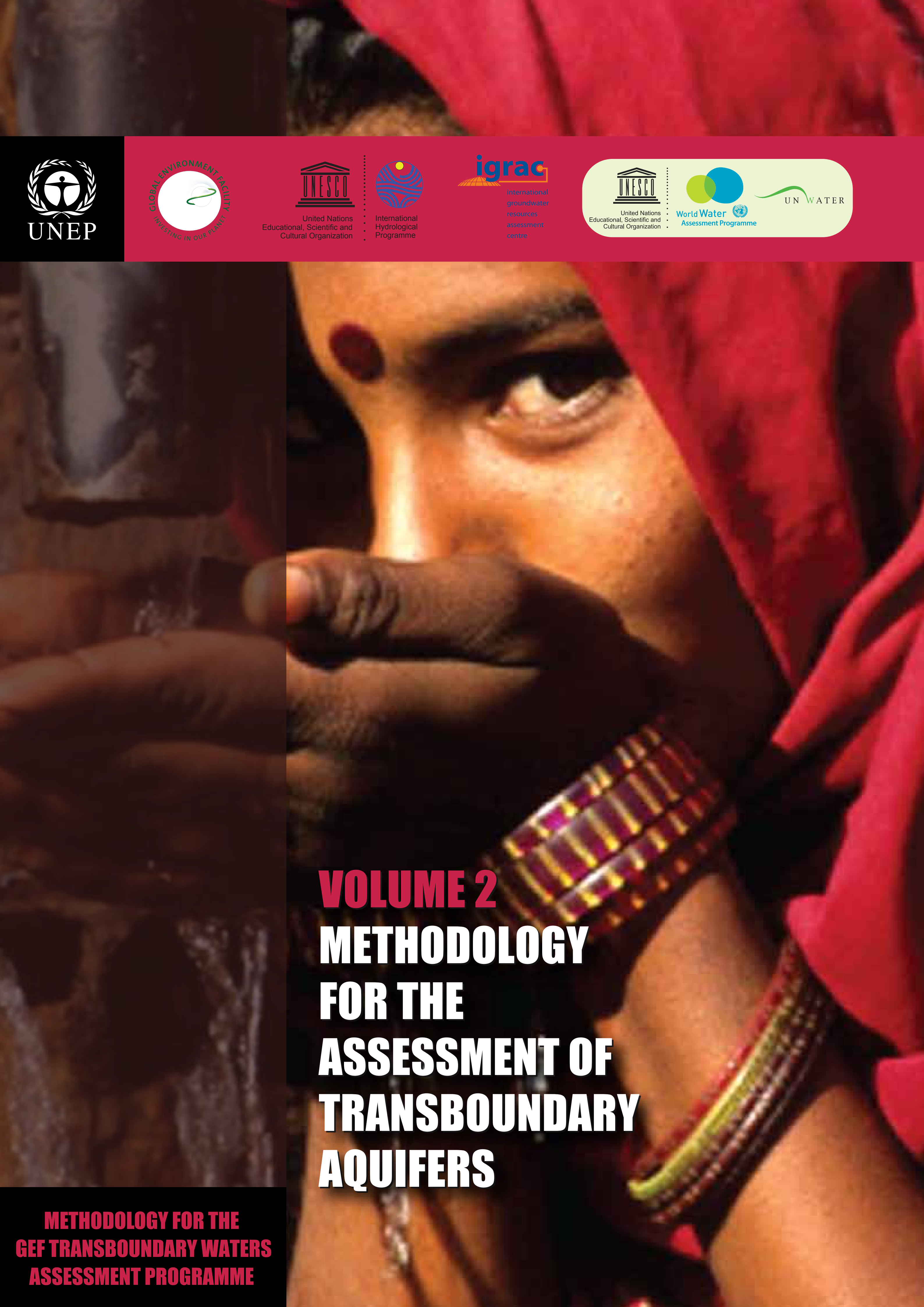

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# VOLUME 2
# METHODOLOGY FOR THE ASSESSMENT OF TRANSBOUNDARY AQUIFERS

METHODOLOGY FOR THE GEF TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

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# METHODOLOGY FOR THE GEF TRANSBOUNDARY WATERS ASSESSMENT

## VOLUME 2

## METHODOLOGY FOR THE ASSESSMENT OF

# TRANSBOUNDARY AQUIFERS

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# PREFACE

The GEF Medium Size Project (MSP) *Development of the Methodology and Arrangements for the GEF Transboundary Waters Assessment Programme,* approved in January 2009, was envisioned as a partnership among existing programmes, which was considered to be more cost effective than the conduct of an independent data and information gathering exercise. The Project Objective was to develop the methodologies for conducting a global assessment of transboundary waters for GEF purposes and to catalyse a partnership and arrangements for conducting such a global assessment.

This Project has been implemented by UNEP as Implementing Agency, UNEP Division of Early Warning and Assessment (DEWA) as Executing Agency, and the following lead agencies for each of the water systems: the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) for transboundary aquifers including aquifers in small island developing states (SIDS); the International Lake Environment Committee (ILEC) for lake basins; UNEP-DHI Centre for Water and Environment (UNEP-DHI) for river basins; and Intergovernmental Oceanographic Commission (IOC) of UNESCO for LMEs and the open ocean.

This Project resulted in developed methodologies for the following five transboundary water systems: (i) groundwater aquifers; (ii) lake/reservoir basins; (iii) river basins; (iv) large marine ecosystems; and (v) open oceans.

The results of this Project are presented in the TWAP MSP Publication, *Methodology for the GEF Transboundary Waters Assessment Programme*, which consists of the following six volumes:

- *Volume 1 – Methodology for the Assessment of Transboundary Aquifers, Lake Basins, River Basins, Large Marine Ecosystems, and the Open Ocean;*
- *Volume 2 – Methodology for the Assessment of Transboundary Aquifers;*
- *Volume 3 – Methodology for the Assessment of Transboundary Lake Basins;*
- *Volume 4 – Methodology for the Assessment of Transboundary River Basins;*
- *Volume 5 – Methodology for the Assessment of Large Marine Ecosystems; and*
- *Volume 6 – Methodology for the Assessment of the Open Ocean.*

Volume 1 is a summary of the detailed methodologies described in volumes 2 – 6. At the back cover of volume 1 is attached a DVD that contains electronic version of all six volumes.

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# SUMMARY FOR DECISION MAKERS

## OBJECTIVES

The objectives of the Groundwater component of TWAP are: (i) to provide a description of the current conditions of transboundary aquifers (TBA) and aquifers in Small Island Developing States (SIDS) that will enable the GEF IW Focal Area to determine priority aquifers/regions for resource allocation; (ii) to estimate how key conditions may change over the next 15-20 years; and (iii) to bring the major issues, concerns and hotspots of these transboundary aquifer systems and SIDS aquifers to global attention, and catalyse action.

It is expected that the TWAP Groundwater methodology and assessment will help the GEF and other potential clients to find answers to, among others, the following questions:

(i) What human and ecosystem uses of groundwater resources are currently affected or impaired (use conflicts, depletion, degradation)?;

(ii) How will water conditions and uses develop during the coming decades (15-20 year projection or outlook)? Global change is likely to produce increased pressures such as higher water demand for food security/irrigation and domestic use, more intensive use of fertilizers and nitrogen, and increasing seawater intrusion in coastal zones;

(iii) Where will all these problems be occurring? Increasing droughts or floods are observed in some areas and have been projected through modelling - these projections need to be incorporated and summarized in the assessment; and

(iv) Which international groundwater systems are likely to prevent, buffer or mitigate water-related problems under increasing stresses during the coming decades?

The GEF-funded TWAP Assessment will be carried out at two levels. **Level 1** includes a baseline global assessment and provides for periodic follow-up monitoring of trends and impacts achieved by GEF and other interventions, applying simple and feasible indicators. It also includes a tentative projection of key conditions and concerns over the next few decades. **Level2** consists of a more detailed assessment of a few selected pilot systems.

## IDENTIFICATION AND CHARACTERIZATION OF TRANSBOUNDARY AQUIFERS AND SIDS

Unlike other water bodies, aquifers are located below the surface and visible only through the eyes of science – hydrogeology. Consequently, while groundwater is being used intensively in all countries, in many cases this is happening in the absence of a full understanding of the nature and characteristics of the resource. This is particularly true for transboundary aquifers, which are often not recognized as shared resources by countries because of differing geological approaches, lack of communication between countries, uneven availability of data, or sovereignty issues. Limited recognition of the nature of shared resources increases their vulnerability to anthropogenic pressures.

It is therefore one of the important objectives of TWAP to make transboundary aquifer systems 'visible' and facilitate their recognition by the countries that share them. TWAP aims to collect, to the extent feasible within the context of TWAP, a set of indicators for each transboundary aquifer which, when combined, give a first description of its current hydrogeological, environmental, socioeconomic, and governance conditions, and its interactions with adjoining water-bodies and ecosystems.

The assessment will build on existing initiatives, most prominently the Internationally Shared Aquifer Resources Management (ISARM) Initiative launched by UNESCO IHP in 2000. ISARM aims at raising international awareness of the need to properly manage these highly vulnerable resources, and has succeeded in completing for the first time a preliminary regionally-based inventory of transboundary aquifers and focusing global attention on these widespread and valuable water resources. The ISARM approach and experience has inspired the methodological design of the 'Identification and Characterization of TBAs' part of TWAP groundwater, which will strive to expand and complement the ISARM inventory of transboundary aquifer systems globally.

## INDICATORS

The assessment of transboundary aquifers will be indicator-based. The TWAP groundwater indicators will allow a comparative assessment of transboundary aquifers (TBAs) and SIDS, in terms of various parameters (quantity, quality, vulnerability, resilience, etc.). These indicators and their integration into indexes will in turn facilitate priority setting for GEF strategies and actions.

When developing the TWAP groundwater indicators, an important requirement is that their global application should be feasible. That means that their design should be such that assigning rough values to the indicators should be possible on the basis of (i) existing databases, (ii) newly acquired information through regional expert networks, possibly complemented by (iii) 'synoptic' information derived from new technologies (remote sensing, models). The TWAP TBA methodology will be focused on two main categories of indicators: current state indicators and projected stress indicators.

1) **Current State Indicators** express basic quantitative and qualitative characteristics of groundwater systems and conditions that relate to the physical and chemical characteristics of the aquifers, such as level of the water table; nutrient loads; health of groundwater-dependent ecosystems; extent of marine intrusion as well as socioeconomic and legal-institutional attributes. The following groups of indicators will be applied:

1 – Transboundary aquifer values and functions;

2 – Human and environmental dependence on groundwater;

3 – Natural and human stresses on groundwater;

4 – Socioeconomic groundwater indicators; and

5 – Governance indicators.

2**) Projected Stress Indicators.** Emphasis is put on projections to 2030 and 2050. The scoring of these indicators will be based on extrapolation by simple models, using the current situation (Current State Indicators and underlying variables) as the initial condition and expected trends of relevant key variables (e.g. demographic and climatic variables) as time-dependent drivers to enable projections of indicator scores over time. The following groups of indicators will be used:

1 – Projected groundwater quantity stress indicators; and

2 – Projected groundwater quality stress indicators.

## DATA AND INFORMATION MANAGEMENT

The assessment of transboundary aquifers is based on large amounts of data and information and will produce even larger amounts of both. Regional institutions and networks of experts will have a central role in developing the indicator values. In order to assess the TBAs and SIDS in as consistent a ways possible, the flow of data and information needs to be as harmonized and streamlined as possible. The TWAP Groundwater Information Management System, to be developed and run by the International Groundwater Resources Assessment Centre (IGRAC), will provide for collecting, storing, analysing and sharing data and information on the TBAs and SIDS in a consistent way. The system will thus be of paramount importance for the TWAP assessment of transboundary aquifers and SIDS.

## PARTNERSHIP AND EXECUTION ARRANGEMENTS FOR THE TWAP FULL SIZE PROJECT

As one of the main outcomes of the GEF Medium Sized Project 'Development of the Methodology and Arrangements for the GEF Transboundary Waters Assessment Programme (TWAP)', UNESCO-IHP, in its capacity as lead agency for the TWAP Transboundary Aquifer and Groundwater component, is currently establishing the *TWAP Groundwater Coalition*, a partnership of institutions and organizations at the national, regional and global level. The members of the Coalition are committed to:

(i) carry out and co-finance the GEF-funded TWAP baseline assessment, adopting the methodology and modalities defined as a result of the TWAP design phase (MSP); and

(ii) explore ways to carry out long-term periodic follow-up assessments and monitoring with non-GEF resources in order to ensure the sustainability of TWAP's Groundwater component.

The Groundwater Coalition consists of three categories of partners based on their specific roles and functions:

1. **The Core Group, led by UNESCO IHP, and consisting of IGRAC, UN WWAP and FAO, along with the global network of UNESCO water-related centres and chairs**. The core group has a central role in guiding and coordinating the TWAP groundwater coalition to successfully execute the global baseline assessment, as well as the periodic follow-up assessments. Consisting of the main players in the field of transboundary groundwater resource assessment and management globally, the Core Group will have overall responsibility and directly perform parts of the assessment. It will appoint a Project Manager and establish cooperation schemes and liaise with key partners. Calling on a wide array of ongoing cooperation and joint activities with many partners, the core group provides the main pillars of the TWAP assessment through programmes such as the Internationally Shared Aquifer Resources Management (ISARM) Initiative, the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), the United Nations World Water Assessment Programme (WWAP) and its triennial World Water Development Report (WWDR), high-resolution global data sets on soils, land use and irrigation from FAO's AQUASTAT and other related programmes, and IGRAC's Global Groundwater Information System (GGIS) as well as the Global Groundwater Monitoring Network.

2. **Regional Coordinators and Expert Networks**. Regional partners will contribute to the assessment with regional coordination mechanisms already in place and provide the direct link to the countries. They will be responsible for organizing the acquisition of data on transboundary aquifers through regional expert networks that already exist (ISARM Americas) or are to be established. They may also serve as data providers, having conducted previous studies and/or assessments at the regional scale or by providing access to existing data and local information systems. Whenever feasible, the management of Regional Coordination and Expert Networks and the promotion of country involvement will be entrusted to Regional Organizations such as OAS, SADC, UNECE, UNECA, UNESCAP, UNESCWA, UNECLAC, OSS and SPC.

3. **Key providers of expertise and data.** Organizations or institutions at the local, national or regional scale will serve as *providers of expertise and information*. This encompasses universities and research institutes from developing and developed countries, geological surveys, international

associations, and non-governmental organizations (NGOs), among others. This group of partners will also have a central role within a Task Force on remote sensing and modelling, aimed at filling data gaps and generating harmonized data at global or regional scales that will be set up and coordinated by IGRAC. In addition to hydrogeological, technical or environmental expertise, the provision of expertise on socioeconomic, legal and institutional issues will be of great important in the framework of TWAP-Groundwater. Key partners falling into only one of the above-mentioned categories may also serve as regional partners, providing both data and expertise.

Partners will benefit from the coalition by broadening the knowledge of transboundary aquifer systems, establishing new partnerships and cooperation, and gaining enhanced access to data and the Groundwater Coalition's information management system. Given the objective of TWAP to provide a basis for science-based allocation of financial resources (GEF and other donors) to priority transboundary aquifer systems, countries and regions will benefit from increased transparency in fund allocation.

Members of the core group and many of the other partners are already co-operating in ongoing transboundary aquifer projects and programmes. Special mention has to be made here of ISARM- and GEF-supported projects/programmes. TWAP may benefit from existing co-operation arrangements.

The execution of TWAP will be supported by the TWAP-Groundwater Advisory Panel, which will consist of individual experts in hydrogeological, socioeconomic, legal and institutional aspects (IAH, Geological Surveys, Academia, etc.) and will provide advice and support to the Core Group with overall coordination of the assessment.

# GENERAL INTRODUCTION

The design of a Transboundary Water Assessment Project (TWAP) was approved by the Global Environmental Facility (GEF) in January 2009 as a Medium-Sized Project (MSP) with a timeframe of 18 months (June 2009-November 2010). The objectives of the MSP were *to develop an agreed methodology for the assessment, to catalyse partnerships and to define the execution arrangements for conducting such an assessment*[1]. Based on the outputs of the MSP, it is expected that a Full-Sized TWAP (FSP) will be funded by GEF, which will include the first 'baseline' assessment and sustainable arrangements for future periodic assessments and monitoring.

The long-term overall goal of TWAP is *'to promote real investment in management and development of transboundary water systems through strong stakeholder engagement'*. The assessment is meant to be a tool for GEF, other international agencies, and policy makers, to set science-based priorities for the allocation of financial resource to transboundary water systems. The assessment will cover five interconnected water system types: river basins, lake basins, groundwater basins, Large Marine Ecosystems (LMEs) and open oceans.

UNESCO-IHP has been entrusted with the execution of the groundwater component in the framework of TWAP.

More specifically, the objectives of the groundwater component are to develop:

(1) the methodology that will enable the GEF IW Focal Area to determine priority aquifers/regions for resource allocation; this will include key indicators that will allow the categorization of aquifers and their comparative assessment and, in specific cases, the monitoring of trends in the evolution of the state of aquifer systems and the impacts of human interventions and climatic change and variability. Further, the sources of existing data required to calculate the indicators and proposals for cost-effective collection of additional data will be provided by the Groundwater Group (GW); and

(2) the execution arrangements for the TWAP baseline assessment and future periodic assessments. This includes setting up a partnership between relevant agencies, organizations and institutions.

This document presents the TWAP methodology for transboundary groundwater systems, which was prepared with the broad involvement of the TWAP Groundwater Expert Group, made up of senior international experts on transboundary groundwater resource assessment and management, covering the various aspects and disciplines relevant to the subject (a list of members of the expert group is attached as Annex 1). The methodology was prepared under the overall supervision of the TWAP groundwater coordinator, supported by the TWAP groundwater task leaders.

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[1] In particular, the MSP will:

(1) Provide a list of major transboundary aquifers, and a characterization of each;
(2) Identify key indicators that will allow the categorization of aquifers and their comparative assessment; and
(3) Propose cost-effective arrangements for the execution of the 'TBA Baseline Assessment' and sustainable mechanisms for long-term monitoring of trends in the evolution of the state of aquifer systems and the impacts of human interventions and climatic change and variability.

The methodology presented in this document has not been tested in practice. Therefore some adjustments may be needed during the course of its application. Please refer also to Part 3.

The document has six main parts: (i) the Conceptual Framework; (ii) Identification and Characterization of Transboundary Aquifers; (iii) Transboundary Aquifer Indicators; (iv) Interlinkages; (v) Data and Information Management; and (vi) Towards Implementation. A list of references is completes these six parts. Various annexes show background information among which a glossary of terms (Annex 2).

# PART 1. CONCEPTUALFRAMEWORK

## 1. INTRODUCTION

The objectives of the groundwater component of TWAP are to:

(1) Provide a description of the present conditions of transboundary aquifers (TBA) and aquifers in small island developing states (SIDS) that will enable the GEF IW Focal Area to determine priority aquifers/regions for resource allocation; and

(2) Bring the major issues, concerns and hotspots of these transboundary aquifer systems and SIDS aquifers to global attention, and catalyse action.

The TWAP Groundwater methodology and assessment is expected to help GEF and other potential clients to find answers to questions, including:

(i) What human and ecosystem uses of water resources are currently affected or impaired (use conflicts, depletion, degradation);

(ii) How water conditions and uses are expected to develop during the next few decades (15-20 year projection or outlook).Global change is likely to produce increased pressures during the coming decades, such as higher water demand for food security/irrigation and domestic use, more intensive use of fertilizers and nitrogen, and increasing seawater intrusion in coastal zones;

(iii) Where all these problems are likely to occur. Increasing droughts or floods are observed in some areas and have been projected through modelling - these projections need to be incorporated and summarized in the assessment; and

(iv) Which international groundwater systems are likely to prevent, buffer or mitigate water-related problems under increasing stresses during the coming decades.

The future GEF-funded TWAP Assessment will be carried out at two levels:

**Level 1** includes a baseline global assessment and provides for periodic follow-up monitoring of trends and impacts resulting from GEF and other interventions, applying simple and feasible[2] indicators. It also includes a tentative projection of key conditions and concerns over the next few decades; and

**Level 2** consists of a more detailed assessment of a few selected pilot systems.

The overall architecture of TWAP and its different phases is shown in Figure 1.

[2] Feasible means that the data required to calculate the indicators are either readily available or can be collected in the framework of the GEF TWAP Full-Size Project.

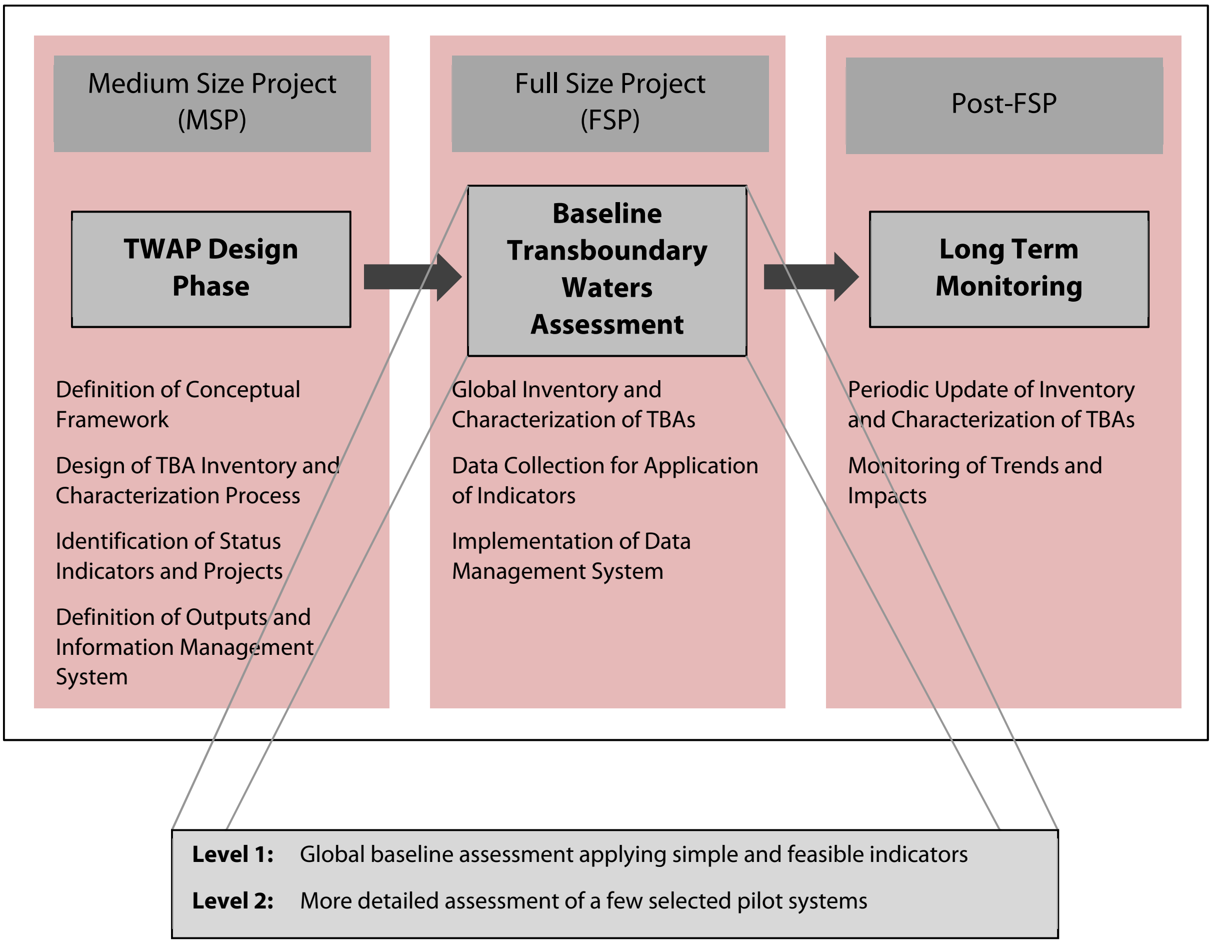


**Figure 1.** Overall architecture of TWAP phases (groundwater).

Notwithstanding the objectives set out above, TWAP and its groundwater component can be interpreted and addressed in many different ways. Individuals involved may have very different ideas of geographical scope, relevant categories of variable to be assessed, level of detail, time interval between successive assessments, how to collect the data, how to process them, etc. Consequently, the TWAP Groundwater Expert Group has converged to a common understanding of the project and made its contributions in accordance with an agreed conceptual framework. This aims to function as an agreed road map for activities to be undertaken as part of the Groundwater Baseline Assessment in the framework of TWAP.

A chapter on terminology and some relevant information precedes the presentation of the conceptual framework, and is followed by an outline of the methodology proposed for the groundwater component of TWAP.

# 2. TERMINOLOGY, CONCEPTS, ACTIVITIES AND PRODUCTS RELEVANT FOR TWAP/GROUNDWATER

## 2.1 Definitions

### 2.1.1 What is transboundary waters assessment? What is monitoring?

*Transboundary waters*: In general, water systems (river basins, lakes, aquifers, large marine ecosystems or deep oceans) that are crossed by administrative boundaries. In the context of the mandate of GEF these administrative boundaries only refer to boundaries between countries.

*Assessment*: quantitative characterization of a chosen object, usually in order to make a judgement on its value or importance from a certain point of view. In hydrology and hydrogeology it mostly refers to a 'snapshot' description or characterization, frozen in time. In that context, it may be distinguished from 'reconnaissance', 'exploration' and 'monitoring'. It is more advanced and more quantitative than 'reconnaissance' or 'exploration' and less focused on change over time than 'monitoring'.

*Monitoring*: continuously repeated measurement of a certain variable at the same location, resulting in a time-series that gives information on relevant variations and trends over time. The interval between successive measurements is tuned to the time-variability of the chosen variable and the adopted monitoring objectives.

The Global Water Partnership (GWP) Toolbox defines 'water resources assessment' (WRA) as 'a tool to evaluate water resources in relation to a reference frame, or evaluate the dynamics of the water resource in relation to human impacts or demand. WRA is applied to a unit such as a catchment, sub-catchment or groundwater reservoir.' GWP observes a trend from traditional water resources assessment aimed at providing a basis for the design of water supply infrastructure to assessments with much a wider remit from an Integrated Water Resource (IWRM) perspective[3]. The World Water Assessment Program (WWAP) describes its global water assessment as the achievement of a better understanding of 'the state, use and management of the world's freshwater resources and the demands on these resources, (to) define critical problems and assess the ability of nations to cope with water-related stress and conflict'[4].

In TWAP 'assessment' has to be interpreted in the wider sense adopted by WWAP and suggested by GWP Toolbox, rather than the narrower sense of traditional hydrological or hydrogeological studies. It is not limited to a single 'snapshot' but aims to capture trends in time, and its scope includes physical water systems as well as human-related and environmental aspects, to allow for a diagnostic characterization. 'Assessment' as expressed in the name 'Transboundary Waters Assessment Program (TWAP)' should be seen as an overarching concept, covering all the project's activities with respect to content.

### 2.1.2 Some groundwater-related definitions[5]

(a) **Aquifer** means a permeable water-bearing geological formation underlain by a less permeable layer and the water contained in the saturated zone of the formation.

(b) **Aquifer system** means a series of two or more aquifers that are hydraulically connected[6].

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[3] http://www.gwptoolbox.org/index.php?option=com_tool&id=24

[4] http://www.unesco.org/water/wwap/

[5] (a) to (h) are the definitions adopted by the UNGA Resolution A/RES/63/124 on the 'Law of Transboundary Aquifers and the Draft Articles contained therein, 2008.

[6] Another possible definition is: 'Aquifer system means an aquifer or a complex of hydraulically interconnected aquifers'. This definition is consistent with the ubiquitous practice to use 'aquifer system' also for indicating one single aquifer only.

(c) **Transboundary aquifer** or 'transboundary aquifer system' means, respectively, an aquifer or aquifer system, parts of which are situated in different States.

(d) **Aquifer State** means a State in whose territory any part of a transboundary aquifer or aquifer system is situated.

(e) **Utilization of transboundary aquifers or aquifer systems** includes extraction of water, heat and minerals, and storage and disposal of any substance.

(f) **Recharging aquifer** means an aquifer that receives a non-negligible amount of contemporary water recharge.

(g) **Recharge zone** means the zone that contributes water to an aquifer, consisting of the catchment area of rainfall water and the area where such water flows to an aquifer by runoff on the ground and infiltration through soil[7].

(h) **Discharge zone** means the zone where water originating from an aquifer flows to its outlets, such as a watercourse, a lake, an oasis, a wetland or an ocean.

(i) **Coastal aquifer** means an aquifer located at the coast, usually hydraulically connected to the adjoining Large Marine Ecosystem.

(j) **Virgin recharge** or **natural recharge** means recharge or replenishment of 'natural' origin (rainfall, runoff, seepage from rivers or lakes, etc.), not significantly affected by human activity (artificial or induced recharge; return flows or other replenishment by used water; surfacing of terrain, etc.).

### *2.1.3 Variable, indicator, index*

***Variable***: Quantity to which a value (or a time-series of values) may be assigned.

***Indicator***: Usually, a combination of variables, intended to convey a message. The message follows from comparing the values of the variables in a normative framework enabling qualifications to be assigned to the variable in a transparent way. Examples of indicators are: income per capita, renewable water per capita, groundwater abstraction rate per $km^2$, groundwater abstraction as a percentage of total abstraction. Eventually, an indicator may also consist of a statistic of a variable (e.g. mean, maximum or minimum of observed values, spatial average or aggregated value).

***Index***: Combination of indicators calculated according to a formal algorithm aimed at determining ranking positions. It is usually dimensionless.

## 2.2 DPSIR Framework

The DPSIR framework is a generally accepted analytical framework for understanding the structure of processes of change. This framework, graphically shown in Figure 2, contributes to understanding the dynamics of changing water resource systems by making a distinction between five interconnected classes of variables:

- Driving forces or drivers (D): root-cause of change;
- Pressures (P): immediate cause of change inside a water resource system, originating from the influence of drivers (D) and/or human responses (R);
- State (S): the quantity, quality and other measurable conditions of water inside the water resource systems;
- Impacts (I): negative or positive effect of changes in state on human society, ecosystems and/or the environment; and
- Responses (R): human action triggered by observed or expected undesired changes in state (S) or impacts (I).

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[7] Another possible definition is: 'zone where significant recharge (=replenishment) of the aquifer's groundwater is taking place, from whatever source of water'.

The DPSIR framework can help identify which variables and categories of variables have to be taken into account.

