocol on Shared Watercourses in the Southern African Development Community (SADC), 7 August 2000. Protocol for Sustainable Development of Lake Victoria Basin. Arusha, 29 November 2003. Nile Basin Initiative, February 1999. East African Community Protocol for Environment and Natural Resources Management Decisions, November 2001.
Treaties on shared groundwater resources Cooperative structures Joint management activities	No treaties recorded Greater Pangani Basin Cross-border Dialogue

Category 5: Assessment	
Hydrogeological specifics relevant to riparian constellations	Interrelated surface-groundwater flows from mountains to plains; recharge takes place on the upper forested slopes, groundwater emerges on the lower slopes.
Cooperation problems	Upstream-downstream constellation with all recharge in the upstream forested areas. Issues for cooperation: integrated management of surface and groundwater, protection of catchment forests, resolution of local use conflicts.
Status of use	Surface water is the major water resource; in drier areas groundwater becomes important; increasing utilization of groundwater for irrigation as surface water becomes scarce.
Status of cooperation	No formal agreement, or cooperation mechanism, but a cross-border dialogue on surface river water which touches on local groundwater conflicts.

Data sheet 2: Lake Chad Basin Aquifer

Category 1: Aquifer information	
Riparian countries	Central African Republic, Chad, Cameroon, Niger, Nigeria
Extension (km^2)	2,434,000 km² (hydrological basin) 1,035,000 km² (conventional basin)
Type of aquifer	
Groundwater recharge	Low to medium (<15 mm/year – 15-150 mm/year)
Renewable: Non-renewable:	Yes
Storage in km^3	170,000–350,000
Category 2: Information about riparian countries	
Population (in million / growth rate per annum)	Central African Republic: 4.3 / 1.5 Chad: 9.7 / 3.1 Cameroon: 17.3 / 2.4 Niger: 12.5 / 2.9 Nigeria: 131.8 / 2.7
GDP in billions of US$ / per capita per year	Central African Republic: 4.6 / 1,100 Chad: 5.5 / 1,200 Cameroon: 39.7 / 2,300 Niger: 11.6 / 1,000 Nigeria: 175.5 / 1,400
Failed States Ranking / scores (Foreign Policy)	Central African Republic: 20 / 93.7 Chad: 7 / 100.9 Cameroon: 53 / 84.6 Niger (not listed) Nigeria: 54 / 84.3

Corruption Perception Index 2006 (Transparency International)	Central African Republic: 130 Chad: 156 Cameroon: 138 Niger: 138 Nigeria: 142
Geopolitical conflicts	Cameroon – Nigeria The former Lake Chad border conflict has been resolved (Barkassi Treaty)
Category 3: Groundwater use in riparian countries	
Total groundwater availability (renewable) per country (km^3/year)	Central African Republic: 56.0 Chad: 11.5 Cameroon: 100.0 Niger: 2.5 Nigeria: 87.0
Water dependency ratio (%)	Central African Republic: 2.4 Chad: 65.1 Cameroon: 4.4 Niger: 89.6 Nigeria: 22.8
Groundwater use per sector as % of total groundwater resources (incl. non-renewable resources)	**Central African Republic** (no data) **Chad** Industrial: 0 Domestic: 29 Agricultural: 71 **Cameroon** (no data) **Niger** Industrial: 4 Domestic: 58 Agricultural: 39 **Nigeria** (no data)

Water withdrawal (irrigation) as % of total renewable water resources	Central African Republic (no data) Chad: 0 Cameroon: 0 Niger: 6 Nigeria: 2
Category 4: Transboundary water relations	
Inter-riparian water agreements	Act Regarding Navigation and Economic Co-operation Between the States of the Niger Basin (incl. Chad, Cameroon, Niger and Nigeria). Niamey, 26 October 1963. Convention and Statute relating to the Development of the Chad Basin (incl. Chad, Cameroon, Niger and Nigeria). Fort Lamy, 22 May 1964. Agreement concerning the River Niger commission and the navigation and transport on the River Niger (incl. Chad, Cameroon, Niger and Nigeria). Niamey, 25 November 1964. Agreement concerning the Niger River Commission and the Navigation and Transport on the River Niger. Done at Niamey, on 25 November 1964 [Rectification] (incl. Chad, Niger, Cameroon and Nigeria). Niamey, 15 May 1968. Moundou Accord reached between Cameroon and Chad in August 1970. The Accord covers water abstraction rates from the Logone River for agricultural production. The Chad-Cameroon Joint Commission was created subsequently. Agreement to Establish a Commission for the Koma-Dogou-Yobe. 3 March 1971 (Niger and Nigeria).

	Establishment of the Niger-Nigeria Joint Commission (NNJC) for Cooperation, 1971 Agreement establishing the Lake Chad basin Commission development fund (incl. Chad, Niger, Cameroon and Nigeria). Yaounde, 22 October 1972. Protocol to the Agreement to Establish a Commission for the Koma-Dogou-Yobe. 22 December 1973 (Niger and Nigeria). Agreement concerning the Niger River Commission and the Navigation and Transport on the River Niger (incl. Chad, Cameroon, Niger and Nigeria) Revised on 2 February 1968 and 15 June 1973. Agreement for the Creation of Development Fund for the Chad Basin Commission (incl. Chad, Cameroon, Niger and Nigeria). Yaounde, 10 October 1973. Convention Creating the Niger Basin Authority (incl. Chad, Cameroon, Niger and Nigeria). Faranah, 21 November 1980. Règlement Financier Revisé de l'Autorité du Bassin du Niger (incl. Chad, Cameroon, Niger and Nigeria). N'Djamena, 27 October 1987. Convention Revisée portant Creation de l'Autorité du Bassin du Niger (incl. Chad, Cameroon, Niger and Nigeria). N'Djamena, 29 October 1987.

Treaties on shared groundwater resources Cooperative structures Joint management activities	Agreement between the Federal Republic of Nigeria and the Republic of Niger Concerning the Equitable Sharing in the Development Conservation and Use of Their Common Water Resources. Done at Maiduguri. Maiduguri, 18 July 1990. Cooperation between Nigeria and Niger with Mali over the use of the Iullemeden Aquifer System which partly underlies the Niger Basin. Since no clear legal framework for cooperation exists, the three riparian countries are supported by international donors (mainly UNDP / GEF) in their steps towards transboundary management of the Iullemeden Aquifer System. Lake Chad Basin Commission.
Category 5: Assessment	
Hydrogeological specifics relevant to riparian constellations	Different water-bearing strata constitute the Lake Chad Basin Aquifer. The upper aquifer is closely linked to Lake Chad and the rivers in the basin and closely interacts with surface water. Groundwater stored at greater depth poses technical and financial challenges to the riparians which only Nigeria appears able to meet. Incentives for cooperation are different for each riparian state depending on its access to surface water resources, its population density, and its financial and technical resources.

Cooperation problems	National use can impact on water quality and quantity. Regarding the upper aquifer, the riparians are in an upstream-downstream constellation where the transboundary direction of flow characterises the cooperation problems. Concerning the deeper aquifers, common interests appear to prevail.
Status of use	Cannot be judged due to lack of information about groundwater storage, use, recharge, and flow. Groundwater is being increasingly used in the countries of the Lake Chad Basin; and a water level decline has been reported.
Status of cooperation	Joint study by the Lake Chad Basin Commission

Data sheet 3: North-West Sahara Aquifer System

Category 1: Aquifer information	
Riparian countries	Algeria, Tunisia, Libya
Extension (km^2)	1,000,000 km^2
Type of aquifer	Porous, fissured/fractured
Groundwater recharge	Low (<15 mm/year)
Renewable: Non-renewable:	~1 BCM recharge/year Yes
Storage in km^3	~1,280 km^3
Category 2: Information about riparian countries	
Population (in million / growth rate per annum)	Algeria: 328.5 / 1.2 Tunisia: 10.1 / 0.9 Libya: 5.8 / 2.3
GDP in billions of US$ / per capita per year	Algeria: 102.3 / 2,730 Tunisia: 28.7 / 2,890 Libya: 38.8 / 5,530
Failed states ranking / scores (Foreign Policy)	Tunisia (not listed) Algeria (not listed) Libya (not listed)
Corruption Perception Index 2006 (Transparency International)	Tunisia: 51 Algeria: 84 Libya: 105
Geopolitical conflicts	None

Category 3: Groundwater use in riparian countries	
Total groundwater availability (renewable) per country (km^3/year)	Tunisia: 1.5 Algeria: 1.7 Libya: 0.5
Water dependency ratio (%)	Tunisia: 9.0 Algeria: 2.9 Libya: 0
Groundwater use per sector as % of total groundwater resources (incl. non-renewable resources)	**Tunisia** Industrial: 4 Domestic: 10 Agricultural: 86
	Algeria Industrial: 5 Domestic: 46 Agricultural: 49 **Libya** Industrial: 4 Domestic: 9 Agricultural: 87
Water withdrawal (irrigation) as % of total renewable water resources	Tunisia: 49 Algeria: 27 Libya: 712
Category 4: Transboundary water relations	
Inter-riparian water agreements	No transboundary surface water bodies
Treaties on shared groundwater resources Cooperative structures Joint management activities	Establishment of the Observatory of the Sahara and the Sahel (OSS), Paris 1992. Establishment of the joint NWSAS research project including the implementation of negotiation mechanisms supervised by OSS, 1989.

Category 5: Assessment	
Hydrogeological specifics relevant to riparian constellations	Multilayered; fossil, non-renewable resource; weak subsurface flows towards the Tunisian coast.
Cooperation problem	Incentives to cooperate are unevenly distributed among the riparian countries.
Status of use	Overutilized in comparison to recharge (2.5 billion m^3/year); increasing in the future; utilization represents spatial distribution; no technical asymmetries.
Stage of cooperation	Coordination of research activities by an established body.

Data sheet 4: Nubian Sandstone Aquifer System (NSAS)

Category 1: Aquifer information	
Riparian countries	Chad, Egypt, Libya, Sudan
Extension (km^2)	2,000,000 km^2
Type of aquifer	Porous, fissured/fractured
Groundwater recharge	Low (<15 mm/year)
Non-renewable	15,340 km^3
Storage in km^3	Estimates range between 15,000 and 372,960
Category 2: Information about riparian countries	
Population (in million / growth rate per annum)	Sudan: 36.23 / 2.0 Egypt: 74.03 / 1.9 Chad: 9.75 / 3.1 Libya: 5.85 / 2.0
GDP in billions of US$ / per capita per year	Sudan: 27.7 / 640 Chad: 5.5 / 400 Egypt: 89.3 / 1,250 Libya: 38.8 / 5,530
Failed states ranking / scores (Foreign Policy)	Sudan: 3 / 104.1 Chad: 7 / 100.9 Egypt: 38 / 88.8 Libya (not listed)
Corruption Perception Index 2006 (Transparency International)	Sudan: 156 Chad: 156 Egypt: 70 Libya: 105

Geopolitical conflicts	**Sudan:** 2 international conflicts involving Chad and Egypt (international power, resources, territory) **Chad:** 1 international conflict with Sudan (international power) **Egypt:** 1 international conflict with Sudan (resources, territory)
Category 3: Groundwater use in riparian countries	
Total groundwater availability (renewable) per country (km^3/year)	Sudan: 7.0 Chad: 11.5 Egypt: 1.3 Libya: 0.5
Water dependency ratio (%)	Sudan: 76.9 Chad: 65.1 Egypt: 96.9 Libya: 0
Groundwater use per sector as % of total groundwater resources (incl. non-renewable)	**Sudan** (no data) **Chad** Industrial: 0 Domestic: 29 Agricultural: 71 **Egypt** Industrial: 0 Domestic: 58 Agricultural: 42 **Libya** Industrial: 4 Domestic: 9 Agricultural: 87
Water withdrawal (irrigation) as % of total renewable water resources	Sudan: 56 Chad: 0 Egypt: 92 Libya: 712

Category 4: Transboundary water relations	
Inter-riparian water agreements	Agreement between the Republic of the Sudan and the United Arab Republic of Egypt for the Full Utilization of the Nile Waters. Cairo, 8 November, 1959. Protocol (to the November 8, 1959 agreement between Egypt and Sudan) Concerning the Establishment of the Permanent Joint Technical Committee. Cairo, 17 January, 1960. Agreement on the Nile Basin Initiative launched in February 1999 by the Ministers of Water Affairs of the 10 countries that share the Nile River (Burundi, Democratic Republic of the Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, Sudan, Tanzania and Uganda) to establish a joint management and development of the Nile Basin's resources.
Treaties on shared groundwater resources Cooperative structures Joint management activities	Establishment of the Observatory of the Sahara and the Sahel (OSS), Paris 1992. Establishment of the Joint Authority for the study and development of the Nubian Sandstone Aquifer, initially adopted in 1992 member states Egypt, Libya, Sudan (since 1998), and Chad (since 1999). Agreement 1 Chad, Egypt, Libya and Sudan for monitoring and exchange of groundwater information. 5 October 2000. Agreement 2 Chad, Egypt, Libya and Sudan for monitoring and data sharing for sustainable development and proper management of the NSAS. 5 October 2000.

Category 5: Assessment	
Hydro-geological specifics relevant to riparian constellations	Non-renewable, deep, extended aquifer in a very arid environment with very limited access to surface water sources, resulting in high dependency of riparians on groundwater. Fragmentation of aquifer into different sub-basins affects the scale of transboundary impact resulting from national use and the time when it becomes apparent. Problems caused by saline water are increasing towards the north.
Cooperation problems	Issues are mainly connected to water quality. Impacts from large-scale development are reported. Transboundary impacts are likely, research is ongoing. Common interests of the riparian states dominate.
Status of use	Recent research and descriptions of impact at the national level indicate overdevelopment. Use is highly asymmetric, with the northern riparians Egypt and Libya making heavy use of the aquifer.
Stage of cooperation	Coordination of research activities by an established body.

