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IW:Science

Enhancing the use of Science in International Waters projects to improve project results

ANALYSIS REPORT

GROUNDWATER

A global Analysis of **Groundwater** science and transboundary management

UNEP

GLOBAL ENVIRONMENT FACILITY 20 YEARS INVESTING IN OUR PLANET

GEF IW:Science Project

Analysis Report of the Groundwater Working Group

IW: Science, or *Enhancing the Use of Science in International Waters Projects to Improve Project Results* is a medium-sized project of the Global Environment Facility (GEF) International Waters (IW) focal area, implemented by the United Nations Environment Program (UNEP) and executed by the United Nations University Institute for Water, Environment and Health (UNU-INWEH). GEF ID Number: 3343.

CORE PARTNERS

Analysis Report of the Groundwater Working Group

March 2012

This report is written as part of the IW:Science series of reports comprising a Synopsis and Analysis for each of five classes of global transboundary water system: River Basin, Lake, Groundwater, Land-based Pollution Sources, and Large Marine Ecosystems and Open Oceans. The findings and content of the Synopsis and Analysis Reports are then integrated into two IW:Science Synthesis Reports to provide a global water view with regard to *Emerging Science Issues and Research Needs for Targeted Intervention in the IW Focal Area*, and *Application of Science for Adaptive Management & Development and use of Indicators to support IW Projects*. All reports can be found on the IW:Science, UNU-INWEH, IW:LEARN and GEF websites.

This report was prepared under the responsibility of the IW:Science Core Partner and Lead Institution of the Groundwater Working Group:

United Nations Educational, Scientific and Cultural Organization
International Hydrological Programme

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Cover photo: Sustainable use of groundwater resources will play a pivotal role in the provision of water for future generations, child in West Africa

List of Acronyms and Abbreviations

ACRONYM	MEANING
AM	Adaptive Management
DPSIR	Driving forces, Pressures, States, Impacts, and Responses
GAS	Guarani Aquifer System
GEF	Global Environment Facility
GIS	Geographic Information System
GIWA	Global International Waters Assessment
GWG	Groundwater Working Group
IAS	Iullemeden Aquifer System
IGRAC	International Groundwater Resources Assessment Centre
ISARM	Internationally Shared Aquifer Resources Management
ITC	International Trade Centre
IW	International Waters
IW:Science	International Waters Science
IWRM	Integrated Water Resources Management
LME	Large Marine Ecosystem
MAR	Managed (Artificial) Aquifer Recharge
MSLME	Mediterranean Sea Large Marine Ecosystem
NSAS	Nubian Sandstone Aquifer System
NWSAS	North Western Sahara Aquifer System
PCU	Project Coordination Unit
RBM	Results Based Management
RBO	River Basin Organisation
SADC	Southern African Development Community
SAP	Strategic Action Programme
SSG	Scientific Synthesis Group
TAG	Technical Advisory Group
TAs, TBAs	Transboundary Aquifers
TBA	Transboundary Aquifer
TDA	Transboundary Diagnostic Analysis
TWAP	Transboundary Waters Assessment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNU-INWEH	United Nations University Institute for Water Environment and Health
WGs	Working Groups
WWDR3	Third World Water Development Report

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Appendix 16 'Aquifers, Hydrology & Eco-Hydrology' for synergizing International Waters and Land Degradation Focal Areas in GEF-IV (FY 2007-2010)

CHAPTER ONE
Introduction

1.1 The GEF IW: Science project

Enhancing the Use of Science in International Waters Projects to Improve Project Results is a GEF IW:Science project launched in 2009 covering the five main areas in the GEF International Waters portfolio: surface water; lakes; groundwater; large marine ecosystems; and deep oceans. A working group was formed to address each of these areas.

The project's objective is to enhance – through knowledge integration and information-sharing tools – the use of science in the GEF IW focal area to strengthen priority setting, knowledge sharing, and results-based, adaptive management in current and future projects. The project has three components:

1. Understanding and documenting, for future analysis and reference, the scientific experience and scientific best practices from the IW project portfolio.

2. Undertaking and reporting a comparative, cross-sectoral assessment of IW:Science, identifying intended users and impacts, contemporary scientific challenges, research and science-policy gaps, emerging issues, and global-scale impacts.

3. Creating an IW scientific learning network for information sharing and mutual learning among IW projects and with the wider water science community.

1.2 Approach and Methodology

The approach adopted by the IW:Science project, directed by UNU-INWEH, relies on parallel information extraction and analysis activities by five working groups (WGs), one for each of the five main areas in the GEF International Waters portfolio, as indicated above. A Scientific Synthesis Group (SSG) will integrate the outputs of these five working groups, creating synergy and a deeper understanding of the role of science in the IW portfolio. UNU-INWEH assists the working groups by establishing a GEF IW projects document database and will create an IW scientific learning network for information sharing and mutual learning.

The activities of each working group consisted mainly of the following two components:

4. Identifying and documenting science as used in GEF IW projects. This was done on the basis of a predefined set of projects and results reported in a Synopsis Report.

5. Analysing the use of science in the selected set of GEF IW projects, against the background of relevant aspects and from different angles of view. To facilitate this analysis, a set of core questions was developed, to be used by all working groups (see Section 1.3). Results of the analysis are presented in an Analysis Report.

1.3 Core Questions

To focus the analysis and facilitate subsequent inter-comparison and synthesis in the next stage of the project (Component 2), the Working Groups were challenged to address a common suite of core questions on critical science challenges as they relate to a specific water system type. Three categories of questions are considered. The tentative issue areas, drafted 4 March 2009, were discussed at the Steering Committee meeting in Bonn, 25-26 March 2009, and again at the project inception meeting in Macao, 25-28 January 2010, after which they read as follows:

A. Critical science issues:

1. What are the critical science challenges "on the horizon" specific to each ecosystem type?
2. What is the significance of regional and global-scale drivers, in particular climate change, in the genesis of transboundary problems?
3. Describe how understanding and managing multiple causality in a transboundary water context is undertaken.
4. How are variable spatial and temporal scales in IW projects accounted for?
5. What approaches were used to understand/assess the coupling of social and ecological systems?
6. What scientific knowledge is available and/or used to evaluate trade-offs between the response options developed by IW projects?[1]

1 Question added in January 2010 at Project Inception Workshop

Aquifer System Salto-Salto Chico, shared by Argentina and Uruguay – Entre Rios Province, Argentina / *E. Diaz*

B. Application of science for adaptive management:

1. Was engagement of both local and wider science communities utilised in IW projects? If not, how can improvements be made?
2. Is scientific expertise and local knowledge well applied within the IW focal area, particularly in accessing existing baseline information, new findings on methodologies, science breakthroughs and scanning for emerging issues?
3. Identify lessons learned for linking science and policy implementation, including policy formulation and broader governance issues.
4. Is adaptive management happening? How to better understand and effectively communicate the scientific dimensions of adaptive management to different user groups?
5. How to better communicate newly-synthesized science knowledge to stakeholders within and external to GEF?

C. Development and use of indicators to support results-based IW projects:

1. How did the projects help build and implement sound indicators and monitoring strategies to support Strategic Action Programme (SAP) implementation and/ or ultimately assess achievement of environmental and social benefits?

2. How can we identify effective proxy indicators for use in IW projects?

3. How to make better use of appropriate science and best practices for Transboundary Diagnostic Analysis?

The core questions were to be addressed by each Working Group in the context of a specific water system type, groundwater[2] in this case, and with a GEF IW-projects focus (what do we observe in existing GEF IW projects in relation to these specific questions?). The analysis should give a picture of practices in GEF projects in relation to each question, highlight strengths and weaknesses, and – where possible – make suggestions for improving the science components of GEF's IW projects.

Water containers to be filled, Northern Kenya */ A. Dansie*

2 The corresponding projects all are related in one way or another to the management of aquifer resources (see also Stephan (2009) and the included UNILC Draft Articles on the Law of Transboundary Aquifers).

1.4 Activities of the Groundwater Working Group

In an early stage of the project, before the Inception Meeting in Macao (25-28 January 2010), the majority of the core questions were already addressed, in a preliminary manner, by the Groundwater Working Group (Tujchneider and Van der Gun, 2010a). This allowed members to become acquainted with the project's approach and develop some provisional results for the analysis, but it also revealed a serious bottle-neck: a lack of access to IW project documents.

The work to inventory project documents, initiated in the autumn of 2009 by the Project Coordination Unit (PCU), continued after the Macao meeting, producing an impressive project document database. Nonetheless, in spite of huge efforts, reports of crucial importance are still missing for many GEF IW projects.

Using a template to facilitate the analysis, members of the Groundwater Working Group reviewed 11 projects. Their project reviews – together with a number of thematic reviews – are presented in a Synopsis Report (Tujchneider and Van der Gun, 2010b).

After the Synopsis Report was finalized, each member was asked to prepare a write-up on one or two of the core questions. A draft Core Questions Report (Tujchneider and Van der Gun, 2010c) was produced, providing a quick overview and digest of the contributions. This was done primarily in order to contribute to focused discussions at the Groundwater Working Groups' second meeting in Perugia, 27-29 September 2010. Discussions in Perugia were fruitful and produced a balanced view from the Working Group on the science components in groundwater related GEF IW projects and on options to enhance these.

Borders of Paraguay, Argentina and Brazil at the confluence of the Parana River and Iguazu River.

1.5 Purpose of this report

This report is intended to present results of the core question analysis by the members of the Groundwater Working Group, particularly the conclusions and recommendations derived from this analysis.