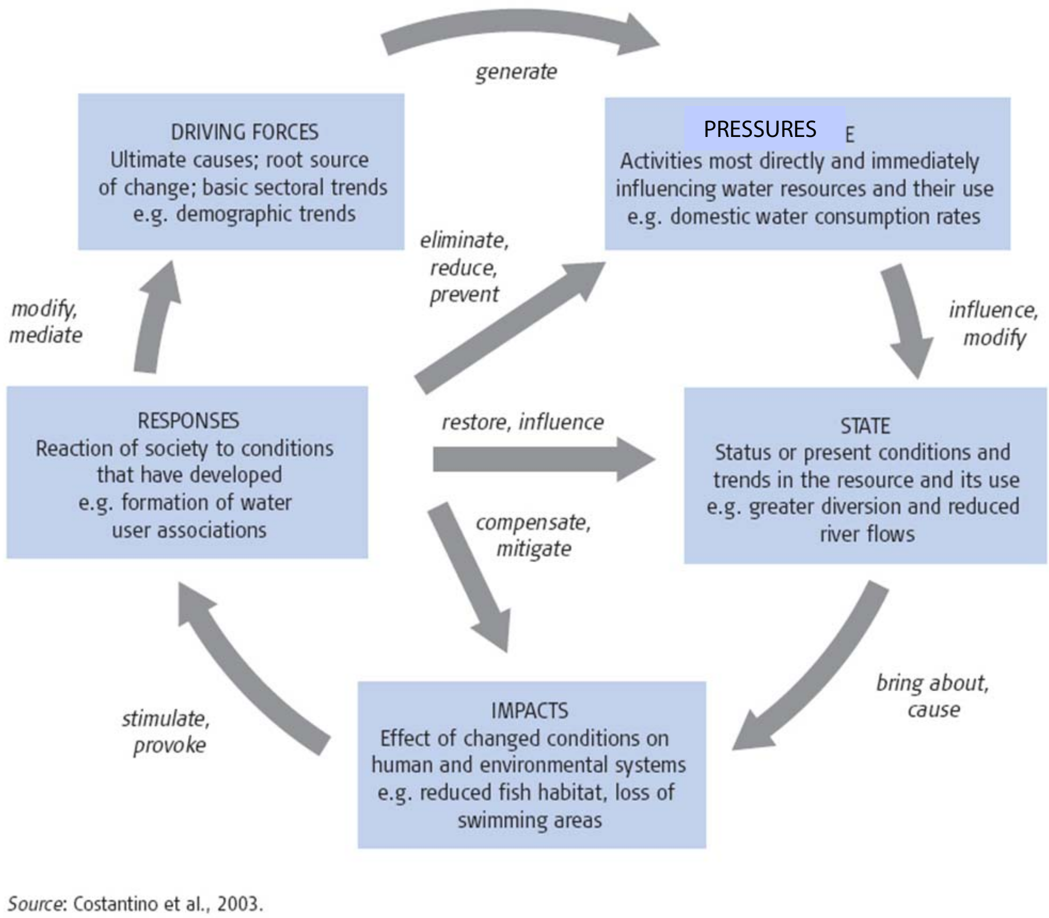


**Figure 2.** The DPSIR Framework of analysis (WWAP, 2006).

## 2.3 The GIWA Project

The Global International Waters Assessment (GIWA) is a project carried out during the period 1999-2006, after GEF's Scientific and Technical Advisory Panel (STAP) had noted in 1996 that the *'lack of an International Waters Assessment comparable with that of IPCC, the Global Biodiversity Assessment and the Stratospheric Ozone Assessment, was a unique and serious impediment to the implementation of the International Waters component of the GEF'*.[8]

Although GIWA's aim was to produce a holistic, globally comparable assessment of the world's international waters, it did not cover transboundary groundwater resources.

The methodology includes the following main components:

- Scaling: subdivides the world into 66 regions, grouped into nine macro-regions;
- Scoping: assesses and scores the severity of present and projected future environmental and socioeconomic impacts for each of 22 predefined issues related to five major concerns: fresh water shortage; pollution; overexploitation of living resources; habitat and community modification; global change;

[8] Detailed project information and downloadable documents can be found on http://www.unep.org/dewa/giwa/

- Causal chain analysis: traces cause-and-effect paths from impacts back to root causes; and
- Policy option analysis: outlines potential course of action for mitigating or resolving problems.

GIWA's methodology has a number of strong elements: it has a good balance between physical and human aspects of water systems, it recognizes the links between freshwater and coastal marine environments, and it provides criteria for assigning scores (in four classes) to each issue, and aggregating these scores, as systematically as possible. Nevertheless, the regions distinguished are too large and not adequate to address individual international aquifer systems. Furthermore, it is not transparent how observations of groundwater and surface water in the field contribute to the scores. Due to its probably strong subjective influence on the scores, the methodology is suitable for producing a global impression rather than for repeated assessments that should reveal changes over time.

## 2.4 AQUASTAT, GEO and WWAP

FAO's on-line *AQUASTAT*[9]presents comprehensive data on water resources and water use as reported and validated at both country and sub-national level where available. In addition to the country profiles and regional analyses that include data on water resources and water use, AQUASTAT includes the following:

- AQUASTAT main country database (more than 100 variables, searchable by country or by region per 5-year period);
- Water resource balance sheets by country, containing information on surface water and groundwater resources by country, taking into consideration agreements between countries sharing the same river basin;
- Agricultural water use, containing irrigated cropping calendars and crop water requirements by country;
- Global distribution of irrigation areas at 5 minute arc resolution in GIS format which has produced a Global Map of Irrigation Areas (GMIA);
- Geo-referenced database on African dams;
- Institutions database (searchable by country, type main activity or keyword);
- River sediment yields (searchable by river, country or continent); and
- Investment costs of irrigation.

Among these, the AQUASTAT main country database, the GMIA, the water resource balance sheets, and the institutions database have relevance for TWAP. The national water use data in the AQUASTAT database are updated every 5 years on a rolling programme allowing the derivation of some time-series for certain countries where data is reliably reported and can be validated. For those countries for which the information is available, groundwater withdrawal in volume is also reported. The GMIA will be updated in 2011 to include the results of a recent global inventory of irrigation dependent upon surface water, groundwater and non-conventional sources of water (Siebert, *et al*. 2010). The supplementary country data on groundwater areas and use are available online[10]. The GIS data for this distribution will also be made available in 2011at the open access FAO GeoNetworks portal[11].

UNEP's *Global Environmental Outlook* (GEO)[12] is a consultative, participatory process emerging out of the fundamental mandate of UNEP to assess and report on the state of the world's environment. The main product of GEO is the periodical GEO-report, of which the first (GEO-1) was published in 1997 and

[9] http://fao.org/nr/aquastat
[10] http://www.hydrol-earth-syst-sci.net/14/1863/2010/hess-14-1863-2010.html
[11] http://www.fao.org/geonetwork/srv/en/main.home
[12] http://www.unep.org/geo/

the fourth (GEO-4) in 2007. GEO-4 follows a DPSIR-based conceptual framework and describes the environment on the basis of 22 regions. It distinguishes four environmental systems: atmosphere, land, water and biodiversity. State and trends in all four systems are assessed for the period 1987-2007, followed by regional descriptions, a review of human dimensions of environmental change, an outlook towards 2015 and beyond, and, finally, a section on options for action. Given the broad scope of GEO, information on water is concise and descriptive rather than accompanied by data with global coverage.

The United Nations *World Water Assessment Programme* (WWAP)[13] is very similar to GEO. Its main product is the World Water Development Report (WWDR), which is published at three-year intervals. The first (WWDR-1) appeared in 2003 and the third (WWDR-3) in 2009. Being limited to freshwater, these reports have much more detail on water than the GEO reports. However, they are equally descriptive in nature, with only a limited number of worldwide data sets (e.g. those on water resource indicators). WWAP brings existing information together rather than producing new information. Water-related indicators are presented in many parts of WWDR-3, although not yet in a rigorously consistent way and usually referring to much larger spatial units than aquifers. Indicators of groundwater quality and quantity are being further developed for WWDR-4, to be launched in 2012.

## 2.5 Global groundwater assessment: ISARM, WHYMAP, IGRAC and other initiatives

In 2002 UNESCO launched a programme dedicated to *International Shared Aquifer Resources Management* (ISARM). Its objectives are to identify transboundary aquifers on each continent, support countries in the assessment of these aquifers and formulate recommendations for their management. ISARM is a multidisciplinary programme addressing hydrogeological, socioeconomic, environmental, legal and institutional aspects of transboundary aquifers. Regional ISARM groups scattered over the globe systematically collect information on these aspects. Most regional groups have produced a series of reports on their inventory and additional work (thematic characterization of the aquifers and case studies). This information forms the point of departure for virtually all global transboundary aquifer products. At the same time, the process of co-operation initiated within the regional ISARM groups is contributing to the development of a mind-set required for coordinated or joint management of transboundary aquifer resources. More information can be found on www.isarm.net.

Within the framework of ISARM the *Atlas of Transboundary Aquifers* (UNESCO, 2009), a comprehensive compilation of all relevant information collected by ISARM since its beginnings. The publication starts with a section on groundwater resources and global maps, followed by a description of the ISARM programme's activities and a section on legal issues. The core of the Atlas, however, is in the third section, in the form of a systematic description of almost 200 transboundary aquifers in different regions of the world. Each aquifer is presented on a separate page: the name of the aquifer and the sharing countries are mentioned, accompanied by a location map and an aquifer map, with a brief groundwater system characterization in key words (size, lithology, hydraulic condition, volume, water use, management concerns, etc.) as well as some remarks on interstate instruments and agreements. In addition transboundary aquifer case studies in each of the regions are mentioned and described.

The *World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP)* – carried out under the leadership of BGR (Germany) with special support from UNESCO - was launched in 2002. The programme compiles data on groundwater from national, regional and global sources, and visualizes them in maps, web map applications and services. The resulting products provide information on quantity, quality and vulnerability of the planet's groundwater resources and help to communicate groundwater-related issues to water experts as well as decision makers and the general public[14]. Most prominent among WHYMAP's products are the Groundwater Resources Map

[13] http://www.unesco.org/water/wwap/
[14] www.whymap.org

of the World, scale 1: 25 000 000 (2008) and the map Groundwater Resources of the World – Transboundary Aquifer Systems, scale 1: 50 000 000 (2006). The latter shows the approximate locations of 98 transboundary aquifers, with the name of each aquifer and the countries sharing it and,forsome ofthe aquifers, the horizontal extension and type of aquifer system.

The *International Groundwater Resources Assessment Centre (IGRAC )*under the auspices of UNESCO and WMO has been operational since the beginning of 2003 (www.igrac.net). Its mission is to make a significant contribution to the worldwide availability of relevant groundwater-related information. It aims to do so by developing a Global Groundwater Information System (GGIS), and Guidelines and Protocols for data collection (G&P), and by carrying out special thematic projects and participating in global or regional projects with a groundwater component. Among the modules of GGIS, the Global Overview (GO) and the Global Groundwater Monitoring Network (GGMN) are particularly relevant for TWAP/Groundwater. The Global Overview (GO) contains variables and indicators aggregated or averaged by country or by so-called Global Groundwater Region[15]. Although many of these variables and indicators are in principle time-dependent, GO is not designed to contain time-series, but rather aims to present the latest available data. The presentation of time-series of aggregated variables and indicators in the Global Groundwater Monitoring Network has been designed, but is still in a stage of initial development.

For transboundary aquifers, IGRAC is responsible for ISARM's website, participates in several global or regional transboundary aquifer projects and has developed a dedicated sub-module in GO with special features for transboundary aquifers. In addition, in 2009 IGRAC produced the 1: 50 000 000 scale map 'Transboundary Aquifers of the World', to be considered as an update of WHYMAP's Transboundary Aquifer Systems map of 2006. It encompasses 318 transboundary aquifers across the globe, shows names and the sharing countries for each, and specifies lateral boundaries, extension and aquifer type for a considerable number of aquifers.

UNESCO, IAEA and IAH have jointly carried out a project on *Groundwater Resources Sustainability Indicators*, which resulted in report no. 14 in the IHP-VI Series on Groundwater (UNESCO, 2007)[16]. Ten groundwater indicators were developed and tested, as a potential contribution to WWAP. Lessons learned included that it is not easy to design 'good' indicators and that availability of good and consistent data is crucial.

Also worth mentioning is the book *'Les Eaux Souterraines dans le Monde' (*Margat, 2008), published jointly by UNESCO and BRGM. This provides an excellent overview of the world's groundwater resources in their geographic setting, paying attention to the different categories of aquifers, their dynamics, exploitation, use and management. Many small-sized maps are included, as well as tables. Special attention is paid to the world's largest aquifers, most of which are transboundary.

Another valuable source of information on a number of large aquifers across the world and their management is the publication *'Non-Renewable Groundwater Resources – a guidebook on socially sustainable management for policy makers'* (UNESCO, 2006). It explores in particular how to manage groundwater resources that are not or not significantly replenished.

[15] IGRAC has developed a telescopic system for scale-dependent subdivision of the World in hydrogeologically relevant zones: it distinguishes 36 Global Groundwater Regions, each of which subdivided in a number of Groundwater Provinces (217 on the entire globe), each of which contains a number of aquifers (Van der Gun et al., 2011).

[16] For download in UNESCO's online database:
http://webworld.unesco.org/ihp_db/publications/GenericView.asp?KEY=524

## 2.6 GEF-IW RAF Transboundary Aquifers

*Indicators Approach Paper for Possible Application of the Resource Allocation Framework to the GEF International Waters Focal Area – Transboundary Aquifers*

In 2009, GEF entrusted UNESCO-IHP with the development of an indicators approach paper for possible application of the Resources Allocation Framework (RAF) to Transboundary Aquifers (TBAs) in the GEF International Waters focal area. This activity is referred to as 'GEF IW:RAF' in the following. The project's main objective was to develop for GEF a simple but effective methodology for ranking priorities among transboundary aquifers suggested as candidates for GEF funding of interventions. A key role in this methodology is played by the so-called GEF Benefits Index (GBI), a measure of the potential to generate global environmental benefits through the International Waters focal area action on the groundwater resources contained in transboundary aquifers. A higher GBI score should correspond with higher priority for GEF support for interventions among the many transboundary aquifers in the world, and among the different types of transboundary aquifers with renewable or non-renewable groundwater resources.

The indicators approach developed by the expert group led by UNESCO-IHP is based on decomposition of the GBI index into three sub-indices, each of which is defined on the basis of a number of indicators. Figure 3 shows the corresponding conceptual framework. In addition to this main framework, two additional discipline-oriented frameworks were developed, but not integrated: one on socioeconomic aspects, one on law and institutions.

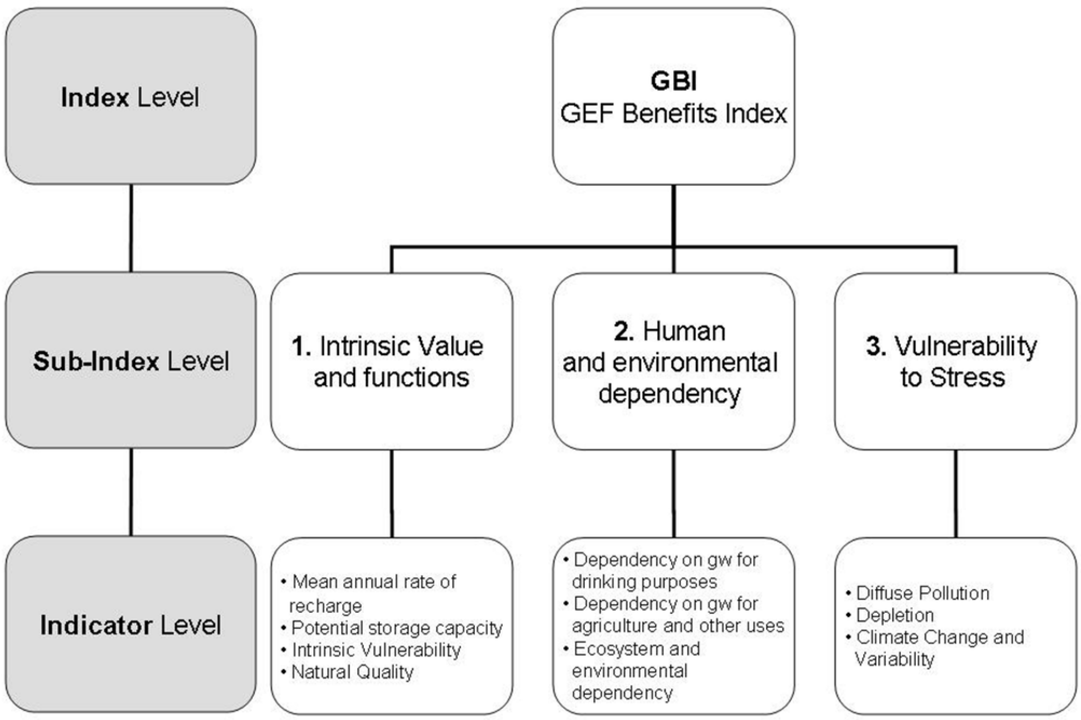


**Figure 3**: Main conceptual framework of GEF IW:RAF/Groundwater

The aim was to develop indicators that can use existing global or regional databases or other easily accessible sources of information to determine values or scores. Very simple indicators were defined and scoring was simply low, moderate or high. Tests were done for several regions, in order to establish the feasibility of the approach. This resulted in a number of concessions, in particular using data characterizing the aquifer-sharing countries as a proxy for data characterizing the transboundary aquifer considered. Such concessions reduce the reliability of the calculated GBI scores, which highlights the importance of assessment at the level of individual aquifers. The complete indicators approach paper is attached as Annex 3.

Both GEF-IW: RAF and GEF-TWAP aim to help GEF to prioritize its investments, by identifying the areas and water bodies where the highest returns can be expected in terms of global environmental benefit. However, the emphasis in GEF-IW:RAF is on how to define and compare values of the GBI, while GEF-TWAP is focused on getting more and better data on the relevant water systems, including time-series that enable repeated assessments.

## 2.7 The GEF IW: Science project

The GEF IW: Science project is being carried out in parallel with TWAP. It has some similarity in structure (dealing with five interconnected water system types) and overall objective (contributing to improved output of GEF support to the IW focal area), but the focus is very different. GEF IW: Science tries to identify useful science aspects and deficiencies in science in the projects of the GEF IW portfolio, in order to enhance the use of appropriate and cutting-edge science in GEF IW projects.

There is potential synergy between the two projects, because they are complementary and can use each other's outputs. GEF IW:Science outputs that may be highly relevant for TWAP include the IW:Science on-line document database and relevant science components and approaches, which may guide the development of the TWAP indicators.

# 3. CONCEPTUAL FRAMEWORK FOR TWAP'S GLOBAL ASSESSMENT

## 3.1 Overall conceptual framework

Figure 4 shows a tentative overall conceptual framework for TWAP's global assessment. Assessment results should alert GEF and local stakeholder institutions in a timely manner about water systems where a particular need for water resource management interventions is emerging or expected (geo-referenced alert) and specify which issues call for particular attention. The level of detail and resolution in space and time of TWAP's Level 1 assessment is generally insufficient for proper area-specific diagnosis and subsequent planning of interventional action. This may be different for Level 2 assessments, depending on their design, but the number of pilot areas for Level 2 assessment activities will be very limited. Therefore, alerting is considered to be the main function of the envisaged TWAP assessment results.[17]

The assessment broadly addresses two categories of area-specific characteristics: time-independent characteristics such as aquifer geometry and hydraulic properties and time-dependent characteristics such as groundwater flow dynamics and groundwater use. Although the second category is of primary importance in this endeavour triggered by processes of change, the former (which includes the identification of systems) is indispensable for interpreting time-dependent variables and indicators correctly. Although the emphasis in TWAP will be on periodic assessments of time-dependent indicators, it seems logical at the same time to steadily improve knowledge of key time-independent characteristics on the basis of the new investigations carried out. The time interval between successive values of time-dependent indicators should be in the range of some years, e.g. six year intervals to match with the three year interval of WWAP (Section 3.2.3). Too frequent repetitions of the assessment would requires huge efforts that would have to be justified by a high probability of significant change,

[17] In principle this conceptual framework is applicable to all five water system types considered. If the methodologies to be followed are consistent, then it will be relatively easy to combine the results of all water system types.

but one has to be reasonably confident that the latest observed values and trends still reflect current conditions.

The degree of detail and other aspects related to the design of a plan of variables and indicators to be assessed periodically needs to be in tune with institutional capabilities and commitments all over the world. Evidently, the ambition of TWAP should be to generate new information that is not already easily available to GEF and the relevant local water resource management institutions and stakeholders. This will require the development of additional data acquisition programmes or innovative methods for using proxy information. If these activities are not compatible with the capabilities and willingness of the selected partner organisations, then TWAP's aspirations are likely to fail.

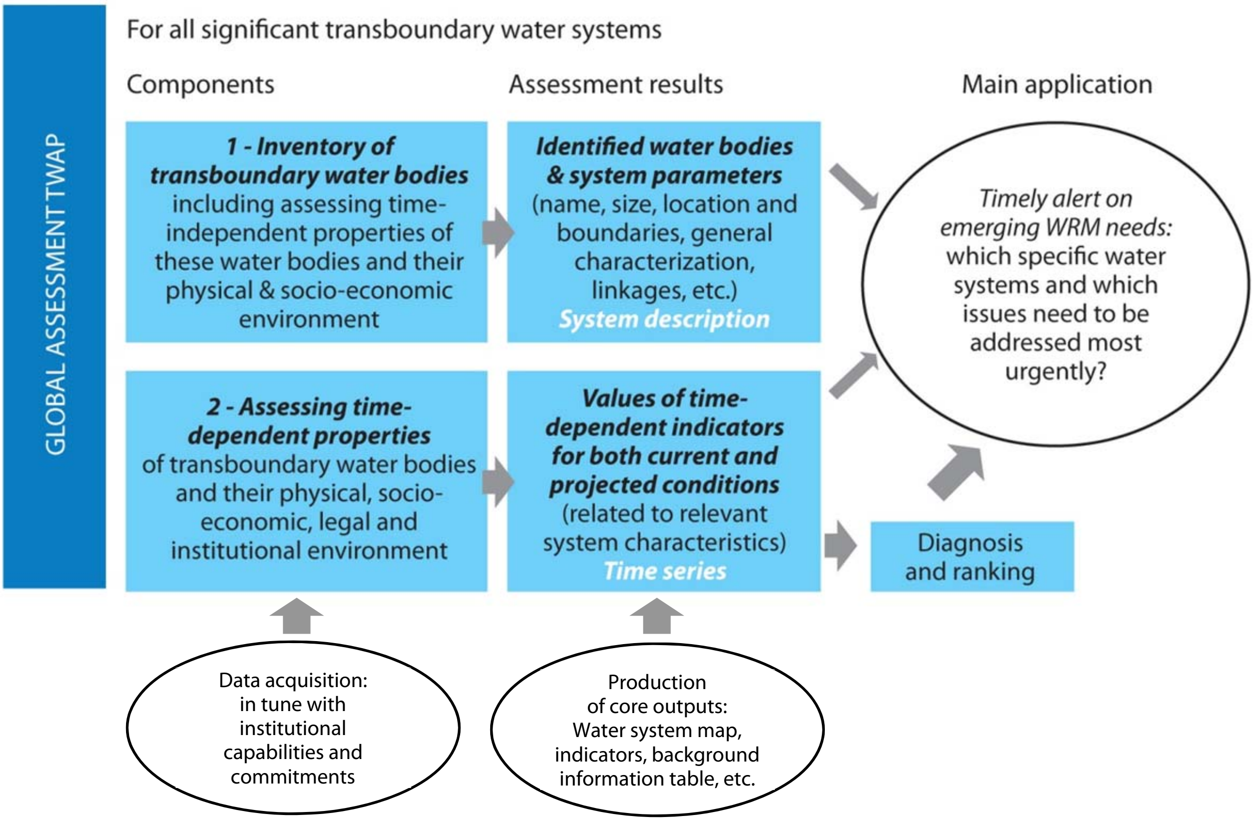


**Figure 4**: Overall conceptual framework for TWAP's global assessment.

## 3.2 The conceptual framework in the context of the groundwater component

Figure 5 shows an extended version of TWAP's conceptual framework, in which the main elements of the groundwater component have been made visible. The outputs of the current design phase consist of (i) a methodology for the base-line assessment under the TWAP FSP and (ii) established partnerships and execution arrangements among agencies and institutions committed to participate in the global assessment activities. Both outputs are essential inputs to the envisaged follow-up TWAP FSP. Some general aspects deserving attention are discussed below.

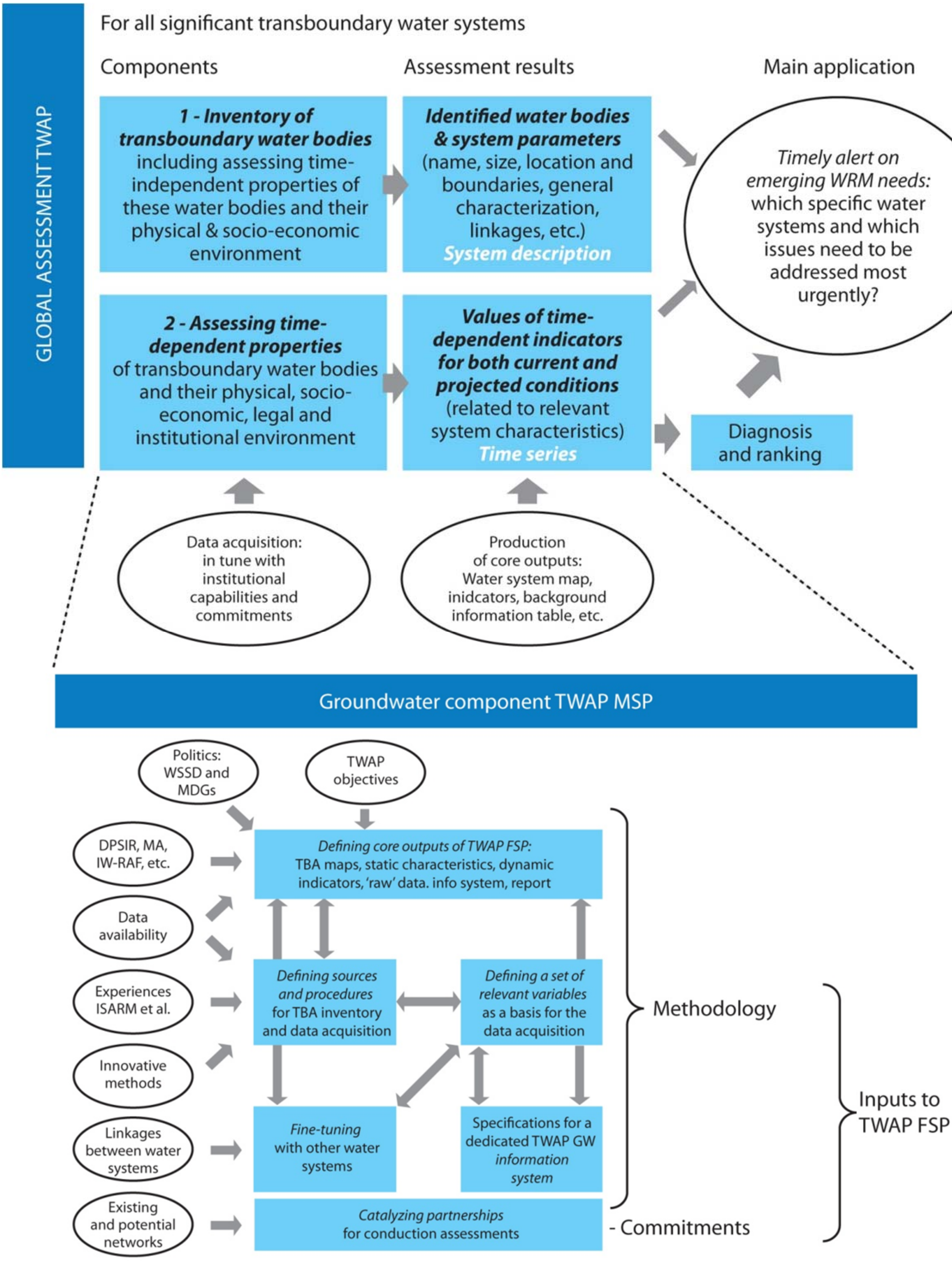


**Figure 5**: Conceptual framework of TWAP Groundwater component in the context of the overall TWAP project.

### 3.2.1 Interpretation of TWAP's objectives

It is important that all participants in TWAP share a common interpretation of TWAP's objectives. It is postulated here that TWAP's aspirations go beyond those of GEF IW:RAF, which was a rapid exercise to develop a (GBI – global benefits) index that could be used for rapid priority rating on the basis of data readily available in global or regional databases, excluding the option to acquire more data. TWAP instead puts emphasis on the acquisition of *sufficient information to understand relevant characteristics and trends of the groundwater systems and the interconnected socioeconomic and environmental systems.* TWAP aims to give a major boost to our understanding of conditions and trends in and around the world's internationally shared water resources. Since this implies that changes in time should be known and understood, the assessment should be repeated periodically, in order to remain up-to-date regarding current conditions and trends.

### 3.2.2 Geographic aspects, scale and geometry

TWAP is designed as a global assessment; hence in principle all transboundary aquifers and Small Island Developing States (SIDS) groundwater systems should be taken into account. However, given the specific purposes of TWAP Groundwater, there is a need to exclude small systems[18] and establish a similar degree of spatial aggregation in transboundary systems across the world. As IGRAC's 2009 world map of transboundary aquifers suggests, the latter needs some attention. A more consistent pattern will be obtained by merging identified local transboundary aquifers (e.g. in Europe) into larger transboundary aquifer systems. This would contribute to global harmonization and better reflect TWAP's global perspective.

If TWAP is to contribute to a better knowledge and understanding of international water bodies in the wider sense, then the spatial resolution of the assessment should be high enough to characterize the present status of individual aquifer systems, including trends and interactions. Past experience – e.g. in ISARM activities and in GEF IW:RAF - shows that it is already very difficult to obtain data at the aggregated level of an aquifer system, which suggests that it is not advisable for TWAP to go beyond this scale level. It is therefore proposed to take national segments of *the transboundary aquifer system*[19] *as the primary spatial unit for TWAP's groundwater activities*. This means that indicators should as far as possible depict the conditions of each national segment of an individual aquifer system and its surroundings. In the case of SIDS aquifers, the whole SIDS is taken as the primary spatial unit for the assessment. The socioeconomic, environmental, institutional and legal systems related to the aquifer body considered tend to be shared partly or entirely with other water bodies in the same region, hence they are often not confined to an aquifer, but only related to it (and to other bodies as well).

An essential element in the assessment is the *delineation of aquifer system boundaries*. At present, reasonably accurate lateral boundaries are known for less than half of the inventoried transboundary aquifers in the world[20]. In many cases (e.g. for Europe) the maps show the locations only symbolically, which precludes any values of corresponding indicators being defined and understood unambiguously. The vertical boundaries of the aquifer systems are important as well as the lateral boundaries, but generally they are even less known. It will be a challenge for TWAP to improve knowledge of the geometry of the world's transboundary aquifer systems, including the delineation of recharge areas, and to produce improved maps and cross-sections, as well as reliable numbers on the size, thickness and volume of the individual aquifer systems.

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[18] E.g. the thousands of small and unconfined aquifers present along international borders. This does not apply to SIDS, where small aquifers may play an important socioeconomic role.