Data sheet 5: The Stamptriet Artesian Aquifer System (South-East Kalahari Karoo Basin)

Category 1: Aquifer information	
Riparian countries	Namibia, Botswana, South Africa
Extension (km^2)	Unclear; probably 70,000 km^2 with 166,00 km^2 on the Namibian side
Type of aquifer	Porous, fissured/fractured, karst
Groundwater recharge	Medium (15–150 mm/year)
Renewable: Non-renewable:	Yes
Storage in km^3	357,000 km^2 on Namibian side
Category 2: Information about riparian countries	
Population (in million / growth rate per annum)	Namibia: 2.0 / 0.5 Botswana: 1.7 / 0.7 South Africa: 45.2 / 1.9
GDP in billions of US$ / per capita per year	Namibia: 6.1 / 2,990 Botswana: 7.7 / 5,951 South Africa: 240.2 / 4,960
Failed states ranking / scores (Foreign Policy)	Namibia (not listed) Botswana (not listed) South Africa (not listed)
Corruption Perception Index 2006 (Transparency International)	Namibia: 55 Botswana: 37 South Africa: 51
Geopolitical conflicts	Namibia – South Africa 1 international conflict (territory, resources)

Category 3: Groundwater use in riparian countries	
Total groundwater availability (renewable) per country (km^3/year)	Namibia: 2.1 Botswana: 1.7 South Africa: 4.8
Water dependency ratio (%)	Namibia: 65.7 Botswana: 79.9 South Africa: 10.4
Groundwater use per sector as % of total groundwater resources (incl. non-renewable resources)	**Namibia** Domestic: 15.8 Agriculture: 84.2 **Botswana** (no data) **South Africa** Domestic: 11 Agricultural: 84 Industrial: 6
Water withdrawal (irrigation) as % of total renewable water resources	Namibia: 1 Botswana: not available South Africa: 22
Category 4: Transboundary water relations	
Inter-riparian water agreements	Agreement between Botswana and Namibia on the Establishment of the Joint Permanent Technical Committee. November, 1982. Agreement between Botswana and Namibia on the Establishment of the Joint Permanent Technical Committee. November, 1983. Agreement between Botswana and Namibia on the action plan for the environmentally sound management of the Common Zambezi River system. Harare, 28 May 1987. Agreement between Botswana and Namibia on the Establishment of the Joint Permanent Commission for Cooperation, 1989

	Agreement Between the Government of Botswana and the Republic of Namibia on the Establishment of a Joint Water Commission. Windhoek, 13 November 1990. Agreement between the government of the Republic of Namibia and the government of the Republic of South Africa on the establishment of a permanent water commission signed at Noordoewer, 14 September 1992. Agreement on the Vioolsdrift and Ngordoewer Joint Irrigation Scheme Between the Government of the Republic of South Africa and the Government of the Republic of Namibia. Pretoria, 26 April 1993. Agreement between the Governments of the Republic of Angola, the Republic of Botswana, and the Republic of Namibia on the Establishment of a Permanent Okavango River Basin Water Commission (OKACOM). Windhoek, 16 September 1994. Agreement between Botswana and Namibia on the Establishment of the Joint Permanent Technical Commission, 1997. Revised Protocol on Shared Watercourses in the Southern African Development Community (SADC). 7 August 2000. Agreement Between the Governments of the Republic of Botswana the Kingdom of Lesotho, the Republic of Namibia and the Republic of South Africa on the Establishment of the Orange-Senqu Commission. Windhoek, 3 November 2000.
Treaties on shared groundwater resources, Cooperative structures, Joint activities	No treaties recorded Extended mandate of ORASECOM

Category 5: Assessment	
Hydro-geological specifics relevant to riparian constellations	Declining water quality towards the southeast; recharge exclusively on Namibian territory.
Cooperation problem	No transboundary impacts of national use reported; water quality declining towards the southeast; population density and water demand low on the Botswana and South African sides. Cooperation problem characterised by highly asymmetric demand, with Namibia as the only significant user of the aquifers.
Status of use	Highly asymmetric use, might be overdeveloped in Namibia, assumingly no further potential for development in Botswana and South Africa due to low water quality.
Status of cooperation	ORASECOM; IWRM plan for the Orange river basin includes groundwater.

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Category 5: Assessment

Based on the case studies in this volume

Part C: International experience

Institutional aspects of groundwater governance

Insa Theesfeld

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Institutional aspects of groundwater governance

Insa Theesfeld

1 Introduction

A profound understanding of the options for national groundwater governance regimes and of the experience gained with them is a precondition for developing recommendations for transboundary groundwater governance in general – and not only for the African continent. As Ostrom (1962, 450) stated nearly 50 years ago: *"Few areas ... offer a richer variety of organisational patterns and institutional arrangements than the water resource arena."*

On the one hand, the present paper focuses on groundwater governance at the national level for two reasons: First, transboundary problems occur as a result of ineffective national governance structures and rules-in-use of daily groundwater use. Second, transboundary groundwater management relies on effective and functional national structures to enforce or facilitate transboundary agreements.

On the other hand, this paper describes institutional aspects of groundwater governance on the basis of an analysis of current national groundwater governance structures. These aspects are crucial: no matter what kind of international groundwater governance regime is chosen, the institutional aspects become highly relevant as soon as concrete policy measures are implemented. The paper therefore seeks to indicate institutional aspects that may either hinder or foster effective policy implementation.

The challenge from an institutional point of view is how to govern and protect groundwater resources while also guaranteeing a reliable supply despite rapidly growing demand. At present, little is known about the institutions and policies that govern groundwater use in many different societies (Mukherji / Shah 2005, 329). Therefore this paper reviews well-documented cases of national groundwater governance.

India, Pakistan, Bangladesh and China account for the bulk of the world's groundwater use in agriculture. In addition, many development aid organisations currently focus on assessing the opportunities for transferring experiences gained in the manufacture and maintenance of irrigation equipment from India and China to Africa, and the appropriateness of doing so. In Tanzania, Malawi and Zambia, for example, the application of modern irrigation technologies is expected to transform previously poor farms into economically viable ones (Kandiah 1997). It can be expected that water use for irrigation in Africa will continue to increase and will therefore make the importance of water governance more critical there. Therefore, it is extremely relevant to study not only the water technologies themselves, but also the experience gained to date in governing groundwater systems.

This paper begins by classifying groundwater as a common-pool resource and introducing three types of policy instruments. It then discusses seven items which have a high impact on windows of opportunity for groundwater governance: groundwater legislation, bureaucracy, economic instruments, participation, information, population density, and technology. Finally, conclusions will be drawn regarding transboundary groundwater management in Africa.

2 Groundwater as a common-pool resource

Groundwater is a **common-pool resource** with the characteristics of subtractability and low excludability. Subtractability, according to Ostrom (1990, 31–32), is typical for a common-pool resource and involves the possibility of approaching the upper limit of resource units which can be produced. In the context of groundwater, this means that the water level drops with every unit extracted and that the resulting increased lift increases the cost of pumping the next unit. Low excludability means that it is difficult to exclude water users, in particular landowners, from pumping water from aquifers.[1]

The consequence is the well-known common-pool resource dilemma of overexploitation. That is, water will be extracted at a rate greater then the social optimum. The exploiter of the resource pays only the recurrent costs of pumping and the capital costs of well construction, since the costs of externalities are often overlooked. Users sometimes extract as much groundwater as possible in order to maintain their water rights. This is widely dis-

1 The term common-pool resource is not intended to reflect the legal status of groundwater as *public, common* or *private* resource.

cussed as the **tragedy of the commons** and denotes the environmental degradation that occurs whenever a large number of individuals share a subtractable resource where no effective property rights regime is in place.

However, it can also be shown for the Asian region that it is actually the "tragedy of open access" that matters (Bromley 1998; Grafton 2000). In regions where depletion is in progress there, appropriation rules are not effective. Rather, unrestricted open access has been the general rule (Shah et al. 2001, 7). The frequent failure to distinguish between a common property regime and no property regime at all is often responsible for pessimism regarding collective action. This conclusion has often led to proposals for institutional change in the management of common-pool resources in the direction of either full private property rights or state control. However, there are many empirically documented cases in which communities have contributed to sustainable resource management by establishing appropriation rules, monitoring the situation of the commons, controlling rule violation, and assigning penalties. Failure and success in solving commons problems have been widely studied for local irrigation systems, in Asia as well (Wade 1994; Lam 1998; Ostrom 1992). However, the focus of these studies has not been on groundwater aquifer management. Although studies of self-governance of whole groundwater aquifers are rare, cases from California show that sustainable groundwater management can also be achieved on the basis of collective action (Blomquist 1992). Besides subtractability and low excludability, other characteristics of groundwater resource systems also determine governance options, as outlined in Box 1.

3 Governance structures and policy instruments

The three categories of governance structures[2] are: **hierarchy, market, and hybrid** (Williamson 2004).[3] "Hierarchy" and "market" stand for a top-down,

2 Governance structures are the organisational solutions for making rules effective, i.e. they are necessary for guaranteeing rights and duties and their implementation in the coordination of transactions.

3 The Williamson framework, initially developed for studying economic organisation of the private sector, has been expanded more and more to include agri-environmental problems (Bougherara / Grolleau / Mzoughi 2005).

Box 1: Additional characteristics of groundwater resource systems

Externalities. Typical of transactions related to groundwater usage is the difficulty of attributing external effects to pumpers or polluters. For example, individual farmers may contaminate groundwater as a by-product of their farming activities. The effects of this on others is not accounted for in their profit-maximisation decisions because it has no financial cost for them. However, it certainly produces social costs for society. The complexity and time lags inherent in many aquifer flow regimes mean that the causes and effects of human actions often tend to become decoupled from one another with regard to both groundwater abstraction and pollution. Individual misconduct is almost impossible to measure.

Irreversibility and time lag. Once a groundwater aquifer is seriously contaminated, it may be difficult, costly, or even technically impossible to reverse this contamination. Together with the long time lag which may occur before an impact on a resource becomes noticeable, this characteristic calls for governance solutions which are based on prevention.

Indivisibility. Although resources (like land) can be divided into individual units for ownership and use, this is not the case with aquifers, since they are interconnected hydrological systems. Although contamination can progress by degrees, it is not possible to fence off part of an aquifer and allow only that part to be contaminated.

Information asymmetry. In groundwater management there is much asymmetry between the information level of the state, that is, the monitoring agency, and that of polluters or abstractors. This leads to inefficient policy implementation, since the transaction costs of the state for monitoring pollution and abstractions are prohibitively high.

Uncertainty and data needs. Reliable groundwater-related data is imperative for making knowledge-based decisions. In most countries, the data available on both groundwater quantity and quality are poor compared to the data available for surface water (Biswas 1999, 8). Moreover, the data are not homogeneous. National data collection and knowledge about the interrelationships between human actions and the extent and timescale of groundwater degradation are lacking. The transmission paths by which contaminants enter aquifers are unknown and, in particular, the potential health effects are uncertain.

Decentralisation of abstraction. A main determinant for regulating groundwater usage is whether countries have a centralised or decentralised (local) system of water uptake. Local development is often due to technological developments which, although they decrease investment costs for small users, increase monitoring costs. A major factor of agrarian growth in e.g. India, Pakistan, Bangladesh and China is the increase of groundwater irrigation by means of small pumps and wells financed mostly by private farmers (Shah et al. 2001, I). Today, the public tube well programs of India and Pakistan lie in complete disarray even though the private tube well economy is booming and is considered more productive than public irrigation systems (Shah et al. 2001).

state-managed system and for the free allocation of goods and resources without any regulatory intervention. Hybrids, such as horizontal non-market coordination structures, are seen as a possible way to manage common-pool resources.

It can be assumed that almost every governance structure in the real world is a hybrid form somewhere between the polar cases of hierarchy and market. In practice, various forms and combinations of governance structures are used to coordinate agri-environmental transactions. Empirical evidence shows that it is very difficult to find suitable combinations of governance structures for facilitating sustainable resource management. Institutional policies generally aim at influencing or encouraging real-world transactions (e.g. the use of pesticides, or the pumping of groundwater) by changing existing rules or creating new ones in order to coordinate these transactions. Thus, the aim of policy instruments is to have an impact on governance structures.

There are three types of policy instruments, **regulatory, economic and voluntary** or **advisory**. In South Asia and China, for instance, a wide range of policy instruments has been implemented, including groundwater laws, licensing and permit systems, tradable property rights to water, and the pricing of groundwater as an economic good. The resulting governance structures, however, have proven to be very ineffective (Shah et al. 2001).

a) **Regulatory** or command-and-control policy measures such as laws, well registration, and allocation of user rights, are compulsory. Due to the large number of small groundwater users it is difficult to implement top-down groundwater management, since effective monitoring of the use of groundwater would be very costly. Enforcement must therefore be rooted in local acceptance.

b) **Economic** policy instruments make use of financial (dis)incentives such as subsidies, taxes, tradable pollution permits, and groundwater pricing. Setting a price on water abstraction, however, is generally combined with regulatory policy instruments such as national or regional water laws. These instruments are important in developing countries, where market systems are largely ineffective due to corruption and rent-seeking.

c) **Voluntary/advisory** policy instruments are those that motivate voluntary actions or behavioural changes without the need of fiat or direct financial incentives. Collective action, a specific hybrid form of governance structures, is of particular interest in managing a common-pool resource like groundwater (Ostrom 1990). In most cases, participation and collective action is facilitated by voluntary/advisory policy instruments. The reason for this is that collective action can be encouraged to a large extent by providing (scientific) knowledge (for example, by making hydrogeological information accessible to and understandable for the real stakeholders), by contributing practical experience, and by providing information that persuades those involved to participate. In addition, collective action is often also motivated by economic policy instruments such as the subsidization of water prices for group members. Such local forms of self-governance must also be supported by legislation which, for example, allows group members to set and change their own statutes, by public oversight (e.g. water quality control), and by regulations (e.g. by defining abstraction quotas).

4 Groundwater governance has to do with groundwater legislation

This section explains how the assignment of disaggregated property rights to groundwater causes incentives or disincentives to manage the recourse. The subsequent paragraphs describe emerging trends in national groundwater legislation and regulatory provisions in the ongoing fight against depletion and pollution. Mechanisms for national groundwater legislation are often combined with market and voluntary/advisory policies. Like most countries, South Asian countries rely to some extent on regulations and legislation to regulate groundwater use. But with a high number of scattered water users, high monitoring and control costs appear and with this the need that formal rules be structured in a way that authorities can count on voluntary compliance.