Fifteen contributions to core questions were received from members. The original contributions are presented as appendices, thereby keeping the body of the report fairly brief. This report reflects an interpretation of contributions by compilers, based on quick reading and summarizing; thus, this interpretation may diverge, to some degree, from the intentions of the contributors. Authors were encouraged to react, in particular, to those aspects that apparently were misunderstood or ignored.

One special and rather long contribution was different in scope and intention compared to all other contributions received. It is a draft policy paper, contributed by *Shammy Puri* entitled *Aquifers, Hydrology and Eco-Hydrology* (Contribution to enhancing GEF-IV, FY 2007-2010). This paper does not address any of the core questions explicitly, but nevertheless is considered valuable as general contextual reference to groundwater in GEF's programme. It is included as the last appendix.

Conclusions and recommendations were defined in a first version during discussions at the meeting in Perugia. Written contributions by individual Working Group members have greatly improved formulation of these conclusions and recommendations. Feedback from the entire working group on the draft version of this report has been received and has enhanced consensus on the Group's thoughts about science in the IW portfolio and options for enhancement.

CHAPTER TWO

What is 'science' in the context of the IW:Science project?

To decide how to interpret the word "science" in the context of the IW:Science project, we may look, on the one hand, to numerous definitions of science, and, on the other, to the nature of the GEF projects under consideration.

The following definitions and statements are typical examples of the way science is regarded.

Sheldon Gottlieb (http://www.theharbinger.org/articles/rel_sci/gottlieb.html) describes science as follows:

> *Science is an intellectual activity carried on by humans that is designed to discover information about the natural world in which humans live and to discover the ways in which this information can be organized into meaningful patterns. A primary aim of science is to collect facts (data). An ultimate purpose of science is to discern the order that exists between and amongst the various facts.*

Karl Popper, in *The Logic of Scientific Discovery*, adds uncertainty as a typical characteristic of science:

> *I think that we shall have to get accustomed to the idea that we must not look upon science as a "body of knowledge", but rather as a system of hypotheses, or as a system of guesses or anticipations that in principle cannot be justified, but with which we work as long as they stand up to tests, and of which we are never justified in saying that we know they are "true".*

Many investigators define science by describing "the scientific method". For example, Frank Wolf defines it as follows (http://teacher.nsrl.rochester.edu/phy_labs/AppendixE/AppendixE.html):

> *The scientific method is the process by which scientists, collectively and over time, endeavour to construct an accurate (that is, reliable, consistent and non-arbitrary) representation of the world. Recognizing that personal and cultural beliefs influence both our perceptions and our interpretations of natural phenomena, we aim through the use of standard procedures and criteria to minimize those influences when developing a theory. As a famous scientist once said, "Smart people (like smart lawyers) can come up with very good explanations for mistaken points of view." In summary, the scientific method attempts to minimize the influence of bias or prejudice in the experimenter when testing an hypothesis or a theory.*

The scientific method is often summarized as a four-step approach *(Journal of Theoretics, Vol 1-3, Aug/Sept 1999, Editorial):*

1. Observation and description of a phenomenon or group of phenomena.
2. Formulation of a hypothesis to explain the phenomena. In physics, the hypothesis often takes the form of a causal mechanism or a mathematical relation.
3. Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.
4. Performance of experimental tests of the predictions by several independent experimenters using properly performed experiments[3].

From the above, we may conclude that science for some (the theoretically oriented scientists) is focusing on hypotheses and theories, for others (applied scientists) rather on producing "useful models of reality".

Given that GEF projects are aimed at producing tangible impacts on the environment, an inclusive rather than restrictive interpretation of the word "science" seems more appropriate, and would encompass everything related to producing "meaningful patterns in the world around us" and "useful models of reality", including how these patterns may change in the future. Similarly, IW: Science should not focus solely on the "natural sciences", but also take into account the social and applied sciences. This broad interpretation was incorporated in the approach of the Groundwater Working Group.

3 This fourth step is obviously meant to validate or falsify the hypothesis.

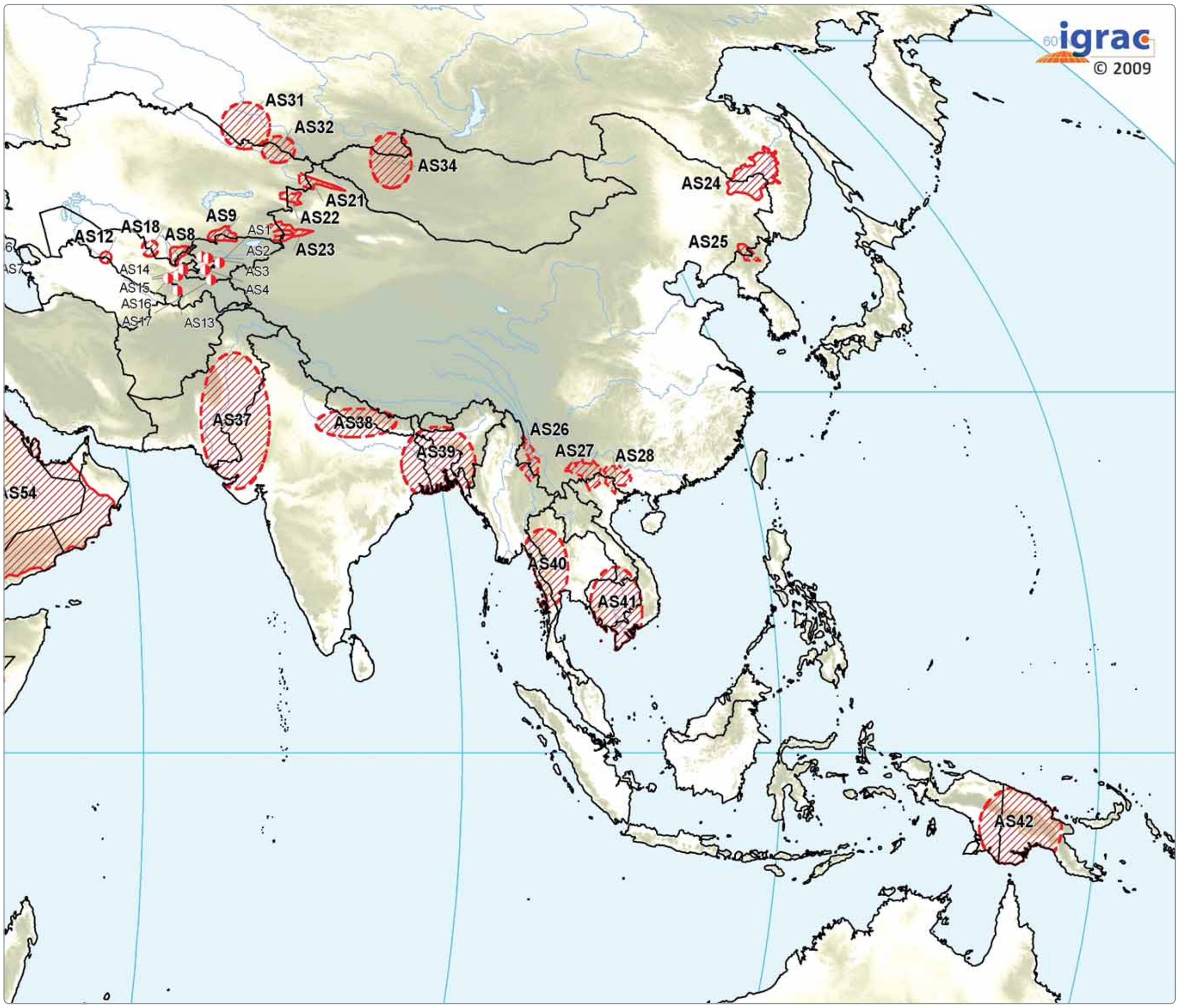


Figure 1 Transboundary Aquifers of South-East Asia Map

The figure depicts South-East Asian transboundary aquifers based on information provided by various organisations and projects dealing with transboundary aquifer assessment and /or management and compiled by IGRAC in 2009. For a comprehensive explanation of this map, please refer to the figure caption on the back inside-cover p. 32).

CHAPTER THREE

Relevant Groundwater-Related IW Projects Considered

Figure 2 Transboundary Aquifers of Latin-American Map

The figure depicts Latin-American transboundary aquifers based on information provided by various organisations and projects dealing with transboundary aquifer assessment and /or management and compiled by IGRAC in 2009. For a comprehensive explanation of this map, please refer to the figure caption on the back inside-cover p. 32).

Table 1 The set of projects reviewed and used as a basis for the Core Question analysis

	GEF #	NAME	STATUS	TYPE OF PROJECT
1	584	Global International Waters Assessment (GIWA)	Completed	Global project – all water system types included
2	970	Groundwater and Drought Management in SADC	Completed	Regional project
3	974	Guaraní Aquifer System (GAS)	Completed	Aquifer system project
4	985	Eastern Desert of Egypt (Renewable groundwater in arid lands)	Completed	Regional project
5	1851	North Western Sahara Aquifer System (NWSAS)	Completed	Aquifer system project
6	2041	Managing Hydrogeological Risk in the Iullemeden Aquifer System (IAS)	Completed	Aquifer system project
7	-	TBA in Asia (emphasis on China) – Amur basin	Completed	Regional project – basin oriented
8	2020	Integrated Management Nubian Sandstone Aquifer System (NSAS)	Ongoing	Aquifer system project
9	3321	Mainstreaming Groundwater in Nile River Basin Management	Ongoing	Regional project – basin oriented
10	-	ISARM	Ongoing	Global project with regional components
11	GFL-2322-2731-4A05	Management of Coastal Aquifer and Groundwater (Mediterranean Sea area)	Recently starting	Regional project

In keeping with the overall project approach, analysis of the core questions focused on relevant groundwater-related projects in the GEF IW project portfolio and similar non-GEF projects. A list is presented in Table 1.