[19] Intrinsically large and including the vertical dimension, as opposed to each specific generally small shallow unconfined aquifer linked to surface drainage.

[20] Not all boundaries of delineated transboundary aquifer systems match perfectly within the productive hydrogeological units shown on WHYMAP's map 'Groundwater Resources of the World' (2008). As the delineation of the transboundary aquifers and WHYMAP units both include simplification and subjectivity, they will have to be adjusted jointly if it is required to make them match.

In some cases, transboundary aquifer systems have been organized and described within larger geographic units in order to highlight their interconnection and/or similarity.

(a) *River basins of the world (*GRDC, 2007): 405 river basins; endorheic (closed) basins and some other territories not covered. Well-defined and often related to well-known rivers, but large numbers, large variation in size, and moderate to weak spatial correspondence with deeper groundwater systems.

(b) *GIWA regions*: 66 regions grouped into 11 macro-regions. The latter are strongly linked to current geographical names but may cause confusion by sometimes having diverging boundaries (e.g. Central America). The regions do not contribute to better understanding of patterns in groundwater characteristics.

(c) *Global Groundwater Regions (IGRAC)*: 36 Global Groundwater Regions have been defined on the basis of physical contrast (mainly geological differences). They help understanding of the general patterns of hydrogeological variation on the globe. They are relatively weakly correlated with river basins. Global Groundwater Regions, Groundwater Provinces and Aquifer Systems represent three different hierarchical levels of a consistent nested system of groundwater zoning.

(d) *ISARM regions*: The ISARM project was carried out with a regional approach and in close cooperation with Member States, several United Nations organizations, other international organizations and associations, and non-governmental organizations. The regions covered are the Americas, Africa, South Eastern Europe, and Asia. ISARM is also cooperating closely with UNECE, which is carrying out transboundary aquifer activities in Europe, the Caucasus and Central Asia.

The need for organizing transboundary aquifers within larger spatial units in TWAP arises primarily for operational purposes (efficient implementation of the assessment). It has therefore been decided to adopt the same regions as the ISARM programme. This is expected to create conditions for cooperation between ISARM and TWAP, producing the highest possible degree of efficiency and synergy between the programmes. Successful elements of the ISARM methodology for the inventory and characterization of aquifer systems will be adopted by TWAP (refer to part 2 for further details).

Apart from transboundary aquifer systems, groundwater systems to be addressed by GEF's International Waters programme include those of Small Island Developing States (SIDS). The corresponding aquifer systems are small compared to most of the transboundary aquifer systems. They may be combined into one single group (SIDS) or three regional groups: AIMS Region[21] (8 SIDS), Caribbean (23 SIDS) and the Pacific (20 SIDS).

### *3.2.3 Time interval between successive assessments*

TWAP is not able to monitor worldwide at a frequency that would allow analysis of detailed processes at the field level. Keeping a reasonably up-to-date picture of local conditions and identifying multi-annual trends of lumped key variables and indicators is already a big challenge.

The time interval between successive assessments after the initial base-line assessment should therefore be of the order of three to six years. Gearing with WWAP would suggest a three-year or a six-year interval. Provisionally, a time interval of six years is proposed. Such a large time interval will strike a good balance between observing significant trends in due time and the considerable efforts needed to do so.

[21] AIMS derives from the initial letters of the marine areas in which the islands in the original group are located; Atlantic (Cape Verde, Guinea Bissau, Sao Tome and Principe); Indian Ocean (Bahrain, Comoros, Maldives, Mauritius, Seychelles); Mediterranean (Cyprus, Malta); South China Seas (Singapore).

### 3.2.4 Measurement scales for presenting assessment results

Commonly, four types of scale are distinguished to characterize observations or measurements:

- Nominal scale: just uses a label e.g. 'igneous rock';
- Ordinal scale: indicates a ranking order, e.g. Mohs' scale of mineral hardness (numerical differences between observations have restricted meaning, ratios are meaningless);
- Interval scale: assigns quantity on a scale with an arbitrary zero, e.g. temperature scale in °C (numerical differences between observations are meaningful, ratios are meaningless); and
- Ratio scale: assigns quantity on a scale with a non-arbitrary zero, e.g. length or weight (numerical differences between observations as well as ratios are meaningful).

Some of the assessment data will by their very nature be in terms of a nominal scale. In IW:RAF an ordinal scale was used consistently for all indicators developed. This was prompted mainly by the lack of reliable and accurate data. Using an ordinal scale, however, limits the options for arithmetic and statistical operations considerably, for example it is hardly possible to define trends if data or indicators are expressed as values on an ordinal scale. An attempt will therefore be made to base the values of TWAP's most relevant indicators of change on a ratio scale.

### 3.2.5 Upscaling information to the spatial unit of assessment

As mentioned in section 3.2.2 the proposed primary spatial units for the TWAP groundwater assessment will be the national segments of each transboundary aquifer and the whole territory of SIDS. Characterising the TBAs and SIDS aquifers in the proposed spatial units with a list of indicators enables such a comparison, provided that the indicators are 'lumped' over the entire spatial unit. According to the type of indicator, different upscaling procedures may be considered to produce a representative and meaningful lumped value:

(1) ***Summation:*** Appropriate for some types of variable (inputs and outputs), but inappropriate for others (local 'state' variables). While local groundwater recharge and discharge components (in $m^3$/year) can be summed to produce meaningful lumped variables related to an entire spatial unit (total aquifer recharge, total aquifer discharge, total abstraction, etc.), this procedure does not make sense in the case of groundwater levels or groundwater quality, because these variables do not belong to the type to which 'additivity' applies;

(2) ***Averaging:*** Producing average values (over the entire spatial dimension) is a valid procedure that in theory may yield correct – although simplified - information on the state of groundwater depletion and pollution (see Figure 6). However, the process of averaging removes information about extreme values and may introduce bias, especially if the aquifer is large and groundwater conditions vary considerably in space. For example, excessive concentrations of nitrate in 20% of an aquifer's extent (which is substantial) may remain unnoticed in the mean value of the nitrate content of the aquifer; and the mean Total Dissolved Solids (TDS) value of a fresh aquifer with a relatively modest sea-water intrusion zone may give the impression of an overall brackish aquifer; and

(3) ***Defining the percentage of the aquifer's area where a predefined threshold value is exceeded:*** The idea here is that, first, to specify a threshold value of the variable being considered. This threshold is linked to some standard (e.g. drinking water quality standards) or in some way represents a value beyond which one may become concerned. Then the percentage of the aquifer's horizontal area where the threshold is exceeded is defined or estimated. This gives an indication of how seriously the aquifer is affected by the assumed undesired conditions.

**Figure 6**: Upscaling spatially-variable data by averaging over the spatial assessment units

The procedure to be followed for upscaling spatially-variable information into single indicator values for the proposed spatial units will be defined for the each of the indicators proposed in Part 3.

# 4. OUTLINE OF A METHODOLOGY FOR TWAP GROUNDWATER

## 4.1 Defining the core outputs

Defining the core outputs is a crucial part of the methodology. As indicated in Figure 4, defining the outputs has to interact with the development of procedures for inventory and data acquisition, because the assessment will not be successful if indicators, maps and other outputs are not tuned to the types of data that are expected to be collected. Interaction with the other TWAP water system components has been taken into consideration (Interlinkages – see Part 4), as the outputs of all five water system types are expected be compatible and consistent. Furthermore, indicators in some of the domains (e.g. socioeconomics, law, institutions) may be partly or completely shared.

The process of developing indicators and specifications for maps and other outputs is guided by a number of major factors:

(a) *TWAP objectives*: global assessment of transboundary water bodies for GEF purposes. As far as indicators are concerned, TWAP is required to develop indicators on current conditions as well as projected conditions (see Part 3);

(b) *Politics*: political goals adopted by the world community, e.g. at the World Summit on Sustainable Development and in the form of the Millennium Development Goals, highlight internationally supported priorities. As far as they relate to water, these should be reflected in TWAP indicators;

(c) *Analytical frameworks*: the analytical framework should provide guidance on the development of a consistent set of indicators, covering all relevant aspects, but avoiding duplication and inconsistencies. The DPSIR framework is probably the best available for the task. Since IW:RAF has been working on a closely related theme, TWAP may benefit from experience gained and elements developed in IW:RAF; and

(d) *Data availability:* the outputs should be tuned to data that are accessible and reliable, including data already available and those that will be acquired in the framework of TWAP.

Proper attention should be given to what kinds of maps are required:

- *Location maps*, showing the boundaries and identification of the world's transboundary aquifers (update and elaboration of WHYMAP and IGRAC world maps of transboundary aquifer systems);
- *Aquifer maps*, showing the boundaries, topographic and/or hydrogeological features and relevant cross-sections for individual aquifers; and

- *Thematic maps*: global, regional or aquifer maps showing the values of selected variables or indicators (for the baseline or any future assessment). These maps are optional (not belonging to the core outputs for Level 1), but may be generated as part of the functionality of the information system for optimal presentation of the information it contains.

Except for the global maps, there is no obvious need to standardize scale and resolution on the computer screen or on hard copies. Standardizing resolution would lead to unnecessary loss of information. Standardizing scale over all international groundwater systems may even be very inconvenient, because the size of the aquifer systems may differ by orders of magnitude. However, it may be useful to prepare all maps for each individual aquifer on the same scale.

All these envisaged outputs can only be produced if relevant sets of basic data are available. The variables for which basis data have to be collected are discussed in section 4.4. Although not belonging to the core outputs, these data are of fundamental importance for TWAP, both for the baseline and for later assessments.

### *4.1.1 Defining the core outputs of Level 1 Assessment*

The envisaged core outputs for Level 1 (global baseline assessment)can be summarized as follows:

(1) List and global map of transboundary aquifer systems and SIDS to be considered (more details on this output can be found in section 4.3);

(2) Location map of all transboundary aquifers and SIDS, if possible with cross-sections;

(3) Description of each transboundary aquifer and SIDS, including name, administrative data, geographic position, and some other 'static' key characteristics (Box 1 gives an idea of parameters to be included);

(4) Values of the set of selected TWAP groundwater indicators, defined to convey clear messages on the needs and relative priority of joint management of international groundwater systems, including the issues to be addressed (Section 4.2 outlines the general approach, with details in Part 3);

(5) Values of the variables collected to enable the outputs (3) and (4);

(6) A dedicated information system to facilitate storage, retrieval and presentation of the outputs and all underlying data (this is elaborated in Part 5); and

(7) A summary report to present the major findings and list the core outputs, indicating how and where these can be accessed.

**Box 1**: 'Static' key parameters for TBA system characterization. SIDS aquifer characterisation will use a similar outline but does not need to differentiate between various national segments.

## TRANSBOUNDARY AQUIFER SYSTEM CHARACTERIZATION SHEET

(time-independent or virtually time-independent key reference data)

| *Insert Map of Transboundary Aquifer System With Cross-sections* |
|---|
| |

### Geography and geometry

- Name of the transboundary aquifer system:
- Number of countries sharing the aquifer system:
- Names of the countries sharing the aquifer system:
- Total area covered by the transboundary aquifer system (km$^2$):

| | Country X | Country Y | Country Z | Total area |
|---|---|---|---|---|
| Absolute share of the system's area (km$^2$) | | | | |
| Relative share of the system's area (%) | | | | |
| Mean aquifer system thickness (m) | | | | |

### Brief aquifer system characterization

| | Country X | Country Y | Country Z | Total area |
|---|---|---|---|---|
| Predominant aquifer lithology: | | | | |
| Predominant type of voids (pores, fissures, fissured karst, mixed): | | | | |
| Predominant hydraulic condition (confined, semi-confined, unconfined, mixed): | | | | |
| Depth: range (min – max) and average (location of top in metres below surface) | | | | |
| Thickness: range (min – max) and average (metres) | | | | |
| Transmissivity: range and average (m$^2$/day) | | | | |
| Predominant sources of virgin recharge (precipitation, runoff, influent streams, lakes, etc.): | | | | |
| Mean annual virgin recharge (million m$^3$/a): | | | | |
| Areal extent of recharge area (km$^2$): | | | | |
| Relative share in the recharge area (%): | | | | |
| Main sources of natural discharge (springs, base flow, outflow into lakes, submarine outflow, evaporation, evapotranspiration): | | | | |
| Interlinked lakes, river systems and large marine ecosystems | | | | |
| Stored volume of fresh groundwater (km$^3$): | | | | |
| Predominant natural groundwater quality (fresh, brackish, saline, mixed): | | | | |
| Predominant natural aquifer vulnerability (high, medium, low): | | | | |

### 4.1.2 Defining the core outputs for Level 2 Assessment

The Level 2 assessment will be carried out in four selected transboundary aquifer case studies. It is foreseen that the case studies will include two transboundary aquifers in developing countries and two in developed countries.

The objective of the level two assessments will be to compare TBAs in developing and developed countries. It is expected that this comparison will allow the derivation of recommendations for the sustainable management of TBAs.

The Level 2 assessment will be based on Transboundary Diagnostic Analyses/Causal Chain Analyses available for the selected four aquifer systems. It will investigate emerging and priority issues within the selected systems in more detail. Interlinkages with the other water system types will be analysed, including physical interlinkages (fluxes of water and dissolved materials from one water system to the other) and non-physical interlinkages, such as legal and institutional settings and socioeconomic conditions.

Outputs of the Level 2 assessment will include in-depth assessments of the four selected transboundary aquifers' priority issues, cross-cutting and emerging issues, taking into consideration interlinkages with other water system types. The assessments take into account physical, socioeconomic, legal, institutional and environmental dimensions of the causality. The Level 2 assessments require sufficient data and information of the aquifer systems concerned in order to carry out the in-depth analyses. The two case studies in developing countries will therefore be selected from the GEF IW portfolio of TBA projects.

## 4.2 General approach to indicator development

The DPSIR framework has been employed in defining the set of groundwater indicators and underlying variables. The DPSIR methodology helps establish the relationships between social, economic and environmental issues and the most burning issues in groundwater resource development, protection and management.

Although the DPSIR framework is very convenient and useful, in practice there may be substantial divergence among its users on what belongs to which component of the framework. In particular, the distinction between Drivers and Pressures appears to be difficult. Table 1 gives some clarification and makes a link to different professional fields (also subject to differences of interpretation). When using the DPSIR framework, it may be helpful to consider the global existence of 'primary concerns' on groundwater. These include maintaining the integrity of groundwater quantity and quality, optimizing benefits from use and environmental functions of groundwater and minimizing negative impacts of changing boundary conditions. 'Secondary concerns' focus on conditions for groundwater management and control (awareness, legal framework, plans and regulations, institutions, stakeholders attitudes, governance, etc.) superposing the social impacts and responses for adaptation to climate change.

The indicators are developed on the basis of variables. The variables relevant in the context of TWAP's groundwater component and related indicators are discussed in section 4.4.

**Table 1:** Diagram showing (tentatively) the prevailing relations between the DPSIR Framework, TWAP indicators in relevant professional fields and GEF's Status and Process Indicators. The central system considered is a groundwater system.

| | **COMMENTS/INTERPRETATIONS** | **INDICATORS RELATED TO DIFFERENT PROFESSIONAL FIELDS** | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Science (hydrogeology, hydrochemistry etc.)* | *Environment, including climate* | *Socioeconomics, including demography* | *Law* | *Institutions* | *Combination* |
| *Drivers (D)* | Root causes of change with respect to 'virgin' conditions (demography, economic development, land use, poverty, politics, climate, etc.) | | X | X | | (X) | X |
| *Pressures (P)* | Factors acting as 'boundary conditions' (stresses) to the groundwater system, often in the form of input/output of substances into/from the groundwater body (groundwater recharge, discharge, abstraction, pollution, imposed water level) | X | X | X | | (X) | X |
| *State (S)* | Physical conditions of the groundwater (water quantity, level and quality) | X | | | | | |
| *Impacts (I)* | Social, economic and environmental functions and effects produced by the groundwater system and its exploitation (benefits and disbenefits/problems, current or expected, i.e. issues of concern) | | X | X | | (X) | X |
| *Responses (R)* | Human actions intended to increase socioeconomic and/or environmental benefits from groundwater or to reduce problems/disbenefits (current and expected). Includes two categories: | | | | | | |
| | (a) pro-active ('enabling environment') | | | X | X | X | X |
| | (b) re-active (measures for control and mitigation) | | | | | X | |

## 4.3 Identification and selection of international groundwater systems

### *4.3.1 Identification of transboundary aquifers*

The point of departure for the identification of transboundary aquifers is three sources: (1) UNESCO-IHP's 'Atlas of Transboundary Aquifers' (2009), the latest overview presented by IGRAC's map 1:50 000 000 entitled 'Transboundary Aquifers of the World' (2009) and WHYMAP's 'Transboundary Aquifers of the World' (2006).

IGRAC's map presents 318 transboundary aquifers across the globe, shows the names and sharing countries for each of these, and specifies lateral boundaries, areal extent and aquifer type for many of them. UNESCO's Atlas includes a smaller number of transboundary aquifers (almost 200), but presents a brief characterization for each (name, countries sharing it, location map and summary information). The Atlas also mentions and summarizes transboundary aquifer case studies in each of the regions.

Based on these sources, a provisional list of aquifers can be prepared. The following steps are foreseen to convert this to a *list of transboundary aquifers selected for TWAP*.

- *Verification, updating and supplementation* of the list, in cooperation with relevant regional networks (regional ISARM groups, UNECE, etc.). Some additional regional networks may have to be formed for this purpose (e.g. in Asia). The objective is to make the list consistent with the latest available information and ensure that important transboundary aquifers are not overlooked.
- *Homogenization* of the list, in cooperation with relevant regional networks (regional ISARM groups, UNECE, etc.). Different concepts and different degrees of spatial aggregation have been used to define transboundary aquifer systems. In particular, there is a need to revise the European transboundary aquifer systems (many are more 'transboundary aquifer zones' than transboundary aquifers) with the aim of integrating them into larger units that are more meaningful in a global context. In some other regions (e.g. the Americas) there are considerable variations in the concepts used to define transboundary aquifer systems.
- *Preliminary classification* of the identified aquifers according to their relative importance. A criterion for relative importance has to be defined – a pragmatic criterion could be the aquifer's horizontal extent ($km^2$). The purpose of this preliminary classification is to reduce the number of transboundary aquifers to be included in TWAP, by removing those considered 'a priori' to be of limited importance.
- *Preparing a list of aquifers to be considered by TWAP***.** This should include all aquifers that are considered relevant for a global assessment. Criteria could include the importance of the aquifers (e.g. deleting all aquifers smaller than in 1 000 $km^2$).

### *4.3.2 Identification of SIDS aquifer systems*

For Small Island Developing States (SIDS), the interpretation of 'international groundwater' does not imply transboundary aquifers, but simply all aquifers within these states.

An overview of SIDS, according to the SIDS portal of UNDESA[22], is shown in Table 2. Note that not all of these are island states (four are on continents) and that some are not really small (four are larger than 50 000 $km^2$and seven have more than one million inhabitants).

As with transboundary aquifers, a list should be prepared of the SIDS to be considered by TWAP. Interaction with GEF should clarify the criteria (size, population, eligibility, etc.) to be used for reducing the list– if it is to be reduced at all.

[22] http://www.un.org/esa/dsd/dsd_aofw_sids/sids_members.shtml

**Table 2**: Small Island Developing States according to UNDESA.

| STATE | POPULATION (year) | TERRAIN | COASTLINE (km) | SIZE* (km²) |
|---|---|---|---|---|
| ***AIMS Region (8 SIDS)*** | | | | |
| Cape Verde | 491 419 (2007) | Rugged, rocky, volcanic | 965 | 4 033 |
| Comoros | 574 660 (2007) | Volcanic islands | 340 | 2 170 |
| Guinea-Bissau | 1 389 497 (2007) | Mostly low coastal plain | 350 | 36 120 |
| Maldives | 304 869 (2007) | Flat | 644 | 300 |
| Mauritius | 1 252 698 (2007) | Small coastal plain, central plateau | 177 | 2 040 |
| Sao Tome & Principe | 154 875 (2007) | Volcanic, mountainous | 209 | 1 001 |
| Seychelles | 84 600 (2007) | Narrow coastal strip, coral, flat | 491 | 455 |
| Singapore | 4 608 167 (2008) | Lowland; gently undulating central plateau contains water | 193 | 693 |
| ***Caribbean (23 SIDS)*** | | | | |
| Anguila | 13 008 (2004) | Flat low-lying coral and limestone | 61 | 102 |
| Antigua & Barbuda | 81 000 (2006) | Low-lying limestone and coral | 153 | 443 |
| Aruba | 103 980 (2007) | Flat | 70 | 193 |
| The Bahamas | 323 000 (2006) | Long flat coral formations | 3 542 | 13 940 |
| Barbados | 23 987 (2007) | Flat, central highland | 97 | 431 |
| Belize | 311 480 (2007) | Flat swampy coast + high mountains | 386 | 22 966 |
| British Virgin Islands | 20 253 (2004) | Flat coral islands + hilly volcanic islands | 80 | 153 |
| Cuba | 11 237 916 (2007) | Terraced plains, hills, mountains | 5 746 | 110 860 |
| Dominica | 79 000 (2005) | Rugged volcanic mountains | 148 | 754 |
| Dominican Republic | 9 482 060 (2007) | | | 48 730 |
| Grenada | 107 379 (2007) | Volcanic, central mountains | 121 | 344 |
| Guyana | 751 558 (2007) | Rolling highlands, low coastal plain | 459 | 214 970 |
| Haiti | 8 407 000 (2007) | Rough and mountainous | 1 771 | 27 750 |
| Jamaica | 2 675 831 (2007) | Narrow coastal plains, mountains | 1 022 | 10 991 |
| Montserrat | 9 245 (2004) | Volcanic mountains, coastal lowland | 40 | 102 |
| Netherlands Antilles | 189 500 (2007) | Hilly, volcanic interiors | 364 | 960 |
| Puerto Rico | 3 944 000 (2007) | Mountainous, sandy beaches | 501 | 9 104 |
| St Kitts and Nevos | 48 000 (2005) | Volcanic, mountainous interiors | 135 | 261 |
| Saint Lucia | 166 838 (2007) | Volcanic, mountainous, broad valleys | 158 | 616 |
| S. Vincent & the Gren. | 119 000 (2005) | Volcanic, mountainous | 84 | 389 |
| Suriname | 509 970 (2007) | Rolling hills, narrow coastal plain | 386 | 163 270 |
| Trinidad & Tobago | 1 300 000 (2005) | Flat and hilly, mountainous | 362 | 5 128 |
| US Virgin Islands | 108 000 (2007) | Hilly, rugged, mountainous | 188 | 352 |
| ***The Pacific ( 20 SIDS)*** | | | | |
| American Samoa | 68 200 (2007) | 5 volcanic islands, 2 coral atolls | 116 | 199 |
| Comm. of N. Marianas | 79 100 (2005) | S: limestone + reefs, N: volcanic | 1 482 | 477 |
| Cook Islands | 21 100 (2007) | N: low coral atolls; S: volcanic, hilly | 120 | 240 |
| Fiji | 833 897 (2007) | Volcanic mountains, coral atolls | 1 129 | 18 270 |
| French Polynesia | 256 200 (2007) | Mix of rugged high and low islands | 2 525 | 4 167 |
| Guam | 173 456 (2007) | Mixed volcanic, coral, limestone | 126 | 549 |
| Kiribati | 92 533 (2007) | Low-lying coral atolls | 1 143 | 811 |
| Marshall Islands | 42 701 (2007) | Low coral limestone and sand | 370 | 181 |
| F.S. of Micronesia | 110 500 (2005) | Coral atolls, volcanic, mountainous | 6 112 | 702 |
| Nauru | 13 287 (2006) | Sandy beach, coral reefs, phosphate plateau | 30 | 21 |
| New Caledonia | 240 390 (2007) | Coastal plains, interior mountains | 2254 | 19 060 |
| Niue | 1 679 (2007) | Limestone cliffs, central plateau | 64 | 260 |
| Palau | 21 196 (2007) | Coral islands, main island mountainous | 1 519 | 458 |
| Papua New Guinea | 5 887000 (2007) | Narrow coastal plains, mountains | 5 152 | 462 840 |
| Samoa | 179 186 (2006) | Narrow coastal plains, mountains | 403 | 2,944 |
| Solomon Islands | 186649 (2007) | Low coral atolls, rugged mountains | 5 313 | 28 450 |
| Timor-Leste | 947 000 (2005) | Mountainous | 706 | 15 007 |
| Tonga | 114 684 (2006) | Coral formation, volcanic | 419 | 748 |
| Tuvalu | 11 000 (2006) | Low-lying and narrow coral atolls | 24 | 26 |
| Vanuatu | 221 417 (2007) | Narrow coastal plains, v. mountainous | 2 528 | 12 200 |

* Note: Size of the SIDS is based on information contained in GGIS.

## 4.4 Defining which data to collect

The envisaged TWAP outputs discussed in section 4.1 define what data should be collected during TWAP's baseline and future assessments. However, the outputs themselves will to some extent be defined by the feasibility of collecting specific types of data. An iterative process is therefore needed. As an input to this process, two lists of relevant variables have been drawn up.

The first, presented in Table 3, contains 17 variables that together give a general, more or less time-independent characterization of each transboundary aquifer system or SIDS groundwater system. Table 4 shows the second list, of 68 time-dependent variables identified with the help of the DPSIR framework and considered as potentially relevant in the context of TWAP. Several sets of 'variables' of the 'yes/no' category could be considered as single variables.

The sources of information mentioned in Table 3 and 4 are the sources to be consulted by TWAP's assessment teams. They basically consist of (i) easily accessible global or regional publications and databases; (ii) regional networks of knowledgeable experts; and (iii) global or regional modelling or remote-sensing projects. These sources, in turn, are based on or have access to more detailed information sources (e.g. national databases or even primary data sources such as project data bases or technical project reports). Together, these two lists will, with other inputs, inform the design of questionnaires for the acquisition of data through regional expert networks (see Part 2).

## 4.5 Current conditions versus projections

The TWAP FSP will provide information on the current and assumed future status of TBAs and SIDS aquifers. For the future status, projections of global change drivers and a limited set of indicators referring to priority issues in the groundwater systems will be developed for the years 2030 and 2050.

The TWAP Groundwater Methodology therefore includes two main types of indicators:

(1) ***Indicators of current conditions.*** These are the core outputs of the baseline assessment. They are based on observations and thus on factual information, although the accuracy and reliability of the underlying data may not be optimal; and

(2) ***Indicators of projected conditions.*** These indicators attempt to predict the future, 20 to 40 years ahead. Unlike the indicators of the previous category, these are not based on observations, but are 'guestimates', based on extrapolation of observed data, assumed trends and some basic transfer relations (models). They are therefore subject to uncertainty and should be used with caution.

All proposed indicators are presented and discussed in Part 3 of this report.

**Table 3**: Key aquifer properties to be defined as a general reference

| *PROPERTY, ASPECT OR CONCERN* | *VARIABLES TO BE INCLUDED IN THE ASSESSMENT* | | *MAIN SOURCES OF INFORMATION* | *HOW TO PRESENT* | *RESOLUTION** |
|---|---|---|---|---|---|
| Aquifer location and geometry | 1 | Geo-referenced boundary | Regional TBA networks; IGRAC map and UNESCO-IHP Atlas | Map | A |
| | 2 | Horizontal extent (km$^2$) | Regional TBA networks; IGRAC map and UNESCO-IHP Atlas | Numerical value | B |
| | 3 | Mean aquifer thickness (m) | Regional TBA networks | Numerical value | B |
| | 4 | Depth, range and average (m) | Regional TBA networks | Cross-sections (combined with lithology) | A |
| Countries sharing | 5 | Names of all sharing countries | Regional TBA networks; IGRAC map and UNESCO-IHP Atlas | Labels | B |
| | 6 | Percentage of aquifer area in each country | Regional TBA networks; | Numerical values | B |
| Aquifer lithology | 7 | Predominant aquifer lithology | | Label (lithology) | B |
| | | | | Cross-sections (combined with aquifer thickness) | A |
| Hydraulic setting | 8 | Predominant type of voids (pores, fissures, fissured karst, mixed ) | Regional TBA networks; UNESCO-IHP Atlas; Hydrogeological maps | Label | B |
| | 9 | Predominant hydraulic condition (confined, semi-confined, unconfined, mixed ) | Regional TBA networks; UNESCO-IHP Atlas | Label | B |
| | 10 | Transmissivity: range and average (m$^2$/day) | Regional TBA networks | Numerical value | B |
| Hydrological setting | 11 | Main sources of virgin recharge (precipitation, runoff, influent streams or lakes) | Regional TBA networks | Label(s) | B |

| PROPERTY, ASPECT OR CONCERN | | VARIABLES TO BE INCLUDED IN THE ASSESSMENT | MAIN SOURCES OF INFORMATION | HOW TO PRESENT | RESOLUTION* |
|---|---|---|---|---|---|
| | 12 | Predominant natural discharge mechanism (springs, baseflow, outflow into lakes, outflow into sea, evaporation/evapotranspiration) | Regional TBA networks | Label | B |
| | 13 | Mean virgin aquifer recharge (million $m^3$/a; mm/a) | WaterGap Model (Petra Döll) Regional TBA networks | Map (mm/a) | A |
| | | | | Numerical value (million$m^3$/a) | B |
| | 14 | Extent of recharge area($km^2$) | Regional TBA networks; | Numerical value ($km^2$) | B |
| | 15 | Groundwater volume ($km^3$) | Regional TBA networks; UNESCO-IHP Atlas | Numerical value | B |
| | 16 | Predominant natural groundwater quality (fresh, brackish, saline, mainly fresh + saline/brackish, mainly saline/brackish+fresh) | Regional TBA networks; IGRAC's draft report on saline and brackish groundwater | Label (methodology still to be defined/elaborated) | B |
| | 17 | Predominant natural aquifer vulnerability to pollution | Regional TBA networks | Overall score (methodology still to be defined) | B |

* ***Resolution:***

A: Depending on resolution of the source of information (e.g. 0.5 degree squares) and desired scale of maps and cross-sections. The latter may vary considerably since even if the minimum size considered is 1 000 $km^2$, then the largest TBA still is almost 4 000 time larger than the smallest one.

B: In principle one value only (aggregated total value, mean value, modus, percentage, label, depending on type of variable) for each national segment of a transboundary aquifer. In the case of SIDS a single value will be assigned to each SIDS.