4.1 Types of property rights and their assignment

A crucial characteristic of groundwater governance is the difficulty in assigning property rights (Dalhuisen / De Groot / Nijkamp 2000). Here it is important to distinguish property rights from ownership rights.

In general, ownership rights to a physical entity include: a) the right to make physical use of physical objects, b) the right to alter them and derive income from them, and c) the power of management, including that of alienation (Furubotn / Richter 2000, 77). Even when the state claims ownership rights to natural resources, individual or collective users may nevertheless hold specific rights. For instance, the state may have ownership rights to a body of groundwater while the irrigators themselves determine who is to have access and withdrawal rights.

Those involved may attribute value to a physical good because, for example, whoever has a right to it enjoys certain benefits; on the other hand, its value may diminish if the rights to it are burdened by cost components. Schlager / Ostrom (1992, 250–251) divide property rights generally into 1) access rights, 2) withdrawal rights 3) management rights, 4) exclusion rights and 5) alienation rights. Property rights may be structured so as to include or exclude any of these five distinct types of rights. The five may be more or less well defined, and how they are combined has an impact on the incentives of those involved to govern and manage their system.

When a system of groundwater rights is introduced it is usually referred to as the right to abstract and the right of use. These rights are subject to terms and conditions which determine how each is to apply, for example in terms of duration, locations for water abstraction and use, purpose of the use, rates of abstraction, specifications for water works, environmental requirements, fees and costs for possession of the right, records of transactions, loss or reduction of the right, suspension of the right, review of the right, and renewal of the right (Garduno et al. 2002–2006).

4.2 Ownership rights to water and land

Both traditionally and on the basis of Roman law, groundwater has been regarded as the possession of the owner of the land above it. For centuries, the owner of surface land was also the owner of water under it. This is still the case in South Africa, for example, where groundwater rights are attached to the land (Mukherji / Shak 2005, 335).

In general, this unspecified stage of property rights implies that the landowner can extract as much water as he desires without any kind of restriction. To prevent overuse, the respective local or national government has the option of limiting unrestricted withdrawal by imposing requirements on groundwater abstraction and use.

Some Islamic schools of thought, such as Sunnism, distinguish between land rights and water rights: the digger of a well – whether on his own land or on unoccupied land – automatically becomes the owner of the well's water as soon as digging is completed. The owner of the well is the sole beneficiary of the right of irrigation (Caponera 1992, 70).

4.3 Regulations for use

The landowner's water rights can be regulated by limiting the amount which he may extract and/or use. For example, he may be obliged to obtain a permit or authorization before constructing a well or drilling a wellhole. In turn, the permit itself may be subject to conditions governing such factors as maximum depth or maximum abstraction rates. Under amended 1998 legislation in Niger, for example, the abstraction of groundwater for whatever purpose may not exceed 40 m^3 per day; otherwise regulatory restrictions become effective (Burchi 1999, 57).

4.4 Statutory vestment in the public domain

For a government to control groundwater, it must declare that the respective groundwater resource is located on property which is in the public domain. The resource is then regarded as being held by the state in trust for the public. This declaration turns the former owner into a user who must himself apply to the state for rights of water abstraction and use. The situation is exemplified by the South African National Water Act of 1998 (Burchi 1999, 58). A critical issue there is whether former owners of groundwater are entitled to compensation for such disenfranchisement.

Property rights in this case become separated from water rights, and only the right to water abstraction and its use accrues to the owner of overlying land or others. In addition, these rights may be cancelled if the resource is not used or upon failure to comply with the law. In detail, such institutional arrangements may also include a broad array of conditions governing the duration of such rights and the quantity and rate of abstraction. For instance, the U.S. State of Iowa restricts the duration of groundwater abstraction permits to less than ten years when aquifer capacity is uncertain (Burchi 1999, 58).

4.5 Supervision of well construction activities

Groundwater legislation may also regulate the licensing of well drilling contractors or may impose controls over the import of pumps and drilling equipment, especially in the case of large-scale, sophisticated facilities requiring external expertise and labour (Nanni et al. 2002–2006). In South Asia, in contrast, pumping facilities are mostly on a small scale and are constructed by the well users themselves.

4.6 Land surface zoning

Land surface zoning as a policy instrument can be used for quantity control and quality protection of groundwater resources. For example, water administrators may pass laws creating special control areas where exceptional restrictions apply. Such areas may be a) resource conservation zones for the control of groundwater abstraction, b) resource protection areas in areas where aquifers are highly vulnerable to pollution. Restrictions on crops, pesticides, and fertilisers are common in such areas as a means of preventing percolation into the groundwater. They generally reduce land values and raise the question of a legal right to compensation payments. Laws governing such areas may be purely mandatory or may also be supported by voluntary policies involving education programs or the promotion of codes of good agricultural conduct. This has been attempted in some regions of South Asia, for example, but the zoning system there is only weakly enforced (Shah et al. 2001, 21).

4.7 Wastewater discharge licensing

To protect groundwater against pollution a licensing system for wastewater discharge can be implemented. This type of legislation follows the ‘polluter-pays-principle’ by which a polluter is charged for the amount of pollution he produces. However, this principle is very difficult to enforce due to the time lag before pollution becomes apparent and the persistence of certain groundwater contaminants. Economic incentives are therefore also required in order to induce the industrial sector and water utilities to invest in adequate wastewater treatment and recycling.

4.8 Aquifer and land use planning

The management of water resources, including their protection from pollution, can be facilitated through long-term groundwater planning in order to ensure informed, forward-looking and participatory decision-making. Such plans can provide for an integrated assessment of all factors involved. For instance, a distinctive feature of the French water-planning system is the participation of civil society in the formation and adoption of the related plans. As can also be seen in France, such plans can have a legally binding nature and can even be challenged in the courts. In the case of France, the present planning is seen as *"the best tool for conservation and protection of aquifers which is available under French law"* (Burchi 1999, 63).

4.9 Conjunctive use

Conjunctive use of surface and groundwater means that both types of water are used in combination in such a way as to minimize the undesirable physical, environmental and economical impact on each and to optimize the balance between water demand and supply. Policy measures directed to conjunctive use may comprise an augmentation of the water supply, allocation of costs, groundwater recharge, the storage of surface water, and a coordination of rights involving the interrelationships between the two kinds of sources.

In India, for example, technical solutions have been developed for channelling monsoon river flows through earthen canals for the irrigation of wet-season crops while recharging underlying aquifers at the same time (Road / Vidyanagar 2002). Putting such a technique into practice naturally requires the cooperation of the respective administrative departments, along with measures to protect the domestic water supply during the monsoon season. This in turn requires new internal working procedures which may in turn be hampered by administrative inertia, an issue discussed below.

5 Groundwater governance has to do with bureaucracy

The problem of fit occurs if the boundaries of a biophysical system, here a groundwater aquifer, do not match the jurisdictional areas of political institutions responsible for managing this resource (Young 1999; 2002). Such institutions may then be incapable of managing the water resource in question since the costs of coordination would be prohibitively high in terms of both time and funds. Institutional change in this case may also be hampered if adverse but historically-deep-rooted structures are already in place. Studies of the implementation of river basin management in Europe, as required for example by the Water Framework Directive, found that federal administrative and political systems like those in Germany are likely to make basin management more difficult (Moss 2003).

The management of transboundary groundwater aquifers may be further complicated if it becomes necessary to set up an additional international administrative unit for this purpose. In some cases, administrative structures for groundwater management may not exist at all. (This, however, can be an advantage rather than a disadvantage, since it offers the opportunity of setting up administrative structures tailored exactly to natural aquifer boundaries). Burke / Moench / Souveplane (1999, 41) have extended the “problem of fit” to social systems. They emphasize that biophysical boundaries and political and administrative boundaries must be in congruence with social boundaries. Since social and cultural variation is often as great as hydrogeologic or climatic variation, this may present an even greater challenge to the development of groundwater management systems.

The problem of interplay occurs when resource management requires the interaction (or interplay) of different levels of the political and administrative hierarchy (national, federal, regional, etc) and/or horizontal interaction across different sectoral units and the related organisations (e.g. spatial planning, agriculture, or water protection) (Young 1999, 2002; Moss 2003). Moreover, when different authorities need to work together, ambiguity often exists in the definition of their respective central and local responsibilities. It is often the case that the central level basically tries to retain control over local decisions while simultaneously reducing expenditures for regional development. In Mexico, for example, a multiplicity of overlapping and even contradictory legal requirements has been described (Biswas 1999, 9). Although aquifer management councils have been established there, which provide for self-governing and innovative solutions on the part of water users, there is an unclear division of tasks and responsibilities between these councils, the irrigation water user associations, the federal and state water management agencies, and the river basin councils (Wester / Pimentel / Scott 1999).

Any administration that needs to implement new formal rules will show some reluctance to implement policies involving substantial changes in procedures. This is understood as political and administrative inertia. It is due among other things to the high transaction costs faced by civil servants (time, meetings, memos, etc.) in order to become acquainted with the new policies and to build new procedures for implementing them properly (Schleyer et al. 2006). Generally speaking, national governance needs to move from resource development to resource management. In Eastern India and in Bangladesh, for example, the governments' goal has been to bring about an agrarian boom through groundwater exploitation. Pakistan, on the other hand, has attempted to maintain high groundwater tables in canal-irrigated areas while actively promoting tube wells in order to encourage agricultural development.

A similar phase in groundwater use can be seen in Africa. Due to high evaporation rates in West Africa, surface water is not always available at the right moment and in adequate quantities for crop requirements. Supplementary irrigation from groundwater resources is seen as having a high potential for irrigation development (Sonou 1997). Likewise, groundwater use in sub-Saharan Africa is still a matter of small-scale irrigation development for food production and for securing food requirements (Kandiah 1997). However, policies have been changing in response to new challenges: water management must now address substantive overexploitation and groundwater quality issues in the region (van Steenbergen / Oliemans 2002). Nevertheless, inertia and a lack of information on the part of the authorities constitutes a hindrance to administrations in making this transition (Shah et al. 2001, 20, 29).

Measures aimed at a major transformation of the activities of local administrations can be expected to meet with strong resistance. This is particularly the case when long-established relationships persist which involve corruption and opportunities for side-payments. New measures, which might change these interrelationships, are thus strongly opposed or are circumvented by both parties to the corruption arrangement.

Another crucial factor is the redistribution of decision-making power. A policy that aims to encourage local initiative and self-organization often includes economic intervention in the form of subsidies. This may imply a loss of power for some in the region, particularly elected representatives. Resistance on the part of these local representatives stems from the fact that they would lose decision-making power and their previous authority to distribute local funds should the participation of other, non-elected, rural groups increase (Schleyer et al. 2006, 128).

6 Groundwater governance has to do with economic instruments

Economic policies may employ financial incentives and disincentives to change behaviour in order to facilitate sustainable resource management. Box 2 gives an overview of policies for setting groundwater prices, establishing formal and informal groundwater markets, and employing subsidies and taxes as policy instruments. It also highlights the institutional environment of groundwater governance in South Asia in the form of regulatory and economic policy instruments.

6.1 Direct and indirect groundwater fees

The levying of fees directly for water abstraction is a straightforward economic policy instrument. The fees may vary according to volume, area, location, and source. The crucial factor, however, is that water metering is needed for this – an impossibility in India, Pakistan and Bangladesh, for example, since the costs of metering and billing some 14 million scattered small users would be prohibitive. This is even more the case if the users have no incentive to comply. In addition, administrative bodies in these countries are regarded as ill-equipped, inexperienced and short of field staff (Shah et al. 2003, 3).

One solution for indirect measurement of groundwater abstraction in such situations is to take the size of an irrigated area as a basis (Burke / Moench / Souveplane 1999, 46). Supervision of groundwater use also has become more enforceable with the development of remote sensing technologies. These make it possible to map crop distribution and to estimate actual evapotranspiration with high-resolution photographs. In general, the difficulty with applying metering leaves little alternative but to resort to indirect methods which rely on public awareness.

Another solution proposed by Shah et al. (2003) is indirect groundwater pricing by introducing an equitable flat tariff for energy (electricity or diesel fuel), e.g. the provision of a certain number of hours of electricity per day. This avoids logistical difficulties and transaction costs, and also circumvents the risk of strong farmer opposition associated with metering water. However, energy fees in many areas of the world are heavily subsidized at present. While it can be legitimate to subsidize poor farmers to improve their livelihood, measures such as lump-sum payments to poor farmers will have a less detrimental effect on water resources than the allotment of subsidies for groundwater abstraction.

6.2 Groundwater markets

A water market is a set of arrangements that permit water rights (for abstraction and use) to be traded. The ability of water rights owners to exchange, lease or sell their rights is essential for successful groundwater management (Blomquist 1992). In some water markets, rights can be sold and bought separately from land rights. This is the case, for example, in Colorado, Nevada and Utah in the U.S.A. and in water markets where rights are acquired as an appurtenance to land, as in Arizona.

Water markets cannot operate without stable, clearly defined and enforceable water rights. Blomquist emphasises that pumping rights, for example, must be clearly assigned and controlled. Unlimited pumping rights lead to a loss in efficiency, since users who stop pumping from a water basin benefit other users but receive nothing in return. Thus basin users have no means of transferring groundwater production to higher-value uses when transferable pumping rights have not been defined. In addition, there must be a requirement that water rights be put to effective and beneficial use (Solanes 1999, 73). Otherwise there is a negative effect on water transaction, on water markets, and on efficient water allocations. In the western states of the USA, water rights transfers are increasingly being considered as a policy alternative for encouraging the optimal use of scarce water resources through private reallocation. Water markets generally have the purpose of moving water from low-value to high-value uses, but they may also exacerbate the problem of over-exploitation in areas with a fragile groundwater ecology, since they set no limit on total groundwater use (Shah 2001, 7). To prevent this, control measures must be worked out and enforced to reduce the total volume of water rights over time.

In contrast to the water markets discussed above, in informal water markets, such as those in South Asia, water sellers produce water to sell, not selling the water they would otherwise use themselves. The latter is, however, an important requirement to prevent monopolies (Solanes 1999, 85). In India, Pakistan and Bangladesh, water markets are rather seen as tools to improve access to the resource pool to those who do not have their own source of irrigation (Solanes 1999, 84).