Initially, the document inventory team suggested 18 GEF projects to be considered as a basis for review and analysis by the Groundwater Working Group. During the inception meeting in Macao (January 2010), however, the list of projects was critically reviewed, resulting in a modified list of 13 GEF projects and two non-GEF projects on transboundary groundwater. The main reason for modifying the list was a lack of documents for several projects. For practical reasons (lack of capacity combined with limited information and initial stage of some projects), a few more projects were deleted, which reduced the list to 11. The Synopsis Report on Transboundary Aquifer Projects – jointly produced by the members of Groundwater Working Group – presents reviews of these 11 projects, together with five thematic reviews (Tujchneider and Van der Gun, 2010b).

Four of these 11 projects focus on a single aquifer system, while five deal with groundwater in a region (or large basin), and two are global projects.

Unfortunately, the project information accessible to date for analysing the core questions is still limited, in spite of significant inventory activities. For the majority of the project – even those finalized – essential documents (e.g., a final technical report or reports on key components of the project) are unavailable, although they may have been produced. Therefore, the analysis, judgements and overall conclusions presented here are subject to some uncertainty, since they are based on accessible information only.

CHAPTER FOUR

Three Interesting Paradigms

Approaches to water resources management are evolving over time. Generally observed trends include an increasing awareness of the complexity of the overall context, a change from mono-disciplinary (hydrological/ hydrogeological) approaches toward multidisciplinary approaches, and adoption of different angles of view. This has produced paradigms such as Integrated Water Resources Management (IWRM), Sustainable Water Resources Development, Stakeholder Participation, etc., all very familiar to those involved in water resources management activities. As is suggested in Section 1.3, two paradigms clearly have played an overarching role in developing the core questions: Adaptive Management and Results-based Management. These were discussed during the Perugia meeting, together with another paradigm that seems highly relevant in the framework of GEF's IW projects: the Social-Ecological Systems approach. A brief summary follows below.

A groundwater pumping station servicing a rural community in the Lebombo Mountains, Swaziland near the Mozambique border / *A. Dansie*

4.1 Adaptive Management[4]

The concept of Adaptive Management (AM) was developed during the 1970s at the International Institute for Applied Systems Analysis in Vienna. In contrast to more traditional approaches to natural resources management that assume all social, economic and environmental factors and issues to be predictable, AM aims to support management of natural resources under uncertainty. It attempts to introduce flexibility in management, since it is considered a logical consequence of uncertainty that adjustments are needed on the basis of observed changes in the state and performance of the systems to be managed. Decisions are made as part of an ongoing science-based process. AM has been described by Holling (1978) as "a systematic approach to improving management and accommodating change by learning from the outcomes of management policies and practices". Bormann et al (1993) call it "learning to manage by managing to learn". Learning, thus, is an inherent feature of Adaptive Management. Usually two types of adaptive management are distinguished:

A. *Passive* adaptive management: values learning only insofar as it improves decision outcomes as by the specialized utility function. In other words, observed outcomes are used to improve decisions for a next planning period. In this sense, AM is in line with common practices in IWRM to adopt a cyclic planning schedule, with periodic plan updates after a number of years.

B. *Active* adaptive management: incorporates learning explicitly as part of the objective function, and hence, decisions that improve learning are valued

4 Introduced to the Working Group by Todd Jarvis and Alfonso Rivera at the 2nd Working Meeting in Perugia, September 2010

over those that do not (Holling, 1978; Walters, 1986). In other words, management actions are taken not only to manage, but also explicitly to learn about the processes governing the system (Shea et al., 1998).

Active AM focuses on learning by experimenting. The general opinion emerging from the Working Group's discussion was that it does not seem to be a suitable concept for groundwater management, for a number of reasons:

- Processes in groundwater systems are extremely slow, which means that the duration of any experiment would be excessively long. Furthermore, since it implies that it will take a long time before potential negative impacts of experimental measures become visible, correcting for such impacts will be very difficult and require much time, if, indeed, it is possible at all.

- Groundwater management, more so than management of surface water, depends strongly on changing the behaviour of people. Since people tend to be reluctant to change their behaviour (which usually means that they have to accept restrictions in their freedom of behaviour), it would be unrealistic to expect they will be prepared to do so merely for the sake of experimenting to learn.

Passive adaptive management, on the other hand, seems compatible with groundwater management conditions. In many parts of the world it is already practiced, although not often under this name.

4.2 Results-Based Management[5]

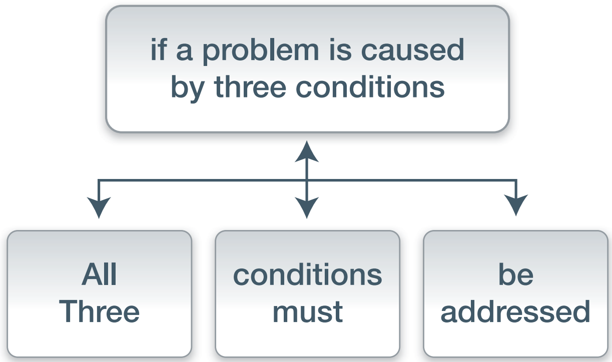
"It is said that if you do not know where you are going, any road will bring you there. This lack of direction is what Results-Based Management is supposed to avoid" (UNESCO, 2010).

Results-Based Management (RBM) is a management approach by which an organization or project ensures that its processes, products and services contribute to the achievement of clearly stated results (ITC, no date). The concept of RBM dates from the 1950s, when Peter Drucker popularized the term "management by objectives" (Drucker, 1954), based on a number of principles that are still very much in line with the RBM approach. RBM is designed to improve programme delivery and strengthen management effectiveness, efficiency and accountability. It helps in moving the focus of programming, managing and decision-making from inputs and processes to the objectives to be met. In the *programming phase* it ensures that there is a necessary and sufficient sum of interventions to achieve an expected result. During the *implementation phase,* the RBM approach helps to monitor and ensure that all available financial and human resources continue to support the intended results (UNESCO, 2010).

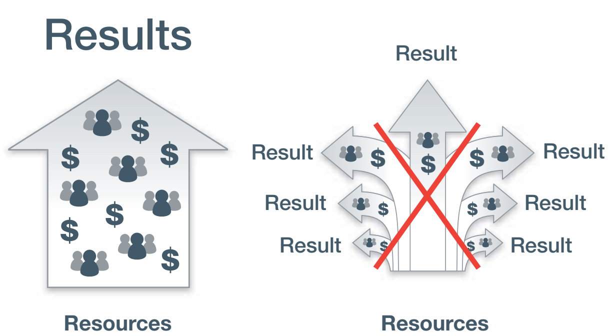
5 Introduced to the Working Group by Todd Jarvis and Alfonso Rivera at the 2nd Working Meeting in Perugia, September 2010.

Figure 3 Typical features of Results-Based Management (according to UNESCO, 2010)

A. in the programming phase



B. in the implementation phase



Documents on RBM use a language and way of thinking very similar to those of the *logical framework* approach. Since the emphasis is on achieving results, monitoring and evaluation are key requirements during the implementation phase, and should make use of relevant and cleverly designed indicators. The straightforward determinism of RBM seems to be somewhat incongruent with the uncertainty that forms the point of departure of AM. Combining the two paradigms, therefore, requires that the objects of both (not exactly identical) are carefully identified (see section 4.4).

4.3 Social-Ecological Systems Approach[6]

Natural resources management is an activity that requires a multidisciplinary approach that links systems of society and nature. Nevertheless, the different types of science components are, in practice, often not properly balanced during plan development: usually natural science components are dominant, with social sciences in a minor position or neglected. Even in projects where natural and social sciences are more or less in balance, they may still represent two parallel, non-interacting clusters of activities.

The *social-ecological systems approach* attempts to link systems of people and nature, by taking their interactions fully into account. The term emphasizes that humans must be seen as a part of, not apart from, nature; and that the delineation between social and ecological systems is artificial and arbitrary. Scholars have also used labels like "coupled human-environment systems", "ecosocial systems" and "socio-ecological systems" to illustrate the interplay between social and ecological systems. Nevertheless, separate social and natural system components may be easily recognized within a social-ecological system; and corresponding administrative, social and natural system boundaries do not usually coincide.

The social or societal system consists of people or groups of people with needs and preferences, and with different levels of access and control to various forms of capital. These actors interact socially at different scales (cooperation and conflict) and try to govern these social processes as much as possible by organizing institutions (norms, values, rules, policies, regulations, organizations).

Natural systems or ecosystems can be characterized by their material composition, processes that take place, relevant scales for each process, and linkages between elements or (sub-)systems (including nesting). The processes are often non-linear, and time-lags occur between causes and effects. The resilience of natural and social systems is a measure of how they can handle external stresses without shifting into a completely different state (regime shift), which would lead to loss of sustainability of ecosystem services (see Table 2) and/or reduced options for human development. Adaptive management may help prevent undesired regime shifts from taking place.