**Table 4:** Time-dependent variables to be assessed for TWAP/Groundwater, in relation to DPSIR framework

| PROPERTY, ASPECT OR CONCERN | | VARIABLES TO BE INCLUDED IN THE ASSESSMENT | MAIN SOURCES OF INFORMATION | HOW TO PRESENT | RESOLUTION* |
|---|---|---|---|---|---|
| **DRIVERS** | | | | | |
| Demography | 1 | Population density (inhabitants/km$^2$) | Regional TBA networks; Global maps | Map | A |
| | 2 | Total population within aquifer | Regional TBA networks; Global maps | Numerical value | B |
| | 3 | Urban population as a percentage of total | Regional TBA networks; National statistics | Numerical value | B |
| Climate | 4 | Mean precipitation P (mm/a) | Regional TBA networks; Global maps and databases | Numerical value | B |
| | 5 | Mean potential evapotranspiration ETp (mm/a) | Regional TBA networks; Global maps and databases | Numerical value | B |
| | 6 | Expected change in P/ETp over next 50 years (in percentage) | Regional TBA networks; Global maps and databases | Numerical value | B |
| Economy | 7 | Mean gross economic product per capita ('aquifer equivalent' of GNP/capita)) | Regional TBA networks; National statistics | Numerical value | B |
| | 8 | Shares of each main economic sector in GNP (%) | Regional TBA networks; National statistics | Numerical values | B |
| | 9 | Current rate of economic growth (% per annum) | Regional TBA networks; National statistics | Numerical value | B |
| Land use | 10 | Percentages of land by main land use category | Regional TBA networks | Numerical values | B |
| Water supply and sanitation | 11 | Percentage of population covered by public water supply | Regional TBA networks; National statistics | Numerical value | B |
| | 12 | Percentage of population covered by public sanitation services | Regional TBA networks; National statistics | Numerical value | B |
| | 13 | Percentage of wastewater treated before discharge | Regional TBA networks; National statistics | Numerical value | B |
| Water scarcity | 14 | Mean annual rate of 'blue water' renewal per capita | Regional TBA networks; National statistics | Numerical value | B |

| PROPERTY, ASPECT OR CONCERN | | VARIABLES TO BE INCLUDED IN THE ASSESSMENT | MAIN SOURCES OF INFORMATION | HOW TO PRESENT | RESOLUTION* |
|---|---|---|---|---|---|
| **PRESSURES** | | | | | B |
| Groundwater recharge | 15 | Natural and induced recharge (including recharge by 'irrigation losses') (million $m^3$/a; mm/a) | Regional TBA networks | Numerical value | B |
| | 16 | Artificial recharge (million $m^3$/a; mm/a) | Regional TBA networks | Numerical value | B |
| Groundwater abstraction | 17 | Total abstraction (million $m^3$/a; mm/a) | Regional TBA networks | Numerical value | B |
| | 18 | Non-abstractional man-induced groundwater outflows (e.g. by drainage) (million $m^3$/a) | Regional TBA networks | Numerical value | B |
| Groundwater pollution | 19 | Percentages of area exposed to minor, medium and severe pollution sources | Regional TBA networks | Numerical value | B |
| Sea-water intrusion | 20 | Current sea-water inflows (minor, medium, severe) | Regional TBA networks | Classes | B |
| **STATE** | | | | | B |
| Groundwater quantity | 21 | Mean static groundwater level (or mean static depth to groundwater) | Regional TBA networks | Numerical value | B |
| Groundwater quality | 22 | Percentage of area where groundwater salinity restricts water use | Regional TBA networks | Numerical value | B |
| | 23 | Percentage of area where groundwater pollution restricts water use | Regional TBA networks | Numerical value | B |
| **IMPACT** | | | | | B |
| Services to and dependencies of humans | 24 | Abstraction for domestic/public water supply (million $m^3$/a; mm/a) | Regional TBA networks | Numerical value | B |
| | 25 | Abstraction for agricultural water supply (million $m^3$/a; mm/a) | Regional TBA networks | Numerical value | B |
| | 26 | Abstraction for industrial water supply (million $m^3$/a; mm/a) | Regional TBA networks | Numerical value | B |
| | 27 | Area of groundwater-fed wetlands & ecosystems($km^2$) | Regional TBA networks | Numerical value | B |
| | 28 | Area of groundwater-fed agricultural land ($km^2$) | Regional TBA networks | Numerical value | B |

| ***PROPERTY, ASPECT OR CONCERN*** | ***VARIABLES TO BE INCLUDED IN THE ASSESSMENT*** | | ***MAIN SOURCES OF INFORMATION*** | ***HOW TO PRESENT*** | ***RESOLUTION**** |
|---|---|---|---|---|---|
| | 29 | Area of groundwater irrigated land ($km^2$) | Regional TBA networks | Numerical value | B |
| | 30 | % of public/domestic supply dependent on groundwater | Regional TBA networks | Numerical value | B |
| | 31 | % of industry dependent on groundwater | Regional TBA networks | Numerical value | B |
| | 32 | % of irrigated land dependent on groundwater | Regional TBA networks | Numerical value | B |
| | 33 | Mean unit price of pumped groundwater | Regional TBA networks | Numerical value | B |
| Impacts on ecosystems | 34 | Combined mean annual yield of springs | Regional TBA networks | Numerical value | B |
| | 35 | Area of groundwater-supported wetlands ($km^2$) | Regional TBA networks | Numerical value | B |
| Other environmental impacts | 36 | Area of groundwater-related land subsidence ($km^2$) | Regional TBA networks | Numerical value | B |
| | 37 | Area of groundwater-supported agricultural lands (plants with roots that extend into the watertable) ($km^2$) | Regional TBA networks | Numerical value | B |
| | | Contribution to base flows (millionm$^3$/a) | Regional TBA networks | Numerical value | B |
| ***RESPONSES*** | 38 | | Regional TBA networks | | |
| Institutional development | 39 | Government institutions in place with mandate for groundwater management policies and strategies? | Regional TBA networks | Yes/no for each country involved | B |
| | 40 | Government institutions in place with mandate for implementation groundwater management policies and strategies? | Regional TBA networks | Yes/no for each country involved | B |
| | 41 | NGOs involved in groundwater management? | Regional TBA networks | Yes/no for each country involved | B |
| | 42 | Joint organization for TBA management in place? | Regional TBA networks | Yes/no | B |
| | 43 | Existing co-operation between the sharing with respect to the TBA considered? | Regional TBA networks | | B |
| Availability of legal instruments | 44 | Laws in place covering groundwater management? | Regional TBA networks | Yes/no for each country involved | B |
| | 45 | Treaties existing on transboundary groundwater management for this specific aquifer? | Regional TBA networks | Yes/no for each country involved | B |
| | 46 | Agreements existing on transboundary groundwater co-operation for this specific aquifer? | Regional TBA networks | Yes/no for each country involved | B |

| PROPERTY, ASPECT OR CONCERN | | VARIABLES TO BE INCLUDED IN THE ASSESSMENT | MAIN SOURCES OF INFORMATION | HOW TO PRESENT | RESOLUTION* |
|---|---|---|---|---|---|
| Existence of aquifer-specific GWRM plans | 47 | Groundwater management plan in place for the national sectors of the aquifer? | Regional TBA networks | Yes/no for each country involved | B |
| | 48 | Joint TBA management plan in place? | Regional TBA networks | Yes/no | B |
| Implementation of measures – Law and regulations | 49 | Groundwater well drilling permits required? | Regional TBA networks | Yes/no for each country involved | B |
| | 50 | Groundwater abstraction permits required? | Regional TBA networks | Yes/no for each country involved | B |
| | 51 | Land-use regulations | Regional TBA networks | Yes/no for each country involved | B |
| | 52 | Regulation on use/control of hazardous substances | Regional TBA networks | Yes/no for each country involved | B |
| | 53 | Waste disposal regulations | Regional TBA networks | Yes/no for each country involved | B |
| | 54 | Waste water treatment obligations | Regional TBA networks | Yes/no for each country involved | B |
| | 55 | Obligatory studies/environmental impact studies | Regional TBA networks | Yes/no for each country involved | B |
| | 56 | Obligatory monitoring | Regional TBA networks | Yes/no for each country involved | B |
| Implementation of measures - Incentives/ disincentives | 57 | Subsidies/credits/taxes on wells | Regional TBA networks | Yes/no for each country involved | B |
| | 58 | Subsidies energy used by wells | Regional TBA networks | Yes/no for each country involved | B |
| | 59 | Taxes on groundwater abstraction (tariff) | Regional TBA networks | Yes/no for each country involved | B |
| | 60 | Subsidies on water saving actions | Regional TBA networks | Yes/no for each country involved | B |
| | 61 | Restrictions on power supply | Regional TBA networks | Yes/no for each country involved | B |
| | 62 | Well retirement bonus | Regional TBA networks | Yes/no for each country involved | B |

| ***PROPERTY, ASPECT OR CONCERN*** | ***VARIABLES TO BE INCLUDED IN THE ASSESSMENT*** | | ***MAIN SOURCES OF INFORMATION*** | ***HOW TO PRESENT*** | ***RESOLUTION**** |
|---|---|---|---|---|---|
| | 63 | Public awareness | Regional TBA networks | Yes/no for each country involved | B |
| Implementation of measures – structural works | 64 | Government well schemes (no. of wells) | Regional TBA networks | Numerical value | B |
| | 65 | Artificial recharge schemes (total mean capacity, million $m^3/a$ ) | Regional TBA networks | Numerical value | B |
| | 66 | Sewerage systems (% of wastewater collected in sewers) | Regional TBA networks | Numerical value | B |
| | 67 | Treatment plants (% of wastewater treated) | Regional TBA networks | Numerical value | B |
| | 68 | Controlled landfills (% of total solid waste) | Regional TBA networks | Numerical value | B |

* ***Resolution:***

A: Depending on the resolution of the source of information (e.g. 0.5 degree squares) and the desired scale of maps and cross-sections. The latter may vary considerably since even if the minimum size considered is 1 000 $km^2$, then the largest TBA still is almost 4 000 time larger than the smallest one.

B: In principle one value only (aggregated total value, mean value, modus, percentage, label, – depending on type of variable) for each national segment

# PART 2. IDENTIFICATION AND CHARACTERIZATION OF TRANSBOUNDARY AQUIFERS[23]

## 5. OBJECTIVES

(a) *Making transboundary aquifer systems[24] 'visible' and recognized by the countries that share them.*

(b) *Collecting, to the extent feasible within the context of TWAP, a set of data for each transboundary aquifer which, when combined, gives a first description of its present hydrogeological, environmental, socioeconomic, and governance conditions, and its interactions with adjoining water-bodies and ecosystems.*

Unlike all other water bodies, aquifers are located in the subsurface and visible only through the eyes of science – hydrogeology. As a consequence, while groundwater is used intensively in all countries, in many cases this is in the absence of a full understanding of the nature and characteristics of the resource. Moreover, aquifer boundaries are often very poorly known and so many aquifers remain unknown or only partly recognized as separate, often unconnected, entities.

This is particularly true for transboundary aquifers, which are often not recognized as shared resources by countries because of differing geological litho-stratigraphic approaches, lack of communication between countries, uneven availability of data, or sovereignty issues. Lack of recognition of the nature of shared resources increases their vulnerability to anthropogenic pressures.

During the last decade, the Internationally Shared Aquifer Resources Management (ISARM) Program launched by UNESCO IHP[25], aimed at raising international awareness of the need to properly manage these highly vulnerable resources, has for the first time completed a preliminary regionally-based inventory of transboundary aquifers and focused global attention on these widespread and valuable resources. The ISARM approach and experience inform the methodological design of the 'Identification and Characterization of TBAs' part of TWAP groundwater, which will strive to expand and complement the ISARM inventory globally.

## 6. METHODOLOGICAL APPROACHES

As stated, the TWAP methodology for implementing the Identification and Characterization activities will draw heavily on the ISARM experience[26], in particular from its most advanced regional effort – ISARM Americas, thus building on what has already been achieved globally in terms of TBA identification and initial characterization. It is expected that by doing so, and by providing new and additional financial resources and overall technical oversight and management, the global TWAP Baseline Assessment of Transboundary Aquifers will be produced within a reasonably short period of time.

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[23] Including SIDS

[24] For a definition, see Part 1

[25] A meeting of experts held in parallel with the International Conference on Regional Aquifer Systems in Arid Zones organized by UNESCO in Tripoli 20–24 November 1999 indicated the need to create an international network supported by IAH, UNESCO, FAO and UNECE. Therefore, with the support of UNESCO and IAH in co-operation with FAO and UNECE, a meeting of experts was held at UNESCO in Paris on 27–28 March 2000. As a result of the meeting a proposal for an international initiative on Internationally Shared/transboundary Aquifer Resources Management (ISARM/TARM) was formulated, and later approved by the IHP Intergovernmental Council.

[26] The ISARM Atlas (2009) contains a synthesis of the methodology and lessons learned so far

The methodology for this part of TWAP Groundwater will adopt the following approaches.

***1. Harmonization of information***

The methodology for the Identification and Characterization of TBAs has been designed in such a way as to provide, within a defined period of time, a harmonized and comparable synopsis of transboundary aquifers globally, reflecting the present state of knowledge and availability of information. This will be achieved by ensuring technical and scientific supervision, using predefined guidelines, methodologies, information formats and forms and coordination of efforts at the regional and global level. The ISARM experience will be of great value in identifying ways to ensure harmonization and comparability of TWAP results.

***2. Regional Approach***

The global Identification and Characterization of TBAs, while using a common methodology, will be regionally based, i.e. executed by 'regions': geographical units with borders represented by oceans or by other major geologic discontinuities (e.g.: the Himalayas – Hindu Kush Chain). This approach will allow a better capture of existing knowledge and expertise, and create partnerships with regional organizations and networks, cornerstones of the TWAP GW execution arrangements. The ISARM regions will be used (Americas, Africa, Western and South Eastern Europe, Caucasus and Central Asia, Middle East, Asia), with the addition of special SIDS groupings.

***3. Country Involvement***

The Identification and Characterization exercise will aim to involve directly all countries likely to share aquifers. Such involvement is considered an essential element of the TBA methodology, given the need to improve data availability and achieve visibility of the aquifers and mutual recognition of their shared nature.

***4. Acquisition of information***

Data acquisition is complex because it encompasses a large number of aquifer systems, spread over almost all countries of the world. Conditions may range from well-documented aquifer systems managed by institutions (only a few!) that monitor all relevant aspects, to poorly-explored aquifer systems that are not monitored or managed at all (the majority).

With the exception of ISARM and its related programmes (WHYMAP, IGRAC and some others), information on TBAs is not being systematically collected or stored in publicly-available databases. *The need to make an effort in the context of TWAP to complement what is already available with newly acquired information has thus emerged as a priority*. Two ways have been identified as feasible within the financial and time constraints of TWAP:

(i) The systematic use of questionnaires and regional networks of experts; and

(ii) Reliance on remote sensing and modelling whenever technically and economically feasible.

Retrieving *data from easily accessible databases* will be the first step. However, experience in IW: RAF has shown that current global databases may only provide an initial limited description of the groundwater systems. For most systems they certainly do not meet the requirements for quantifying even a simple set of indicators at the aquifer level, let alone enable the fulfilment of TWAP's ambition to assess trends over time.

Other steps are needed to ensure that sufficient data becomes available. A very evident one is to form *partnerships with groundwater-related institutions* all over the world and involve the accessing, processing and compiling information from databases within their countries. The work will be guided by dedicated questionnaires. This is basically the ISARM methodology. Regional ISARM groups will be invited to contribute to TWAP and new groups of this type will be established in areas not yet covered. Eventually, these may be motivated to expand their field assessment and monitoring programmes. As demonstrated by ISARM, well-designed questionnaires are a powerful tool for targeted, efficient and standardized collection of data by these regional working groups.

Questionnaires will be used to guide and organize the Identification/Characterization process in a harmonized way, and to complement existing information. They will be directed to country and regional experts thus strengthening country/local participation and ownership. Responses will be the responsibility of 'regional expert networks', which will coordinate country inputs and complement them (e.g. through regional geological considerations and expertise) whenever possible. An example of the ISARM questionnaire is shown in Annex 4.

Questionnaires will address primarily:

- The existence and spatial distribution of TBAs and their mutual recognition by countries sharing them;
- Information on the key elements that characterize their *status*, and the situation relating to governance and other *processes* (see Tables 3 and 4);
- The identification of issues of transboundary concern; and
- Interactions with other water bodies.

An ad hoc event organized by UNESCO and IGRAC in Utrecht in April 2010[27] explored the feasibility of using, in the context of TWAP Groundwater, newly collected data from satellite image processing, and from modelling, in addition to the information derived from national and regional sources and expert networks. The experts at that meeting concluded that these tools might in some cases be a cost-effective way of filling gaps in information coverage, complementing/extrapolating available information, producing projections and scenarios, and identifying parameters to be monitored over time (see Annex 5).

It is envisaged that, for the purposes of the TWAP baseline assessment, a special task force on innovative approaches will be created to complement, whenever feasible, the work of regional networks as they advance in the characterization of transboundary aquifers with newly acquired information.

## 7. EMERGING & PRIORITY ISSUES AND HOTSPOTS

Within TWAP, an **emerging issue** is defined as *a problem, opportunity or concern that has only recently started to develop or be perceived* (the latter may relate to current conditions or expected future conditions). A **priority issue** is defined as a problem, opportunity or concern that needs to given priority. Priorities may change over time, gradually (in response to gradually changing conditions) or suddenly (in response to disasters or other sudden events). A **hotspot** is defined as a demarcated geographical location or zone requiring special attention from a certain point of view, usually because of a specified current or potential problem or concern.

There are some complicating factors surrounding these issues that need to be clarified before one can decide how these issues are addressed in TWAP. First, the selection and definition of emerging and priority issues and hotspots involves a strong element of human perception and preferences (subjectivity). Second, the scale at which we want to define emerging and priority issues and hotspots is important. A priority issue can be chosen within the limits of a single transboundary aquifer and/or SIDS but may also can be selected at a global scale.

[27] The report of the Utrecht workshop is attached as Annex. 5.

We suggest two scales for identifying emerging issues, priority issues and hotspots:

- *Scale of individual transboundary aquifer and/or SIDS*: The regional networks of groundwater experts describing and characterizing the individual transboundary aquifer and/or SIDS (see Part 2) give a narrative description of at least one emerging issue and one priority issue. They identify hotspot zones within the transboundary groundwater system and/or SIDS where the emerging and priority issues (and cross-cutting issues) are occurring. This identification takes place in the Level 1 assessment; and

- *Scale of the global TWAP assessment*: The indicator-based Level 1 assessment (with lumped figures of various indicators for each transboundary groundwater system and/or SIDS) reveals which groundwater issues occur often and which locations have many issues. GEF (with the help of the TWAP groundwater core group) prioritizes issues that require more GEF attention thematically, and transboundary groundwater systems and/or SIDS that require more GEF attention geographically. This 'ranking' exercise should be based on the needs and objectives of GEF IW. Consequently, the ranking criteria (like weighting factors) are defined by GEF. At this scale and only at this stage, a number of global groundwater hotspots are selected for Level 2 TWAP assessment.

## 8. OUTPUTS[28]

*Inventory:*

The inventory will consist of a list, by region, of all major[29] known TBAs and their spatial distribution and expression on the surface. A tentative delineation of aquifer boundaries will be attempted using the physical boundaries of the host rock formation to provide a rough approximation of the boundaries of aquifer systems, which are difficult to identify with precision. A name will be assigned to each aquifer system (scientific, international, local).

The inventory will be based on existing specific information (e.g. ISARM atlases); newly acquired information (questionnaires/regional networks, remote sensing and modelling); and regional geological considerations (wherever, in the absence of specific information, regional geology suggests the likely presence of important aquifer systems).

The Inventory will also delimit areas with no information, or where information is thought to exist, but is not readily available.

The Inventory will include a listing of SIDS and their categorization based on their geomorphological nature.

*Characterization:*

The output will include:

(1) All collected data and information, organized according to Box 1. This represents the cornerstone of all TWAP outputs; and

(2) A short narrative for each aquifer system, which aims to include, but may not be limited to (see Tables 3 and 4):

(i) Scientific information: hydraulic state, hydrogeological nature of the host rock, its three-dimensional distribution, storage capacity, its recharge and discharge zones, the regional hydrology, climatic conditions and likely scenarios, the natural physical and chemical characteristics of the water, and the aquifer's role and relevance in

[28] See also Part 4.
[29] See Part 1 for a definition.

maintaining the integrity of ecosystems (wetlands, base flow of rivers, oasis, alluvial plans, etc.);

(ii) Legal information: the legislative context in each country sharing the aquifer; the existence of legally-defined management systems; the presence of and adherence to international agreements, aquifer treaties, soft law guidance etc.; the relationships with river/lake basin authorities and management frameworks;

(iii) Socioeconomic information: human uses and trends (domestic, agriculture, industry, energy, environment), socioeconomic drivers;

(iv) Institutional setting: existing institutional frameworks and governance issues;

(v) Environmental conditions: anthropogenic and natural stresses/disturbances such as pollution and level of abstraction, saline intrusion; impacts of climate variability and change; level of integrity of groundwater-dependent ecosystems;

(vi) Issues of Transboundary concern: whenever possible, the main stresses requiring the coordinated mitigation actions of countries sharing the aquifer will be identified; and

(vii) Interactions with other water bodies.

Particular emphasis will be placed on collecting information and data relevant to the application of the TWAP GW Indicators (Part 3).

The collected data sets are to be stored in an information system, readily available for retrieval and presentation in different formats, but also as key elements for scientific verification of all TWAP's outputs.

*Cartographic representation:*

The imperative of making TBAs 'visible', which underpins the whole methodology, requires that each TBA is, to the extent possible, represented *two dimensionally* on a map. Such a map contains its approximate boundaries, and recharge and discharge areas including dependent ecosystems, and *three dimensionally* in geologic cross-sections of the subsurface, indicating the approximate geometry of the aquifer, its varying depth, its relations with aquitards and aquicludes, the major tectonic discontinuities and preferential permeability pathways and barriers. This will be a fundamental contribution of TWAP to better understanding and governance of groundwater resources globally.

A preliminary systematic attempt at representing aquifers on maps and sections has been made by ISARM, IGRAC, and WHYMAP. In several cases the geographic location of TBAs was provided using symbols, often along political boundaries. More recently WHYMAP has produced possibly the best examples of cartographic and web-based representations of various types of aquifer (using a simple and very effective legend), including transboundary aquifers at a global and continental scales.[30] We have to bear in mind however that WHYMAP's level of spatial aggregation of hydrogeological units is different from what is appropriate at the level of most individual transboundary aquifers, with the exception perhaps of some very large ones. This is why WHYMAP units and transboundary aquifer boundaries often have an imperfect match. The TWAP Groundwater Component will build upon and complement the ISARM-IGRAC-WHYMAP approach, whenever possible.

[30] While TWAP will have to build upon previous efforts at the global/regional scales, it will nonetheless be useful to analyze, during TWAP execution, the results of the Guarani Aquifer Project as far as mapping and three-dimensional representation of this huge aquifer system is concerned (in the case of the Guarani, countries sharing the aquifer agreed on a common legend and a common geographic and geological cartography for the aquifer system).

# PART 3. INDICATORS

## *Background*

The main functions of indicators are: simplification, quantification, communication, ordering and allowing comparison of different countries and groundwater regions; providing condensed information on the functioning of the aquifer system and its response to stress in an understandable format; and acting as an important communication tool for policy and decision makers, planners and the public. They also help to translate information needs into data that have to be collected, and translate the collected data into policy-relevant information. However, an indicator is an instrument for identifying, not solving problems. The most common use of indicators is *description* of the state of the resource. Regular measurement of indicators provides time-series that show trends and may thus provide information on the functioning of the system or its response to stress. Another important function of indicators is *communication*. An indicator value can also be compared to a reference condition and so can be used as a tool for *assessment*. Finally, indicators can be used for *projections*. When models are linked to indicators, time-series projections may be derived.

Indicators must be selected by a carefully planned and implemented process. Developing 'good' indicators requires statistically meaningful time-series of reliable data to meet defined criteria. Because the same indicator may often relate to conflicting but equally important social, economic and environmental issues, deriving indicators becomes an objective-maximization exercise constrained by the available time, human and financial resources and partnership arrangements. The challenge lies in identifying or developing denominators common to as many cases as possible, so that comparisons may be made. If data can be gathered according to commonly-agreed or standardized measures, then lessons can be drawn that may be transposable from one case to another. However, scaling is an important attribute of indicator development and implementation.

During the design phase of TWAP (MSP), monitoring and evaluation requirements have been discussed during a number of general meetings with the following conclusions:

- Each water system working group (WG) should develop indicators covering state, process and stress factors, taking into consideration the scientific, socioeconomic and governance issues with overarching emphasis on impairment of ecosystem goods and services. The indicators should be linked to ongoing regional and global processes and related political goals and targets such as the World Summit on Sustainable Development (WSSD) and the Millennium Development Goals (MDG); and
- The WGs should consider a common approach for the scoring of the indicators, for example the use of numerical values, arrows, traffic lights, and maps. Harmonization of scoring should be further discussed.

The following cross-cutting issues should be considered by the working groups:

- Nutrients (in particular nitrates); and
- Mercury

The WGs emphasized the need to focus on the interlinkages between water system indicators and how indicators link with and relate to each other.

## 9. OBJECTIVES

(i) The set of indicators selected for TWAP Groundwater represents what would ideally be needed to capture the current state and projected trends of transboundary groundwater resources globally, as a basis for continuing, long-term monitoring. Due to the scarcity and uneven distribution of data and information however, the whole spectrum of proposed indicators will only be applicable in a few cases. Once the Identification and characterization phase is completed, the availability of data and information on transboundary aquifers in many hydrogeological regions of the world should be substantially improved, allowing a more systematic application of indicators. The proposed groundwater indicators are divided into **core** and **priority indicators. The set of 13 core indicators** will be applicable to several transboundary aquifers. A good example is the TWAP groundwater indicators used for the transboundary aquifer system in the Great Mekong River Basin covering parts of China, Burma, Thailand, Cambodia and Vietnam (Zaisheng and Jing, 2010). In many cases, however, due to data scarcity, it will be possible to develop only some of the proposed core indicators. **Priority indicators** are data-demanding and will only be applied in a few cases.

(ii) Groundwater indicators allow a comparative assessment of transboundary aquifers (TBAs), in a region or globally, in terms of various parameters (e.g. quantity, quality, vulnerability). These indicators and their integration into indexes will in turn facilitate priority-setting for GEF action and strategies.

(iii) They will also allow monitoring of the evolution of these parameters over time, and may therefore provide a measure of the effect of stress-reduction measures being implemented by the GEF and others.

## 10. DATA FOR THE FORMULATION OF TWAP GROUNDWATER INDICATORS[31]

The application of TWAP groundwater indicators will have to be feasible using the type of information to be obtained through the TBA Inventory and Characterization Activities (Part 2), which will be based on:

- Existing databases;
- Newly acquired information through regional expert networks, possibly complemented by;
- 'Synoptic' information derived from new technologies (remote sensing, models).

The variables that are relevant in this respect are listed in the Tables 3 and 4.

## 11. INDICATOR CATEGORIES

As already stated in section 4.2, the proposed TWAP transboundary aquifer methodology will focus on the following categories of indicators:

1) **Current State Indicators**[32] express basic quantitative and qualitative characteristics of groundwater systems and conditions that relate to an aquifer's physical and chemical characteristics, such as level of the water table, nutrient loads, health of groundwater-dependent ecosystems extent of marine intrusion, as well as socioeconomic and legal/institutional attributes; and

[31] See also Part 4, as well as Parts 1 and 2

[32] In the July 2010 TWAP meeting in Geneva it was decided to abandon the former distinction between the Status Indicators and Process Indicators. In order to avoid confusion, the newly merged category is not called 'Status Indicators' (as was suggested), but 'Current State Indicators' as opposed to 'Projected Stress Indicators'.

2) **Projected Stress Indicators.** The emphasis is on projections to 2030 and 2050. The scores of these indicators will be based on extrapolation by simple models, using the current situation (Current State Indicators and underlying variables) as the initial condition and expected trends of relevant key variables (e.g. demographic and climatic variables) as time-dependent drivers to enable projections of indicator scores over time.

## 12. CURRENT STATE INDICATORS

The proposed **set of 13 Current State Indicators for transboundary aquifers** reflects the present state of groundwater, socioeconomic and legal/institutional data availability and reliability. Access to this information is somewhat restricted for a number of reasons, including national groundwater monitoring networks and databases are not fully operational or have not yet been established in many countries; data are usually provided at the global, regional or country level, but only exceptionally at the aquifer or transboundary aquifer level; and the mutual comparability of existing groundwater data is often low, because groundwater monitoring methods, sampling procedures and data assessment and reporting are not yet internationally standardized. Socioeconomic and legal-institutional data are also collected on the country, not the transboundary aquifer level. TWAP Groundwater therefore foresees the systematic collection of data directly in the regions through expert networks, making use of questionnaires following the ISARM approach (see Part 2) and the groundwater databases of individual countries.

Groundwater data obtained through terrestrial measurements and satellite-based and remote sensing will also be used for the implementation of conceptual and mathematical models which will be applied in the development of projected transboundary stress indicators.

### Current state groundwater core indicators

The proposed current state groundwater core indicators provide information about groundwater quantity, quality and vulnerability; human and environmental dependence on groundwater; and human and natural stresses on groundwater resources in transboundary aquifers. Each of the proposed indicators describes a specific aspect of the groundwater system and is based on an aggregation of selected variables.

Groundwater-related indicators may be expressed in numerical values (e.g. groundwater recharge in $km^3$/year, chloride content in mg/l), or as a percentage (e.g. groundwater percentage of total drinking water use); some indicators are dimensionless (e.g. groundwater vulnerability). Scores are also used when data scarcity prevents numerical evaluation. The first group of indicators (those expressed in numerical values) is based on regularly measured data, provides time-series, and shows changes, trends, response to stress and other space- and time-dependent information. Dimensionless scores show relative differences in the characteristics of the aquifers and do not represent absolute values.

This report uses a scoring system that assigns three or more categories ranging from very high to very low for each variable used for indicator formulation. The final scores provide relative measures about groundwater characteristics in different TBAs, or areas of a TBA, and also facilitate mutual comparison of TBAs. However, if relevant data is available, a numerical value has been added.

Some of the proposed groundwater current state indicators may be combined into indices[33], which provide compact and targeted information about:

- Transboundary aquifer values and functions;
- Human and environmental dependence on groundwater; and
- Natural and human stresses on groundwater.

[33] Indices are dimensionless and a rating system is applied in their construction.

The indexes and indicators (core and priority) are shown in Tables 7, 8 and 9 together with an indication of the main data and information sources for the calculations. As explained above, we assume that **the set of 13 core indicators** will be applicable to many transboundary aquifers. The proposed indicators focusing on the natural groundwater system are presented in sections 12.1 to 12.3, the socioeconomic indicators in 12.4 and the governance indicators in 12.5.

## 12.1 Transboundary aquifer value and functions indicators

The following **four core indicators** represent TBA value and functions:

a) Mean annual groundwater recharge or

Total annual groundwater abstraction / Mean annual groundwater recharge;

b) Annual amount of renewable groundwater resource per capita;

c) Groundwater quality; and

d) Groundwater vulnerability.

**a) Mean annual groundwater recharge (km$^3$/year)**

Groundwater recharge is the replenishment of the groundwater of an aquifer. It is usually expressed as an average rate of millimetres of water per year over the total aquifer's extent, similar to the way precipitation is measured and reported.