6.3 Subsidies and taxes

Since electricity or diesel power is required to pump groundwater to the surface for use, there is a strong link between groundwater and energy. Instead of direct subsidies, farmers often receive electricity subsidies; this results in overuse of energy and water in groundwater-irrigated agriculture. Heavy subsidies to the farming sector have been one reason for the collapse of many state electricity boards in India (Biswas 1999, 9). Annual groundwater withdrawal for agriculture in some of the most overexploited areas in India might be reduced by 12–20 km^3 simply by eliminating electricity subsidies (Mukherji / Shah 2005, 341).

Another form of economic incentive lies in providing subsidies which encourage the use of more efficient irrigation technologies to achieve real water savings. Incentives to reduce agrochemical leaching are needed in order to control pollution from agricultural cultivation. Subsidies for fertilisers and pesticides need to be re-targeted. A further step might even be the introduction of an environmental tax on fertilisers and pesticides.

Box 2: The institutional environment for groundwater governance in South Asia

The region has a high population density with predominantly small landholders and an overwhelming dependency on groundwater for agricultural production.

Governmental intervention primarily concerns supply quantities with little concern about overexploitation of aquifers.

Water quality issues are almost completely absent and have not yet been addressed.

New groundwater laws are not enforced.

Groundwater rights are attached to land ownership; withdrawal rights are not regulated, with the accompanying risk of overdraft.

Community resistance to regulations restricting water use is high and has a strong political impact due to voting power in these parliamentary democracies.

The projected costs of metering and supervision are prohibitive due to the high number of scattered water users.

Informal water markets have developed which are not subject to any kind of regulatory authority. This leads to an increase in pumping and the sale of groundwater, thus hastening resource depletion in areas where the groundwater base is already scarce.

Since electric utilities are practically the only point of contact between the government and water users in the region, measures such as the rationing of electricity may indirectly offer an institutional window of opportunity in this regard.

Source: Mukherji / Shah (2005); van Steenbergen / Oliemans (2002).

7 Groundwater governance has to do with user participation

Policy instruments encouraging user participation are mainly voluntary in nature, since farmers may choose to participate or not. However, participation can also be enforced from the top down, as in the special-purpose water and land associations in Germany. Similarly, participation may be encouraged by economic instruments such as reduced water tariffs for group members. In Turkey, for instance, the members of groundwater user cooperatives are rewarded with subsidized electricity rates.

Stakeholder and community participation is a hybrid form of governance structure which takes place at various levels. Groups which practice self-governance by distributing groundwater from wells to their members, mostly for irrigation, are widely known as "water user associations". In the case of aquifer management, there is an additional need for so-called "aquifer management organisations", that is, systems of higher-level user and stakeholder participation.

In southern California, groundwater is managed by local organisations. Numerous local governance structures have been created to design and implement management programs for many of the groundwater aquifers. Eight water basin examples from Southern California show that centralized governmental control is not required when citizens have the opportunity to engage in self-government. In Orange County, for example, the management regime has proved effective in reversing critical overdraft of the aquifer and preventing its destruction through overextraction and seawater intrusion.

Groundwater management can be successful if it is embedded in other governance systems, that is, if it is coordinated with other organisations and if conditions for adaptability are provided. In the latter case, water users must be provided with institutionalised means for modifying watershed programs to meet variable water conditions, or the water user associations must have the option of attaining legal status in order to benefit from agricultural credit programmes. This situation is termed a facilitative political regime (Ostrom 1990, 137; Blomquist 1992, 335 f.). Blomquist has stressed that the attitude of California's state officials toward local self-government and local water management has been crucial for the formation of basin governance structures which make collective decisions on basin management. In California, the preference for local management reflected the attitude that groundwater resources are important to the state (Blomquist 1992, 336). Moreover, the state government acted as an active facilitator of local management.

In contrast to this, all groundwater policies in Pakistan in the last 50 years have been initiated and implemented from the top down, that is, from the provincial or federal down to the local level. There has been no involvement of local farmer organisations or local governmental bodies (van Steenbergen / Oliemans 2002, 328). The only exception to this was the Groundwater Rights Administration Ordinance of 1978, which was enforced in the mountain province of Balochistan in Pakistan.[4] This legislation facilitated common-property management and provided a framework for local resource management by involving both local administrators and tribal elders and by allowing flexibility in determining usage rules. Unfortunately, local self-governance failed to develop as expected because community initiatives did not evolve spontaneously. Nevertheless, water user organisations are seen by some as the only viable solution for some regions of Pakistan (van Steenbergen / Oliemans 2002, 337, 341).

8 Groundwater governance has to do with population density

8.1 Population density

An attempt to transfer institutional approaches to water management from the industrialised world to developing countries may fail due to high population densities and multitudes of tiny water users in the latter (Shah et al. 2001, II). Intensive groundwater irrigation in these countries is concentrated in highly populated areas such as those in India, Pakistan, the Punjab, and North China (Shah et al. 2001, 9, 13). In India, for example, the number of diesel and electrical pumps leaped from 87,000 in 1950 to 12.6 million in 1990 (Burke / Moench / Sauvelage 1999, 40). For instance, in the Santa Clara Groundwater District south of San Francisco the total number of farmers is probably less than a thousand, whereas an area of comparable size in Asia would contain 100,000 farmers (Shah et al. 2001, 22). The question therefore arises whether local, self-governing water user collectives could be a solution. It is a misconception that common-pool resource regimes based on collective action are applicable only to small groups of resource users. Rather, the key is a collective understanding of the scarcity of the resource and effective operational rules, as shown by the Tampa Bay region in Florida. Here, a cooperative resource management system has evolved which successfully manages the shared groundwater resources of 2.1 million users (Rowland 2000).

4 This area is very different from the Indus plains. In Balochistan, small surface streams are the only source of irrigation of a small proportion of the land.

Europe presents a different situation. Although it too has a high population density, it can afford to rely on other policy instruments such as financial incentives and support from technological innovations. For instance, the Netherlands spends five times the total per capita income of rural North Gujarat in India on managing its groundwater (Shah et al. 2001, 30).

8.2 Voluntary compliance

Water users sometimes ignore or violate restrictions imposed on them. Voluntary compliance is therefore a key issue (Pistor 2002, 73) since supervision is costly due to the resource system's characteristics and the high number of potential water users. As the number of water users increases, the costs of enforcing national groundwater legislation may become prohibitively high.

Moreover, the transfer of modes of governance which have been successful in other parts of the world should be approached with caution. For example, such transferred laws can be enforced in recipient countries only if four premises are fulfilled: First, formal legal systems and organisational forms and institutions which are imposed must respond to and foster demand. Second, there must be an alignment of formal norms with underlying social norms and beliefs. Third, the laws or institutions in question must provide solutions for actual conflicts and take the various interests behind such conflicts into account; otherwise, they will be ignored (Pistor 2002). Fourth, voluntary compliance implicitly assumes a certain level of common understanding and knowledge about the resource at stake.

If people are sceptical about such transferred formal structures, whether this be in the form of democratic systems such as water user boards or hierarchically imposed rules, voluntary compliance will be lacking. Users will continue to ignore the new governance structures and will seek other solutions to their problems. The primary challenge for groundwater agencies in this regard thus lies less in formal regulations for use than in being able to communicate with a wide array of groundwater users to encourage sustainable use of the resource.

Taking California’s groundwater management as an example, Blomquist (1992, 302) has shown that compliance with formal rules can be extraordinarily high. According to him, the high rate of compliance there is due to two factors a) management programs were generally developed by the water users themselves, and b) the management programs included some form of monitoring which made the actions of each user known to all fellow users. This feature is often discussed in combination with a system of graduated sanctions in which the participants themselves undertake monitoring and sanctioning and where the initial sanctions are surprisingly low (Ostrom 1992, 69 ff.). Quasi-voluntary compliance therefore appears to be a viable concept. In other words, as long as all users acknowledge the rules, the individual user will follow them. Each user’s compliance thus depends on the compliance of the others. Users are thus motivated to monitor each other's behaviour in order to be sure that the rules are being followed. Monitoring can also be a by-product of existing rules, as is observed in rotating irrigation systems.

In India and Pakistan, drafts of groundwater laws have been discussed for decades, but there is no political will to enforce them. In India, such laws would have to be enforced upon millions of farmers operating irrigation pumps scattered throughout a vast countryside. This is almost impossible when voluntary compliance is missing. For instance, China’s new water law requires that all pumpers apply for a permit, but, as in India, the law is not enforced (Shah et al. 2001, 23).

8.3 Traditional and informal rules

It is often repeated that traditional local practices are not to be ignored when new management schemes or technological innovations are implemented. Nevertheless, this still happens. A typical example is found in parts of Eritrea, where traditionally a system for protecting and allocating well water is established during drought periods to conserve water. This system of informal rules was sustainable under previous abstraction regimes but is now endangered by a program of upstream dam construction which will alter the traditional recharge regimes (Burke / Moench / Sauvelage 1999, 48). The contrary has been reported in Ethiopia, where the traditional system of rudimentary irrigation has no control structures and farmers have no way of regulating their water supply (Kandiah 1997). Here too, the lack of local rules has implications for the imposition of rules transferred from the outside, since the local population is not accustomed to follow rules of allocation.

Voluntary compliance with regulatory provisions is strongly linked with the world view of persons in each region and their social and cultural context. Traditions and religion shape this world view. The Middle East and North Africa are home to 300 million Muslims. Thus, it is important in these regions to develop an understanding of the Islamic perspective on proposed water management policies. The basic principles of Islamic water law are still observed and strictly followed by the local population (Caponera 1992, 68). In Moslem tradition, water is a public commodity, a gift of God which cannot be owned. Although it would be a misconception to think that water can never be priced in Islamic countries and must be accessible to everyone there without limitations, Muslims do in fact regard water as a present from heaven and see no need to manage it. This has long been observed in Asia (Shah et al. 2001, 31). For example, Faruqui / Biswas / Marad (200) found that Islam allows water providers to recover their costs. Although water itself cannot be sold, because it is considered a social good and owned by the community, fees may be charged for the provision of water services. Governments, municipalities, and contractors can thus recover their costs for collecting, storing, treating, and distributing drinking water, and for treating wastewater. In Iran, for example, private water companies are allowed to charge prices amounting to the average total cost of providing water services. However, they must also provide 25 litres of water per capita per day for free, as a ”lifeline”. Islamic law also sets penalties for those who do harm to others, thus opening the door for legal penalties against water polluters.

8.4 Conflict resolution mechanisms

In many African countries, the number of conflicts between rivalling ethnic groups is high. For example, a total of five national conflicts related to issues of autonomy and regional predominance have been listed for the Sudan (cf. data sheets in this volume). The conflict potential within a country is a good indicator of how conflicts are resolved locally, that is, either through negotiations or by armed confrontation. The prevalence of armed conflicts in the region indicates that there is a need for learning how to resolve conflicts through negotiation. One possibility might be to empower mediators as authorities accepted by all rivalling parties. Aquifer management involving rivalling ethnic groups, whether they are transboundary or not, is a challenge. Moreover, when one local ethnic group is very powerful, the influence of national and local administrative authorities is very limited in all areas, including the water sector.

In general, political negotiations across national boundaries often involve a compromise on conflicting issues such as access to water, land, mineral resources, and political power. Agreement on each issue, including transboundary groundwater, becomes increasingly complicated as the number of issues on the political agenda increases. However, despite the tensions inherent in such settings, riparian nations have shown tremendous creativity in approaching regional development, often through preventive diplomacy. Examples of cooperation in the history of hydropolitical relations overwhelmingly outnumber the incidents of conflict (Jarvis et al. 2005).

8.5 Political economy

When water legislation is introduced or updated, difficulties arise due to the social pressure placed on water users and their political associates to grant exceptions. Particularly in developing countries, this has a negative impact when resource management is controlled by rent-seeking stakeholders. Well-organised special interests in such cases promote self-serving policies in the absence of a transparent governmental and information system which would allow other stakeholders to counterbalance their influence (Burke / Moench / Sauvelage 1999, 52).

All countries in South Asia have adopted parliamentary democracy. There is evidence that one consequence in these infant democracies is an inability of politicians to enforce measures which affect the livelihood of the people. In India, the ruling party was defeated in recent parliamentary elections precisely in states with a precarious groundwater situation. And groundwater irrigators in Asia have emerged as a huge, powerful base of voters which political leaders cannot ignore when discussing energy subsidies or financial support measures for agricultural product markets (Shah et al. 2001, 21). Likewise, a registration of wells and the supervision of their operation remains unrealistic in India or Pakistan. Thus, community acceptance and an understanding of water requirements are prerequisite for ensuring support for measures aimed at protecting natural resources.

9 Groundwater governance has to do with information

Groundwater data is often patchy, outdated, or inaccessible. Often there is scientific uncertainty regarding the health of the resource, the impact of human actions on it, and its potential future. Even in Pakistan which has based its agricultural boom on irrigation and has conducted many scientific studies on irrigation technologies and local management, there is an urgent need for improved monitoring of groundwater levels and groundwater quality (van Steenbergen / Oliemans 2002). In Africa the lack of data on groundwater aquifers is even greater, as pointed out by Scheumann et al. in the present volume.

This lack of information has three implications for groundwater governance: First, a common understanding of the operation and interrelationships of a management system is a prerequisite for self-organisation (Ostrom 2000). Without sufficient information on groundwater aquifers, the local population cannot understand the dangers threatening these natural resources and will willingly fool itself that the aquifers are in good condition.

Second, as described above, one prerequisite for voluntary compliance with groundwater regulations is public awareness. When knowledge about the extent of depletion, the danger of groundwater pollutants for personal health, or the irreversibility of falling groundwater tables is inadequate, it is difficult to motivate humans to change their behaviour voluntarily and to refrain from otherwise profitable actions.

Third, a lack of information prevents administrations from taking the step from resource development to resource management and addressing the issues of overexploitation and groundwater quality. Without an understanding of the complexity of the groundwater system, the irreversibility of groundwater depletion, and the necessity of precautionary protection, collaboration will be ineffectual. For instance, the Kafue Basin's development in Zambia is based on a very limited understanding of the basin's overall resources. As a result, measures to protect this aquifer from urban, industrial and mining pollution have thus far been ignored (Burke / Moench / Sauvelage 1999, 48).