6 Introduced to the Working Group by Frank van Weert at the 2nd Working Meeting in Perugia, September 2010

Table 2 Overview of groundwater ecosystem services
(after Frank van Weert's presentation in Perugia, with a few modifications)

	IN TERMS OF PROVISION	REGULATING	SUPPORTING	CULTURAL
Extractive	Use in public, domestic, agricultural and industrial sectors		Spring flow, baseflow and environmental flow of river systems	Aestetics. Spiritual and cultural symbol
In-situ	Direct evapotranspiration from groundwater dependent vegetation	Volume buffering. Natural attenuation capacity	Groundwater-dependent ecosystems. Habitat for groundwater bacteria.	Existence and bequest value

4.4 Comments on AM versus RBM

In the Groundwater Working Group some debate has taken place on Adaptive Management (AM) versus Results-Based Management (RBM) as an overarching approach for GEF IW projects. Discussions and some confusion, at least initially, were triggered by the following:

- By listing one group of core questions under the heading "Application of Science for Adaptive Management" and associating another group with " in support of results-based IW projects" the suggestion is made that both paradigms apply to GEF IW projects.
- However, as mentioned before, the straightforward determinism of RBM seems to be somewhat incongruent with the uncertainty that forms the point of departure of AM.
- In addition, among GWG members there were (and probably still are) differences in interpretation of these concepts and different associations as to which objects they may refer to — projects or management processes?

The majority of opinions can be accommodated by the following overall view[7]:

- AM is dealing with uncertainty and may be adopted as a philosophy underlying *transboundary aquifer management as a continuous activity*. This implies a medium-to long-term perspective, because in the short term insufficient new information and knowledge will become available to justify new water resources management decisions overruling previous ones.
- RBM is typically designed for a *project situation*, and thus is meant to support successful and efficient performance of a project. The approach reflects in particular the control required by those who invest in a project.

In this way, the two paradigms are related to different objects: the water resources management process (AM) and individual projects (RBM), respectively. This makes them, in principle, compatible, with the projects as rather "rigid" steps embedded in a flexible long-term water resources management process.

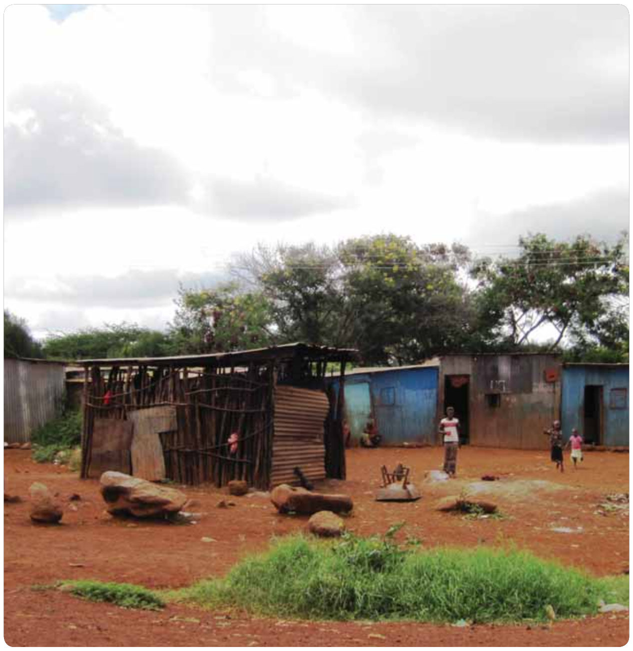
7 As far as they have expressed themselves about this, all GWG members share this view, but differences of opinion may still exist on a more detailed level (e.g. RBM only for projects or more widely applicable?).

CHAPTER FIVE

Core Questions on Critical Science Issues

5.1 Core Question A1: What are the critical science challenges "on the horizon" specific to each ecosystem type?

Shammy Puri addresses Core Question A1 by pointing to the usual compartmentalization in project financing and science regarding water. This approach is unlikely to contribute to full environmental sustainability. He refers to the 2007 policy document (Appendix 17), states that aquifers exemplify inter-linkages, and articulates the need to integrate groundwater in the global dialogue on water. In conclusion, there is a need to develop synergies within the GEF programme. In his opinion, integration of land management policies with aquifer resources management policies constitutes a most critical science challenge "on the horizon".



Sustainable use of groundwater is an important aspect facing large and small communities around the world, Northern Kenya / *A. Dansie*

5.2 Core Question A2: What is the significance of regional and global-scale drivers, e.g., climate change, in the genesis of transboundary groundwater problems?

Core Question A2 is addressed by *Jac van der Gun*. To provide a general background, he refers to the DPSIR framework as a suitable conceptual framework for analyzing the interaction of groundwater-related changes with their causes, impacts and human responses. This framework associates "drivers" with "root causes" of change, thus differentiating them from more "immediate causes" (equivalent to "pressures" in the DPSIR terminology). Elaborating on Part 1 of the WWDR3 (2009), eight categories of drivers of change are distinguished:

1. Demographic
2. Economic
3. Social
4. Science/knowledge (awareness, uncertainty, differences in perception, etc.)
5. Technological innovation
6. Policy, laws and finance
7. Climate variability and change
8. Natural and anthropogenic hazards.

The project documentation consulted suggests that the term "drivers" does not belong to the standard terminology (and methodology) of GEF IW projects. It is more common to read the word "threats", used indiscriminately both for drivers and for more immediate potential causes of change (or problems). A few projects (GIWA, Guaraní, Iullemeden) have applied causal chain analysis and then use "root causes" more or less as a synonym of "drivers". In some of the other projects, the drivers, root causes or threats are not explicitly addressed, but rather hinted at in the contextual description. Mostly these hints refer to demographic drivers or threats and more rarely to economic factors and climate change.

Absence of attention to drivers seems to affect project results negatively in several cases:

- **NWSAS:** an opportunity missed to link modelling scenarios to realistic scenarios of drivers (in particular demography, climatic variability/climate change, international trade);
- **Eastern Desert:** climate change (and related change in water demands) were apparently overlooked;
- **Nubian Sandstone Aquifer:** an action programme for integrated management of the NSAS, but the focus is still on studying the aquifer's behaviour. Drivers may broaden the project focus.

Changes related to aquifer systems, and hence transboundary aquifer problems, find their origin in drivers. Consequently, attention to drivers is crucial for all projects aiming to understand the causes of (potential) problems and to plan for their control. Although population growth and climate change are very important, the relative importance of drivers cannot be defined in a general way; they may vary from case to case.

Obviously, *drivers currently play a minor role in GEF's groundwater project portfolio. Many of the projects would benefit if their identification and analysis were included more structurally in the design.*

5.3 Core Question A3: Describe how understanding and managing multiple causality in a transboundary water context is undertaken

Alfonso Rivera addresses Core Question A3 by first exploring the concept of causality. The main assumption behind causality in transboundary aquifers (TAs) is that understanding the "root causes" of problems emerging in transboundary aquifers will help prevent or mitigate transboundary problems. Next, he explains the methodology of causal chain analysis, suggesting that problems in practice have usually multiple immediate causes and root causes.

Looking at the selected groundwater-related projects, it appears that only one GEF-project has undertaken management of multiple causality in a transboundary water context: the Global International Waters Assessment (GIWA). But even in that case, the concept was applied to surface water, not to groundwater. The Guaraní Aquifer System (GAS) project has not undertaken management of multiple causality, but made a first step toward that end in 2007 with establishment of guidelines for design of causal chains and identification of a preliminary list of the critical issues for consideration.

Rivera argues that *in an ideal setting, a causal chain would be produced by a multi-disciplinary group of specialists that would statistically examine each successive cause and study its links to the problem and to other causes; and that this approach would use far more resources and time than those generally available to GEF-Projects*. For this reason, it has been necessary to develop a relatively simple and practical analytical model for gathering information to assemble meaningful causal chains.

5.4 Core Question A4: How are variable spatial and temporal scales in IW projects accounted for?

Two people addressed Core Question A4 . *Frank van Weert* begins by calling attention to how to interpret the term "scale" (in spatial and temporal scales). Geographical scales are described by "extent" (size, area, duration, and so on), sometimes used in a relative sense (e.g., macro-, meso-, micro-); and by "grain", alternatively used to indicate "resolution" or "integration volume of each measurement". The two are related to "outer boundaries" and "inner boundaries", respectively, of the system considered. Besides spatial and temporal, other types of scales can be distinguished, such as functional scales and sociological scales. *A mismatch of relevant scales of social organization and environmental variation creates problems, which is the rationale behind transboundary water management.* Furthermore, multiple scale levels have to be considered in managing natural resources and socio-environmental systems, among others, to provide a level playing field for the parties involved.

In the set of projects reviewed in the Synopsis Report, use of spatial scales was mentioned for the GIWA, GAS and Iullemeden projects. It is not clear whether this scarcity of reference is due to limited information on the projects or limited attention by the projects to variable and temporal scales. The latter seems to prevail in traditional "engineering approaches" in water management, as opposed to what occurs in the realm of non-technical scientific research (especially on socio-ecological systems).

Han Zeisheng presents a rather different interpretation of the core question. With regard to spatial scale, he observes that all transboundary aquifers considered are larger than 10,000 km2 and that the distribution of the 11 selected projects is not balanced over the continents: six are in Africa, one each in South America, Europe and Asia, and the remaining two are global projects. In relation to temporal scales, he remarks that six of the projects have/had a duration of more than five years, whereas the other five are shorter (perhaps partly due to not having been finalized yet?)

5.5 Core Question A5: What approaches were used to understand/ assess the coupling of social and ecological systems?

Core Question A5 is addressed by *Fabrice Renaud*. He states that social and ecological systems are intrinsically connected and that in order for a project to have a long-term sustained impact on the ground, the interactions between social and ecological systems must be well understood, as must be all feedback mechanisms between these two systems, across various spatial and temporal scales.