The reliability of groundwater recharge data depends mainly on the accuracy of identification of prevailing recharge conditions (e.g. topography, land use, vegetation cover, soil type) and the accuracy of delineation of transboundary aquifer recharge areas. Existing geological and hydrogeological maps and satellite-based images may be used for area delineation.

TWAP's mean annual groundwater recharge indicator should be representative of current conditions and aim to be a long-term average. Estimates based on simulations of the Water GAP Global Hydrological (WGMH) model (Döll, et al., 2003) refer to the period 1961 – 1990; they have been used in the WHYMAP programme. In Döll's report, model estimates of diffuse groundwater recharge at the global scale, (spatial resolution 0.5° by 0.5°) are presented. It must, however, be noted that groundwater recharge in WGMH refers only to diffuse recharge from the soil to the groundwater. Groundwater recharge from streams and lakes and artificial recharge are not included. The RS SEBAL model for determination of evapotranspiration may be used in aquifers where precipitation and river runoff are fairly well known (see Annex 5).

The WGMH model and data collected from WHYMAP's Groundwater Resources Map of the World (GWRMW) are convenient for assigning a value to the groundwater recharge indicator where such values have not been determined by local aquifer studies. Five categories of groundwater recharge are shown in the GWRMW (Table 7). Spatial delineation of transboundary aquifers and their recharge areas may be provided by regional experts, if needed to complement WHYMAP and IGRAC transboundary aquifer maps and the ISARM Transboundary Aquifers Atlas, country maps and satellite-based measurements.

If data on groundwater abstraction for drinking, agricultural, industrial and other uses are available, groundwater recharge will be combined with groundwater abstraction and the recharge indicator will be replaced by:

***Total annual groundwater abstraction / Mean annual groundwater recharge (dimensionless)***

This indicator is a measure of total withdrawal of groundwater from a given TBA from wells and other devices to abstract groundwater. Data on groundwater abstraction are available in countries where permits for groundwater abstraction are obligatory and registered. Where such permit systems are lacking or do not cover all wells, groundwater abstraction may be calculated on the basis of observed water use (e.g. domestic, irrigation and industrial). In both cases, the level of uncertainty always has to be considered. The indicator is time-dependent and informs whether groundwater resources are being sustainably developed or over-exploited. While the ratio *Total groundwater annual abstraction / Mean annual groundwater recharge* is dimensionless, each of the two indicators can also be expressed volumetrically.

**b) Mean annual groundwater renewal per capita ($m^3$ /year/ capita)**

This driving force core indicator is defined as the mean annual amount of renewable groundwater resource of the aquifer divided by the number of people living on top of the aquifer. It is based on the recharge indicator described above (a) and current population statistics.

**Priority indicator related to groundwater quantity core indicators**

***Aquifer storage ($km^3$)***

This indicator expresses the amount of groundwater stored in an aquifer. It may be calculated on the basis of the thickness of the aquifer, its areal extent, and its mean saturated porosity or fissure percentage and estimated specific yield. Such a simplified indicator does not show how much water the aquifer will yield, but it gives basic information about the amount of groundwater in the aquifer (high, moderate, low) and thus information about the aquifer's importance in terms of its buffering capacity.

If numerical information is not available, a simplified approach for TWAP for evaluating this groundwater storage indicator has been proposed[34] based on a simple and feasible evaluation method. The three categories of aquifers applied in the Groundwater Resources Map of the World may be used as proxy values for aquifer storage.

**c) Groundwater quality**

This indicator provides information about the present status and trends of groundwater quality. It makes also possible to identify and foresee the outcome of processes leading to degradation of groundwater quality. However, the indicator has limitations, because groundwater data is obtained by point sampling of individual wells/springs and is applied on the aquifer scale. This may produce problems of spatial representation of groundwater quality in the aquifer even if the indicator is mainly intended for use at a broad spatial scale. See Part 1 for suggestions on how to upscale point data to the aquifer level.

The availability of data on the quality of groundwater-derived drinking water (WHO drinking water guidelines) which includes different types of organic compounds (e.g. aromatic hydrocarbons, chlorinated alkanes, and other miscellaneous organic constituents) is in many countries restricted and formulation of the relevant indicator will often not be possible. TWAP's groundwater quality indicator may be therefore formulated in a simplified form and based on data which is mostly measured and available at the country (groundwater monitoring networks) and local (water supply and irrigation groundwater quality measurements) level.

**One core groundwater quality indicator** is proposed (Table 7). Based on data availability, one of the following three will be implemented.

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[34] Calculation of groundwater storage and relevant indicator based on integration of terrestrial measurements and satellite-based data may be proposed, to be realized in the Level 2 of GEF project implementation.

1. Indicator of **drinking water standards** (assuming a large groundwater quality database is available).
2. Indicator based on a **composite value of electrical conductivity, chloride and nitrate content** (assuming a moderate groundwater quality database is available).When regularly analysed, these together provide a good indication of current status as well as changes in groundwater quality of natural and man-made origin. Many human activities produce pollution and release a salinity load that results in changes in groundwater electrical conductivity and chloride concentration. Natural nitrate concentration in groundwater is generally low (less than 10 mg/L) and higher concentrations are associated with man-made pollution. Additionally, nitrate and chloride are mobile and persistent in many shallow groundwater environments. An increase in the concentration of these may also indicate that other pollutants (e.g. volatile organic compounds) are present in groundwater and that more extended chemical analyses are needed to identify their concentrations and clarify their origin.
3. Indicator based on **individual variables: electrical conductivity, chloride, or nitrate** (assuming groundwater quality data is only available for one variable). For coastal aquifers, aquifers in arid and semi-arid zones and aquifers near salt deposits a **groundwater salinity indicator based on chloride content** may be developed and classified into four categories. A **cross-cutting indicator: nitrate content in groundwater** will also be expressed in four categories related to the nitrate drinking water standard.

**Priority indicators related to groundwater quality core indicator**

For naturally-occurring groundwater constituents that restrict the use of that particular water, the substances of main concern are **arsenic and fluoride**. If some of these are present in a transboundary aquifer (or some areas of the aquifer) at high concentrations, a relevant indicator will be developed and the aquifer area(s) with corresponding groundwater quality restrictions will be delineated on the map.

The groundwater quality indicator may be complemented with a **groundwater treatment requirements indicator** developed within the UNESCO IHP project. The indicator categories are: (1) Suitable for specific use without treatment (appropriate quality; (2) Simple treatment needed (dilution, filtration, disinfection, adjusting alkalinity, removal of iron or manganese by separation; (3) Specific chemical treatment needed; and (4) Technologically demanding treatment needed (membrane methods, reverse osmosis, flocculation and others).

The proposed indicators are based on data collected at the global, regional and country level and there are feasible evaluation methods for their formulation. Regular in-situ groundwater quality monitoring by national or local networks and water supply companies in water supply wells and springs provides the most valuable data for indicator formulation. Changing or increasing concentrations of monitored variables need to be supported by statistical evidence from data obtained over a longer observation period. However, sudden changes in quality are also important because they may indicate an emergency pollution problem.

**d) Groundwater vulnerability**

The proposed **groundwater vulnerability indicator is** based solely on hydrogeological factors and is defined as a natural property of a groundwater system that depends on the sensitivity of the system to human and/or natural impacts. This differs from **specific vulnerability** (risk of the groundwater system becoming exposed to specific contaminant loading), which is not considered for TWAP[35] groundwater. The proposed indicator is based on parameters of the DRASTIC index (Aller, et al., 1987) such as recharge, topography, soil media, depth to groundwater, thickness of the unsaturated zone, aquifer

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[35] Both natural and specific groundwater vulnerability have been formulated in the Groundwater Vulnerability Assessment Report (US National Research Council, 1993) and the Guidebook on Mapping Groundwater Vulnerability (UNESCO-IAH, 1994) and are used in many publications related to groundwater vulnerability.

media and hydraulic conductivity.

However, all these parameters will seldom be available for evaluating the vulnerability of transboundary aquifers and formulating indicators. The Groundwater Resources Map of the World (GWRMW) provides information about the *rate of groundwater recharge* and *aquifer media*, both of which affect the rating in the DRASTIC index. Regional and particularly country-level data may be available about the topography, soil media, depth to groundwater, and in many cases rock composition of the unsaturated zone, in which case more accurate evaluation of groundwater vulnerability will be possible (Table 5).

**Table 5:** Selected parameters for evaluation of groundwater vulnerability and their weight in the DRASTIC index.

| HYDROGEOLOGICAL PARAMETER | WEIGHT |
|---|---|
| Groundwater recharge | 4 |
| Depth to groundwater table | 5 |
| Soil media | 2 |
| Aquifer media/ type | 3 |
| Impact of unsaturated zone | 5 |

A simplified range and rating classification will be assigned to each parameter and the products summed to obtain the final numerical score that provides relative measures of the vulnerability of different areas of the aquifer and across aquifers. Both range and ratio will be scored between 1 and 3. An example is given in Table 6. The higher the index the greater is the groundwater vulnerability.

**Table 6:** Ranges and rating for depth to groundwater table (will be multiplied by weight 5).

| RANGE | RATING |
|---|---|
| 0 – 3 m | 3 |
| 3 – 10m | 2 |
| > 10m | 1 |

Three categories of groundwater vulnerability are proposed for the formulation of groundwater vulnerability indicators, based on groundwater recharge and type of aquifer applied in the GWRMW map (Table 7). However, in transboundary aquifers with available data on other parameters, a simplified DRASTIC methodology described above will be applied. Both data and the evaluation method applied for indicator formulation are feasible.

## 12.2 Human and environmental dependence on groundwater indicators

The indicators on human and environmental dependence on groundwater are based on social, economic and ecology-related data expressing population, agricultural, industrial and ecological dependence on groundwater. **Two core indicators** are proposed: **1) A common indicator of human dependence on groundwater**; and **2) Ecosystems dependence on groundwater.**

### a) Common indicator of human dependence on groundwater as a percentage of total water use

The indicator will be developed in case of difficulties in locating adequate data for calculation of individual sectors dependent on groundwater (Table 8). However, if data are available the indicator may be divided into individual sectors and **three scenarios** of its formulation are possible.

1) ***Human dependence on groundwater for drinking purposes*** (Table 8)

   The evaluation method for this indicator is simple and feasible. Records of groundwater abstraction for drinking water supply and the percentages of human dependence on groundwater for drinking purposes are available at worldwide, regional and country levels in several water reports and in national and municipal drinking water statistics, and are registered by water supply companies. Data on groundwater use from domestic wells can be based on qualified estimates (number of people not connected to public supplies / estimated water use per capita / day). In many countries groundwater abstraction for drinking water and other uses is registered in individual catchment areas. Data collected at the country or catchment level has to be translated into the transboundary aquifer level.

2) ***Agriculture dependence on groundwater as a percentage of total water use in the agricultural sector*** (Table 8)

   The availability of sufficient groundwater in a particular place, its usually good quality and higher efficiency (defined as agricultural output per unit of water used)compared with surface water, have resulted in increasing use of groundwater for irrigation and other agriculture uses, particularly in less-developed countries. The partial global coverage of AQUASTAT (Global map of irrigation areas), the globally complete LADA (Land Degradation Assessment in Drylands) datasets and other data sources collected in FAO databases relating to this will be explored as well as data at the country level.

3) ***Industrial dependence on groundwater as a percentage of total water use in the industry sector***
   An indicator based on similar criteria to 2) may be developed for industry dependence on groundwater in countries with significant industrial production.

**b) Ecosystem dependence on groundwater**[36]

The Ramsar, WHYMAP and UNEP databases and maps and countries data make an evaluation method for indicator formulation feasible. Evaluation of ecosystem dependency on groundwater and formulation of the relevant indicator will generally be based on evaluation of: (1) aquifer type (shallow water table, coastal, karst, deep unconfined, deep confined, fossil); (2) ecosystem extent (extensive-hundreds of km$^2$, moderate extent – tens of km$^2$, small extent- less than 10 km$^2$) and position in the aquifer (recharge, groundwater flow or discharge area); (3) groundwater level below ground; and (4) groundwater quality (Table 8). E.g. ecosystems underlain by shallow aquifers with groundwater level close to ground are highly dependent on groundwater and its quality. However, it must be noted that both ecosystem and groundwater quality depend on land use and agriculture, industrial and other human activities occurring in the transboundary aquifer area.

**Priority indicator related to agricultural dependence on groundwater core indicator**

The **Agriculture dependence on groundwater** indicator may be complemented by an indicator developed within the UNESCO IHP project expressing **dependence of population working in the agriculture sector on groundwater.** It indicates the percentage of a country's population that depends on groundwater to support livelihoods and household incomes.

[36] Groundwater dependent ecosystem may be inland or coastal wetlands, karst and other subterranean hydrological systems, springs, oasis, geothermal wetlands. Groundwater discharges also supply surface water (rivers, streams, lakes) dependent wetlands and ecosystems.

## 12.3 Groundwater stress indicators

Natural and human stresses on groundwater are expressed by **three core indicators** focused on current human (depletion, pollution) and natural (climate variability and change) stresses impacting transboundary aquifers and their groundwater resources (Table 9). These may be detrimental in space and time to the present and future availability and use of groundwater resources.

### a) Groundwater depletion

This core indicator expresses **excessive groundwater withdrawal from the aquifer which leads to groundwater depletion**. The following variables indicate potential groundwater depletion and may be applied individually or in combination, depending on data availability, for indicator development (Table 9): (1) groundwater recharge; (2) aquifer vulnerability; (3) groundwater level (continuous, long term decline of groundwater level, piezometric level or spring discharge in spatial extent); (4) amount of groundwater withdrawal; (5) base flow (drastic reduction or even loss of base flow); (6) groundwater quality and age (gradual or sudden changes in groundwater quality and age); and (7) land subsidence (in aquifers composed of porous sediments).

Groundwater level decline has to be carefully evaluated because it may be subject to temporal fluctuations resulting from seasonal climate variability. Groundwater level decline can also be associated with a long transient evolution from one steady-state to another and does not necessarily reflect aquifer over-exploitation. Temporal and local decline of groundwater level caused by the proximity of water supply, irrigation or other production wells has to be distinguished from larger-scale aquifer groundwater level decline. Reliable conclusions on groundwater decline trends need to be based on long-term observations.

#### Priority indicators related to the groundwater depletion core indicator

The groundwater depletion indicator is associated with **groundwater recharge, storage and groundwater withdrawal indicators.** Evaluation of these may provide indications on whether groundwater abstraction is sustainable or not. However, the combination of such indicators requires sufficient reliable data and may only be realized for a limited number of TBAs (Level 2 of TWAP).

### b) Groundwater pollution

This core indicator is focused on **diffuse nitrate pollution stress on groundwater quality caused by agricultural activities** (mainly crop farming and irrigation). In particular, unconfined aquifers in areas with high recharge and shallow water table (less than 3m below the surface) overlain by sandy soils are highly susceptible to nitrate pollution from crop farming activities.

Deterministic transport models are often applied to study nitrogen transport and transformation processes in the crop-soil-water-rock environment and the vertical and lateral distribution of nitrate in groundwater system. To obtain reliable model outcomes many climatic, hydrological, soil, unsaturated zone and aquifer measurements and observations must be made as well as collection and evaluation of agricultural data related to the origin, type and amount of nitrogen fertilizers, form and time of their application with respect to cultivated agricultural products, sowing procedures, crop rotation/ monocultures and irrigation regime (if applied).

For instance the carbon/nitrogen ratio provides information on the extent to which organic matter is stabilized in the soil. Perturbation of the organic carbon/nitrogen balance in soil has significant consequences for the amount of nitrogen leached in the soil-unsaturated zone – saturated zone and controls the nitrate content of groundwater. Measurements of the carbon/nitrogen ratio which change seasonally are important for model application and essential for gaining insight into the physical, chemical, and biological processes that take place in the unsaturated and saturated zones of soil and for formulating indicators of the current state and potential trends in groundwater nitrate pollution.

Application of the Global Nutrient Export from Watersheds (Global NEWS) model to gain a broad understanding of land-ocean linkages for carbon and nutrients at the regional and global scale (with 0.5° by 0.5° resolution) will also be used to estimate dissolved inorganic nitrogen in groundwater in TBAs.

Airborne remote-sensing techniques combined with geo-botanical methods and IR photography can be applied to detect vegetation stress manifested by loss of reflectance. Over-fertilizing crops above shallow water table aquifers with potential leakages of nitrogen into soil and groundwater systems are detectable by both true and infra-red colour films. For example common species of corn show as dark green in soils and shallow groundwater with high content of nitrate. These techniques can produce supplementary and useful data for indicator formulation.

The following variables may be proposed for formulation of an indicator of diffuse nitrate pollution stress on groundwater quality from agricultural activities (Table 9): (1) spatial extent of agricultural activities; (2) soil type (texture, structure and content of organic matter); (3) aquifer type in areas with farming activities; (4) nitrate content in groundwater; (5) groundwater level below surface; and (6) groundwater recharge (in areas with high precipitation (> 100 mm/year) that plays an important role in transporting pollution into the aquifer). Data for these variables are mostly available from soil, geological and hydrogeological maps on the global, regional and country level.

**Priority indicators related to the groundwater pollution core indicator**

Reliable data for the development of a priority indicator for groundwater pollution by **pesticides** is scarce, especially in developing countries. Development of a relevant stress indicator will only be considered in aquifers (or some areas of aquifers) in which high pesticide concentrations in groundwater have been identified.

Groundwater pollution from **point-sources** (e.g. oil refineries, ore mines) may also be indicated in transboundary aquifer maps and a relevant priority indicator may be applied in parts of aquifers with intensive industrial or mining activities.

**c) Climate variability and change**

This core indicator will be evaluated in terms of **the stress produced on groundwater and related ecosystems by climate variability and change**. The variables with decisive influence on the formulation of the indicator are changes in groundwater recharge, types of aquifers, and their location in different climatic zones (e.g. arid, semi-arid, humid) (Table 9). Climate-change scenarios related to groundwater and specifically to groundwater recharge developed in the Water GAP Global Hydrology model (Döll, et al., 2003) may support indicator formulation.

Development of this indicator faces several uncertainties, particularly with respect to the long response time of aquifers – especially deep ones - to climate change due to the very long residence time of groundwater. Study of the potential influence of climate change on hydrological system inclusive of groundwater will be based on modelling predictions. Climate models with usually simplified presentation of the subsurface geology should be combined with groundwater models using many variables for complex representation of the groundwater system in order to evaluate the impact of climate change on different types of aquifers.

The influence of the possible scenarios of climate change on groundwater proposed in the Indicators Approach Paper elaborated by the UNESCO Expert Group may be considered. Changes in the volume and distribution of precipitation affect the timing and magnitude of diffuse recharge (often in a non-linear manner); fewer but more intense precipitations, predicted for a warmer atmosphere, increase groundwater demand as a result of more variable soil moisture and heightened evapotranspiration. Another possible impact of climate change on groundwater quality is a reduction in the quality of groundwater in shallow coastal and SIDS aquifers through increased salinity resulting from sea-level rise.

**Table 7:** TBAs value and functions index and related indicators, their classification, and sources of data. Different classes are assigned for each indicator.

| INDEX | CORE INDICATOR | CLASSIFICATION / SCORING | | GLOBALLY ACCESSIBLE DATA SOURCES |
|---|---|---|---|---|
| 1. GROUNDWATER VALUE AND FUNCTIONS | **Mean annual groundwater recharge:** Mean annual rate of current groundwater recharge. | 1 | **Very low**<br>< 2 mm/year | Groundwater Resources Map of the World 1: 25 000 000 (GWRMW), Water GAP Global Hydrological Model (WGHM), ISARM and IGRAC maps, AQUASTAT, Margat report, CRU-Climate Research Unit, Regional / country data/maps |
| | | 2 | **Low**<br>2 – 20 mm/year | |
| | | 3 | **Medium**<br>20 – 100 mm/year | |
| | | 4 | **High**<br>100 – 300 mm/year | |
| | | 5 | **Very high**<br>> 300 mm/year | |
| | Where data on groundwater abstraction for drinking, agricultural, industrial and other uses are available, groundwater recharge will be combined with groundwater abstraction and the recharge indicator will be replaced by:<br>**Total annual groundwater abstraction/Mean annual groundwater recharge (dimensionless ratio)** | 1 | **Low**<br>Abstraction / recharge < 0.1 | WGHM model,<br>WHYMAP GWRMW map, ISARM and IGRAC maps, WWAP, WWDR, AQUASTAT, Margat report, World Map of the Köppen-Geiger Climate Classification updated, IGRAC – GGIS,UNEP – GRID, Regional and country data and maps |
| | | 2 | **Medium**<br>0.1 <Abstraction/ recharge < 0.5 | |
| | | 3 | **High**<br>0.5 < Abstraction/recharge < 0.9 | |
| | | 4 | **Very high**<br>Abstraction/recharge > 1.0 | |
| | **Mean annual groundwater renewal per capita** ($m^3$/yr/capita) | 1 | **Low**<br>< 1 000$m^3$/capita/year | |
| | | 2 | **Medium**<br>1 000 – 5 000 $m^3$/capita/year | |
| | | 3 | **High**<br>> 5 000$m^3$/capita/year | |
| | **Priority indicator**<br>**Aquifer storage** ($km^3$): Based on thickness and spatial extent of the aquifer, its porosity and specific yield (default proxy based on type of aquifer in the GWRMW map) | 1 | **Low**<br>areas with local and shallow aquifers | |
| | | 2 | **Medium**<br>areas with aquifers in complex hydrogeological structures | |
| | | 3 | **High**<br>major groundwater basins | |
| | **Groundwater quality:** Based on data availability, one of the following scenarios will be applied:<br>1) Drinking Water Standards (DWS);<br>2) Composite value of electrical conductivity (EC), chloride (Cl), and nitrate ($NO_3$); or<br>3) Individual composite parameters: electrical conductivity, chloride, or nitrate. | 1 | **Very low groundwater quality**<br>– not meeting DWS; EC, Cl, $NO_3$, toxic/harmful variables present<br>$NO_3$> 100 mg/L<br>Cl > 3 000 mg/L<br>Technologically-demanding treatment needed | WHYMAP GWRMW map, IGRAC GGIS,<br>GEMS, UNEP – GRID,<br>Regional and country data and maps |

| INDEX | CORE INDICATOR | CLASSIFICATION / SCORING | | GLOBALLY ACCESSIBLE DATA SOURCES |
|---|---|---|---|---|
| **1. GROUNDWATER VALUE AND FUNCTIONS** (cont.) | **Priority indicators**<br>**Arsenic and fluoride variables** (high content restricts groundwater use for drinking purposes)<br>**Groundwater treatment requirements** | **2** | **Low groundwater quality**<br>Meets DWS only locally, toxic/harmful variables are not present<br>$NO_3$ 50- 100 mg/L,<br>Cl 1 000-3 000 mg/L<br>Specific treatment needed | |
| | | **3** | **Modest groundwater quality**<br>Meets seasonal DWS in aquifer spatial scale<br>$NO_3$ 15-50 mg/L,<br>Cl 250 -1 000 mg/L<br>Simple treatment needed | |
| | | **4** | **High groundwater quality**<br>Meets DWS in aquifer spatial scale<br>Cl < 250 mg/L<br>$NO_3$< 15 mg/L<br>Suitable for specific use without chemical treatment | |
| | **Groundwater vulnerability:**<br>Based on groundwater recharge and aquifer media data in the GWRMW map and WGHM model<br>Other DRASTIC index parameters will be applied if data available[37] | **1** | **Low** deep confined aquifers, fossil aquifers, recharge < 20mm/year) | WHYMAP GWRMW, ISARM and IGRAC maps<br>Regional and country data and maps |
| | | **2** | **Moderate** deeper unconfined aquifers, recharge 20 – 100 mm/year | |
| | | **3** | **High** shallow, coastal, karstic aquifers, aquifer lens in small island, recharge > 100 mm/year | |

[37] Class 1, 2 or 3 should be assigned if one of the criteria is fulfilled. In case of double-matches or conflicting criteria the most unfavourable class in terms of vulnerability should be selected.

**Table 8**: TBAs human and environmental dependence index and related indicators, their classifications and sources of data. Different classes have been assigned for each indicator.

| INDEX | CORE INDICATOR | CLASSIFICATION / SCORING | | GLOBALLY ACCESSIBLE DATA SOURCES |
|---|---|---|---|---|
| 2. HUMAN AND ENVIRONMENTAL DEPENDENCE ON GROUNDWATER | **Human dependence on groundwater as a percentage of total water use**<br>If data are available the indicator may be divided into the three indicators below | 1 | **Low** (< 20%) | WWAP, WWDR AQUASTAT<br>SEDAC , UNEP – GRID, IGRAC - GGIS<br>WHO, UNICEF,<br>Country statistics |
| | | 2 | **Medium** (20-50%) | |
| | | 3 | **High** ( 50-80%) | |
| | | 4 | **Very high** (> 80%) | |
| | **Human dependence on groundwater for drinking water** as a percentage of total drinking water use<br>**Agriculture dependence on groundwater** as a percentage of total water use in the agricultural sector<br>**Industry dependence on groundwater** as a percentage of total water use in the industrial sector | 1 | **Low** (< 20%) | WWAP,WWDR AQUASTAT, FAOSTAT, World Land Use Map (WLUM), Global map of irrigation areas, LADA - Land Degradation Assessment in Drylands, ISARM, IGRAC, Country statistics |
| | | 2 | **Medium** (20-50%) | |
| | | 3 | **High** (50-80%) | |
| | | 4 | **Very high** (> 80%) | |
| | **Ecosystem dependence on groundwater** based on:<br>1) aquifer type;<br>2) ecosystem position in the aquifer;<br>3) groundwater level below surface; and<br>4) groundwater quality | 1 | **No dependence**<br>Ecosystems above deep confined/fossil groundwater | WHYMAP maps,<br>RAMSAR,<br>Earthtrends -Water Resources and Freshwater Ecosystems,<br>UNEP – GRID, ISARM,<br>Regional and country data and maps |
| | | 2 | **Moderate dependence**<br>Ecosystems above unconfined deeper aquifers, groundwater seasonally close to surface | |
| | | 3 | **High dependence**<br>Ecosystems above shallow, coastal, and/or karstic aquifers, groundwater level close to surface | |
| | | 4 | **Very high dependence**<br>Ecosystems in groundwater discharge areas | |

**Table 9**: TBAs groundwater stress index and related indicators, their classifications and sources of data. Different classes are assigned for each indicator.

| INDEX | CORE INDICATOR | CLASSIFICATION / SCORING | | ALREADY EXISTING DATA SOURCES |
|---|---|---|---|---|
| 3. NATURAL AND HUMAN STRESSES ON GROUNDWATER | **Groundwater pollution** as a percentage of total aquifer area based on:<br>1) spatial extent of agricultural activities (crop farming, cattle-breading, irrigation);<br>2) type of soil;<br>3) type of aquifer;<br>4) groundwater level below surface;<br>5) content of nitrate in groundwater in mg/L; and<br>6) groundwater recharge in regions with high precipitation ( > 100 mm/year) | 1 | **Low -** deep confined aquifers, clayey soils with high content of organic matter, spatial extent of agricultural activities < 20%, $NO_3$< 15 mg/L | FAO world map on intensive agriculture areas, LADA - Land Degradation Assessment in Drylands,<br>Global NEWS model,<br>AQUASTAT,FAOSTAT<br>WWAP, WWDR, WHYMAP, ISARM and IGRAC maps, Regional and country data and maps |
| | | 2 | **Moderate -** deeper unconfined aquifers, clayey soils, spatial extent of agricultural activities 20-50%, $NO_3$ 15-50mg/L | |
| | | 3 | **High -** shallow, coastal, karstic aquifers, aquifer lens in small island, sandy soils, groundwater level > 3m below surface, spatial extent of agricultural activities 50-80%, $NO_3$ > 50 mg/L | |
| | | 4 | **Very high** - shallow, coastal, karstic aquifers, aquifer lens in small island, sandy soils, groundwater level > 3m below surface, spatial extent of agricultural activities > 80%, recharge > 100 mm/year,$NO_3$ > 50 mg/L | |
| | **Groundwater depletion** as percentage of total aquifer area based on:<br>1) groundwater recharge;<br>2) aquifer type;<br>3) groundwater level decline;<br>4) groundwater withdrawal;<br>5) loss or reduction of base flow;<br>6) changes in quality and age of groundwater; and<br>7) land subsidence. | 1 | **Low stress**: recharge > 100 mm/year, aquifers in sedimentary basins, large groundwater storage, seasonal groundwater level fluctuation, controlled groundwater withdrawal | GWRMW, WHYMAP, ISARM and IGRAC maps, IGRAC – GGIS, Regional and country data / maps |
| | | 2 | **Moderate stress**: recharge < 100 mm/year, aquifers in complex structures, variable groundwater storage, temporal groundwater level decline, base flow reduction, changes in groundwater quality, groundwater withdrawal not fully under control | |
| | | 3 | **High stress** -recharge < 20 mm/year, local and shallow aquifers with limited aquifer storage, long-term groundwater level decline, loss of base flow, changes in groundwater quality/age, potential land subsidence, mostly uncontrolled groundwater withdrawal | |
| | **Climate variability and change stress on groundwater** based on different types of aquifer located in different climatic zones and evaluated with respect to their susceptibility to climate change | 1 | **Low**: deep, confined and fossil aquifers in different climate zones | UNESCO IHP: G-WADI project,<br>UNEP,GPCC-Global Precipitation Climatology Centre, World Map of the Köppen-Geiger Climate Classification updated CRU Climate Research Unit |
| | | 2 | **Moderate**: deeper unconfined and confined aquifers in semi-arid zones | |
| | | 3 | **High**: coastal, shallow water table aquifers, karst aquifers in arid and super-arid zones | |

## 12.4 Socioeconomic groundwater indicators

The TWAP groundwater socioeconomic current state indicators aim at measuring the ratios between abstracted flows and profit gained from water use and ecological impact costs. The socio–economic groundwater attributes put the focus on and provide the proxy for socioeconomic drivers and water-use values and costs.

Clusters of **economic** cross-cutting groundwater and generic indicators:

- groundwater reliance: total groundwater-based GDP to total GDP per capita;
- groundwater use efficiency: GDP per unit of abstracted groundwater; and
- vulnerability: per capita damage to GDP from climate-change impacts on groundwater.

Clusters of **social** cross-cutting groundwater and generic indicators include:

- access to safe drinking water and sanitation;
- adult literacy;
- life expectancy; and
- vulnerability: number of deaths per 100 000 persons from climate-change impacts.

In the context of the goal of sustainable socioeconomic development, the GEF-IW TWAP **socioeconomic indicators** measure progress in the management of human activities and behaviour to maximize the derivable socioeconomic benefits and minimize the negative impacts of actual and adopted interventions in the transboundary water body. These indicators are measured in social and economic values common to the five GEF-IW waters categories. The indicators include pro-active foundational work and institutional reform for an enabling environment as well as alternative reactive measures of economic management instruments and incentives.

The progress/performance of joint responses at the level of individual transboundary aquifer or aquifer systems measured by two GEF-IW TWAP socioeconomic core indicators in support of the identification of: 1) socioeconomic drivers; and 2) socioeconomic water use values and costs.