10 Groundwater governance has to do with technology

Treadle pumps are the simplest groundwater lifting devices for using shallow water tables no deeper than 25 feet below the surface. These foot-operated devices are commonly used to irrigate small plots of land. They are low-cost, simple in design, and easily manageable. They are also mobile. Treadle pumps are regarded as an ideal investment for small landholders. They are popular in Bangladesh, where more than a million are already in use. However, recent evidence shows that the prevalence of treadle pumps has decreased, in particular in Bangladesh, due to the availability of affordable Chinese-made tube well pumps (Roy / Mainuddin 2003). On the other hand, treadle pumps continue to be important in parts of Africa where groundwater is shallow (Mukherji / Shah 2005). They have also been identified as appropriate for African countries such as Zambia, Malawi, Tanzania, and Zimbabwe (Kandiah 1997).

Besides treadle pumps, there has been an immense increase in private groundwater lifting devices for deeper water tables. In Pakistan's Punjab, the number of mechanized wells and tube wells increased from a few thousand in 1960 to 0.5 million today. In Bangladesh, the number of tube wells increased from 93,000 in 1982 to almost 0.8 million in 1999. Likewise, recent studies have shown an increase in groundwater use for irrigation in Africa. A study of the Limpopo Basin, in South Africa, Zimbabwe and Mozambique showed that there are currently 35,000-old irrigation wells, and that 20 new ones are being installed every day (Tewari 2003). Tunisia and Morocco too have experienced a rapid growth in groundwater irrigation (Bahri 2002; Mukherji / Shah 2005, 330).

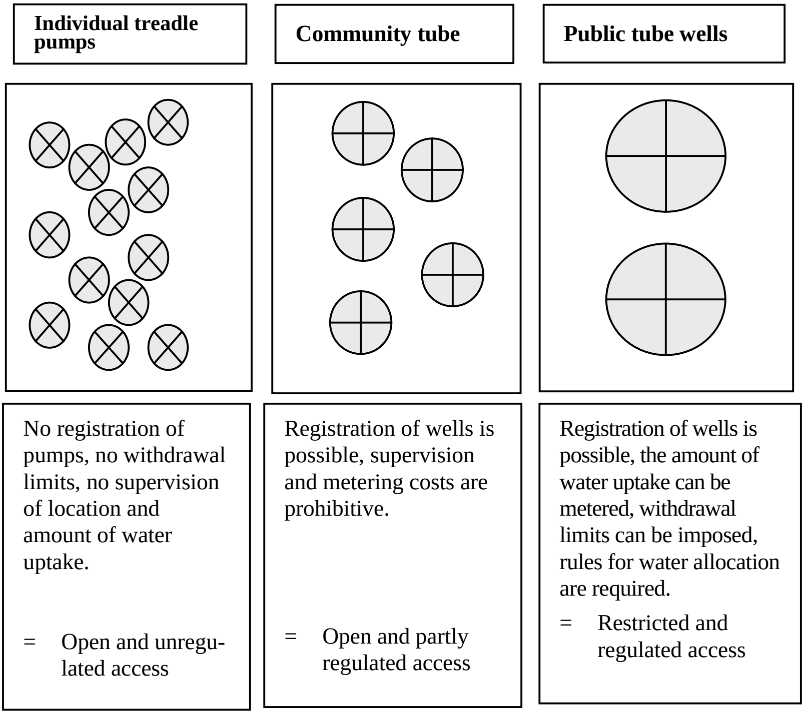
Not only the total number but also the variety of simple, low-cost but labour-intensive well drilling techniques has increased. The use of deep aquifer groundwater has not been very successful in West Africa due to high construction and per-volume-unit costs of water abstracted from deep wells. Therefore, shallow tube wells have been constructed with locally available materials for the expansion of small-scale irrigation. In Nigeria, 15,000 shallow tube wells have been introduced as part of a development project. A new project was initiated in 1992 to construct 50,000 additional shallow tube wells in Nigeria. This technology has also reached Chad and the Republic of Benin. Other programmes have been set in motion to introduce this shallow tube well technology in Niger, Burkina Faso, and

Ghana (Sonou 1997). Shallow irrigation devices are also being advocated for Ethiopia. A study showed that the importation of irrigation equipment from Asian countries will make this equipment available to smallholders in Africa at an affordable price, although the costs can be much higher than in Asian countries depending on the equipment. For example, the cost of locally manufactured treadle pumps in Malawi and in Zambia respectively was 200 and 400 % higher than in Asia (Kandiah 1997).

In Pakistan's Punjab, the Private Sector Groundwater Development Project in the late 1990s encouraged the conversion of public tube wells to community-operated tube wells. The political objective was to reduce the costs of operation and maintenance of these facilities, which in some cases had remained inoperable for years. Registration of big, permanently installed wells is relatively easy. Metering of water uptake is possible, but water tariffs are usually paid according to the area irrigated. Water use rights are restricted to group members, and additional users have access only if the present members approve. Shifting the focus from privately managed devices to group management raises the issues of equal opportunity for becoming a group member and equal water allocation among group members.

As outlined, a vast range of technologies exist for pumping groundwater. They range from simple treadle pumps to highly sophisticated public tube wells. Some of these technologies have characteristics which affect the choice of governance structure. These are the size and the mobility of the devices, as well as their total number and distribution in the respective region. Figure 1 illustrates this for Pakistan, showing the possibilities for regulating water access via treadle pumps, community tube wells, and public tube wells.

Figure 1: Governance of groundwater lifting devices in Pakistan



Source: Own compilation

11 Implications for transboundary groundwater governance

Transboundary water development poses the question of how to achieve sustainable governance of transboundary groundwater aquifers. With the exception of a few hydrogeological studies, investigations of institutional transboundary groundwater aquifer management have been rare. As the present study has shown, there is much to be learned from well-documented cases of national groundwater governance, mainly in South Asia. Without a functioning system of national groundwater governance it is difficult to establish transboundary governance, since the required structures are lacking. The empirical insights presented here underscore seven essential aspects of institutional groundwater governance: 1) groundwater legislation, 2) bureaucracy, 3) economic instruments, 4) participation, 5) information, 6) population density, and 7) technology. These issues must always be taken into consideration in framing both national and transboundary groundwater governance systems.

For transboundary groundwater governance, the following conclusions in particular can be drawn. Groundwater aquifers are very complex natural systems. This is due among other things to the long period before impacts on them become noticeable. They require specific governance solutions to protect their quantity and quality. Groundwater management, therefore, requires a fine-tuned balance of three policy instruments: regulatory, economic, and voluntary/advisory.

Options widely discussed at present for groundwater governance regimes involve extending the mandates of existing transboundary river and/or lake basin organisations or establishing new transboundary aquifer organisations. Due to interrelationships with surface water systems, it might be an option to transfer groundwater aquifer management to existing transboundary surface water organisations. This option assumes that the problem of matching or mismatching national and biophysical boundaries (the "problem of fit") is taken into consideration in institutional arrangements. In this case, however, the institutional aspects of bureaucracy (e.g. interplay and inertia) will arise and must also be considered.

When the number of resource users is large, regulatory agreements (including international agreements) are difficult to monitor and control. Governments must rely on voluntary compliance. The formulation of any regulatory framework in such cases should be supported by public awareness campaigns. In particular, a heightened awareness is required in order to establish a change in focus from groundwater development to sustainable groundwater management. Much of the thinking of both local users and administrators is still dominated by the views of eras when groundwater exploitation to facilitate agricultural development was a top priority. Without this heightened awareness, it will be difficult to obtain compliance and to enforce any regulations (Steenbergen van / Oliemans 2002). On the other hand, this requires accurate data. Moreover, it remains essential to recognize regional traditions and local rules-in-use.

Finally, collective action has proven to be a successful way of groundwater resource management at the local, regional and even national levels. It needs to be considered to what extent collective action can contribute to transboundary groundwater management. The prerequisite for engaging in collective action is the conviction that there is a problem. Therefore, scientific knowledge is required. In addition, mechanisms for sharing information and acquiring homogeneous data must be improved between countries (Arnold / Buzás 2005). This remains a challenge for transboundary resource management.

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Transboundary groundwater management – non-African case studies

Theresa Steyrer

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Transboundary groundwater management – non-African case studies

Theresa Steyrer

1 Global groundwater resources and the need for transboundary management

Pressure on global groundwater resources

Global groundwater resources are threatened in both quantity and quality by unsustainable rates of consumption and inefficient usage patterns amongst others. The result is overexploitation and pollution. In addition, global society is becoming increasingly dependent upon groundwater due to the increasing scarcity of surface water. This dependency is further fueled by strong economic activity and high population growth worldwide.

Further pressure is experienced in regions where groundwater resources are of a transboundary nature. Where access to and the allocation of transboundary groundwater resources between riparian states is unregulated, water extraction is commonly characterized by a "first-come, first-serve" approach. Fearing that their neighbours will not engage in efforts to save water under such a rivalry situation, riparian states tend to maximize their groundwater extraction rather than restricting its withdrawal to sustainable amounts.

The transboundary nature of aquifer systems

Most of the nearly 240 aquifers mapped across the world are of a transboundary nature (Jarvis 2006). According to the United Nations Economic Commission for Europe (UNECE), no less than 89 aquifers are located beneath international borders of the ECE member countries (Almássy / Buzás 1999). In Africa, the UNESCO recognizes 38 transboundary aquifer systems (Scheumann / Neubert 2005).

Due to growing socio-economic dependency on groundwater resources and, in many cases, the gradual exhaustion of these resources due to overutilization, riparian states worldwide will be increasingly confronted in the near future with conflicting cross-border groundwater issues. This will presumably force neighbouring countries all over the world to strengthen their bilateral and multinational cooperation in order to avoid cross-border disputes and conflicts.

This trend towards a greater need for transboundary cooperation is not going unnoticed. The world community increasingly recognizes the need for governance and management frameworks regarding bilateral and multilateral aquifer management.[5] In the case of transboundary groundwater resources, however, this increasing recognition stands in stark contrast to the status quo of cross-border aquifer cooperation.

The status quo in transboundary groundwater management

While transboundary surface water has long been the subject of numerous bilateral and multinational treaties and agreements, this is not the case with its subsurface counterpart. Visible steps towards formalization of shared groundwater management are rare. Of approximately 400 international freshwater treaties currently in place, no more than approximately 15 percent entail provisions for groundwater (Jarvis 2006, 1).[6] Moreover, most of the latter deal only indirectly with groundwater resources and regard them as only one component in the overall water system. Worldwide, only a handful of treaties and agreements explicitly address the management of cross-border aquifers as separate bodies of water (Ulfstein / Werksman 2003).

On the international level, numerous agreements have been concluded and documented in response to multinational issues associated with transboundary waters. These include the International Law Association's Helsinki Rules of 1966, the Seoul Rules of 1986, and the groundwater-related

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5 *Governance* in this context is used as an umbrella term for the existence and the interplay of institutions and organizations. According to North (North 1992), the term *institution* refers to formal rules such as laws and policies as well as to informal rules such as codes of conduct. "Organization", in contrast, is used for groups of individuals and legal entities such as public institutions and corporations. North illustrates the interplay of institutions and organizations by comparing it to a game that consists of players (the organizations) and rules (the institutions).

6 This stands in direct contrast to the greater importance of groundwater resources in terms of sheer size: According to estimates in the UN World Water Development Report, global transboundary groundwater resources have a volume of 23.400.000 km3 compared to transboundary river waters with a volume of 42.800 km^3 (WWAP 2003).

efforts of the UN Convention on Non-Navigational Uses of International Water Courses of 1997. A further framework for cooperation in bilateral and multilateral surface water and ground water management is the UN-ECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes of 1992 (UN/ECE 1992). All of these international efforts and conventions, however, are of a non-binding nature and thus cannot replace legally binding agreements between riparian states.

Purpose and procedure of this paper

Despite their rarity, the few existing cases of bilateral and multilateral aquifer cooperation can provide valuable insights and lessons for countries that are presently considering joint management of shared groundwater resources. In view of this, the purpose and procedure of this paper will be:

(1) to examine three examples of transboundary groundwater management and their respective governance frameworks;

(2) to identify lessons gained from these case studies and

(3) to draw conclusions and make recommendations in respect to future cooperation in transboundary aquifer management in Africa.

For this purpose, Section 2 will investigate the following three examples of bilateral and multinational cooperation in aquifer management:

(1) the North American *Hueco Bolson Aquifer* in the United States and Mexico;

(2) the South American *Guarani Aquifer* System in Argentina, Brazil, Paraguay and Uruguay; and

(3) the European Franco-Swiss *Genevese Aquifer* in France and Switzerland.

After an overview of the main features of each respective system of cooperation and its institutional, organizational and legal framework, the achievements, challenges and further issues associated with cooperation will be identified where possible. Based on these findings, Section 3 will provide recommendations and refer to open issues regarding bilateral and multinational transboundary aquifer management in Africa.

2 Examples of transboundary groundwater management

2.1 The Hueco Bolson Aquifer – United States, Mexico

2.1.1 The aquifer system

The Hueco Bolson Aquifer is one of at least eighteen groundwater bodies shared by the United States and Mexico. It is located within the Paso del Norte region encompassing the US states of New Mexico and Texas and the Mexican state of Chihuahua. The aquifer is divided by an international river basin (Rio Bravo/Rio Grande) which represents the boundary between the US and Mexico (UNESCO / OAS / ISARM 2004). The area is characterized by free-trade driven industrial and agricultural expansion and high rates of economic and population growth.[7] The region is further typified by a semi-arid to arid climate, very little rainfall, and a severe scarcity of water resources. It has experienced several droughts in recent years (Nauman 2005).

Groundwater resources within the Hueco Bolson aquifer constitute the primary source of drinking water for over 2 million people in this area (Brown et al. 2003). Further beneficiaries are the vastly expanding industrial sector and, to a lesser extent, the Mexican agricultural sector. The two main municipalities most dependent on Hueco Bolson water in the border region are El Paso (Texas) and Ciudad Juárez (Mexico), with annual withdrawals of around 6,000 acre-feet (El Paso) and 124,000 acre-feet (Ciudad Juárez) respectively.[8] In the latter case, groundwater from the Hueco Bolson Aquifer is the only source of urban and industrial water. In contrast, El Paso relies on the aquifer's water for about 44 percent of its municipal and industrial water supply (Brown et al. 2003).