Examining the project reviews in the Synopsis Report and, in more detail, the Iullemeden project documents, he concludes that there is a lack of consideration of social sciences in most of the GEF projects, with a much stronger focus on natural sciences. And, if social aspects were considered, it is often in a narrow sense, e.g., linked to potential harmful activities. Furthermore, social and ecological systems were not considered as coupled systems in most projects. Only three projects (MSLME, SADC, Guaraní) seem to have considered, in one way or another, the coupling of social and ecological systems explicitly; however, the exact nature of the frameworks used for this process is not apparent from the Synopsis Report.

It is important to note that understanding complex coupled systems cannot be achieved simply by having one component on social sciences and one on natural sciences running in parallel, but rather by planning the interactions between the two at project design in order to enable capturing the "coupling" itself and all the feedback loops at play at various temporal and spatial scales. The ecosystem approach, as reviewed in the Synopsis Report could serve as one useful tool/framework for this process.

5.6 Core Question A6: What scientific knowledge is available and/or used to evaluate trade-offs between the response options developed by IW projects?

Core Question A6 was not explicitly addressed. Nevertheless, it seems that the question refers to situations where alternative management measures or strategies have been developed and need to be compared. Probably none of the reviewed projects has reached that stage yet.

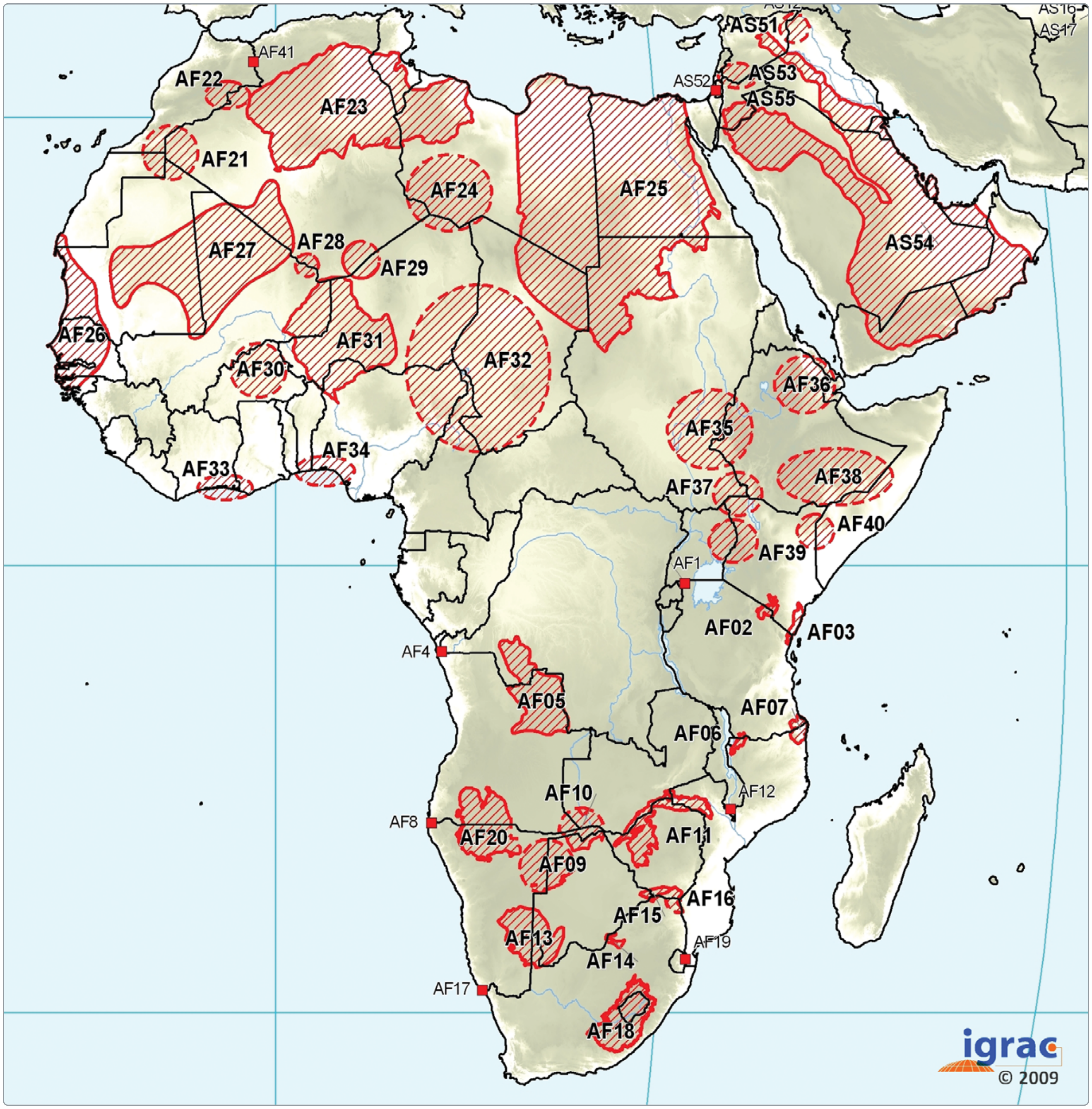


Figure 4 Transboundary Aquifers of Africa Map

The figure depicts African transboundary aquifers based on information provided by various organisations and projects dealing with transboundary aquifer assessment and / or management and compiled by IGRAC in 2009. For a comprehensive explanation of this map, please refer to the figure caption on the back inside-cover p. 32).

CHAPTER SIX

Core Questions on Application of Science for Adaptive Management

6.1 Core Question B1: Was engagement of both local and wider science communities utilised in IW projects? If not, how can improvements be made?

In addressing Core Question B1, *Ofelia Tujchneide*r states that with regard to GEF's transboundary aquifer projects there is in general good engagement of both local and wider science communities. Experiences during the preparation of the Guaraní and La Plata projects show enthusiastic collaboration between both types of science communities. This type of co-operation in an early stage contributes to a more comprehensive project design, ensuring a multi-disciplinary framework for linking results with a holistic way. A weaker point of current practice is the *insufficient acknowledgment of the work done by local knowledge experts*. More attention to this can be easily paid: e.g., by mentioning the role and inputs of the local community explicitly in the final reports of the projects.

6.2 Core Question B2: Is science expertise and local knowledge well applied within the IW focal area, particularly in accessing existing baseline information, new findings on methodologies, science breakthroughs and scanning for emerging issues?

Core Question B2 is closely related to the previous one. *Andrea Merla* emphasizes the importance of establishing the GEF Council in 1996, representing one of the major international accomplishments in the water sector after the Rio Conference. Stakeholder involvement (including the local science community) and the use of sound science and proven technical innovations are among the basic principles adopted by this organization for water sector projects, while a science-based Transboundary Diagnostic Analysis (TDA) is included in GEF's methodology.

GEF's first project in the water sector (Eastern Desert of Egypt) was based largely on the work of Egyptian experts. This project remains one of the best examples of the use of science, particularly local science, to solve water related issues. Furthermore, the majority of the TDAs and other scientific work of the Guaraní, NWSAS and Iullemeden projects was done by local scientists. In the case of NWSAS and Iullemeden, these scientists worked under a regional entity, which allowed full engagement of experts from national bodies and academia. The Guaraní project, on the other hand, was entrusted mainly to private sector companies, to encourage quality control and quick delivery of outputs, but had a less suitable modality to include national stakeholders, including scientists. Another project to note here is the SADC Groundwater and Drought Management Project that entrusted all scientific and technical work to local experts and entities. The results of all these mentioned projects have greatly benefited from local scientists, who contributed not only in the identification and provision of basic data, but also in the conduct of the scientific work.

Unreliable access to safe surface water places increased reliance on groundwater resources / *A. Dansie*

6.3 Core Question B3: Identify lessons learned for linking science and management, including policy formulation and broader governance issues.

Two contributions were received on Core Question B3: from *Stefano Burchi* and *Mark Zeitoun*.

Stefano Burchi's contribution focuses on linking science with formulation of legally binding arrangements in the transboundary groundwater context. Only three of the selected projects have a clearly discernable legal/institutional component and deliverable: Guaraní project, NWSAS project and the Iullemeden project. The former two projects currently have signed agreements (signed in August 2010 and mid-2008, respectively), while a draft agreement for Iullemeden has been endorsed in 2009, with one unresolved issue still pending. The SADC and NSAS projects only allude to such a legal/institutional component.

In the three agreements (Guaraní, NWSAS and Iullemeden), science appears to be seen as both a trigger and effect of institutionalized cooperation. Probably a GEF project stands more chances of achieving formal agreement and institutional arrangements among the countries concerned by a transboundary water system if it steps in at a sufficiently mature stage of pre-existing cooperation on-going at the technical level, i.e., after a scientific base – if only preliminary – has been generated.

Mark Zeitoun pays attention to the question how socio-political economy enables, or disables, the uptake of science into policy for international transboundary waters. The relations between riparian countries greatly influence the uptake, and important factors to consider in this respect are:

- Relations at the broader political level (are these good, or poor?)
- History of sharing (including customary arrangements)
- Interests (i.e., economic or political incentives to "see" the merits of science)
- Power (does the hegemony lead or coerce?)
- Power relations (extreme or minor? Challenged by leveling players or the playing field? Are the interests of hegemony met?)

He notes that the template used to populate the database disallows collection of this type of information. He suggests the above factors be used as proxy indicators to be captured in future projects, leading perhaps to a characterization of "governance interaction".