The scoring of the indicators is presented in Table 10. The economic governance indicators as presented under 12.5.2 characterize the key socioeconomic aspects and the completion of adopted or optional policy and institutional reforms and investments.

Other proposed socioeconomic indicators are on the level of **priority indicators** (see Section 9. Objectives).

### *12.4.1 Socioeconomic drivers*

*Definition*: existence and relevance of socioeconomic drivers.

*Unit of measurements/parameters*: dimensions of relevant current socioeconomic drivers:

***a) Economic dimension:***

Drivers: socioeconomic growth and diversification of productive economic sectors, agriculture, energy and mining, industry, services and tourism, and their contribution to GDP, export, import and employment.

***b) Environmental dimension:***

Drivers: income-producing activities resulting indirect and indirect environmental costs such as loss of water quantity and quality, productivity or ecological value.

***c) Public health and safety dimension:***

Drivers: activities that result in waterborne contamination, reduced access to safe drinking water and food security and resulting in social hardship and losses; also natural and anthropogenic threats to TBAs resulting in reduced public health, the need for natural hazard mitigation and meeting the costs of rehabilitation and production losses.

***d) Social and demographic dimension:***

Drivers: urban population growth and concentration, changes inurban and rural incomes and poverty levels. Population concentration, with associated high level of economic development and diversification.

*e) Institutional dimension:*

Drivers: Capacity and level of policy enforcement, including allocation and protection.

*Data sources:*

(i) Formal sources; national and regional administrative, planning and policy review and reform documents, EIAs, regional and national and sectoral socioeconomic development and investment plans; land-use policy and planning; national environmental assessments, national water resources policy reform; and

(ii) Direct information on progress, collected by regional networks, TBA networks, transboundary aquifer projects, coordination mechanism and basin organizations.

Direct basic country data CIA, The World Fact book.

Indirect information in global socioeconomic development and global indices data sheet (UNDP –HRDI; World Bank Poverty Map, etc.).

### *12.4.2 Water-use values and costs*

The true economic cost of groundwater includes the societal costs of groundwater use. Full-cost pricing of water would reflect third-party or external costs of water use as well as the scarcity of water. This discussion of water use values and costs, along with Table 10, reflects the available information.

Definition: Lowest of the ratios between (1) direct water-use value and full use, non-use and indirect/ecosystem value, and (2) water price and full economic water cost.

Unit of measurement/parameters: Measurement in quantitative (%) or qualitative economic terms.

Under-pricing represents the main causes of groundwater and ecosystem depletion and degradation. Indicator 12.4.2 provides a proxy for the need and scope for intervention by economic instruments and incentives and for the need for joint intervention management to track groundwater shadow prices at the national level as a base for economic water governance, and, on a selective basis, the option of market mechanism for efficient alternatives for water re-allocation at the transboundary level.

Data sources: Country water-use statistics. Water-use shadow prices. Marginal irrigation benefits; marginal social values = costs of drinking water supplies; marginal industrial use benefits.

Regional TBA networks: social opportunity costs and externality costs.

**Table 10:** Classification/Scoring of socioeconomic state core indicators.

| INDICATORS | CLASSIFICATION / SCORING | |
|---|---|---|
| 12.4.1. Socioeconomic drivers<br>Existence of key driver dimensions | **1** | **Low**: 0-1 Key driver dimensions |
| | **2** | **Medium**: 2-3 Key driver dimensions |
| | **3** | **High**: 4-5 Key driver dimensions |
| 12.4.2. Water-use values and costs<br>The lower of: direct water-use value/full value (%) and actual water price/full economic cost (%) | **1** | **Low:** < 30% |
| | **2** | **Medium:** 30- 60% |
| | **3** | **High:** > 60% |

## 12.5 Governance indicators

Governance architecture includes laws and regulations, institutional arrangements at the governmental and non-governmental (mostly user) level, and economic institutions and instruments. Separate but partly complementary indicators are proposed.

Two indicators are proposed on the level of **core governance indicators:**

1) Performance of legal instruments and institutional arrangements in a transboundary context; and
2) Performance of the domestic legislation and the national government water resources administration

Other proposed governance indicators are on the level of **priority indicators** (see chapter 9 Objectives).

### *12.5.1 Legal/institutional governance*

**Background and rationale**

Indicators of 'hotspots' where a transboundary aquifer may present opportunities for cooperation among the concerned countries, and as a result invite action by the donor community in general and by the GEF-IW window in particular, must include the governance structure of the TBA and the countries concerned. Such structure is made up of:

1. legal instruments such as agreements, treaties and conventions, made by the countries sharing a TBA or a transboundary river or lake (TBRL) connected to the TBA;
2. bi-lateral or multi-lateral institutional arrangements such as joint committees or commissions, made by the countries concerned with the administration of a TBA or TBRL agreement;
3. the laws and regulations for groundwater resource management in force in the countries sharing a TBA or TBRL;
4. the national government water administrations of the countries sharing a TBA or TBRL;
5. water user groups – formal and informal - active at the local level; and
6. the courts of law for the adjudication of disputes between water users, and between them and the government water administration.

Discrete indicators are desirable in respect of the constituents of TBA governance, such that the aggregate total yields a credible measure of the kind and level of sophistication of the governance structure in place, and how it fares in practice. If components 1 and 2 of the governance structure are not in place, because the concerned countries have not made any agreement and no joint institutional arrangements are in place, then components 3 to 6, and the relevant indicators, are still relevant since the national portions of a TBA or TBRL are governed by the domestic laws and institutions of each of the countries sharing the TBA or TBRL. In this case, the governance structure of the TBA is just the aggregate total of the governance structures of each concerned country, however diverse.

Separate indicators are proposed in respect of the two chief levels at which governance structures for TBAs and TBRLs exist and operate (Table 11): the transboundary level, and the domestic level of the countries sharing a TBA or TBRL, as follows:

**Governance structures at the transboundary level**

a. *Existence and contents of a legally binding instrument setting out the terms of engagement of countries sharing a TBA*. The nature and scope of such instruments range from a Memorandum of Understanding (MOU) setting out terms of engagement restricted to the life of a project (these instruments are generally 'upstream' of full-blown cooperation, and seek to sow the seeds and nurture cooperation in its formative stages) to treaties and agreements setting out the substantive and procedural terms of mature cooperation. These can be specific to the TBA or TBRL, or 'framework-type' and regional in scope, yet binding. Two non-binding instruments of global scope are also relevant to the scope of this exercise, and will be accounted for in it.

   This component can be measured in two ways:

   - quantitatively, i.e. whether a legally binding instrument exists or not; and
   - qualitatively, i.e. through an analysis of the contents of the instrument, and of the scope and extent of the undertakings made.

b. *Institutional arrangements for the administration of the legally binding instrument*. The scope and nature of such arrangements range from a multi-country secretariat administering cooperation under the terms of a project agreement and for the life of it, to the multiple variations found in the practices of States as they cooperate in the management and development of TBRLs in general, and TBAs in particular. This component can be measured in two ways:

   - quantitatively, i.e. whether a multi-country institutional arrangement exists or not; and
   - qualitatively, i.e. through an analysis of the mandate, structure, modus operandi, resources, and lines of accountability of the institutional arrangement.

c. *Core indicator 1 - Performance of legal instruments and institutional arrangements*. The mere existence of a legal instrument (a simple MOU or a complex treaty) and a multi-country institution tasked with the administration of such an instrument, does not *per se* imply adherence by the Parties to the terms of the instrument, or delivery by the institution of the goods and services it is tasked to provide. Reliable proxy indicators of performance of a legal instrument and the institution tasked with its administration would include, in no particular priority order:

   - compliance by the Parties with the legal obligations, substantive and procedural, underwritten in the legal instrument setting out the terms of transboundary cooperation;
   - instances and frequency of recourse to dispute resolution mechanisms, if any, provided for by the legal instrument;
   - number and frequency of meetings held by the multi-country institution administering the legal instrument;

- number, nature and contents of deliberations, and compliance by member countries of the institution;
- availability of records of deliberations, actions taken and tasks carried out by the institution;
- availability of official documents (policy directives, manuals, flowcharts, operational guidelines, etc.) for the internal organization and functioning of the institution and the conduct of its business;
- volume and nature of resources allocated to the institution by the member countries, and frequency of replenishment; and
- nature and frequency of interactions of the institution with the national administrations of the member countries.

**Governance structures of TBA countries at the domestic level**

The relevance of the domestic governance structure of the countries sharing a TBA or TBRL is due mainly to the fact that undertakings made at the transboundary level must translate into domestic action, notably through adaptation of domestic groundwater legislation (and relevant institutional arrangements if need be) to the agreed terms of cooperation, and through effective administration and vigorous enforcement of such legislation. As noted earlier, however, the domestic governance structure of the countries sharing a TBA or TBRL is also relevant where no such structures exist at the transboundary level, since in that case the national portions of the TBA or TBRL are governed by the domestic laws and institutions of each of the countries sharing the TBA or TBRL, acting independently or in a coordinated/harmonized fashion.

Indicators of the domestic governance structure of countries sharing a TBA would consist of:

a. *Existence and contents of domestic legislation on groundwater in the countries sharing a TBA* (Act of Parliament and/or Regulations) governing the development, use, and protection from pollution, of groundwater, either as part of a general water resources statute, or as an independent groundwater-specific statute. This component can be measured in two ways:
    - quantitatively, i.e. whether a national water resources law exists or not; and
    - qualitatively, i.e. through an analysis of the contents of the law and the scope, nature, reach and sophistication of the regulatory and other mechanisms in it.

b. *National government water resource administration*, for the administration of the legislation. This component can be measured in two ways:
    - quantitatively, i.e. whether a national government water resource administration exists or not; and
    - qualitatively, i.e. through analysis of the mandate, structure, modus operandi, resources, and lines of accountability of such an administration.

c. *Core indicator 2 - Performance of the domestic legislation and the national government water resource administration.*

    The existence of domestic legislation and a national government water resource administration does not imply actual delivery of the services, regulatory or others, that the administration is tasked with providing by the water laws in force. In particular, regulatory services provided is proposed as a proxy indicator of performance, measured by:

- number of groundwater abstraction permit/licence applications processed and permits/ licences granted every year;
- number of wastewater disposal permit/licence applications processed and permits/ licences granted every year; and
- number and type of administrative and law enforcement action taken in a year by the national government water resource administration to restrain illegal behaviour by the holders of groundwater abstraction permits/licences and wastewater disposal permits/licences, and by the owners/operators of un-licensed (illegal) wells and waste disposal facilities.

d. *Formal and informal (ground)water user-level groups*. Formal and informal water user groups tend to play an increasingly significant role in domestic water resource management inthe vast majority of countries. This is in response to a deliberate policy of governments to devolve responsibilities – also financial – for the administration and policing of water rights and infrastructure to the lowest possible level, especially in connection with irrigation. These user-level institutions can be relevant to a TBA or TBRL institutional analysis insofar as they have the potential for embryonic cooperation between rural communities straddling the international boundary line between the countries they belong to, and drawing water from a transboundary source - an aquifer, river or lake. Under these circumstances, indicators for such institutions are appropriate, measured:

- quantitatively, i.e. whether formal and informal water user groups in general, and groundwater user groups in particular, exist; and
- qualitatively, i.e. through an analysis of the mandate, structure, functioning, resources, and lines of accountability of such groups to the government.

e. *Specialized Water Courts, and regular courts of law* for the adjudication of disputes. Litigation between water users and between them and the government water administration is an important component of the legal framework for groundwater resources, and the court system (the 'judiciary') is, as a result, an important component of the general-purpose governance structure of a country. Where they exist, Water Courts, in particular, are an important component of the special-purpose governance structure for water resources. The number of water-related cases disposed of, as evidenced by the available law reports, is proposed as a proxy indicator of judiciary performance. The indicator is appropriate and should be used for specialized Water Courts, if any such courts exist, but also for general-purpose courts if no Water Courts exist.

The ***reliability*** of the performance indicators proposed at (c) and (e) depends on the availability of official evidence or official records of administrative or judicial actions taken. If records are mandatory, a lack will be interpreted as an indicator of an institution performing below standard. However, the performance indicators proposed at (c) and (e) are relative to the volume of work, administrative or judicial, generated by the water laws and the circumstances. They are by no means absolute indicators of performance. In other words, the dearth of licence or permit applications processed by the government water administration over a period of time may be due to the lack of competition for water resources or the full allocation of available resources, and have nothing to do with a malfunctioning of the institution. Likewise, the dearth of water-related case law can be an indicator of the effectiveness of regulatory legislation in preventing conflict over the use of groundwater resources, and have nothing to do with a non-performing judiciary. With these caveats, the proposed indicators are useful proxies for performance as long as official evidence or records are available.

**Scoring of the proposed indicators**

A scoring system is proposed for each indicator, ranging from high to medium to low in absolute terms, and relative to the transboundary focus of the exercise. As a result, all indicators proposed at the transboundary level (described above) will score from high to medium to low as absolutes, as all have high relevance. Of the indicators proposed for the domestic level of countries sharing a TBA or a TBRL, the existence of water user groups and specialized Water Courts will score from medium to low in view of the comparatively secondary role these play in relation to the transboundary level of engagement of countries. All other indicators proposed for the domestic level of countries sharing a TBA or a TBRL will score the full range from high to medium to low in view of their significance to the transboundary level of engagement of countries.

**Methodology of application and testing**

Applications will require a mix of desk work, questionnaires and interviews with officials of the cooperating countries and those of institutional arrangements for transboundary groundwater (or surface water) cooperation, and the procurement and analysis of available records. In particular:

- all 'other-than-performance' indicators can be tested and applied through desk work, on the basis of information obtained from reliable online sources, notably FAOLEX38 and WATERLEX39 for the domestic water resources legislation of countries, and ECOLEX40, WATERTREATIES41 and the Transboundary Freshwater Dispute Database42 developed by Oregon State University, for water treaties and agreements; and
- all 'performance' indicators require information which is not available online, and which must be obtained through questionnaires and interviews with government officials.

As the credibility of the exercise depends on the reliability of the selected indicators, and as all the proposed indicators are quite novel and un-tested, the importance of testing them before full-scale application cannot be overestimated. Testing will allow any necessary fine-tuning, and will minimize the risk of misrepresenting the governance structures of TBAs.

[38] http://faolex.fao.org/
[39] http://waterlex.fao.org/waterlex/srv/en/home
[40] http://www.ecolex.org/start.php
[41] http://faolex.fao.org/watertreaties/
[42] http://www.transboundarywaters.orst.edu/database/

**Table 11:** Synopsis of Governance Indicators (legal/institutional systems).

| SUB-INDEX | INDICATOR | DESCRIPTION/COMMENT | SCORE |
|---|---|---|---|
| **Transboundary legal framework** | Existence and contents of agreement on TBAs | Cooperation exists and is formalized in an agreement. The scope of an agreement and the nature, reach, and level of precision of its provisions provide an indicator of the quality of the obligations underwritten by the Parties. | High to Medium depending on content<br>Low if no agreement exists |
| | Existence and contents of agreement on surface water body(ies) connected/related to TBAs | If an agreement exists it might be possible to extend its scope to include TBAs. The scope of an agreement and the nature, reach, and level of precision of its provisions provide an indicator of the quality of the obligations underwritten by the Parties. | High to Medium depending on content<br>Low if no agreement exists |
| | Ratification of global or regional framework conventions on international/transboundary waters, namely: the UN Watercourse Convention (1997) (not yet in force, but its core principles are part of international customary law); the UN ECE International Rivers and Lakes Convention (1992);the SADC Revised Protocol (2000)<br>Endorsement of UNGA Resolution 64/124 carrying draft Articles on the Law of Transboundary Aquifers (as signified by appropriate official instruments or pronouncements) | These Conventions provide a framework for cooperation on transboundary waters (international watercourses in the case of the UN Watercourse Convention and SADC Protocol). They are a source of inspiration when negotiating an agreement on a specific transboundary water body. However, they are also a source of binding obligations ranging from very loose (UN Watercourses Convention) to precise (UNECE Water Convention 1992, SADC Protocol 2000).<br>The draft Articles are not binding, however some basic principles are part of customary international law and are, as a result, binding. | Medium<br>Low if no global or regional convention ratified<br>High if endorsed, score-neutral if not |
| | Participation in a process or project on TBAs, and scope of relevant obligations | These projects are generally a start of a confidence-building process among technical people from the participating national institutions in charge of water resources, and can be a precursor to more permanent legal and institutional arrangements. The engagement of participating countries is crystallized in a legal instrument (project agreement), valid only for the life of the project. | Medium, but lack of processes or projects is score-neutral |
| | Performance of an agreement, measured by<br>• compliance by the Parties<br>• recourse to dispute resolution mechanisms | Discrete instances of compliance or non-compliance help to gauge a performing or non-performing agreement. Actual recourse to Dispute Resolution Mechanisms (DRMs) indicates problematic performance, however the lack of it is no safe indicator of a performing agreement. This is a tricky indicator to gauge. | High to Low |

| SUB-INDEX | INDICATOR | DESCRIPTION/COMMENT | SCORE |
|---|---|---|---|
| **Transboundary institutional framework** | Mandate, structure, *modus operandi,* resources, and lines of accountability of institutional arrangements at the bi- or multi-lateral level for the administration of an agreement or other legal instrument (including a project agreement), and relevant performance measured by:<br>▪ number and frequency of meetings<br>▪ number, nature and contents of deliberations<br>▪ availability of records of deliberations, actions agreed and tasks carried out by the institution<br>▪ availability of official documents (policy directives, manuals, flowcharts, operational guidelines, etc.) for the internal organization and functioning of the institution and the conduct of its business<br>▪ volume and nature of resources allocated to the institution by the member countries, and frequency of replenishment<br>▪ nature and frequency of interaction of the institution with the national administrations of the member countries. | The existence of an institutional arrangement tasked with the administration of an agreement does not imply actual delivery by the institution. Proxy indicators of performance are proposed, by reference to available records. | High to Low depending on the performance of the institutional arrangement<br>Low if no institutional arrangement in place |
| **Domestic legal framework** | Existence and contents of a national law (Act of Parliament and/or Regulations) governing the development, use and protection from pollution of water resources in general, or groundwater in particular | The waters of the domestic portion of a TBA (or TBRL) are regulated by the domestic water law of the concerned countries. The scope of such law, and the nature, reach and sophistication of the regulatory and other mechanisms provided by the law provide useful indicators of the quality of the law. | High to Low depending on content<br>Low if no national water law exists, and if there are no groundwater-specific provisions in national water law |
| **Domestic institutional framework** | Mandate, structure, *modus operandi,* resources, and lines of accountability of a national government water resource administration, and relevant performance measured by<br>• number of groundwater abstraction permits/licences processed and granted on average in x months<br>• number of wastewater disposal permits/licences processed and granted on average in x months<br>• administrative action taken by the government water resource administration to restrain illegal wells and illegal behaviour by the holders of groundwater abstraction and wastewater disposal permits/licences | The existence of a national apex government water resource administration, or a government water resource administration at other appropriate level(s), does not imply actual delivery of services, regulatory or otherwise, by the administration. Regulatory services provided, as evidenced by the available record, is proposed as a proxy indicator of performance. | High to Low depending on performance<br>Low if no such administration exists |

| SUB-INDEX | INDICATOR | DESCRIPTION/COMMENT | SCORE |
|---|---|---|---|
| **Domestic institutional framework** (cont.) | Mandate, structure, *modus operandi,* resources and lines of accountability (if any) of formal and informal (ground)water user-level institutions | | Medium |
| | Performance of specialized Water Courts, if any, or the regular courts, measured by the available case law | The number of water-related cases disposed of, as evidenced by the available law reports, is proposed as a proxy indicator of judiciary performance. | Medium to Low |

### 12.5.2 Economic governance

Economic governance is measured by two indicators: 14.4.1 socioeconomic institutional processes, and 14.4.2 economic instruments and incentives. The former addresses pro-active components of economic governance, the latter reactive ones.

**Indicator 1: Socioeconomic institutional processes**

Definition: stage of completion of the institutional processes for joint action on policy/institutional reform and investment to reduce environmental stress on the transboundary aquifer. There is complementarity between this indicator and indicators 14.1.2 and 14.1.3. This will be sorted out at the testing stage of the proposed indicators.

*Unit of measurement, at two levels of detail:*

Level 1: Existence of an operational inter-country coordination mechanism for joint economic planning and economic cooperation relevant to the transboundary aquifer system, e.g. adoption of a socioeconomic advisory panel to address socioeconomic aspects of joint transboundary work. Measurement: 'yes/no' or 'under development/in place'.

Level 2: Country adoption of joint inter-sectoral social and economic planning policies, socioeconomic national development plans, and instruments.

**Indicator 2: Economic instruments and incentives**

Definition: tracking the existence and cost-effectiveness of common economic instruments for implementation of alternative economic governance measures in the transboundary aquifer system. As economic instruments and incentives are generally implemented through the domestic legislation of TBA countries, there is complementarity between this indicator and indicator 14.1.3. This will be sorted out at the testing stage of the proposed indicators.

Options for economic instruments for changed user behaviour to more efficient water use/resource conservation and pollution control include:

*Category 1. Changing Groundwater Abstraction Costs;*

1. direct pricing through resource abstraction fees;
2. indirect pricing through modified energy tariffs;
3. groundwater markets;

*Category 2. Economic Incentives;*

4. reform of agricultural and food trade policies;
5. subsidies for investment in more efficient irrigation technology through water-saving measures;
6. subsidies to decrease agrochemical leaching; and
7. subsidies for industries and municipalities to implement appropriate water treatment, artificial recharge and reuse technology.

The scoring for the above indicators is presented in Table 12.

**Table 12:** Classification/Scoring of economic governance, instruments and incentives.

| INDICATORS | CLASSIFICATION / SCORING | |
|---|---|---|
| Economic institutions<br>Progress in implementation and enforcement | **1** | **Low** |
| | **2** | **Medium** |
| | **3** | **High** |
| Economic instruments and incentives<br>Use and effectiveness of economic instruments and incentives | **1** | **Low**: no instruments; inappropriate incentives |
| | **2** | **Medium**; recovery of financial costs |
| | **3** | **High**: full cost recovery/cost-effective, well-targeted incentives |

## 13. PROJECTED GROUNDWATER STRESS INDICATORS

Proposed groundwater projected stress indicators reflect:

- Priority issues with respect to GEF's interests and TWAP's scope and objectives;
- Groundwater core issues related to: current and projected state of basic quantitative, qualitative and vulnerability characteristics of groundwater system; use of groundwater in transboundary aquifers (particularly for drinking and irrigation); current and projected future human stresses (pollution, depletion) and natural stresses on transboundary aquifers (projected climate variability and change, e.g. sea-level rise and salinization of coastal aquifers, changes in the volume and distribution of precipitation and their effect on timing and magnitude of groundwater recharge, changes in groundwater level, increasing frequency of natural disasters); and
- TWAP cross-cutting issues agreed across all water system and used for formulation of cross-cutting indicators.

The proposed Level 1 TWAP groundwater indicators show the projected changes in transboundary stresses in medium–term scenarios, to 2030 and 2050. The projections are based on extrapolation of available groundwater data on the global, regional and country level, using different types of simulation and forecasting models. Data may be retrieved from terrestrial observations or remote-sensing measurements. The present situation (baseline) will be used as the initial condition. However, it must be noted that there are specific assumptions for each particular region or country in the scenarios for social change (population migration, growth or decrease), economic development (and related increasing demand for water resources and sanitation facilities as well as increasing human impact on water quality), land-use changes (urbanization, deforestation, industrial development, changes in agricultural structure) and changes in climatic conditions (regional variability in increasing / decreasing precipitation and temperature). These assumptions all have to be considered in the formulation of the projected groundwater stress indicators.

Level 2 will focus on more comprehensive assessment of actual data and information on pilot transboundary aquifers with a causal chain analysis, aiming to find the best methodology and practices for the Level 2 assessments.

The proposed projected groundwater stress indicators are derived from core current state indicators and focus on the quantity and quality attributes of groundwater resources.

## 13.1 Core indicators for projected groundwater quantity stress

Projected **groundwater quantity stress indicators** will be based on a combination of: groundwater recharge ($km^3$/year), annual amount ($m^3$) of renewable groundwater resources per capita, population dependence on groundwater (as a proxy for drinking water stress), and groundwater abstraction ($km^3$/year). All these variables have been described in more detail in section 12.

The following core indicators are proposed.

**a) Total groundwater abstraction / Mean annual recharge**

This indicator mirrors indicator a) of section 12.1. To define a score, projections need to be made of changes in total groundwater abstraction due to economic development and groundwater recharge due to climate and land-use changes.

**b) Annual amount of renewable groundwater resources per capita**

This indicator mirrors indicator b) of section 12.1. To define a score, projections need to be made of changes in mean annual groundwater recharge and population (growth / decrease).Population decrease may occur in some parts of the world. Climate change in many regions will be reflected in changes in recharge conditions that also involve modelling of projected renewable groundwater resource scenarios, particularly for a short-term horizon in shallow aquifers.

**c) Human dependence on groundwater for drinking purposes as a percentage**

Projections will show changes in population dependence on groundwater for drinking purposes (compared with percentage dependence on surface water and on water produced by desalinisation of sea water), considering, in particular, increasing access to drinking water and sanitary facilities in developing countries as well as future economic and social development on a global and country scale. The Indicator has been applied on a country level within WWAP and WWDRs. However, if data becomes available for agricultural, industrial and other sectors, the indicator may be formulated as dependence of individual sectors on groundwater.

### Projected priority stress indicator

In the Level 2 TWAP assessment, groundwater recharge may be combined with a **groundwater storage indicator.** Formulation of a storage indicator very much depends on long-term series of groundwater level measurements and aquifer geometry data, which are seldom available. However, for example in the case of the Guarani and Lullemeden Aquifer Systems, data are available for the formulation of a storage indicator in the Level 2 TWAP - groundwater assessment.

### Data availability and needs for formulation of projected indicators

Core indicators of projected groundwater stress will be based on extrapolation of Current State Indicators, as discussed in the previous section. Such indicators serve as an initial condition for projecting changes over the projection period. Crucial is the availability of estimated trends of the variables that are considered to be the most significant drivers of change.

For more detailed information on data collection and projection methods please refer to Annex 6.

### Classification / Scoring

As the projected indicators are to a large extent based on assumptions and not observations, a qualitative scale of expected changes seems to be the most appropriate way to address these. Five categories will be used: (i) significantly increasing, (ii) increasing, (iii) insignificant change, (iv) decreasing and (v) significantly decreasing.

## 13.2 Projected groundwater quality stress core indicator

This indicator mirrors indicator c) of section 12.1.

**The projected groundwater quality stress core indicator** is linked to the Millennium Development Goals and provides information about the current status and projected trends in groundwater quality. Variables used for the formulation of this core indicator are mostly expressed in mg/L or other relevant units. Series of groundwater quality data enable the identification and projection of the outcome of bio-geochemical processes that lead to groundwater quality changes. However, the indicator application is limited because groundwater data obtained by point sampling at individual monitoring stations (wells, springs) has to be applied on a larger area, transboundary aquifer scale. This may produce problems in spatial representation of groundwater quality. The density of monitoring stations therefore needs to be considered if groundwater quality data are to be applied on an aquifer scale.

Based on data availability, one from the following scenarios projected for **groundwater quality stress core indicator** will be analysed in the TWAP Level 1 assessment:

1) Indicator of **drinking water standards** (large groundwater quality database is available);
2) Indicator based on **composite values of variables: electrical conductivity, chloride and nitrate** (moderate groundwater quality database is available); and
3) Indicator based on **individual variables: electrical conductivity, chloride, or nitrate** (groundwater quality data are only available for one composite variable).

The cross-cutting groundwater **nitrate indicator/variable** ( reflects the intrinsic nitrate content in groundwater as well as potential pollution by diffuse nitrate produced by agricultural activities) and the groundwater **salinity indicator/variable** based on **chloride content (**reflects natural and human stress particularly on coastal aquifers and aquifers in arid and semi-arid regions)are both part of all scenarios of groundwater quality stress.

The proposed scenarios for the core indicator of groundwater quality stress provide basic information about the current state (initial conditions) of groundwater quality and the projected situation (projected effects of human impacts or climate change on the stability or variability of groundwater quality). The proposed variables should also provide good indication of short-term or sudden changes in groundwater quality or groundwater pollution.

**Priority indicator of projected groundwater quality stress**

The occurrence of arsenic and fluoride in groundwater has become important in recent decades because of their impact on human health. Both may restrict the use of groundwater for drinking purposes. If their content in groundwater in a transboundary aquifer (or some areas of the aquifer) are expected to be high, a relevant indicator will be developed.

The proposed indicator of projected groundwater quality stress and related variables is based on current knowledge of groundwater quality (initial conditions) and data collected at the regional and particularly the country level. Regular operation of current groundwater quality monitoring programmes at the country and transboundary level and monitoring of the quality of groundwater drinking water supplies by water companies both provide reliable time- and space-dependent data for the indicator formulation. Various global monitoring programmes such as the UNEP/GEMS Water global monitoring system also produce valuable sets of groundwater quality data.

Projected changes in groundwater quality or the content of individual variables (e.g. nitrate, chloride) need to be supported by statistical evidence which will be used for calibration of the models. Regular operation of current groundwater quality monitoring programmes at the transboundary and country level and groundwater quality monitoring by water companies operating groundwater supply systems are also needed to provide reliable time- and space-dependent data for projected groundwater quality indicators. However, data referring to sudden changes in groundwater quality are equally important since they may indicate serious groundwater quality deterioration or pollution in transboundary aquifers. The projected core indicator will be based on implementation of mathematical simulation models describing pollutant transport and transformation processes in groundwater systems.

**Data availability and needs for indicator formulation**

The indicator of projected groundwater quality stress will be based on extrapolation of the current state groundwater quality indicators as discussed in the previous section. Such indicators serve as an initial condition for estimating change over the projection period. Crucial is the availability of trend projections for the variables that are considered to be the most significant drivers of change.

**Classification / Scoring**

As projected indicators are to a large extent based on assumptions rather than observations, a qualitative scale for the projected changes seems to be the most appropriate way to proceed. Five trend categories will be used: (i) significantly increasing, (ii) increasing, (iii) no significant change, (iv) decreasing and (v) significantly decreasing.

For more detailed information on data collection and projection methods please refer to Section 2 and Annex 6.

# PART 4. INTERLINKAGES WITH OTHER WATER SYSTEMS

## 14. INTERLINKAGES BETWEEN WATER SYSTEMS

The international groundwater systems obviously have physical and other interlinkages with the other water systems considered in TWAP. The physical interlinkages are related to inflows and outflows of water and dissolved matter (components of the water cycle and other mass balances). There are also environmental and socioeconomic interlinkages, but these are more complex.

*Physical Interlinkages*

Table 13 describes possible inflows and outflows of water with certain qualities (chemistry, temperature, biology) between groundwater systems and the other water systems.