Given the very limited supply of surface and ground water and a history of cross-border conflicts over water allocation from the Rio Bravo & Rio Grande, the continuing rapid increase in sectoral and communal water demand is putting a heavy strain on the Hueco Bolson Aquifer's resources.

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7 Population in the Paso del Norte region is expected to double by 2024 at the current growth rate of around 3 % per year (Brown et al. 2003).

8 Figures for the year 2000 (PdNWTF 2001). One acre-foot equals approximately 1,233.5 m^3.

The situation is further exacerbated by quantitative and qualitative unsustainability in use patterns. Long-term groundwater withdrawals have led to a significant drop in the water level. As a result, brackish water has entered fresh water zones and has further diminished the volume of fresh water stored in the aquifer. Estimates of future availability are that potable groundwater from the Hueco Bolson aquifer will be exhausted by 2025 at current withdrawal rates. Since Mexico has a higher rate of population growth and simultaneously finds itself in a weaker position regarding water allocation,[9] the situation is more critical on the Mexican side of the border (Brown et al. 2003).

2.1.2 Cooperation structures

Although the importance of water resources to the region and the riparian states is undisputed, the issues of sustainable water use and water management have long been ignored by policy makers on both sides of the border. Especially in the case of groundwater resources, appropriate management mechanisms, infrastructures, and a governance framework which can meet present and future needs are still lacking (Klein / Woosley 2003).

Existing institutions and water agreements

No official agreement between the U. S. and Mexico deals explicitly with the management of transboundary groundwater resources, in particular with the Hueco Bolson Aquifer (Hardberger 2004). As will be discussed later, this is largely due to US resistance in initiating bilateral cooperation, along with Mexico's reluctance to propose any action in this regard. In

9 Asymmetries in the allocation of surface water resources between Mexico and the US stem from outdated allotment schemes. Surface waters were originally distributed under the Rio Grande Compact in 1924 according to a formula based on parameters such as population, irrigated land, average annual flow at the time, and projected future flow rates. As a result of these estimates, Mexico today receives 60,000 af, New-Mexico 494,979 af, and Texas 376,862 af each year. Thus the US allocation is approximately 93 % of total available surface water. However, population and irrigated areas have changed considerably since then and, as a result, the allocation scheme fails to reflect present needs (Brown et al. 2003). This asymmetry in water allocation persists mainly because of Mexico's reluctance to address cross-border water allocation issues for fear of possible negative impacts on the relationship with the USA more detailed discussion on these asymmetries is provided in section 2.1.3.

contrast, cross-border issues related to surface water resources have attracted considerable attention from both sides of the border within the last few decades; authorities on all governmental levels have repeatedly been forced to respond to severe water disputes within that region. In the El Paso/Juarez area, considerable disagreement about the allocation of surface water from the binational Rio Grande River has compelled both sides to convene and negotiate a management framework; since that time, this framework has turned into a complex set of institutions and organizations for the management of water and its extraction within the area. Water management agreements between the two riparian states have therefore been settled exclusively in response to pressing water issues that left no other option than to cooperate. It can be expected that these dynamics will continue to shape cooperative aquifer management, since the quantity and quality of water within the Hueco Bolson is already deteriorating quickly.

Despite the absence of an explicit treaty on shared groundwater resources between Mexico and the US, some important agreements on general and/or surface water resources implicitly govern other water resources within the border region and affect the way in which groundwater resources, including in the Hueco Bolson, are handled (Hardberger 2004). Organizations set up as part of the framework for surface water management thus also serve as templates for agreements entailing groundwater management. This integration of groundwater management into the surface water management framework appears to make sense, since surface and groundwater issues in the Mexico-US border region are intimately connected in terms of hydrology (close link between surface and groundwater), socio-economic aspects (e.g. dependency of the border area on both water sources), and political-administrative relationships (presence of a well-established agency with experience in transboundary issues).

The key agreement in this context is Minute 242, a bilateral agreement drawn up in 1973 as an adjunct to a 1944 agreement in response to the Colorado River salinity crisis. Minute 242 is the only agreement between Mexico and the US which directly addresses the management of groundwater resources. As set out in Resolution 6, both countries are required to " […] *consult with each other prior to undertaking any new development of either the surface or the groundwater resources, or undertaking substantial modifications of present developments, in its own territory in the border area that might adversely affect the other country*" (IBWC 1973, 2). Furthermore, Resolution 5 limits groundwater pumping on both sides of the border to 160,000 af annually until an agreement has been worked out which explicitly deals with groundwater resources.[10]

A further bilateral arrangement with implications for joint groundwater management is the La Paz Agreement of 1983. Even though it does not specifically mention groundwater resources, this agreement has occasionally been applied for the resolution of groundwater disputes in the past (Hardberger 2004).

In addition, the creation of a free trade zone between Canada, Mexico and US in 1994 and its legal configuration under the North American Free Trade Agreement (NAFTA) influences the management of water resources in the border area. Although it acknowledges the interrelated nature of trade and the environment and addresses environmental issues in the US-Mexico border region, the North American Agreement on Environmental Cooperation (NAAEC) fails to regularize them.

Binational organizations

In order to ensure successful implementation and effective enforcement of the above-mentioned water agreements, several government agencies have been established on a binational level. However, the responsibilities of these organizations extend first and foremost to water in general or surface water in particular. Following are the most important agencies for binational water management.

The main international authority responsible for enforcing and monitoring boundary and water treaties and agreements between the US and Mexico and for settling disputes arising from these agreements is the International Border and Water Commission (IBWC),[11] consisting of a US section and a Mexican counterpart. The two sections operate independently, and both are headed by an Engineer Commissioner appointed by the national Presidents. IBWC in the past has focused exclusively on surface water re-

10 "*Pending the conclusion by the Governments of the United States and Mexico of a comprehensive agreement on groundwater in the border areas, each country shall limit pumping of groundwaters in its territory within five miles (eight kilometers) of the Arizona-Sonora boundary near San Luis to 160,000 acre-feet (197,358,000 cubic meters) annually*." (IBWC 1973)

11 The Mexican equivalent is called Comisión Internacional de Limites y Aguas (CILA).

sources; only recently has it been given with the authority to oversee groundwater issues related to cross-border aquifers. Additionally, recent working groups and policy discussions indicate that future groundwater agreements will most likely stem from the administrative sphere of the IBWC (Hardberger 2004).

Equipped with what Mumme describes as a "*virtual monopoly on agreements dealing with transboundary water management*" (Mumme 2001, 1), IBWC has been subject to considerable criticism for its enduring concentration on the engineering aspects of water resources management, thus narrowing down management options to technical aspects and missing out on a broader and more politically oriented approach.[12]

A more recent binational, non-governmental forum for the management of regional transboundary water resources is the Paso del Norte Water Task Force (PdNWTF), which was established in 1999. This is a non-political advisory organization with a strong scientific and community-based focus. Geographically, the Task Force concentrates exclusively on the tri-city region of Las Cruces, El Paso, and Ciudad Juarez, where the Hueco Bolson Aquifer is located.

Within NAFTA, and in accordance with its collateral agreement on environmental cooperation (NAAEC), two international government organizations have been established to support and facilitate the implementation of water projects in the border region, namely the Border Environment Cooperation Commission (BECC) and the North American Development Bank (NADB). The BECC is run by a binational board of directors consisting of five members from each country. It represents the respective federal, state and local governments as well as the public border society. Its formal duty is to conserve, protect and enhance the environment in the border region by functioning as a developer and certifier of environmental infrastructure projects.[13]

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12 The IBWC's technical orientation is defined by its official function as the "*premiere federal agency responsible for addressing technical transboundary management issues in the United States – Mexico border region*".

13 Projects must be related to water pollution, waste water treatment, municipal solid waste management, hazardous waste, water conservation, hookups to water and sewer systems, waste reduction and recycling, air quality, transportation, clean and efficient en-

National and regional organizations

On the federal, state and regional levels, a variety of organizations have been formed in recent years in response to increasingly urgent water issues. These mostly public authorities have been given diverse degrees of responsibility in relation to water management.[14]

Regional water utilities located in the drainage area of the Hueco Bolson, namely the Junta Municipal de Agua y Saneamiento de Juarez (JMAS) in Mexico and the El Paso Water Utility (EPWU) in the US, are responsible for the technical issues of groundwater resource management and carry out artificial aquifer recharge in this capacity (UNESCO / OAS / ISARM 2004).[15]

The Good Neighbor Environmental Board (GNEB) is a federal advisory board established by the US Congress in 1991. The GNEB advises the US President and Congress and identifies environmental and infrastructure projects contributing to good neighbourly relations with Mexico. Comprised of representatives from the government, NGOs and the private sector, the GNEB's public hearings and annual reports contribute to a heightened awareness of Mexican and cross-border issues (Klein / Woosley 2003). Although its mandate is strictly consultative and its influence on national water politics and policies is limited, the GNEB's recommendations gain recognition from federal and national decision makers and thereby help to shape the national agenda.

Multi-organizational projects

Considerable efforts have been made to address regional water management issues in the form of multi-organizational projects. The main forces behind such joint efforts are universities, private foundations, and NGOs

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ergy, and municipal planning and development, including water management (http://www.cocef.org/background.htm).

14 It would go beyond the scope of this paper to identify all institutions whose duties and responsibilities are directly and/or indirectly related to the Hueco Bolson aquifer. Therefore only those with greatest impact are discussed here.

15 Approximately 10 million gallons of wastewater are treated each day to bring them up to potable water standards; half of this amount is subsequently injected into the aquifer (UNESCO / OAS / ISARM 2004).

(Brown et al. 2003).[16] Since local organizations and especially universities are perceived as a reliable broker in the region and enjoy the advantage of credibility, these establishments are able to spearhead regional dialogue, e.g. by providing a platform for the exchange of experience and the support of mutual understanding. However, the results are often marginal in terms of concreteness and are seldom followed up by concrete actions.[17]

2.1.3 Governance and cooperation

Several barriers hamper binational aquifer management cooperation between the US and Mexico. Of these, two are identified by Hardberger (Hardberger 2004, 1234). First, dialogue is hampered by relatively dissimilar forms of government and policies in the two countries. Secondly, the management of border water resources is complicated by the large number of government agencies involved in the process of consensus building. Theesfeld refers to these issues as the "problem of interplay" that arises when different levels of political and administrative hierarchy are involved in the same process (Theesfeld in this volume).

According to Brown et al. (Brown et al. 2003), effective regional Water resources management (WRM) is greatly hampered by differently organized areas of water law jurisdiction in the US and Mexico. Water issues in Mexico are governed at the national level, thus giving the government considerable decision-power regarding the proprietary use of groundwater resources (Mumme s.a.). In contrast, US water law decisions are made on the state level, with significant variations in water legislation from one

16 One example is the University of Texas' "El Paso Water Project" in 1990, which brought together water planners and policy makers from both countries in order to share information, increase understanding, and work towards long-term communication (Brown et al. 2003).

17 A good example in this context is the 1997 "Transboundary Aquifer and Binational Groundwater Data Base Report – City of El Paso-Ciudad Juárez Area". This scientific, research-based project was carried out by multiple agencies including IBWC, the Environmental Protection Agency (EPA), the Texas Water Development Board, the Junta Central de Agua y Saneamiento (JCAS), and others. The authors of the report gathered of data on groundwater hydrology, water levels, pumping rates, water quality, and present and future extraction estimates. However, the report did not go beyond this, e.g. to provide a comprehensive analysis. Nor did it offer any recommendations on groundwater management options (Brown et al. 2003).

state to the next. In Texas, groundwater extraction is ruled by the "law of capture", and water rights are tied to land ownership, meaning that each owner of a piece of land is entitled to withdraw unlimited amounts of groundwater from below his property (Mumme s. a.).[18] In New Mexico, groundwater is perceived as state property and is allocated according to the "rule of prior appropriation", meaning that extraction rights are based on criteria such as the user's previous and beneficial use of water (Hardberger 2004).

As a result of these national disparities in the allocation of water competence (in particular at the state and federal levels), regional efforts and attempts towards implementation of transboundary WRM on the local level, e.g. between states and communities, are hampered. As a result, legally binding agreements on transboundary water management between the US and Mexico have so far been entered into exclusively on the national/federal level, and local initiatives have been limited to non-binding, voluntary agreements.

Mumme (Mumme s. a.) too has identified significant barriers to cross-border WRM stemming from the two US states New Mexico and Texas. These states often have diverging interests and try to enforce their own agendas by exerting considerable influence on federal water administration policies. In particular, federal agencies with water policy authority in the US are commonly perceived as "Dependencies of Congress" (Mumme s. a., 8). This applies especially to the US section of the IBWC, which is expected to refrain from proposing or initiating any action unless it receives clear instructions from the US states.[19] This makes it comparatively difficult to find a uniform position on transboundary cooperation on the US side. The complex realities of water legislation in the US induce Mumme to conclude that "*decentralization of groundwater management at the state level is a serious impediment to bilateral groundwater management initiative*" (Mumme s. a., 8).[20]

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18 Withdrawal may, however, be restricted in cases where a neighboring proprietor is harmed.

19 Furthermore, each border state has a *de facto* veto right over initiatives of the IBWC's US section in most matters (Mumme s. a.).

20 Bilateral groundwater management initiatives on the US state level seem to be more realistic or achievable. This is exemplified by water-related initiatives between Texas and New Mexico (Brown et al. 2003).

As mentioned above, regional and local projects receive much attention from organizations on both sides of the border. These include government agencies, representatives of academia and industry, and private organizations. Together, they direct significant resources towards monitoring, protecting and restoring transboundary water resources. Unfortunately however, these efforts are commonly characterized by poor coordination and an insufficient exchange of data and information among organizations and project groups. Even worse, organizational policies, rivalries and mistrust make concerted binational efforts less successful. Furthermore, technical issues such as divergent techniques of sampling, analytical methods and data interpretation and management further complicate this problem (Klein / Woosley 2003).