He endorses *Bo Appelgren*'s statement that "not all GEF groundwater projects address socio-economic aspects ....and that an immediate opportunity for institutional, economic and economic governance sciences is to define the scope for economic management and governance interaction in the approximately 200 internationally shared aquifers identified under the ISARM program".

Drilling with hammer in basalts, Guarani Aquifer System in Uruguay / *O.Tujchneider*

6.4 Core Question B4: Is adaptive management happening? How to better understand and effectively communicate the role of science in adaptive management to different groundwater user groups.

According to *Greg Christelis*, co-operation between countries on jointly locating and investigating transboundary groundwater systems, actively involving the appropriate stakeholders, is very important for effective management of the shared groundwater resources. Scientific components of projects should be designed to meet the needs of different stakeholders involved in integrated water resources management.

Parties involved in transboundary groundwater resources projects should communicate and agree on the project objectives, the enabling environment, the stakeholders involved, the scientific information required, the technologies that can be applied, the legal and institutional frameworks, and a strategy for implementation. Science, including conceptual models and joint monitoring activities, may be very effective in communication. For implementation, the Water Authorities should encourage the creation of a Water Management Body, with representation of local stakeholders in a Council and an Executive Committee. If a River Basin Organization (RBO) does exist, then it is preferred to integrate the joint management of TBAs within such institutions, with a special Transboundary Aquifer Task Team.

In the set of selected groundwater projects, mechanisms for understanding and effectively communicating the role of science in the adaptive management to different groundwater user groups include the following:

- Enhancing public and stakeholder participation, social communication and environmental education (Guaraní)
- Expanding/consolidating the scientific and technical knowledge on the aquifer system (Guaraní, NWSAS, Eastern Desert, NSAS, ISARM, Mediterranean)
- Awareness raising on groundwater risks, potential impacts and managing groundwater (Guaraní, SADC, GIWA, TBA Asia/Amur)
- Identification of major transboundary risks (Iullemeden, NWSAS, Mediterranean)
- Formulation of a joint risk mitigation and sharing policy (Iullemeden)
- Establishment of a joint legal and institutional consultative mechanism (Iullemeden, NWSAS, NSAS)
- Identification of mitigating measures (NWSAS, SADC)
- Establishing a centre for knowledge management (SADC)
- Web-based information system (Eastern Desert)
- Design of holistic transboundary water approaches and appropriate assessment protocols (GIWA).

In conclusion, it is argued that it would be worthwhile to focus less on “science” and more on “science communication”. Engagement of national stakeholders, social communication and environmental education may significantly contribute to developing a relevant profile for groundwater management. A regional groundwater management institute may also serve as an important vehicle toward effectively communicating the role of science in adaptive management to different groundwater user groups.

Shibam town overlying the alluvial aquifer of Wadi Hadramawt

6.5 Core Question B5: How to better communicate newly-synthesized science knowledge to stakeholders within and external to GEF?

UN Photo

Addressing Core Question B5, *Todd Jarvis* starts by presenting some interesting views on communicating knowledge in general and groundwater in particular. He states that the importance of effective communication in science focuses on negotiating "mental models", reducing conflict, and moving towards collective thinking and action as "there can be no negotiation without communication" (Fisher et al., 2001). Communication in the earth sciences clearly has to extend beyond the limits of its own academic discipline. Groundwater specialists will have to explain to a broader audience "why groundwater is central to the well-being of world populations". Complications are that education about groundwater is not a priority in most cultures and countries, and, secondly, that the interests and options in the communication and negotiation over water are not easily defined without the assistance of specialists who can interpret causal chains. Thus, science remains at the core of communication regarding groundwater.

Besides communication within the GEF framework by submitting of reports, the selected projects have used a wide range of other methods for communicating science knowledge beyond GEF:

- Web pages (most of the projects)
- Conferences/ workshops
- Journalism
- Public participation
- Schools/universities
- Video
- Social networking (topical blogs)

The Guaraní project has communicated science most actively, using the greatest variety of methods. GIWA, SADC, Eastern Desert and Iullemeden are/have also been using a variety of communication methods.

Conclusions: Changing existing approaches to communication of groundwater science certainly disrupts the status quo, but consideration of concepts "outside the current paradigm" is essential, given the wide range of stakeholders and the extent of ensuing negotiations over newly-synthesized information regarding hidden groundwater resources. Discipline-based solutions in groundwater hydrology are still important but must be tempered by the problem-based approach through multiple forms of communication given that each stakeholder learns a little differently than the other. Cultural competency is vital when communicating groundwater issues given the resource is considered both a commodity and a culturally significant resource. The investment in time to ensure that science-based information is understood by the various stakeholders is offset by the reduction of time needed for dealing with conflict and for building trust in the value of groundwater science and scientists.

A. Dansie

CHAPTER SEVEN

Core Questions on Development and Use of Indicators to Support Results-Based IW Projects

7.1 Core Question C1: How did the projects help build and implement sound indicators and monitoring strategies to support SAP implementation and/or ultimately assess the achievement of environmental and social benefits?

Addressing Core Question C1, *Julio Kettelhut* begins by making a distinction between indicators of the current situation (aquifer characteristics, socio-economic, legal, institutional and environmental aspects) and post-project indicators (for future assessments of achievements and impacts of management action). The former are applied in all projects (assessment of current conditions), the latter (for assessment of management impacts and other changes in the future) are virtually absent in the reviewed projects. Several projects include forecasting, but forecasts of socio-economics, legal, institutional and environmental aspects have very little detail. Predictability of actions that occur after completion of the project is limited, given that GEF financial and organizational resources are no longer available.

Nevertheless, in several projects (e.g. Guaraní, SADC) there are elements that could facilitate future monitoring in the post-project phase: e.g., agreed common indicators for a first baseline assessment, protocols and manuals developed in consensus, proposed institutional structures that allocate post-project activities among the countries involved.

A major concern is to establish a joint systematic post-project monitoring system for transboundary aquifers. Major challenges related to this include:

- Finding a sustainable financial basis for the continued activities;
- Defining and agreeing upon the monitoring plan (variables, quality, operational and institutional aspects, etc.);
- Interfacing with surface water and ecosystem monitoring;
- Mitigating impact on the monitoring programme of different implementation paces for technical, institutional and political achievements; and
- In large transboundary aquifers, focusing the monitoring programme on priority zones in order to achieve cost-effective monitoring.

7.2 Core Question C2: How can we identify effective proxy indicators for use in IW projects?

Core Question C2 is addressed by *Frank van Weert*. He begins by defining indicators (“can reveal relative changes as a function of time”) and proxy indicators (“not in itself of any great interest, but from which a variable of interest can be derived”), and lists a number of criteria for “effectiveness”. These criteria include: acceptance by society, ability to show causality and/or to include long-time horizons, reproducibility and scientific rigour, and communicative potential.

Almost all the project plans of the projects reviewed contain reference to the GEF IW monitoring and evaluation principles and to the use of process, stress reduction and environmental status indicators. Proxy data are used in cases where “hard data” (e.g. on total groundwater abstraction) are missing (NWSAS, Iullemeden). The impact indicators of GIWA and the social welfare indicators of the Guaraní and SADC projects are mentioned as well, but the use of proxy indicators in other projects remains unclear.

The use of effective proxy indicators in the GEF IW: Groundwater projects is relatively limited, and most projects have a strong hydrogeological focus. Communication of results to a wider audience – for which clearly understandable indicators might be helpful – seems to be limited.

7.3 Core Question C3: How to make better use of appropriate science and best practices for Transboundary Diagnostic Analysis

Bo Appelgren addresses Core Question C3 and refers to a focused use of science in support of GEF-IW's TDA-SAP approach. TDAs have been completed for two of the selected groundwater-related projects only (Guaraní, Iullemeden), and two other TDAs are expected to be implemented under ongoing projects (NSAS, Mediterranean).

The TDA of the Guaraní project covers a comprehensive range of aspects and reflects the involvement of hydrogeologists, engineers and water lawyers. The TDA will be revisited and adjusted for alternative options, with economic institutions and instruments to manage and control groundwater pollution and support and promote social uses and priorities to protect drinking water supplies.

The TDA for Iullemeden is focused on data collection, for hydrogeological knowledge and assessment and mathematical modelling of the aquifer system. The three main transboundary issues are (i) critical supply-demand water balance in specific sub-areas, (ii) groundwater-related land degradation, and (iii) threat of climatic change and variability. The Iullemeden (IAS) TDA formulation was carried out predominantly by water resources scientists, hydrogeologists and public administration experts, with participation and guidance of legal professionals.

Principles for the IW TDA-SAP process include:

- full participation,
- ecosystem approach: adaptive and pragmatic,
- operational management,
- decentralized and multi-sectoral management,
- outward vision economic consideration, inter-sectoral policy building, and
- government commitment.

Key steps for TDA formulation are:

- project idea and concept,
- joint fact-finding,
- transboundary issues with socio-economic consequences,
- inventory causal chain analysis of institutions, laws, policies and projected investments.

The principles and steps under the TDA-SAP process have diverse requirements and opportunities for the use of science: natural science with natural and economic geography; hydrogeology; economic sciences with economic governance; legal and administrative sciences; and stakeholder involvement with social and political sciences. As formulated in Appendix 15: "It is evident that in spite of the principles and the recognized generic road map the IW-aquifer TDAs show a wide variety in scope and outcomes, and where the interventions of different science sectors with hard natural science and social and political sciences would balance individual TDAs for inclusiveness and uniformity." Furthermore, it is suggested that emerging problems will require alternative and new solutions, less bias toward "hard science", and inclusion of new social and economic science in the TDA process.