**Table 13:** Inflows to and outflows from groundwater systems (only the five TWAP water type categories are considered)[43]

| | | RECEIVING WATER SYSTEMS | | | | |
|---|---|---|---|---|---|---|
| | | GROUNDWATER | LAKES | RIVERS | LME | OPEN OCEAN |
| SUPPLYING WATER SYSTEMS | GROUNDWATER | - | Groundwater discharging into lake | Groundwater discharge into rivers (contributing to base-flow) | Sub-marine groundwater discharge | Abstracted groundwater leading to global sea level rise |
| | LAKES | Lakes recharging underlying groundwater system | - | - | - | - |
| | RIVERS | Rivers recharging underlying groundwater systems | - | - | - | - |
| | LME | Seawater intrusion | - | - | - | - |
| | OPEN OCEAN | El Niño-like events affecting precipitation patterns and hence groundwater recharge | - | - | - | - |

43 Atmosphere, soil, biosphere and human society (water use, waste and wastewater) are not taken into account.

In the Level 1 assessment, the regional networks of experts may identify, for each TBA and SIDS, whether potential physical interlinkages exist with the other water TWAP systems. This qualitative and Boolean-type assessment will be described and based simply on the existence of a physical connection between the water systems. For example, a deep confined aquifer like the Nubian Sandstone Aquifer System has no physical connection with the Nile River. The shallow and inland Lullemeden Aquifer System is connected to the Lake Chad, but has no interactions with West-African LMEs. Some of the transboundary karst aquifers in the Balkan stretch out and are physically connected to the transboundary Adriatic Sea.

*Other Interlinkages*

There may also be socioeconomic and institutional interlinkages. For example in some areas farmers use both surface water and groundwater for irrigation. The relative ease of accessing one of these resources may affect conservation of the other. For example, farmers in Central Gujarat have been using groundwater for irrigation for decades, depleting the groundwater aquifer rapidly. The new Narmada surface water scheme transfers surface water from Madhya Pradesh and Maharashtra to Gujarat, conserving the Gujarati groundwater resources. This is obviously not an international transboundary issue but a transboundary Indian state issue, but it clearly shows how transboundary rivers and groundwater can be linked economically.

Institutional interlinkages exist when the management of different water resources is organised in an integrated manner. An example is the River Basin Organisations in the SADC region that are responsible for managing both the transboundary rivers and the aquifers. Policies and regulations based on IWRM and ICZM that explicitly address the whole water system and whole water cycles are illustrations of such interlinkages.

In the Level 1 assessment, the regional networks of experts may be invited to identify and briefly describe such socioeconomic and institutional interlinkages with other water systems for each TBA and SIDS.

## 15. INPUT-OUTPUT ANALYSIS

Although the physical inflows and outflows of water are conceptually simple, input/output analysis of the flows between transboundary groundwater systems and other transboundary water systems during the baseline assessment (Level 1) does not seem feasible in most cases. This is because all data are lumped over the systems considered and the systems tend to be neither perfectly serially arranged, nor to have common boundaries. Consequently, part (but not all) of the groundwater recharge produced by a certain transboundary river basin A may feed transboundary groundwater system B, which - in turn - may contribute to baseflow in river basin A, but also to baseflow in other (non-transboundary) river systems. Similarly, groundwater system B may contribute to water storage and water quality of LME C, but the total inflow to this LME is likely also to include many non-transboundary terrestrial water systems. Unless there is a clear and exclusive one-to-one relation, it is not possible to carry out an input/output analysis based on lumped data. This type of analysis can only be carried out in more detailed groundwater studies (pilots of Level 2), if conditions are favourable, in particular in terms of data availability.

## 16. CROSS-CUTTING AND COMMON ISSUES

**Cross-cutting issues**, within the context of TWAP, are defined as *a problem, opportunity or concern shared by several TWAP water system types, often interlinking them to some extent*. Nutrients and mercury have been defined and agreed as cross-cutting issues for the TWAP FSP-phase.

Nutrients, as a cross-cutting issue, are assessed in transboundary groundwater systems and SIDS. Variables like nitrate concentration in groundwater, Total Dissolved Solids and ground-level decline are all related to these cross-cutting issues and are inputs for some of the selected indicators for the groundwater assessment (see part 3). The values for the particular indicators related to the cross-cutting issues in a certain transboundary groundwater system and/or SIDS, together with the level of interlinkages of that system with other water systems, complete the picture of cross-cutting issues.

Mercury as a cross-cutting issue is of little relevance in groundwater systems. This issue was raised repeatedly throughout the preparation of the methodology and highlighted again during the peer review validation session of the TBA methodology. It was suggested that the groundwater group should focus on arsenic instead (please refer also to section 22 – Validation).

**Common issues**, within the context of TWAP, are defined as *a problem or concern shared by several TWAP water system types*. In practice, they difficult to distinguish from cross-cutting issues, although the emphasis on interlinking may be less. Common issues may be identified by comparing the reports on all water system types.

# PART 5. DATA AND INFORMATION MANAGEMENT

## 17. BACKGROUND

This part of the report looks at the TWAP groundwater assessment from an information management perspective. The assessment will clearly be based on large amounts of data and information and will produce even larger amounts of both. Data and information sources are likely to differ from one TBA and /or SIDS to another, and the regional networks of experts, key to developing the indicator values, may have different interpretations of what data and information is requested by TWAP. In order ensure consistency, the flows of data and information need to be harmonized and streamlined as much as possible - in other words an information management system is crucial.

Since both 'data' and 'information' are often used in this section, we define data as the raw measurements of property values of systems. Interpretation of that data leads to information. In that sense, the indicators are 'information' as they are based on analysis of other data. On the other hand, the indicator values will be inputted into a multi-criteria prioritization and as such are 'data'.

The information management system enables us to collect, store, analyse and share data and information on the TBAs in a consistent way. The approach to be followed should be simple and transparent to ensure understanding of how information flows from inputs to the final outputs. Furthermore, a systematic approach enables us to replicate and repeat the various assessment steps in a consistent way, and the system is extendible so that future assessments can easily be added.

## 18. INFORMATION MANAGEMENT SYSTEM COMPONENTS

The information management system consists of (Figure 7):

1. Data and information;
2. Information and communication technologies (ICT); and
3. Processes and protocols.

***Data and information***

This component consists of all data and information used in the assessment as a reference and source, interim products, and the final products on which GEF will base prioritization. It can be in the form of datasets with geospatially-referenced data (GIS-layers), tabular data with indicator values for each TBA and SIDS, descriptive data, and images, e.g. aquifer profiles and pictures.

The information system will also contain meta-information by data type. This describes how the data were generated - what data, by whom, etc. The data products of this TWAP TBA and SIDS assessment are discussed in more detail in section 4.

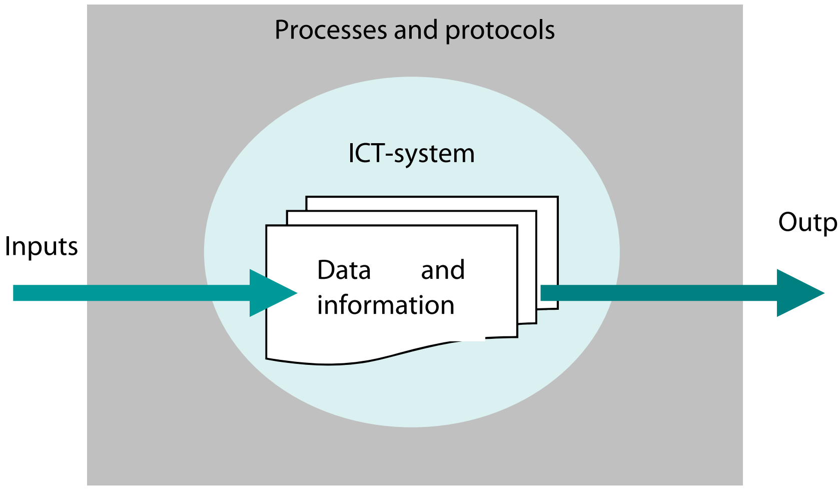



**Figure 7:** Information management system components.

***ICT***

This component consists of software that enables storage, processing and visualization and combination of various types of data and information (geo-referenced maps, tabular data, images and descriptive texts. It allows for (geospatial) processing of data (e.g. aggregating high resolution data to a single value for each national TBA segment or SIDS) and easy searching of maps and tables.

By storing all available data on a server of a designated organization, all information can be made accessible to various audiences via web-based interfaces.

***Processes and protocols***

Many different regional expert groups and regional or global groundwater-related organizations will contribute to this assessment, possibly providing data and information subject to some intellectual property conditions. The final result of the assessment will be a prioritization by GEF to allocate their financial resources, and hence the interests of various inputting groups may be high. It is therefore of the utmost importance that all contributing groups are informed on and agree with the processes and protocols of how this assessment is conducted. These include the way the data and information provided is stored, processed and shared.

The bulk of the data is assumed to come from the various TBA and SIDS regional networks. It is important that the organization where the data are stored (and which is likely to do some of the processing) provides data security. The organization should be trusted by the various networks, persons and countries that are going to contribute to the assessment.

As stated above, the information system will contain source data, interim products and the final products plus meta-information on the algorithms used to develop the indicator values. This full transparency enables the contributing partners to check their inputs. It improves confidence in the data integrity and soundness of the assessment.

Another important aspect of using the same set of rules is that it will lead to a consistent assessment of all TBAs and SIDS, and that the data and information in the system are harmonized as much as possible.

The web-based accessibility of the assessment results should provide an incentive to the contributing partners. Results of the regional network's efforts will be displayed in attractive maps and tables. The querying and GIS functionality of the information systems enables further analysis of their TBA or SIDS and comparisons with others. The contributing partners will be acknowledged in the meta-information, providing another type of incentive.

## 19. INFORMATION MANAGEMENT SYSTEM STEPS

From the information management perspective, this assessment has four steps (Figure 8):

1. Input;
2. Data handling;
3. Database; and
4. Output.

The figure shows the assessment as a flow of information from input to output and shows how an operational workflow of activities can be carried out to make the assessment robust.

***Input***

The information management system serves as the technical backbone of the assessment. Until the data and information are harmonized, digitized and checked, they are considered as inputs, which will be delivered by TBA/SIDS networks in the form of filled-in questionnaires based on their collected source data and various global data sets. For this first step, many organizations will be contributing their data, information and knowledge to the assessment, coordinated by a TWAP Groundwater core team, also from various organizations.

***Data handling***

The second step will be to process the inputs. This includes digitizing maps and profiles in GIS-layers and images, and developing indicator values for each TBA/SIDS based on questionnaires and global data sets. Data are checked for consistency and correctness. It is assumed that this data handling will be conducted by a designated (neutral) organization experienced in this type of geo-data handling and supervised by the TWAP groundwater core team.

The regional networks of experts will also need to do substantial data handling. They need to interpret and analyse various sources of information to be able to complete the questionnaires. However, this is a different type of data handling to that being described here, which is a necessary step to enable comparison of all the individual inputs from the potentially hundreds of assessed TBAs and SIDS.

To make this data handling step as simple and lean as possible, questionnaires with strict formats will be used. The networks can be sent digital forms for inputting of descriptions and estimates of indicator values in certain data entry slots. Such forms can be uploaded automatically into the database, reducing the risks of data transfer noise.

***Database***

The database infrastructure will need to be created by the designated organization, and only filled in at this stage. It is assumed that the database will be on the computer server of the designated organization. Database maintenance and updating needs to be agreed from the very start of the assessment. This is an ongoing activity with associated costs, even long after the initial assessment has been carried out.

***Output***

The final step of the assessment is to generate the products that GEF needs in order to be able to do a prioritization. Currently, it is assumed that prioritization will be by GEF and not the TWAP Groundwater core team. Possible end products or outputs that may facilitate GEF carrying out this task are information sheets for each TBA and SIDS. Global maps and tabular data showing all TBAs and SIDS and allowing for multi-criteria weighting of indicator values are also assumed to be useful tools.

The exact forms and types of final products should be based on GEF's needs and therefore discussed with them. The outputs suggested here could be assessed via a special dedicated website. Hardcopy versions of the various products are another obvious option.

The results of this assessment will be very useful for many stakeholders as well as the GEF. The extent to which these other stakeholders will be allowed to use the data and information generated remains to be agreed with GEF.

## 20. THE FLOW OF INFORMATION IN THE ASSESSMENT

This subsection discusses the various components of the flow of data from the input to the output stage in more detail.

### *TBA/SIDS-specific source data*

It is assumed that relevant data exists for each TBA and SIDS on the hydrogeological, socioeconomic, institutional and legal status of the system. This may include various kinds of maps, reports, monitoring networks and census data. In some cases, remote-sensing studies and computer model results may be available. The source data will often be country-based so data sources for the various national segments of TBAs are likely to differ.

One has to accept that the amount and accuracy of the data to be used for TBAs across the world will be diverse.

### *Regional TBA/SIDS networks*

The regional networks of experts and SIDS have an important role in harmonizing the diverse set of data sources with varying quality into information that can be included in the assessment.

### *Questionnaires*

The most important instrument in this harmonization process is the questionnaire. This will generate descriptive information, maps and hydrogeological profiles and tabular data with estimates of the indicator values. Crucial for the streamlining of the assessment is that the questionnaires have a pre-set format.

Clear instructions will be given to TBA/SIDS Regional networks on how to calculate and determine the various indicator values (see section 3.2.5). One instruction covers the features to include on the maps and in the profiles.

Figure **9** shows a dummy that might be used by the regional experts as a basis for sketching hydrogeological maps for their TBA or SIDS.

The map should include information on:

- Aquifer delineation and national boundaries;
- WHYMAP classification on type of aquifer and level of recharge;
- Major recharge and discharge zones;
- Location of hydrological features such as rivers and lakes;

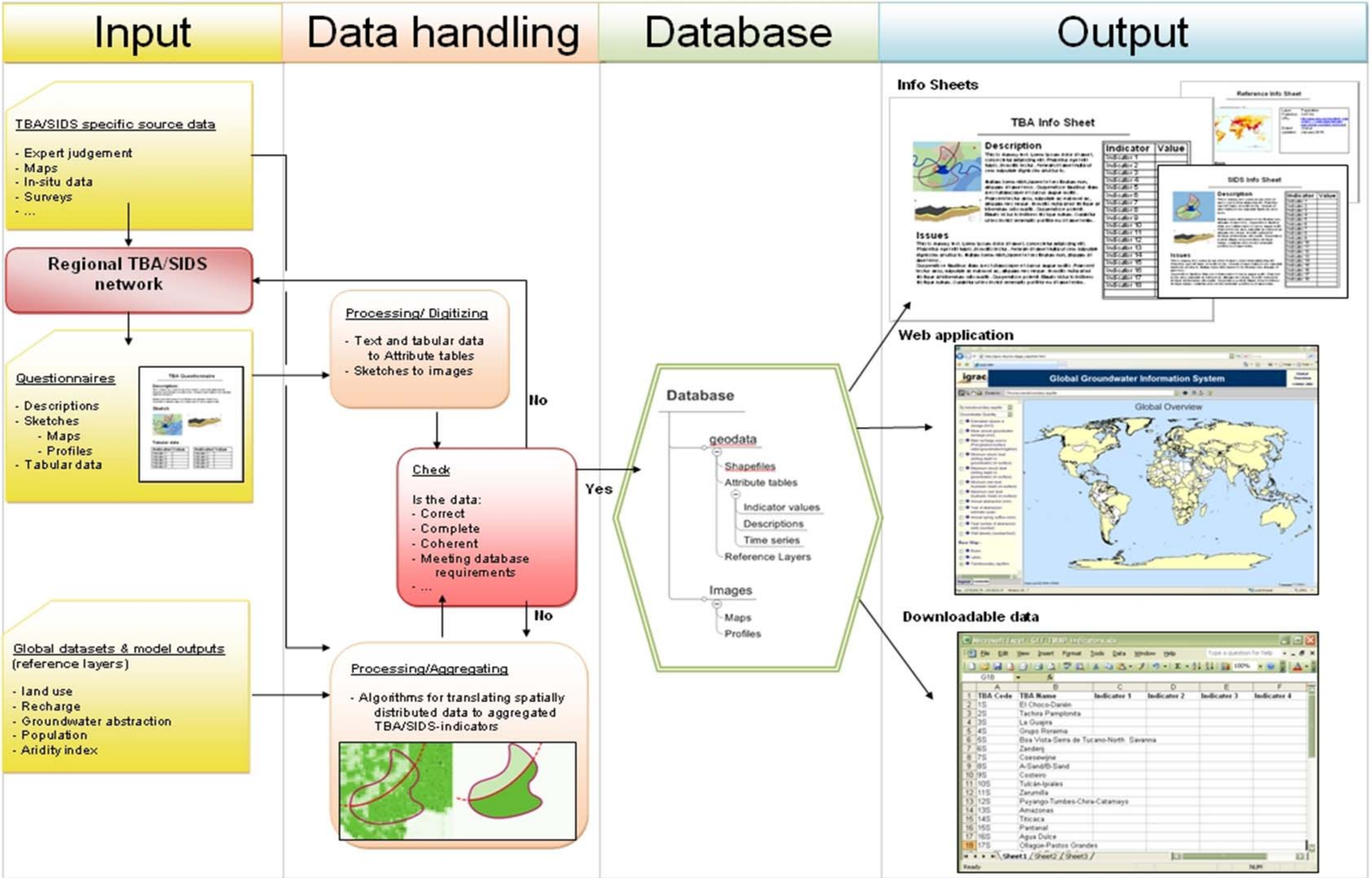



Figure 8: TWAP Groundwater assessment Information flow chart.

- Presence and location of groundwater-dependent ecosystems; and
- Locations (hotspots) of priority and emerging issues and concerns such as groundwater over-abstraction, salinization, pollution and cross-cutting issues.

A similar systematic approach is needed for the profiles.

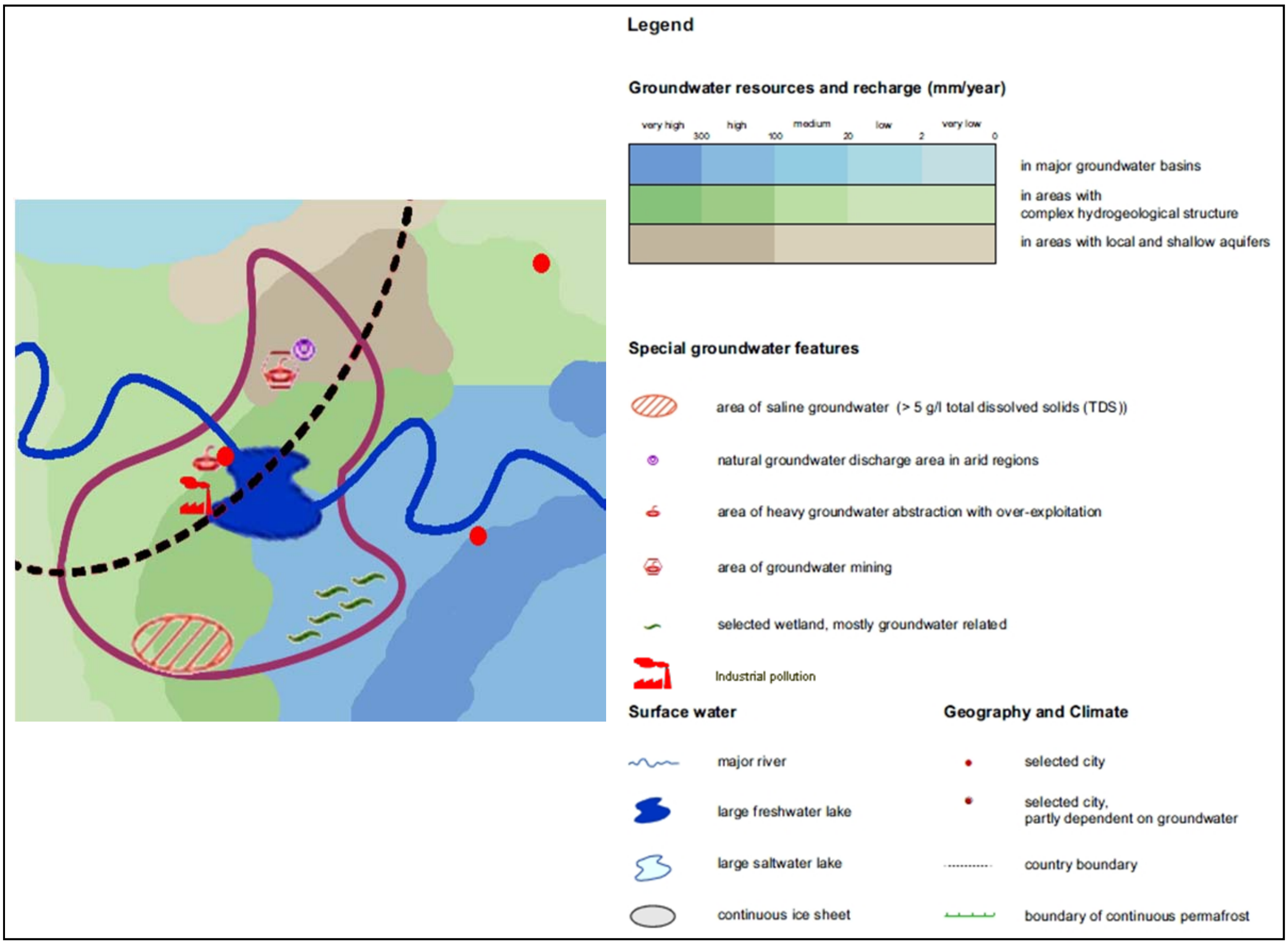



**Figure 9**: Dummy map of a TBA with possible legends - mainly based on the WHYMAP legend.

### *Global data sets and model outputs*

One way to overcome the issue of having varying data sets across national boundaries is to use datasets with global coverage. Various global datasets with information on change in groundwater storage (GRACE), groundwater recharge (from global hydrological models), groundwater abstraction (Utrecht University, irrigational (groundwater use (FAO, IWMI), and Aridity Index are likely to be useful for the TWAP assessment. Such datasets often have spatial resolutions of 1 to 0.5 degree.

### *Processing/digitizing*

Data and information from the questionnaires needs to be in a digital format to enable it to be included in the database. As mentioned earlier, the questionnaires will be formatted so that the information inputted by the regional experts meets requirements for easy uploading into the database. Other information such as sketches of maps and profiles might still be in a non-digital form. Ideally, maps should be digitized and developed into GIS-layers by the designated organization.

***Processing/aggregating***

It has been agreed that the national segments of TBAs should be used as the spatial unit in this assessment. Indicator values used in the assessment are thought to be representative of such national segments. However, some of the data and information provided may be at higher resolution and aggregation of this data into national segment values may be needed. Algorithms for this aggregation will be developed by the designated organization.

***Checks***

Before the data is stored in the database, it should be tested for consistency, correctness, completeness and compliance with database requirements. If data fails to meet these tests, attempts will be made to improve it with the help of the regional networks. Clear rules need to be developed by the designated organization, on what requirements need to be met and how information is to be used if these are not met.

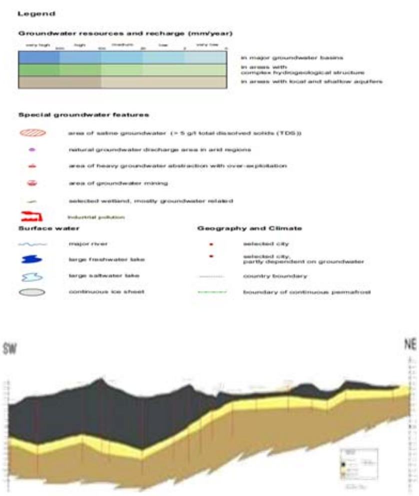
***Database***

Data and information are stored in a central database as GIS-layers with attribute tables. Some of the tables will contain the indicator values by national segment of the TBAs and SIDS. Others will contain the descriptive information. Images will also be stored. The database will be developed, updated and maintained by the designated organization.

***TBA /SIDS Information sheets***

These information sheets will provide a quick, easy-to-interpret overview of each TBA or SIDS assessed. A dummy version of such an information sheet is shown in Figure 10.

TBA Info Sheet



Description

This is dummy text. Dummy text dummy text dummy text dummy text dummy text dummy text dummy text. Dummy text dummy. Text dummy text dummy text.

This is dummy text. Dummy text dummy text dummy text dummy text dummy text. Dummy text dummy text dummy text dummy text dummy text dummy text dummy text dummy text dummy text. This is dummy text dummy text text dummy text dummy text text dummy text dummy text text dummy text dummy text text dummy text dummy text. This is dummy text. Dummy text dummy text dummy text dummy text dummy text.

Issues

This is dummy text. Dummy text dummy text dummy text dummy text dummy text. Dummy text dummy text dummy text dummy text dummy text dummy text dummy text dummy text dummy text. This is dummy text dummy text text dummy text dummy text text dummy text dummy text text dummy text dummy text text dummy text dummy text. This is dummy text.

| Indicator | Value |
|---|---|
| Indicator 1 | |
| Indicator 2 | |
| Indicator 3 | |
| Indicator 4 | |
| Indicator 5 | |
| Indicator 6 | |
| Indicator 7 | |
| Indicator 8 | |
| Indicator 9 | |
| Indicator 10 | |
| Indicator 11 | |
| Indicator 12 | |
| Indicator 13 | |
| Indicator 14 | |
| Indicator 15 | |
| Indicator 16 | |
| Indicator 17 | |
| Indicator 18 | |
| | |

**Figure 10**: Dummy TBA Information sheet

***Reference Layer Information sheets***

These information sheets provide a quick, easy-to-interpret overview of the reference data and information used in the assessment.

***Web application***

The web application provides access to the database, its derived products and meta-information. One of its features will be a navigational world map containing all the assessed TBAs and SIDS. GIS-functionality like zooming, panning, identification and querying will allow easy comparison and analysis.

***Downloadable data***

Data will, to some extent, be downloadable by a number of stakeholders.

## 21. ORGANISATIONAL INFORMATION MANAGEMENT STRUCTURE

The groundwater WG's intention is to build the TWAP groundwater database using previous experience and existing databases and information management systems within the ISARM programme. It makes sense that the TWAP assessment inputs coming mainly from these ISARM groups is going to contribute to these existing databases.

IGRAC was set up by the international groundwater community (initiated by UNESCO and WMO with strong support from UNEP and IAH) as the centre for global data and information on groundwater resources. IGRAC has the specialized knowledge and expertise to develop such a groundwater-related information system and is able to serve as such a centre not just for the duration of the TWAP FSP but on a permanent basis. IGRAC has proved is usefulness in various ISARM projects, has developed information management systems and has built networks with various partners in the field of international aquifer management. Fragmentation of the role of the global groundwater information centre over multiple organizations risks confusing the partners in the existing networks and reducing their commitment to contribute to the Groundwater TWAP. Assigning this task to UNEP Grid probably would need investment to obtain the same level of groundwater-specific knowledge.

Within the TWAP MSP, it is also agreed that there is a need to have a central platform to coordinate the data needs of the whole TWAP, including the assessments of rivers, lakes, groundwater, SMEs and open oceans. UNEP, the executing agency for the TWAP FSP, will coordinate this using existing networks such as the NEWS model, DHI, IGRAC, GRID centres and also possible links with the GEF-IW:LEARN project. It is, however, emphasized that the GEF data portal cannot replace other existing information systems with a focus on specific water systems like the TWAP Groundwater database to be developed by IGRAC.

# PART 6. TOWARDS IMPLEMENTATION OF THE ASSESSMENT OF TRANSBOUNDARY AQUIFERS

## 22. VALIDATION

A peer review session aimed at validating the TWAP transboundary aquifers methodology was held during a side event at the ISARM2010 International Conference: 'Transboundary Aquifers: Challenges and new directions', at the UNESCO HQ in Paris, on 8 December 2010. More than 50 experts from UN agencies, international and regional organizations and associations, academia/research institutes, geological surveys, and donor institutions attended. The detailed presentation of the TWAP transboundary aquifers methodology was followed by a constructive discussion. The recommendations received were related to two main issues:

(i) The number of indicators was considered too high, which led to a discussion regarding their feasibility and applicability in the light of the limited data availability. This comment was addressed by introducing two different categories of indicator in this final version of the methodology document: 'Core indicators' to be applied for each transboundary aquifer or transboundary aquifers system throughout the Level 1 assessment and 'Priority indicators', which are more complex and require more data and will be used for the Level 2 assessment only, for selected transboundary aquifers or transboundary aquifers systems; and

(ii) It was highlighted that mercury is not relevant to groundwater quality globally. It was suggested that the groundwater methodology should consider arsenic instead.

These recommendations have been taken into consideration during the process of finalizing the methodology and are reflected in the final version of the document.

## 23. PARTNERSHIP ARRANGEMENTS

As one of the main outcomes of the GEF Medium Sized Project 'Development of the Methodology and Arrangements for the GEF Transboundary Waters Assessment Programme (TWAP)', UNESCO-IHP in its capacity as lead agency for the TWAP Transboundary Aquifer and Groundwater component is currently establishing the *TWAP Groundwater Coalition*, a partnership of institutions and organizations at the national, regional and global level.

The members of the Groundwater Coalition are committed to:

(i) carry out and co-finance the GEF-funded TWAP baseline assessment adopting the methodology and modalities defined as a result of the TWAP design phase (MSP); and

(ii) explore ways to carry out long-term periodic follow-up assessments and monitoring with non-GEF resources in order to ensure the sustainability of TWAP Groundwater.

The Groundwater Coalition consists of three categories of partners based on their specific roles and functions:

1. The Core Group, led by UNESCO-IHP, consisting of IGRAC, FAO, UN WWAP, and the global network of UNESCO water-related centres and chairs;
2. Regional Coordinators and Expert Networks; and
3. Key providers of expertise and data.

Partners will benefit from the coalition by broadening the knowledge of transboundary aquifer systems, establishing new partnerships and cooperation, and having access to the data and information management system. Given the objective of TWAP to provide a basis for science-based allocation of financial resources (GEF and other donors) to priority transboundary aquifer systems, countries and regions will benefit from increased transparency in fund allocation.

Members of the core group and many of the other partners are already co-operating in ongoing transboundary aquifer projects and programmes. Special mention has to be made here of ISARM- and GEF-supported projects/programmes. TWAP may benefit from their existing co-operation arrangements.

The proposed composition of the TWAP Groundwater Coalition is displayed in Figure 11. The circles represent (from inner to outer circle): (i) UNESCO-IHP led core group; (ii) regional coordinators and expert networks; (iii) providers of data and expertise.

**1. TWAP Groundwater Core Group**

The core group has a central role in guiding and coordinating the TWAP groundwater coalition to successfully execute the global baseline assessment, as well as the periodic follow-up assessments. Consisting of the main players in the field of transboundary groundwater resource assessment and management globally, the Core Group will have overall responsibility and directly perform parts of the assessment. It will appoint a Project Manager and establish cooperation schemes and liaise with key partners.

Calling on a wide array of ongoing cooperation and joint activities with many partners, the core group provides the main pillars of the TWAP assessment through programmes such as the Internationally Shared Aquifer Resources Management (ISARM) Initiative, the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), the United Nations World Water Assessment Programme (WWAP) and its triennial World Water Development Report (WWDR), high resolution global data sets on soils, land use and irrigation from FAO's AQUASTAT and other related programmes, and IGRAC's Global Groundwater Information System (GGIS) as well as the Global Groundwater Monitoring Network.