A further difficulty of a political and diplomatic nature is Mexico's reluctance to advance proposals for transboundary groundwater management. Although Mexico is more dependent than the US on transboundary water bodies and is also legally and politically in a better position due to its centralization of water legislation at the federal level, Mexico's government has been very reluctant to advance any kind of federal proposal. Mumme (Mumme s. a.) believes that this stems from a fear of politicizing the water issue, thereby threatening the positive relationship with the US As a result, the IBWC's Mexican section CILA operations have been limited and subject to heavy influence by from the Foreign Ministry.[21]

Future challenges and threats with respect to bilateral agreements between the US and Mexico concerning the management of transboundary aquifers are not trivial. Especially in the case of the Hueco Bolson Aquifer, which, in spite of its heavily depleted and contaminated groundwater, constitutes Juarez' only and El Paso's main source of communal drinking water, the pressure to find a viable solution increases every day. The current policy of ignoring the situation cannot go on forever, since potable water resources within the Hueco Bolson Aquifer will soon be exhausted. Stakeholders on both sides will therefore have no alternative but to sit down and work out a joint management plan that defines a sustainable extraction plan for the Hueco Bolson.

21 Although the IBWC's Mexican commissioner theoretically has the authority to propose a transboundary groundwater agreement to his US counterpart, in practice this has been done only once in a request to negotiate a specific groundwater dispute.

In fairness to present and past achievements of US-Mexico cooperation, it can be said that it is more difficult to identify the positive aspects of existing transboundary water and groundwater resources management between the United States and Mexico than it is to detect barriers and threats. Existing assessments of the institutions and organizations which are involved, although intensively mapping out weaknesses and challenges, address few aspects which have proven promising and might therefore serve as a lesson to other countries.

However, certain promising aspects and opportunities can be identified. Common interests can help the discordant parties to reach a consensus. The two communities of El Paso and Juarez have one major interest in common: both depend on the same source of drinking water, and both are therefore threatened by present and future issues of scarcity in its supply. Sooner or later, bilateral agreement on how to share this diminishing resource will no longer be postponable as water tables fall and prices for urban demand escalate. However, the above-mentioned barriers to cooperation induce Mumme to conclude that in the case of groundwater, "*it would be overly optimistic to predict that the two countries would strike a formal agreement any time soon of the sort contemplated in Minute 242*" (Mumme s. a., 20).

2.2 The Guarani Aquifer in South America

2.2.1 The aquifer system

The Guarani Aquifer, named after the Guarani Indigenous Nation, constitutes one of the largest groundwater reservoirs worldwide, with an estimated storage of 40.000 km^3 (UNESCO 2001). Located below Argentina, Brazil, Paraguay and Uruguay, the aquifer serves as a source of water mainly for domestic and industrial purposes as well as for agriculture and thermal tourism services in the region (Eriksson / Rogers 2006). Total annual extraction by the approximately 15 million people in the region is estimated to be about 200 km^3 compared to a natural recharge rate of approximately 166 km^3 per year (Thimmel 2004; Eriksson / Rogers 2006, vi).

Although water resources within the Guarani Aquifer are still abundant in quantity and quality, uncontrolled extraction and contamination is increasing rapidly. This constitutes a future threat to groundwater resources and therefore to socio-economic stability and development in the region. Withdrawal rates already exceed natural recharge, and the aquifer is subject to mining. The main threat to the aquifer, however, stems from uncontrolled pollution in extraction and recharge areas.

Table 1 provides an overview of the main aspects of the aquifer.

2.2.2 Governance and cooperation

In general, South America's national governments have thus far been characterized by a loose approach to dealing with groundwater issues, along with a short-term view and a lack of management mechanisms for controlling extraction and pollution. As a result, there are to date no official binational and/or multinational agreements that define sustainable groundwater resource management among riparian countries.
The only major transboundary aquifer-related project thus so far has been the "Project for Environmental Protection and Sustainable Development of the Guarani Aquifer System", initiated by universities from the four countries. Based on the recognized need for strategic intervention in the field of groundwater management in order to address current over-exploitation and pollution and its future impact, a meeting of representatives from the national governments and civil society was organized in 2000 in order to initiate a dialogue on the Guarani Aquifer System (GAS).

The outcome of this first gathering was the development of a joint project involving Argentina, Brazil, Paraguay and Uruguay with the objective of establishing a long-term management plan for the Aquifer. The project was concretized during the subsequent two years, and financial support was provided by both the Global Environmental Facility (GEF) and the World Bank (Eriksson / Rogers 2006). The project, originally set up for a four-year period (2003–2007) and later extended to approximately 6 years (2003-2009), currently has a total budget of US$ 28 million.

Table 1: Main characteristics of the Guarani Aquifer System

Issues / Countries	Argentina	Brazil	Paraguay	Uruguay
Approximate extent of the Guarani Aquifer (km^2)	225,500	839,800	71,700	45,000
Percent of Territory occupied	6	10	18	25
Characteristics of the Aquifer	Supply source	Recharge and supply area	Recharge and supply area	Recharge and supply area
Extent of exploitation	9 deep wells for thermal use; about 100 wells for drinking and irrigation	Almost 500 cities partially or entirely supplied by the Guarani Aquifer System	About 200 wells mainly for domestic water supply	135 wells for public water supply, irrigation and thermal tourism (7).
Principal Environmental Issue	1. Potentially uncontrolled drilling and extraction 2. Subject to pollution effects from other countries	1. Point and non-point source pollution 2. Uncontrolled drilling and extraction	1. Point and non-point source pollution 2. Uncontrolled drilling and extraction 3. Subject to pollution impact from other countries	1. Point and non-point source pollution 2. Uncontrolled drilling and extraction 3. Subject to pollution impact from other countries
Level of information available	Limited information available, expecially about the western extent of the Guarani Aquifer System	Considerable information available but dispersed in different states and institutions	Limited structured information available	Considerable information available

Source: Amore (s. a., 261)

The official long-term target of the project is "sustainable management and use of the Guarani Aquifer System in Argentina, Brazil, Paraguay and Uruguay, through an adequate and functional management framework, based on appropriate technical, scientific, institutional, legal, economical and environmental guidance" (UNESCO / OAS / ISARM 2004, 2). The project comprises of the following seven components:

(1) Expansion and consolidation of current scientific and technical knowledge concerning the Aquifer.

(2) Joint development and implementation of a management framework based on an agreed Strategic Action Plan.

(3) Promotion of public participation, social communication, and environmental education.

(4) Project monitoring and evaluation, and dissemination of project results.

(5) Development of groundwater management and mitigation measures within identified areas (so-called "hot spots").

(6) Assessment of the potential use of geothermal energy and "clean energy" from the Aquifer.

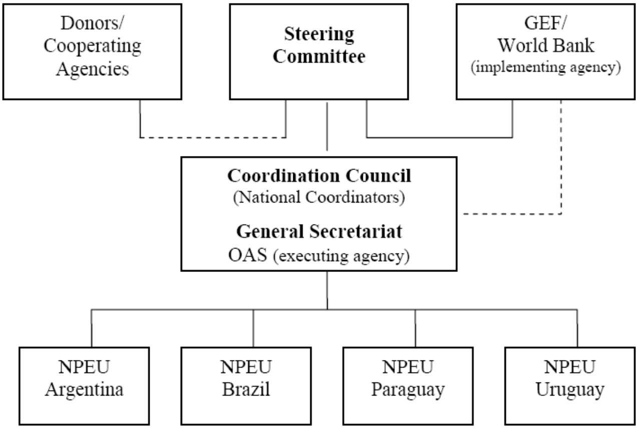
(7) Project coordination and management.[22]

The project is headed by the GEF as the funding agency, the World Bank as the implementing agency, and the Organization of the American States (OAS) as the regional execution agency (UNESCO / OAS / ISARM 2004).[23] Project management and implementation is carried out by a range of different organizations specifically set up for the project: a multinational *Steering Committee* (SC), a *Coordination Council* (CC), a *General Secretariat* (GS) and four *National Project Executing Agencies* (NPEUs). See figure 1 for an overview of the organizational structure.

22 This component thus aims at providing the organizational, institutional and administrative framework for the implementation of the project.

23 Additional funding is provided by the Dutch and German governments as well as by the International Atomic Energy Agency (IAEA).

Figure 1: Organizational structure of the Guarani Aquifer Project



Source: Eriksson / Rogers (2006, 21)

The Steering Committee is composed of representatives from the national ministries and operates on the highest ministerial / secretarial level. It approves policies and strategies with direct impact on the national agendas. As an adjunct to the SC, the Coordination Council's is the executive agency for both the SC and the General Secretariat and consists of technical officials and leading staff personnel from the NPEUs. It also functions as an intermediary between the SC and GS. The GS consists of six multinational members appointed by OAS, while the NPEUs are made up of national and local governments representatives and members from civil society and NGOs. Daily business is carried out by the General Secretariat in close cooperation with the NPEUs. Further project support comes from national government organizations, universities, and professional consultants.

Water legislation and decision-making is organized differently in each member country. In Argentina, water legislation is worked out at the provincial level, whereas water resource policies and laws in Brazil are settled on both the national and state levels. Uruguay, in contrast, is a unitary state and as such formulates water regulations on a national level only. Paraguay, also a unitary state, is characterized by a complete absence of water laws. Hence the settlement of legal water issues is very uneven within each of the four riparian states. This is, however, not the case for general transboundary issues, which in all four countries are settled at the national level.

2.2.3 Barriers to cooperation and progress to date

Generally, the structure of governance of the Guarani Aquifer Project (GAP) appears relatively representative. In view of the absence of a comparable role model for transboundary groundwater management, the organizations carry out their tasks reasonably well (Eriksson / Rogers 2006), and in spite of its complexity, the institutional, organizational and management framework of the Guarani Aquifer Project appears to work effectively in general. The efforts of the National Project Executing Agencies (NPEUs) to integrate the public into the decision-making process, have turned out reasonably successfully and have had considerable influence on the coordination of programs among and within the four countries. All organizations set up under the GAP entail the participation of civil society, and the project is carried out for the most part on a regional level. This is especially true in Uruguay, where it is run mostly by consulting firms and university researchers (Eriksson / Rogers 2006).

However, the World Bank Independent Evaluation Group has also identified a series of issues which have hampered the effectiveness of the project both during its initial setup and during the implementation phase. Specifically, implementation of the project faced considerable delays at the beginning as a result of tedious negotiations, especially regarding organizational agreements. In addition, Further time lags occurred in undertaking initial transboundary diagnostics and establishing economic cost-benefit analysis's of different alternative management approaches.. This led the Evaluation Group to conclude that "*reported progress on the scientific work has been limited, due primarily to the substantial delays in negotiating the large contracts*" (Eriksson / Rogers 2006, viii). Furthermore, the time frame associated with implementation of the project and its governance structures turned out to be too ambitious, and the project has therefore been extended by an additional 2 years.

Of further concern is the lack of appropriate indicators for measuring the project's achievements. While the objectives of the project and the management framework are well defined, there is no clear understanding on how to measure progress. None of the currently employed indicators displays the development of the project, its governance and management framework, and the adequacy of the achievements within the project outline. As a result, it is comparatively difficult to make a statement about progress to date regarding efforts to protect the Guarani Aquifer System.

Efficiency issues arise with the intensive coordination which is required between the different organizations of the GAP governance framework. The General Secretariat and the Steering Committee, for instance, are obliged to harmonize their actions even in cases of minor decisions, thereby slowing down the implementation of policies and activities. Similarly, the roles of the OAS and the World Bank overlap, since the two organizations carry out responsibilities that could theoretically be managed by only one. Both agencies, although operating in separate areas, have similar roles in managing funds, providing technical expertise and monitoring regional implementation of the GAP. This diminishes the project's time-effectiveness and cost-effectiveness (Eriksson / Rogers 2006).

However, a certain rationale exists for maintaining the two agencies separately. One reason is that the OAS, with its background of experience in regional water management activities, enjoys credibility in the region. On the other hand, it is also pointed out that the OAS lacks both convening power and the technical depth which is particularly needed during the initial project stages and which the World Bank is said to possess (Eriksson / Rogers 2006).

Of further concern are the uneven starting conditions among the four member countries, whose technical and financial capabilities differ greatly on both the national and regional levels. The comparatively richer countries of Argentina and Brazil have relatively more and better resources. In the view of the World Bank Independent Evaluation Group, such a disparity leads both to participation problems and to inequality in the way capacities are shared between the national organizations (Eriksson / Rogers 2006).

No concept for regional cooperation exists for the time after the GAP expires in 2009. Based on present observations, the Evaluation Group is apprehensive that any form of groundwater management after 2009 is likely to be of a unilateral or bilateral nature at best (Eriksson / Rogers 2006). To what extent the present governance framework will remain in place after the project remains unclear. Additionally, institutional and organizational capabilities of some of the participating countries, especially Paraguay and Uruguay, may not suffice for any form of joint management subsequent to 2009.

2.3 The Franco-Swiss Genevese Aquifer

2.3.1 The aquifer system

The Franco-Swiss Genevese Aquifer is located mainly underneath the Canton of Geneva between the southern end of Lake of Geneva and its effluent into the Rhone river. Its southernmost part is of a transboundary nature, since it underlies the border between the Canton of Geneva and the French Department of Haute Savoie. The Aquifer's recharge stems from the River Arve in France, a tributary of the Rhone. France is therefore the upper riparian and the main contributor to the Genevese Aquifer.

As shown in Figure 3, the aquifer is tapped for drinking water purposes by a total of 5 wells on the French side and 10 wells on the Swiss side. Total water extraction from the aquifer is estimated at around 15 to 17 million m^3 per year, with France being allocated an annual share of 5 million m^3. In contrast, yearly natural recharge averages around 7.5 million m^3, and an additional 11 million m^3 can be artificially recharged by a facility on the Swiss side of the border (Yamada 2004).

Water withdrawal from the Genevese Aquifer between 1940 and 1960, was very close to natural recharge. Since the 1960s however, the Genevese aquifer has been subject to more and more over-drafting, with the result that extraction rates progressively exceeded natural recharge. Consequently, the water table dropped by more than 7 meters within 20 years, and total groundwater storage was reduced by one third (Wohlwend 2002).