CHAPTER EIGHT

Conclusions

8.1 General conclusions

GEF IW groundwater-related projects have produced and are producing valuable scientific outputs

Science is a major component of the GEF IW groundwater portfolio, particularly the science of hydrogeology. Scientific components are sound, and almost all projects make systematic use of local scientific expertise and human resources. The science in the GEF IW groundwater projects belongs to the category *applied science*, aimed at producing useful models of reality in the project areas.

Projects vary considerably in objectives, scope and approach

Significant variation is evident in the objectives and available resources of the reviewed projects, and thus also in their scope and approach. Projects should not be seen, therefore, as area-specific realizations of one single *standard project type* for which an *optimal* scope and approach would exist.

Relevant project documentation, particularly scientific outputs, should be made accessible and disseminated effectively to enhance learning from GEF IW groundwater projects

A few projects in the groundwater portfolio (notably GIWA and the Guaraní project) have made huge efforts to disseminate project results and make technical/scientific project reports publicly available. Not only does help realize the envisioned impacts in the project target area, it also enables other projects to replicate useful methodological components and approaches. For some of the completed projects, however, an adequate set of technical-scientific project reports appeared to be either non-existent or non-accessible. This undermines the credibility and impact of the scientific conclusions of the project and certainly precludes learning.

8.2 On critical science issues[8]

Transboundary groundwater resources management is not an isolated policy field, but compartmentalization of projects and their financing is still common practice

Groundwater is interwoven with other components of the physical environment (e.g., surface water, land use, ecosystems) and with socio-economic development. Except for projects with a very specific, narrow objective (e.g., the Eastern Desert of Egypt project: assessing groundwater renewal), most groundwater-related projects of GEF's IW portfolio would probably have benefited from adoption of a holistic approach in which the interdependency of different policy fields was taken into account during the design phase.

Knowledge of relevant drivers of change and their inter-linkages is required for understanding and predicting change in the water resources conditions

In several of the reviewed projects (e.g. GIWA, Guaraní, IAS) drivers or *root causes of change* are explicitly addressed, using the causal chain analysis methodology. In some other projects, there may be implicit assumptions about drivers, but failure to present them explicitly reduces the potential for scientific explanation of phenomena and for convincing predictions of the future (e.g. NWSAS project). Attention for multiple-causality, both at the level of root causes and more direct

8 There is a common denominator in the majority of comments produced on critical science issues. With exception of some projects with a very specific limited purpose, the projects tend to have a more limited scope than desired for optimal project impact

causes, was not observed in the reviewed projects. It is surprising that climate change as a driver of change is absent in the majority of the reviewed projects.

There is scope for improving the balance between natural and social science components in the projects, as well as their coupled analysis

Natural science, in particular hydrogeology, is the dominant science component in most of the transboundary aquifer projects in GEF's IW portfolio. Social science components are under-represented (specially in the older projects), and social science-related activities, if present, are often carried out in parallel to natural science activities instead of being integrated with them. None of the reviewed projects addresses social-ecological systems, which is a new paradigm for most hydrogeologists and engineers. Economists and other social scientists are becoming more prominently involved in discussions of groundwater resources management.

Projects pay little or no attention to scale considerations

Physical, social, economic and political processes occur at different scales, from local to supra-national scales. Each one should be analyzed at the appropriate scale level, sometimes at multiple scales. Mismatch of scales versus objectives may reduce the usefulness of project results considerably.

Large transboundary aquifers may require different approaches for monitoring and modelling

Often, information is not available for entire aquifers, only for certain areas, and usually it is not feasible to collect complete information for very large aquifers. Because of this scarcity of data, activities such as modelling the entire aquifer can easily produce results that are unreliable or inaccurate at the local level. The same is true for other types of aquifer-wide analysis.

8.3 On generating and using science for underpinning management policies/strategies[9]

Adaptive management, motivated by and reflecting uncertainty, allows action to be taken in spite of missing information and knowledge. There are limits, however, to the applicability of adaptive management to transboundary aquifer management

These limits are explained by considering the commonly made distinction between *passive* and *active* adaptive management. *Passive adaptive management* – which basically means periodic plan adjustment on the basis of progressively acquired information and knowledge – seems perfectly applicable to transboundary aquifer management, and is common practice already in some parts of the world. However, *active adaptive management* – which includes learning as a main objective and consequently is experimenting with interventions – may be an attractive philosophy but is less suitable for aquifer management in practice, due to the inertia of groundwater systems and to people's unwillingness to change behaviour.

A well-balanced involvement of local science communities and wider science communities is evident in the majority of the projects, usually to good effect.

Stakeholder involvement, including that of local science

9 Modified heading, replacing "On the application of science for adaptive management", in an attempt to reflect better the commented issues.

communities, along with use of sound science and proven technical innovations are among the basic principles adopted for GEF's water sector projects. In practice, most projects strongly rely on local science communities, usually under responsibility of a regional entity. They contribute not only to identification and provision of data, but also to the conduct of scientific work. Except in projects entrusted mainly to the private sector (e.g. Guaraní), the local science community is part of the national stakeholder community, which contributes to strengthening capacity and a sense of ownership. There is scope for improving acknowledgement of the role of local science communities.

Methodological innovation is produced

Transboundary Diagnostic Analysis (TDA) and Strategic Action Programme (SAP) are science-supported methodologies, enhanced and replicated within the IW project portfolio. In some cases other innovative approaches have been successfully tested (e.g., Eastern Desert of Egypt), and experiences and methods that could be shared for replication have been identified (see IW:Science Groundwater Synopsis Report).

Science can be seen as both a trigger and an outcome of institutionalized cooperation

GEF-instigated or pre-existing collaboration among scientists of TBA countries has been a trigger of institutionalized cooperation when the political level has been engaged. This has been achieved either through TDA and SAP processes, or it existed prior to GEF intervention. Frameworks for permanent cooperation (governance) favour development of scientific activities in co-operating countries.

The transition from science to policy depends on many factors

GEF's IW projects – if properly designed and implemented – may help trigger the transition from science to policy, but many external factors also play a role. These include political relations, history of sharing, interests of each country, and economy and power (style and relations). The example of the recent agreement over the Guaraní shows how such factors can either be overcome or employed to encourage the uptake of science. The project reviews suggest that GEF's IW projects may play an important role here: for example by producing knowledge (e.g., on risks and opportunities); by enhancing stakeholder involvement and other activities that create a spirit of ownership and co-operation; by awareness raising and public information services; by developing consultative or co-operation mechanisms; by jointly conducting TDA; and by formulating joint policies (in the form of SAP or other methods). The hypothesis remains untested, however, and the objectives of several of the reviewed projects are such that the envisaged scientific outputs cannot be linked directly to policy.

Communication is important in transboundary aquifer projects and may take many forms

Without communication, the results of scientific investigations will not become widely known, and thus will have no impact. Communication of science knowledge has historically relied on approaches such as technical reports and articles, but may expand to methods such as increased use of web-based topical blogs, documentary film, science journalism, and open-access journals, as employed by the Guarani Aquifer project. In several of the reviewed projects, communication or media plans are not evident.

8.4 On projects aiming for the transition from science to management[10]

In general, little attention is paid to what will or should happen after the end of project implementation

Post-project activities have no more financial support from GEF, and, without financial resources, no follow-up activities are possible. Often, this issue is not considered until the end of the project rather than being discussed at the project's outset. It is very important that monitoring be continued beyond the lifetime of the project, since most project outcomes and impacts will only then become available or observable. This again requires budgetary provisions to be made early on in the process.

10 Modified heading, replacing "On the development and use of indicators to support results-based IW projects", in an attempt to reflect better the commented issues.

TDA may help a focused use of science but proper balance of disciplines is required

TDA has been carried out for only two of the reviewed set of projects: Guaraní and IAS. For two other ongoing projects it is expected to be implemented (NSAS, Mediterranean). So far, natural science aspects are dominant, while socio-economic components are scarce or missing.

Apparently there is not, as yet, a comprehensive methodology or guideline on indicators for IW projects

This conclusion is suggested by the analysis of the projects.

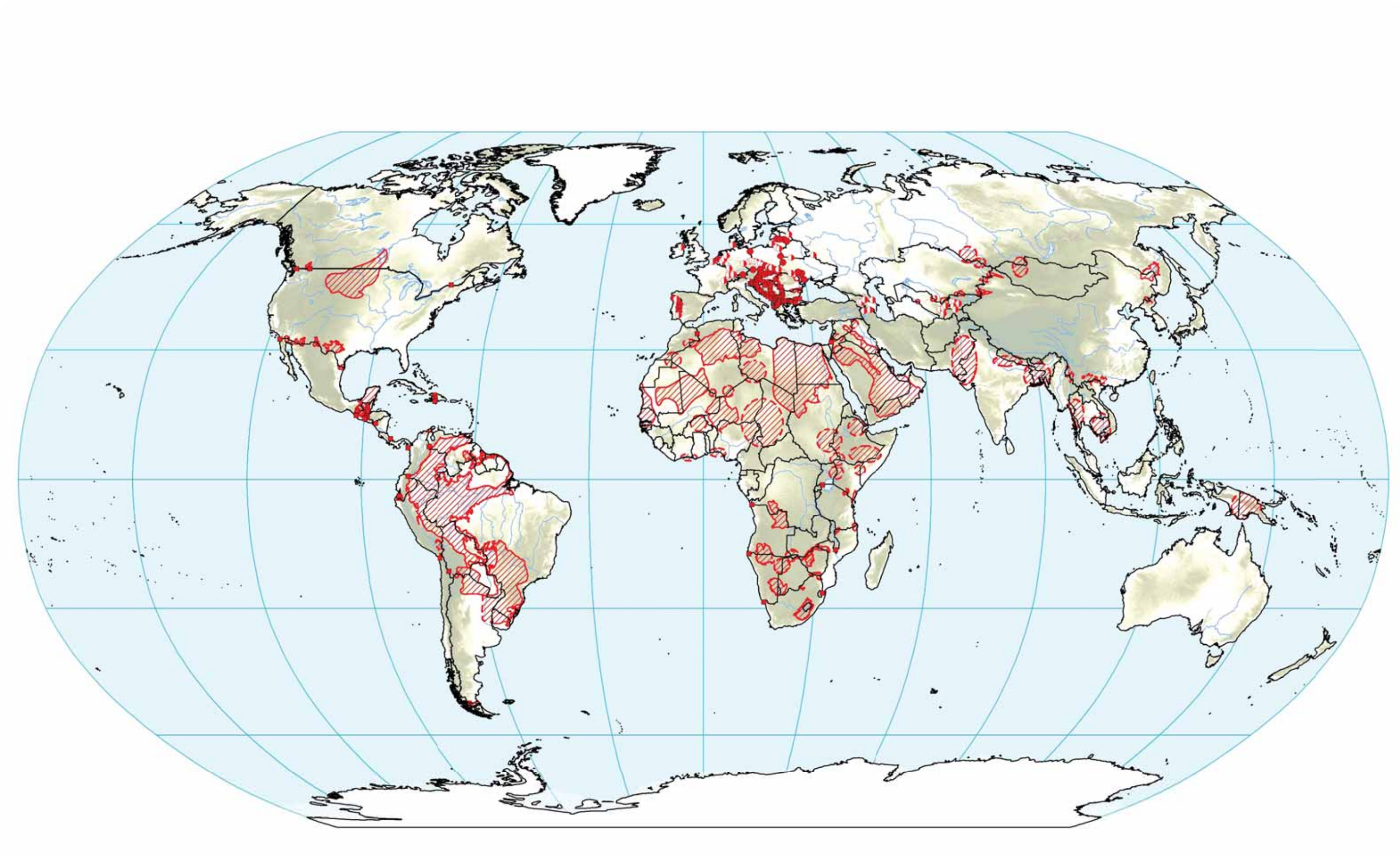


Figure 5 Transboundary Aquifers of the World

Information on transboundary aquifers as was known in 2009. The information is provided by various organisations and projects dealing with transboundary aquifer assessment and /or IGRAC compiled the available information in this TBA map based on the guiding principle to stay as close as possible to the information provided by the original sources, while presenting the information as appropriately as possible for the originally chosen scale of the map (1:50,000,000). The TBA map shows aquifer extent (if known), for aquifers with an area larger than 6,000 km2. Smaller aquifers are represented with squares. If the exact aquifer boundaries are known and acknowledged by all sharing countries, they are delineated with solid red lines. If not, they are delineated with dashed red lines. Small (filled or half-filled) circled are used to depict aquifers whose extent is not known. A filled circle represents an aquifer whose occurrence is confirmed by all countries involved; if an aquifer is not recognized by all countries, it is depicted by a half-filled circle.

CHAPTER NINE

Recommendations

9.1 General

- Special provisions are needed to ensure all projects report duly and in sufficient detail on the scientific outcomes of their activities and that reports are properly disseminated, shared and made permanently accessible to the scientific community. Ensuring permanent accessibility requires special arrangements external to the projects, since projects have no permanent repository or portals for scientific outputs.

- The GW group supports the knowledge management approach developed in IW:Science, including expansion of a central database repository. Document capture, categorization and storage should be an inherent aspect of all projects, ensuring quick access to documents of interest.

9.2 On critical science issues

- A holistic perspective should be adopted when designing new projects on transboundary aquifers. Depending on the project objectives, inter-linkages with related policy fields (such as land use management) should be adequately taken into account.

- Systematic identification and analysis of relevant drivers of change should be included as a standard component of all projects that investigate possible futures or strategies for management and control. Causal chain analysis is a useful methodology to handle this and to assess the related issue of multiple causality.

- Project designs should aim for a balance between natural science and social science components and reflect their coupled nature by adopting the social-ecological systems approach. This approach places the more classical hydrogeological approach in a wider context of a trans-disciplinary assessment and management of TBAs, and thus may require a different project design and execution than seen so far.

- Multiple dimensions of biophysical, social, economic and political processes need to be considered and captured in the framework of analysis.

- In large transboundary aquifers, analysis and management actions should be concentrated in a priority area in order to achieve cost effectiveness and to facilitate governance.

- Model studies should include proper model calibration and a mechanism for critique of the uncertainty in predictions to ensure quality control and data reliability.

9.3 On generating and using science for underpinning management policies/strategies [11]

- Relations between local and international science staff should be properly discussed and defined during the preparation stage of the projects, including giving due recognition to the contributions of all parties.

- Project design and inception should include effective science communication and wide dissemination of results to user groups and project stakeholders.

11 Modified heading, replacing "On the application of science for adaptive management", in an attempt to reflect better the commented issues.

- Media plans should be required for all GEF IW projects to enhance communication and enable learning. GEF should support publication in open-access journals that can be accessed by stakeholders and scientists in disadvantaged countries.

9.4 On projects aiming for the transition from science to management[12]

- GEF project designs should include an arrangement for permanent post-project cooperation as one of the project goals, grounded on the political support to be obtained through the TDA/SAP processes and facilitated by collaboration amongst scientists from the TBA countries. Financial and other operational aspects of SAP implementation and post-project monitoring should be discussed and planned from the beginning of any project.

- For the short term (individual projects), results-based management rather than adaptive management would be a preferred approach. A methodology specifying the required set of indicators should be developed. These indicators primarily measure the extent to which project outputs have been or are being achieved.

- A different set of indicators are needed to improve understanding, analysis and policy on transboundary groundwater systems, science and cooperation. Such indicators are being developed in the framework of the TWAP project[13].

- Science needs to be supported, planned and integrated during the entire project cycle, starting at first identification for project formulation and continuing through successive stages, including the entire implementation stage.

- In relation to social aspects, more attention must be focused on achieving a shared vision between the states for successful management of transboundary aquifer systems.

A.Dansie

12 Modified heading, replacing "On the development and use of indicators to support results-based IW projects", in an attempt to reflect better the commented issues.

13 Tranboundary Waters Assessment Programme, initiated in 2009 (design phase) and intended to support GEF's IW projects portfolio.

CHAPTER TEN

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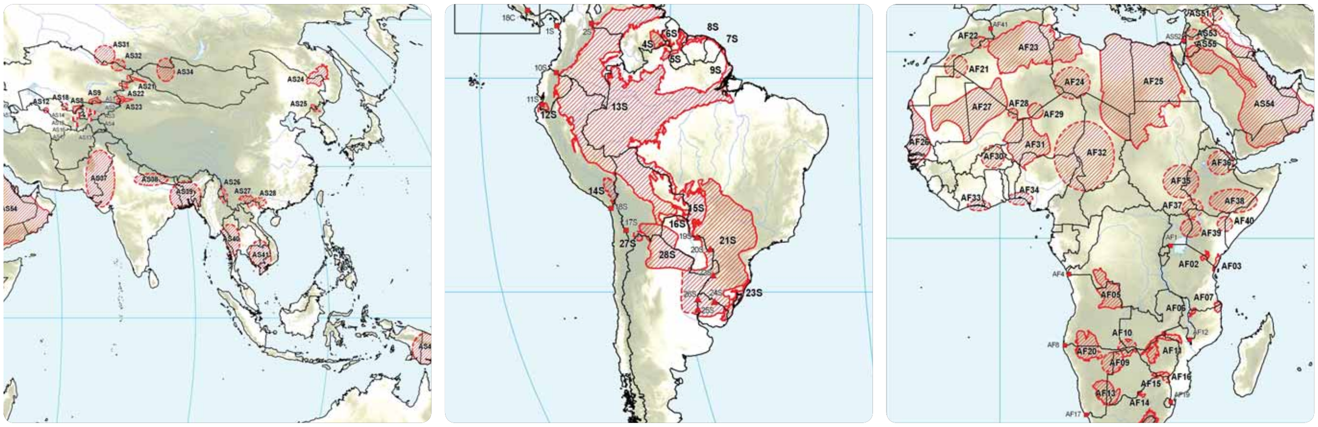

Transboundary Aquifer (TBA) maps provided by IGRAC: The map fragments presented in this report bring together information on transboundary aquifers as was known in 2009. The information was provided by various organisations and projects dealing with transboundary aquifer assessment and /or IGRAC compiled the available information in this TBA map based on the guiding principle to stay as close as possible to the information provided by the original sources, while presenting the information as appropriately as possible for the originally chosen scale of the map (1:50,000,000). The TBA map shows aquifer extent (if known), for aquifers with an area larger than 6,000 km2. Smaller aquifers are represented with squares. If the exact aquifer boundaries are known and acknowledged by all sharing countries, they are delineated with solid red lines. If not, they are delineated with dashed red lines. Small (filled or half-filled) circled are used to depict aquifers whose extent is not known. A filled circle represents an aquifer whose occurrence is confirmed by all countries involved; if an aquifer is not recognized by all countries, it is depicted by a half-filled circle.

IW:Science

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