2.3.2 Governance and cooperation

In response to nearly two decades of over-draft of the Genevese aquifer and the resulting necessity to address it, the Canton of Geneva initiated a dialogue with the French Department of Haute Savoie in 1977 with the intention of jointly developing a system of aquifer recharge and management (Yamada 2004). The talks were of an exclusively regional nature, and the negotiators were authorized to deal directly with international authorities on the subsidiary level.[24] The national governments were kept up to date. The consultations resulted in the signing of the *Arrangement on the Protection, Utilization and Recharge of the Franco-Swiss Genevese Aquifer*[25] in 1977 (Ulfstein / Werksman 2003).

The agreement provided for the creation of a Genevese Aquifer Management Commission consisting of three members from each side of the border.[26] The Commission's mandate is to develop an annual aquifer utilization program based on estimated needs of all users on both sides of the border. Furthermore, the Commission provides technical expertise and proposes groundwater protection measures to regional authorities (article 1–6). The Commission's overall function under the Franco-Swiss Genevese Aquifer agreement can be seen as being of a purely technical-consultative nature, since the regional authorities subsequently make the final decisions with respect to the Commission's recommendations.[27]

Since the majority of groundwater extraction takes place in Switzerland, the agreement defines the Canton and Republic of Geneva as exclusive owner of and investor in the groundwater recharge infrastructure (including a treatment plant), which is employed to refill the aquifer, thus balancing water extraction and recharge (Article 8). At the beginning of each year, user groups on both sides of the border forward their estimated water requirements to the Commission. The latter then calculates total water needs and sets extraction limits which may not exceed total recharge levels. French users are usually allowed to extract up to 5 million m^3 of

24 That is, local authorities may negotiate with their counterparts on the other side of the border but not with those on higher (e.g. provincial) levels.

25 Originally known as the 'Arrangement relatif à la protection, à l'utilisation et à la réalimentation de la nappe souterraine franco-suisse du Genevois'; here: the Genevese Aquifer Agreement.

26 At least two of the three must be water specialists.

27 However, this technical-consultative approach also has an allocating function, since the management plan issued by the Commission specifies annual withdrawal and recharge rates based on technical estimates of the aquifer's contents.

groundwater each year (article 9).[28] Operation and maintenance costs of the recharge facility are shared by France and Switzerland in proportion to the total volumes of water used by each. Groundwater quality is regularly assessed by both parties on the basis of standard qualitative analysis criteria developed by the Commission (article 16). The agreement furthermore addresses potential water quality threats (e.g. pollution accidents) by maintaining a warning system (Article 17) and by clarifying responsibilities between the two countries (Yamada 2004).

2.3.3 Barriers to cooperation and progress to date

In force since 1978, the Genevese Aquifer Agreement constitutes "*one of the oldest and most successful international treaties on groundwater resources in the world*" (Hardberger 2004). A significant part of this success can be ascribed to the regional nature of the agreement, inasmuch as it has been negotiated and signed between local authorities on both sides of the border. This enables the regional level which is directly concerned to operate efficiently and to respond quickly to local water needs and requirements without being hampered by bureaucratic structures or the need to clear procedures beforehand with higher authority levels. Another decisive factor is the agreement's "*pragmatic approach*" (Yamada 2004, 6), which is reflected in the consultative and technical work of the Commission. The power constellation between the two countries appears to be very well balanced by the specifications of the agreement. For example, since water extraction on the Swiss side usually exceeds France's water withdrawals but the bulk of natural recharge stems from French surface waters, the agreement provides that Switzerland is to be in charge of the artificial recharge plant while France receives a free allocation of 2 million m^3 of water each year.

Another characteristic of the agreement is that each state maintains its sovereign prerogatives. This means that the aquifer has no particular legal status but is rather regarded by both parties as a joint resource to be man-

28 This includes a free allocation of 2 million m^3 in recognition of the fact that France is both the major contributor of natural recharge water to the aquifer and a comparatively minor extractor. In cases of necessity, however, Swiss users may request their French neighbors to give up part or all of this free allocation of 2 million m^3 in favor of Swiss users (article 9).

aged for the benefit of all users irrespectively of nationality and geographical characteristics (Wohlwend 2002).

In any case, the Franco-Swiss Aquifer Agreement is widely regarded as both highly successful and as an excellent lesson for others (e.g. Yamada 2004; Hardberger 2004; et al.).

3 Recommendations and open issues for transboundary groundwater management in Africa

> "*The most important step in the creation of an international groundwater agreement is realizing one is necessary*" (Hardberger 2004, 1244).

3.1 Recommendations for transboundary groundwater management

Important lessons can be learned from these case studies on cooperative groundwater management. Moreover, these insights can help to formalize recommendations for other countries, especially the African states, on how to manage their own transboundary aquifers together.

A strong and independent authority is needed on the multinational level. As seen above, problems in joint management of the Hueco Bolson Aquifer stem not only from differences in governmental perceptions and policies between the US and Mexico but also from the sheer number of national agencies involved in the process of consensus building. This makes it much more difficult for the two parties to reach agreement. One solution would be a strong multinational, independent authority heading up the process on a transboundary level.

This in turn requires considerable willingness to cooperate. It requires that governments hand over the control of water and cross-border related decisions to a sovereign organization, with a concomitant loss of control over sensitive areas with political and socio-economic impact.

In the case of Africa, it can be assumed that turning over decision-making powers to binational or multinational organizations will meet with considerable resistance, especially from countries where water resources are of strategic importance. This is the case for the many African states characterized as “water-stress economies”, since water scarcity within their borders increasingly forces them to turn to water resources from outside their own national borders (Scheumann / Neubert 2005). Securing maximum decision-making power over transboundary water resources can thus be seen as a high national priority. On the other hand, the prevalence of a range of African bilateral and multinational organizations dealing with transboundary surface water management reflects governmental acknowledgement of the fact that cross-border issues in many cases require a subnational authority whose responsibilities were previously located at the national level.

Strong local and regional integration. As shown in Section 2 above, an important element of all cross-border cooperation is active regional planning and management of transboundary groundwater resources. Public participation and the involvement of local agencies such as research institutes and non-governmental organizations from all riparian states is crucial in this context, especially since present and future challenges and opportunities in relation to transboundary groundwater resources arise first and foremost on the regional level. As exemplified by the Hueco Bolson Aquifer, efforts from local universities, private foundations and NGOs from both sides of the border, carried out in the form of joint projects and dialogue platforms, have proven successful (Brown et al. 2003).

Also, the collection and sharing of data and information on transboundary aquifer systems such as cross-border withdrawal and recharge rates requires that organizations from the riparian states operate and cooperate on the lowest possible level. Although not an alternative, local and regional forces constitute an important and effective element of water governance and are therefore an indispensable complement to any legal and administrative efforts on a higher level.

This is in line with the recommendations of the World Bank Independent Evaluation Group, which views subsidiarity as a key criterion in assessment of the GAP (Eriksson / Rogers 2006). The Group came to the conclusion that responsibilities and powers in this regard should be allocated first and foremost to local authorities rather than to authorities on the national level.

In Africa however, regional organizations and authorities in the field of surface water management have turned out to be largely ineffective, and the existing river- and lake-basin organizations there are commonly characterized by an inability to fulfill their mandates. Scheumann / Neubert (2005) have underscored the need to build up capabilities not only on the national but also the regional and local level in order to strengthen the effectiveness of these organizations. Viewed in this light, an effective regional and local integration of transboundary groundwater management bodies is at the top of the priorities list.

Technical foundations for agreement. Experience with bilateral and multilateral agreements regarding transboundary aquifers has shown that cooperative efforts are usually easier to achieve when they are based on an exchange of technology and scientific data and are also more effective than agreements based largely on, for example, political aspects. A good example of this is the Franco-Swiss Genevese Aquifer agreement discussed in Section 2. Its success has been largely ascribed to its technical approach, which provided a good starting point for bilateral and multilateral cooperation. It is often easier to arrive at an agreement based exclusively on scientific data than one based on political aspects. As collaboration progresses and dialogue builds, more complex technical and managerial issues can be addressed on a growing basis of mutual trust (Brown et al. 2003).

However, it cannot be ignored that transboundary water cooperation is almost always both political and technical in nature (Scheumann / Neubert 2005). Thus political concerns need to be acknowledged, even if this makes it more difficult to reach an agreement.

Integration into existing frameworks for the management of surface water. Another frequent recommendation is that binational or multinational groundwater management be integrated into existing surface water governance structures. Such use of established structures could also greatly facilitate the implementation of a groundwater management system. Africa already offers an impressive track record in this regard: 20 of its 63 transnational riversheds are already managed under international agreements, and 16 of these agreements provide for setting up organizations for the coordination of activities in this regard. However the regional extensions of African surface and ground water resources – the catchment areas – do not always coincide hydrogeologically. Where such differences are considerable, an integrated form of management of both surface and ground water resources might be difficult from an organizational point of view.

3.2 Hindrances to transboundary groundwater management

In general, there is no panacea for numerous issues related to transboundary groundwater cooperation, as described in the following.[29] It might then be useful to firstly examine potential hindrances and secondly prepare for these obstacles when moving towards a joint groundwater management.

Economic and political power imbalances. A crucial issue identified in Section 2 was the economic and political power imbalance between Mexico and the US As already mentioned, Mexico's fear of politicizing water issues and thereby endangering its presently good relationship with the U. S. explains why it refrains from putting forward proposals for binational groundwater cooperation.

The issue of power imbalance appears particularly important in the African context, especially in southern Africa, where the ability of riparian states to manage their transboundary water resources cooperatively depends largely on the political and economic power of the respective countries (Scheumann / Neubert 2005). It stands to reason that economically and politically weaker countries might well refrain from initiating cross-border groundwater cooperation in order not to endanger their binational relationships.

However, recent developments provide encouraging evidence that such power-related hindrances can be overcome. The founding of the African Ministers' Council on Water (AMCOW) as a continent-wide forum on cooperation is one example.[30] Moreover, South Africa, the dominant power in the region, continues its strong support for cooperation and inte-

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29 The development of adequate strategies for coping with these hindrances will require a country-by-country review. Such a discussion lies outside the scope of this paper.

30 Further examples in this context are the Southern African Development Community (SADC) and the Water Division of the Economic Community of West African States (ECOWAS).

gration with respect to transboundary surface waters, and this approach could well be extended to transboundary groundwater in the near future.

Legal structures in water allocation. As exemplified by the US-Mexico situation, obstacles to effective WRM also stem from differences in water law jurisdiction between federated states. In the US, decision-making power regarding water use is centralized at the federal level whereas in other cases, the states themselves hold water regulation power. Such disparities in legislative competences make regional and/or local cooperation comparatively more difficult. As a result, all agreements between the US and Mexico have so far been settled at the national or federal level, with regional and local stakeholders relegated to voluntary and non-binding cooperation.

Technical and administrative capacity imbalances. As seen in the case of the Guarani Aquifer Project, Argentina and Brazil have larger technical and financial resources than the other project members Paraguay and Uruguay. As mentioned, this imbalance has led to participatory and capacity-sharing problems among respective organizations in the four nations. The same is likely to be true of many of the African countries: their substantial differences in administrative, technical and financial capacities will most likely influence both their ability and their willingness to cooperate (Scheumann / Neubert 2005).

Experience with surface water agreements in Africa shows that international donors, by contributing financial, technical and administrative resources, have played a crucial role in the establishment of nearly all river and lake basin organizations there (Scheumann / Neubert 2005). It therefore appears that the implementation of transboundary cooperation in Africa still requires external support in order to take place. Applying this experience to groundwater resources, international donor agencies are likely to have a crucial role in the establishment of transboundary aquifer cooperation by closing the capacity gap that prevails both within and between countries.

Agreement negotiations. As illustrated by the Guarani Aquifer System Project, agreement negotiations may be characterized by considerable disagreement among the respective parties. In this example, it proved particularly difficult to reach a consensus regarding governance structures. This could be even more the case when the stakeholder group is more diverse and interests deviate from one another even more widely. Furthermore, it becomes increasingly difficult to satisfy the expectations of all sides when more parties are involved. This in turn is likely to result in very difficult negotiations and increased costs.

Organizational rivalries and overlapping responsibilities. As illustrated by the GAS project, organizations involved in water governance often have overlapping responsibilities. The main reason is that the different stakeholders want to equip their respective organizations with maximum decision-making power. Such rivalries in the allocation of competences make it more difficult to reach agreements. As a result, the agreements may turn out to be compromises regarding the overlap of organizational responsibilities. This is likely to cause inefficiency, since more resources are needed to both to exercise these responsibilities and to harmonize the actions of diverse organizations and agencies.

4 Conclusion

Bi- and multilateral cooperation on transboundary aquifer management, although still very much in its infancy, provides us with some insightful "lessons learned" drawn from the few examples that can be found throughout the world. Agreements on shared aquifers from the three case studies examined here differ widely with respect to their triggering forces, their implementation, their effectiveness, and their achievements. All, however, offer valuable insights and lessons with respect to effective cooperation and allow us to derive recommendations for future groundwater cooperation efforts in the world and specifically in Africa.

A crucial point identified in this context was the establishment of a strong and regionally integrated management framework of organizations and institutions responsible for local implementation. Where governance structures are already in place for dealing with transboundary surface water, it might make sense to integrate groundwater management into this setup.

In addition, the case studies examined here illustrate the possible obstacles to cooperative transboundary aquifer management. Economic and political power imbalances between countries can hamper cross-border initiatives. Moreover, it is often easier to find a common ground when the starting point for agreement is of a purely technical nature. This implies that political concerns and more complex mattes should be left out of the picture until relationships between the respective riparian parties have become somewhat more stable.

Further hindrances may occur in the form of imbalances in technical and administrative capacities, divergences in water legislation among the riparian states, and the presence of diverse stakeholder groups with largely heterogeneous interests. Even after agreement on joint management has been reached, organizational rivalries and overlapping responsibilities among the management organizations may reduce the efficiency of cooperative efforts.

Applying these conclusions to the management of shared aquifers in Africa is not a straightforward matter, since the respective political, economic, social and hydrogeological realities of countries there differ widely. Taken together with experience already gained in transboundary surface water management in Africa, however, the above recommendations and the overview of hindrances presented here can nonetheless help in understanding and preparing for the challenges lying ahead for this continent as it moves towards transboundary aquifer management.

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