**2. The Regional Coordinators and Expert Networks**

*Regional partners* will contribute to the assessment through regional coordination mechanisms already in place. They will be responsible for organizing the acquisition of data on transboundary aquifers through regional expert networks already existing (ISARM Americas) or to be established. They may also serve as data providers, having conducted previous studies and/or assessments at regional scale, or by providing access to existing data and local information systems. Whenever feasible, the management of Regional Coordination and Expert Networks and the promotion of country involvement will be entrusted to Regional Organizations such as OAS, SADC, UNECE, UNECA, UNESCAP, UNESCWA, UNECLAC, OSS and SPC.


**Figure 11:** Proposed composition of the TWAP Groundwater Coalition, with the groundwater core group and associated entities and networks[44]. The circles represent (from inner to outer circle): (i) UNESCO-IHP led core group, (ii) regional partners and (iii) providers of data and expertise.

[44] The listing of organizations and institutions is not meant to be exclusive, but represents the current state of development of the Groundwater Coalition. More partners are likely to be added during the process. A formal commitment of partners will be requested during the FSP preparation phase.

### 3. Key Providers of Expertise and Data

Organizations or institutions at the local, national or regional scale will serve as *providers of expertise and information*. This encompasses universities and research institutes from developing and developed countries, geological surveys, international associations, and non-governmental organizations (NGOs), among others. In particular, this group of partners will have a central role with regard to the Task Force on remote sensing and modelling aimed at filling data gaps and generating harmonized data at the global or regional scale. As well as hydrogeological, technical or environmental expertise, the provision of expertise on socioeconomic, legal and institutional issues will be of great important in the framework of TWAP-Groundwater.

Key partners falling into only one of the above-mentioned categories may also serve as regional partners, providing both data and expertise.

## 24. EXECUTION ARRANGEMENTS

The Execution structure and arrangements of the TWAP Transboundary Aquifers and Groundwater component are displayed in Figure 12.

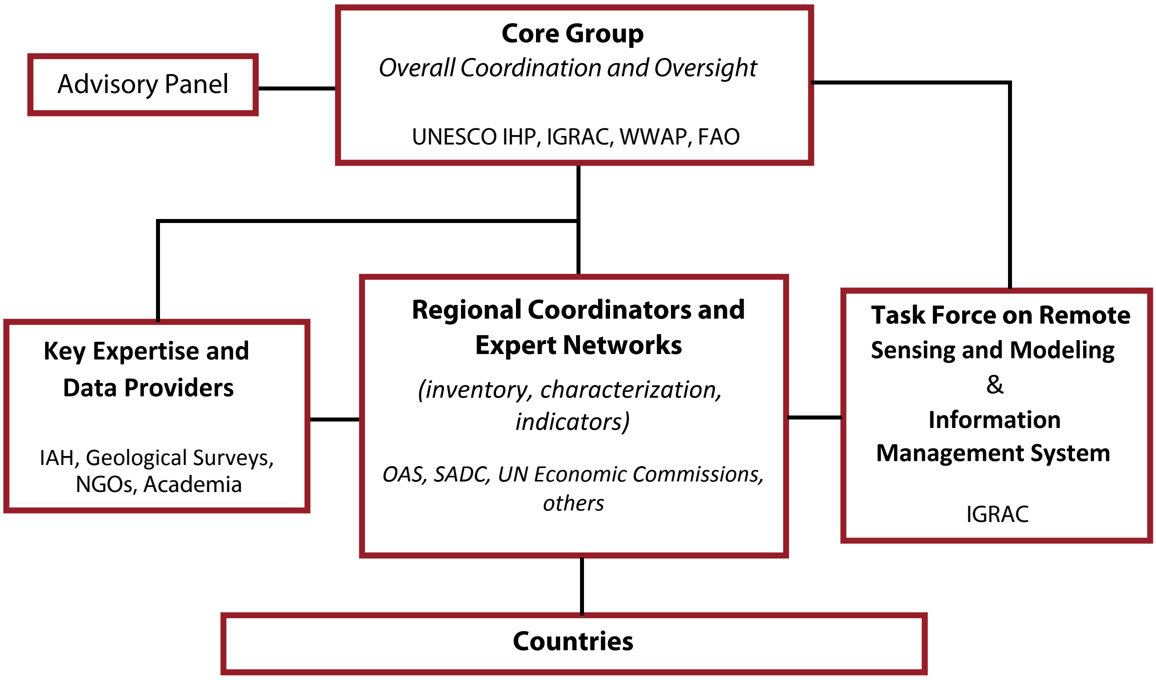



**Figure 12:** Execution structure and arrangements of the TWAP Transboundary Aquifers and Groundwater component.

The Information Management System will be organized and managed by IGRAC and will provide the backbone of the TWAP assessment through efficient data and information management, allowing for storing, managing and visualizing the data gathered for TWAP.

In addition to the gathering of existing data at the global scale, TWAP-Groundwater will also work towards filling data gaps by applying state of the art earth observation technology and modelling techniques. For this purpose, a Task Force on remote sensing and modelling will be established and managed by IGRAC. The TWAP-Groundwater Advisory Panel will consist of individual experts in hydrogeological, socioeconomic, legal and institutional aspects (IAH, Geological Surveys, Academia, etc.) and will provide advice and support to the Core Group on the overall coordination of the assessment.

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# ANNEX 1
## TWAP UNESCO GROUNDWATER EXPERT GROUP

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# ANNEX 2
## GLOSSARY OF TERMS

***Aquifer*** means a permeable water-bearing geological formation underlain by a less permeable layer and the water contained in the saturated zone of the formation;

***Aquifer State*** means a State in whose territory any part of a transboundary aquifer or aquifer system is situated;

***Aquifer system*** means a series of two or more aquifers that are hydraulically connected[45];

***Aquiclude*** means a porous formation that absorbs water slowly but will not transmit it fast enough to furnish an appreciable supply for a well or spring;

***Aquitard*** means a bed of low permeability adjacent to an aquifer; may serve as a storage unit for groundwater, although it does not yield water readily;

***Baseflow*** is the portion of streamflow that comes from "the sum of deep subsurface flow and delayed shallow subsurface flow";

***Coastal aquifer*** means an aquifer located on the coast, usually hydraulically connected to the adjoining Large Marine Ecosystem;

***Discharge zone*** means the zone where water originating from an aquifer flows to its outlets, such as a watercourse, a lake, an oasis, a wetland or an ocean;

***Recharging aquifer*** means an aquifer that receives a non-negligible amount of contemporary water recharge;

***Recharge zone*** means the zone that contributes water to an aquifer, consisting of the catchment area of rainfall water and the area where such water flows to an aquifer by runoff on the ground and infiltration through soil[46];

***Transboundary aquifer*** or ***transboundary aquifer system*** means an aquifer or aquifer system, parts of which are situated in different States;

***Utilization of transboundary aquifers or aquifer systems*** includes extraction of water, heat and minerals, and storage and disposal of any substance;

***Virgin recharge*** or ***natural recharge***: recharge or replenishment of 'natural' origin (rainfall, runoff, seepage from rivers or lakes, etc.), not significantly affected by human activity (artificial or induced recharge; return flows or other replenishment by used water; surfacing of terrains, etc.).

[45] Another possible definition is: 'Aquifer system means an aquifer or a complex of hydraulically interconnected aquifers'. This definition is consistent with the common practice of using 'aquifer system' for indicating a single aquifer only.

[46] Another possible definition is: 'zone where significant recharge (=replenishment) of the aquifer's groundwater is taking place, from whatever source of water'.

# ANNEX 3
## GEF RESOURCE ALLOCATION FRAMEWORK FOR GROUNDWATER

Click below to access the Indicators Approach Paper for Possible Application of the Resource Allocation Framework to the International Waters Focal Area of the GEF.

**Indicators Approach Paper**

**for**

**Possible Application of the Resource Allocation Framework**

**to the**

**International Waters Focal Area of the GEF**

**Transboundary Aquifers**

February 2009

Expert Group Coordinator: Jaroslav Vrba

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GEF RAF Indicators Transboundary Aquifers, February 2009 1

# ANNEX 4
## EXAMPLE OF ISARM QUESTIONNAIRE

UNESCO-OAS ISARM AMERICAS PROGRAMME

**Questionnaire #3**
**Sustainable Socioeconomic and Environmental Aspects of Transboundary Aquifers**

The ISARM Programme Framework document sets out five focal areas of concern when dealing with transboundary aquifers. In the course of the ISARM Americas programme information has so far been collected by the Countries of the region on three of these focal areas: scientific aspects of transboundary aquifers and the legal and the institutional frameworks in the course of the past few years. The last two focal areas have been combined, to address the socioeconomic and environmental aspects. Assessment of the current trends in environmental actions suggests that this approach is more appropriate.

Responding to these trends the following survey collects basic socioeconomic and environmental information that will help to define a region assessment for the sustainable management of the transboundary aquifer systems of the hemisphere. This combined focal area of ISARM addresses the interactions and interdependencies between human communities, natural ecosystems, and the transboundary aquifer systems. A consideration of these interactions and interdependencies will simultaneously help to develop instruments and tools that will sustain human development and preserve ecosystem services.

The survey includes two parts. PART 1 including detailed information to complete the questionnaire and PART 2 is the actual questionnaire.

**EXPLANATORY NOTE:**
The questionnaire relates to each of the *transboundary aquifers and the areas they cover* that have been identified in the Inventory compiled by the ISARM Americas Programme. The ref no. (i.e. 1N; 15S...) as used in the Inventory should be entered in the reference box.

## QUESTIONNAIRE ON SOCIOECONOMIC & ENVIRONMENTAL ISSUES

| | | |
|---|---|---|
| **AQUIFER Ref** | | |
| **Country responding** | | |

## INSTRUCTIONS

***PART 1:***

To process this questionnaire, please visit the OAS ftp://207.237.157.65/ virtual site and find the folder "**Mapas A.T. Americas**" with all the final maps included in Volume I of the UNESCO-OAS ISARM-Americas Series.
In order to fill out Questionnaire No. 3 please extract information from Questionnaire No. 1 (i.e. from the Hydrogeological Data form), if still valid.

Using the relevant aquifer map please identify the recharge and discharge areas to the extent possible and draw them with **black dots pattern and the initial capital R and D in black**.

*From the socioeconomic and environmental point of view the key "management" areas in aquifers are on their recharge and discharge areas, so they need to be identified, as far as possible, on the map. This will also help in a clearer understanding of some of the responses to the questions.*

***PART 2***: PLEASE FILL OUT THE FOLLOWING QUESTIONNAIRE AND TRANSFER RELEVANT DATA TO MAP, IF POSSIBLE.

On the whole the questions that have been formulated below are based on the factors that contribute to the equitable and reasonable use of the transboundary aquifers. In responding to the questionnaire, some answers will be numerical and some narrative; if numerical, please enter the relevant numbers on the box on the right of the question. If narrative, please insert the response within the box with the question.

# SOCIAL AND HUMAN ASPECTS

### *Human populations*

| | |
|---|---|
| What is the size of the population dependent on the aquifer or aquifer system in your country and where is it located ? (How is it distributed?) | |
| What percentage is rural and what percentage is urban? | |
| Estimate population located in the recharge areas . | |
| Estimate population located in the discharge areas . | |
| What is the population annual growth rate? | |
| What are projected population increases/decreases over the next 30 years for urban communities? | |
| What are projected population increases/decreases over the next 30 years for rural communities? | |
| What percentage of the population is indigenous? | |

### *Current water use from aquifers*

| | |
|---|---|
| Of the water currently withdrawn from the aquifer in your country, what proportion, in percentages, is used for :<br>agribusiness,<br>irrigation,<br>domestic use,<br>industry, and<br>other uses? Specify: ______________________<br><br>Please specify the percentage in recharge areas and the percentage in discharge areas, if known. (If proportions are not known, simply indicate priorities. If priorities are unknown then simply identify whether use exists or not.) | |

# PHYSICAL ISSUES AFFECTING TRANSBOUNDARY AQUIFERS

### *Current & expected climatic issues affecting the transboundary aquifer areas*

| | |
|---|---|
| What have been the changes in the quantity, intensity and periodicity of rainfall over the aquifer in the last decade? Percentual changes can be used.<br><br>Have they had any impact on the recharge patterns?<br>If so, what impacts are expected? | |
| What are the expected rainfall changes in the future two decades?<br><br>Are there any expected changes in recharge patterns?<br>If so, what are the expected changes? | |

| | |
|---|---|
| What is the impact on the aquifer of extreme events (floods, droughts, earthquakes)? (is there any plan for the development of the aquifer, particularly during drought periods?) | |
| What use is done of the aquifer during and/or after extreme events? | |

***The 'water' in the transboundary aquifers***

| | |
|---|---|
| What widespread (not localized) changes have been noticed in the availability and quality of water in the aquifer? | |
| ▪ Increasing/Declining water table?<br>▪ Nutrient contamination?<br>▪ Microbiological contamination?<br>▪ Chemical contamination?<br>▪ Color, odors and/or taste?<br>▪ Change in Salinity?<br>▪ Disease?<br>▪ Other? | |

| | |
|---|---|
| In the case of present or future (possible) high extraction or contamination of aquifers, what other alternative water sources are available? | |
| Are they transboundary or purely national in nature? | |

## LAND USE & LAND MANAGEMENT ISSUES

| | |
|---|---|
| If possible, define what 'landscape' units are found in the area of the transboundary aquifer (ie, productive, natural lands, urban, aquatic, etc) | |
| What was the original (pre-development) natural land cover above the aquifer? | |
| What is the current land cover/use above the aquifer? (including industrial use) | |
| What is the cover/actual use above the aquifer (including industrial use)? **If possible, please indicate on the map with circles or ellipses, and put a small-letter initial for use in red (such as agricultural: a; forest: f; industrial: i...)**<br><br>Specify and provide the percentages of: crops and cropping systems<br>▪ industrial animal densities for industries and management systems (feedlots, pasture and dairy)<br>▪ natural land cover/ecosystems (forests, grasslands, etc.) | |

## WATER & LAND USE PLANNING & REGULATIONS

| | |
|---|---|
| Is (are) there any "plan/planes de ordenamiento territorial" for the area of the aquifer? (Attach or reference)<br><br>If so, describe the plan or the predominant common features of the plans for the area of the aquifer.<br><br>Is (are) any plan(s) being implemented? | |

| | |
|---|---|
| Will any components of the plan have an impact on recharge to the aquifers? | |
| Is there any "plan de manejo de recursos hidricos" for the area of the aquifer?<br>If so, describe (attach/reference website) the plan for the area of the aquifer.<br><br>Is this plan being implemented?<br>If so, describe (attach/reference website) the plan for the area of the aquifer.<br><br>Does this plan also include any measures that ensure that 'infiltration'; of annual recharge is unaffected? | |

| | |
|---|---|
| Do the "plan de ordenamiento territorial" and/or water management plan recognize ground water and/or include measures to maintain and enhance the recharge of the aquifer and sustainability?<br><br>If so, describe. | |

## PROTECTED / CONSERVATION AREAS

| | |
|---|---|
| Indicate what protected areas are located on the aquifer **(on the map, please use squares with the perimeter in green).** Indicate areas with forest or soil conservation and/or restoration programs **(big green dot).** | |
| Describe any important groundwater-dependent ecosystems fed by the aquifer. **If possible, indicate them in the map with perimeter-in-blue squares and the ecosystems in blue capital initials):**<br><br>Lakes (**L**).<br>Streams (**S**)<br>Rivers (**Ri**)<br>Wetlands (**W**)<br>Ponds (**P**)<br>Cyprus forests (**CF**)<br>Wildlife watering zones (**WZ**)<br>Bird flyways (**BF**) | |

| | |
|---|---|
| Are there any streams / rivers / lakes (mentioned above) that receive important natural groundwater discharge from the transboundary aquifer, especially during dry periods? | |

PLEASE ATTACH THE LEGEND USED

## ECONOMIC BENEFITS DERIVED FROM THE USE OF TRANSBOUNDARY AQUIFERS

| | |
|---|---|
| Taking into account the land use and production from activities in the area of the transboundary aquifer, what is the economic benefit drawn from the use of the water? Please quantify by converting to U.S. dollars. | |
| How is the local economy (agriculture / industry /natural resources -biodiversity) dependent on the access to the resource water? | |
| What is a percentual estimate of the poverty level of the populations that use the water resources of the aquifers? (Please also provide the average incomes in U.S. dollars.) | |
| Taking into account the groundwater-dependent ecosystems that use the discharge of the water from the aquifer, what livelihoods (economic losses) would be at threat, if the aquifer system were impacted negatively? | |

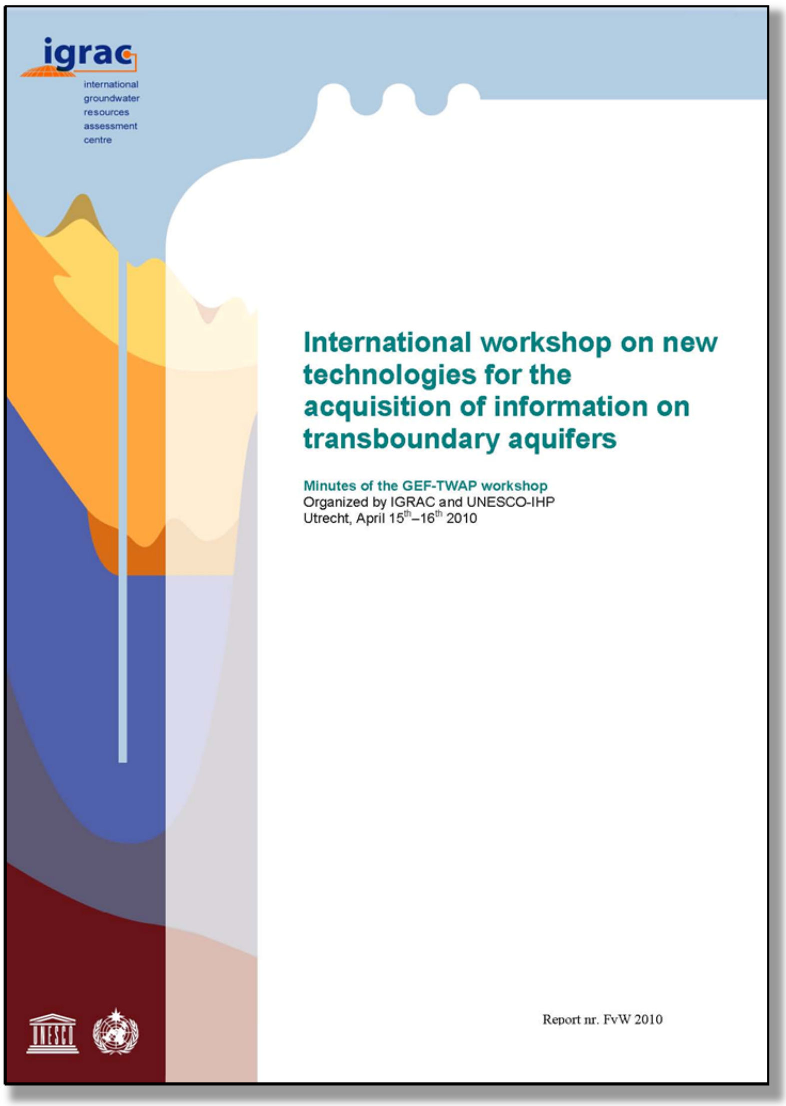
## COMPETITION FOR WATER RESOURCES IN THE TRANSBOUNDARY AQUIFERS

| | |
|---|---|
| How many interactions (official or non-official discussions, treaty, etc.) related to transboundary aquifers has taken place in the last 20 years?<br>How many of them are based on mutual collaboration?<br><br>How many of them are based on competition? | |
| Is there competition with your neighboring countries for the use of the aquifer?<br><br>What triggered the competition?<br><br>When did the competition start?<br><br>If there is competition, what efforts are being done to address it? | |
| Is there cooperation with your neighboring countries in the aquifer usage? | |
| What is being done: | |
| a) To <u>anticipate</u> possible escalation of the competition? | |
| b) To <u>prevent</u> the development of competition? | |
| c) To <u>improve</u> existing cooperation? | |

THANK YOU FOR YOUR TIME AND EFFORT!

# ANNEX 5
## MINUTES OF UTRECHT WORKSHOP

Click below to access the Minutes of the GEF-TWAP Workshop report, Utrecht, 15-16 April 2010.



# ANNEX 6
# DATA AND INFORMATION SOURCES

The two main sources of information for TWAP Groundwater are:

- accessible global information sources; and
- information sources to be used by regional expert networks.

## Global information sources

This first group contains information and data on relevant groundwater parameters with often a full global coverage. These data sets are derived by various techniques such as global assessments (like Aquastat, IGRAC's GGIS and GGMN, UN WWAP), satellite-based remote sensing (like GRACE) and or global hydrological modelling (like WaterGap)

The advantage of these global information sources is that they provide a boundary-free and consistent dataset covering all TBAs and SIDS. These datasets are relatively easily and freely accessible and can often be derived from the internet in digital formats. The global data generated by remote sensing and results from global hydrological models are not 'owned' by countries. Using such data may overcome the problem of not having access to the often nationally-organized conventional data.

A disadvantage of using such global datasets is their low spatial resolution (pixels of 0.5 degree). In case of small TBAs and SIDS, indicators need to be based on a few or even only one pixel value. A second disadvantage of using global remote sensing and modelling information is that it needs to be ground-truthed and calibrated. Table 1 contains a list of the most relevant global information sources. A number of them are discussed in more detail.

**Table 1:** Main global groundwater-related Information sources

| | DATASETS<br>CATEGORIES OF INFORMATION | CENTRE/ PROVIDING COMPANY | CURRENT INTERNET LINK |
|---|---|---|---|
| 1 | **Climate data**;<br>▪ Precipitation, temperatures, pressure… | Climate Research Unit **(CRU)** | http://www.cru.uea.ac.uk/ |
| 2 | **AQUASTAT**;<br>▪ Land use and population<br>▪ Climate and water resources<br>▪ Water use, by sector and by source<br>▪ Irrigation and drainage development<br>▪ Environment and health<br>▪ LADA, World Land Use Map (WLUM) | Food and Agriculture Organisation **(FAO)** | http://www.fao.org/AG/AGL/aglw/aquastat/main/index.stm<br>http://maps.howstuffworks.com/<br><br>**LADA information:**<br>http://www.fao.org/nr/lada/index.php?option=com_content&task=blogsection&id=4&Itemid=158<br><br>World Land Use Map (WLUM)<br>Global map of irrigation areas |
| 3 | **FAOSTAT**<br>▪ Land use and Irrigation,<br>▪ Fertilizer and pesticides statistics | Food and Agriculture Organisation **(FAO)** | http://faostat.fao.org/ |
| 4 | **GEMSTAT**<br>▪ Surface and ground water quality data sets | **GEMS Water**,<br>UNEP | http://www.gemstat.org/ |
| 5 | Global precipitation analysis | Global Precipitation Climatology Centre **(GPCC)** | http://gpcc.dwd.de |

| | DATASETS<br>CATEGORIES OF INFORMATION | CENTRE/ PROVIDING COMPANY | CURRENT INTERNET LINK |
|---|---|---|---|
| 6 | ▪ Water fluxes into the oceans<br>▪ Discharge statistics<br>▪ Composite runoff fields<br>▪ Global terrestrial network for river discharge (GTN-R) | **GRDC**<br>Global Runoff Data Centre | http://grdc.bafg.de |
| 7 | **GGIS** Global groundwater information system<br>▪ Aquifer characteristics,<br>▪ Groundwater quantity<br>▪ Groundwater quality<br>▪ Groundwater development<br>▪ Groundwater Problems | **IGRAC**<br>International Groundwater Resources Assessment Centre | www.un-igrac.org |
| 8 | ▪ land cover<br>▪ population density<br>▪ biodiversity for 154 basins and sub-basins around the world | **IUCN** water atlas<br>World Conservation Union | http://www.iucn.org/themes/wani/ea tlas/ |
| 9 | **ETOPO5** and **ETOPO2**<br>▪ Global relief (land and oceans) | **NGDC** National Geophysical Data Centre | http://www.ngdc.noaa.gov/mgg/flier s/01mgg04.html |
| 10 | Gridded population of the world | **SEDAC**<br>Socio economic Data and Application Centre | http://sedac.ciesin.columbia.edu/gpw / |
| 11 | **GRID** Global Resources Information Database<br>▪ Freshwater<br>▪ Climate<br>▪ Population … | **UNEP** | http://www.grid.unep.ch/data/index. php<br><br>http://geodata.grid.unep.ch/ |
| 12 | **TOPO30**<br>**STRM**<br>▪ elevation data (land)<br>**HYDRO1 k**<br>▪ streams, drainage basins | **USGS** United States Geological Survey | http://edc.usgs.gov/products/elevati on.html |
| 13 | **Earthtrends**<br>▪ Water Resources and Freshwater Ecosystems | World Resources Institute | http://earthtrends.wri.org/searchable _db/index.php?theme=2 |
| 14 | **UNEP** Environmental Outlook (GEO 4) | | http://www.unep.org/geo/geo4/med ia/ |
| 15 | **WHYMAP** Web-Mapping and Database | **WHYMAP** World-wide Hydrogeological Mapping and Assessment Programme, BGR/UNESCO | http://www.whymap.org<br><br>http://www.bgr.bund.de/groundwate r/ |
| 16 | **IAEA** Isotopic properties Database (recharge flow, etc) | **IAEA** | |
| 17 | GIAM, Global irrigated area map: Gridded information on surface water-and groundwater-based irrigation | **IWMI** | http://www.iwmigiam.org/info/main/ index.asp |
| 18 | Aquifers Map of the World - update 2009 | **ISARM (IGRAC)** | http://www.igrac.net/publications/32 3 |
| 19 | Global Groundwater Monitoring Network | **IGRAC** | http://www.igrac.net/publications/28 1 |

| | DATASETS<br>CATEGORIES OF INFORMATION | CENTRE/ PROVIDING COMPANY | CURRENT INTERNET LINK |
|---|---|---|---|
| 20 | Groundwater recharge and baseflow estimates from global hydrological models | **Water GAP (University of Frankfurt)**<br>**PCRGLOBW (Utrecht University)** | |
| 21 | Change in groundwater storage with GRACE | **NASA, other groups** | |
| 22 | Sustainable Living in Small Island Developing States Programme | **UNESCO** | http://portal.unesco.org/fr/ev.php-URL_ID=12123&URL_DO=DO_TOPIC&URL_SECTION=201.html |
| 23 | Les eaux souterraines dans le monde | Margat, UNESCO-BRGM 2008 | |

**Ad 2:** AQUASTAT, FAO's information system on water and agriculture and FAO's atlas of water resources used for irrigation at river basin and country scales provide valuable information for the development of groundwater resource abstraction indicators.

**Ad 7**: IGRAC (UNESCO-WMO groundwater centre) has produced global groundwater indicator maps (groundwater abstraction as a percentage of average groundwater recharge, total exploitable non-renewable groundwater resources / annual abstraction of non-renewable groundwater resources, dependence of agricultural population on groundwater) for the UN WWAP and the UNESCO IHP project on development of groundwater resource sustainability indicators. Furthermore, IGRAC's Global GIS includes world-wide coverage of many variables and indicators of potential relevance for TWAP Groundwater.

**Ad 15:** UNESCO's WHYMAP provides a global picture of the location, characteristics and lateral extent of 98 main transboundary aquifers or groups of aquifers. Other UNESCO-IHP regional maps and databases complement WHYMAP's synoptic global maps with more detailed information, including maps, organized at the regional level. The WHYMAP groundwater resources map (2008) also shows mean annual recharge based on the global water GAP model (Döll and Fiedler, 2008). In addition, hotspots of unsustainable groundwater abstraction or groundwater mining are shown, as well as assumed groundwater-dependent ecosystems.

**Ad 18:** The ISARM Project, UNESCO IHP: more than 270 transboundary aquifers have so far been identified. Approaches followed include many similarities, but there are substantial differences in the degree of aggregating subsurface hydrogeological units into the transboundary aquifer systems. Moreover, horizontal transboundary aquifer system limits are available for less than one-third of the aquifers.

Within the framework of the UNESCO IHP VII phase, IGRAC has prepared an updated version of the world map of transboundary aquifers, presented at the 5th World Water Forum at Istanbul, in March 2009. The preparation of such a map is time-consuming and requires the participation of experts from different regions and from the UNESCO network. Various methodologies have been used on different continents to define TBAs, however this needs additional harmonization to enable the compilation of a new homogeneous world map of TBAs.

**Ad 19:** IGRAC is establishing the Global Groundwater Monitoring Network (GGMN) aimed at using monitored groundwater data for a periodic assessment of global groundwater resources. It is expected that the periodic assessment will bring a new insight into the state of global groundwater resources, their dynamics and the impact of various human activities and climate change on the quality, quantity and regime of groundwater resources. IGRAC intends to collaborate with the remote sensing (GRACE) and global hydrological model communities to couple the application with other groundwater observation sources.

GGMN's purpose is not to collect 'raw data' but to take advantage of the national expert's knowledge to share 'aggregated data' (1 degree cells). The aggregated data and information are stored in a database and the country expert retains control of the country data. This way often disputed 'delivering' of data to an international organisation is weakened if not completely dismissed.

GGMN will initially focus on collecting groundwater parameters that are less difficult to retrieve: groundwater levels and EC. At a later stage, additional groundwater parameters like abstraction and quality data can be collected. GGMN will be an open access tool free to be used by anyone. GGMN is or is proposed to be embedded in several international water programmes/networks like IGWCO, GEO, GTN-H, Graphic, AEGOS and WWAP.

**Ad 20**: Various global hydrological models have been developed in recent decades (e.g. Water GAP by Frankfurt University, PCRGLOBWB by Utrecht University). These models often focus on surface runoff and do not model groundwater flow explicitly. However, such models do estimate groundwater recharge and base flow. Spatial resolutions are 0.5 degree and temporal resolutions are typically months or days. Dr. Wada (Utrecht University) has developed a method where IGRAC's GGIS-country statistics for groundwater abstraction are downscaled to 0.5° based on total water demand.

**Ad 21:** Groundwater data collected by various satellite remote-sensing programmes (e.g. GRACE, ESA, WHYCOS-World Hydrological Cycle Observing Programme, IGOS-Integrating Global Observing System, IGWCO-Integrated Water Cycle Observation) with the recent advent of spatially discrete and high-resolution Earth system data sets, significantly support groundwater databases for deriving TWAP groundwater indicators. These digital products are often global in domain, are spatially and temporally coherent, and provide a consistent, political 'boundary-free' view of the major elements defining the terrestrial water cycle, including groundwater. However, space-based groundwater data should be calibrated and validated according to the data acquired from terrestrial observation.

GRACE measures changes in the earth's gravity field and is therefore useful for detecting changes in the earth's total water column. The groundwater part of this water column is obtained by removing ice caps, soil water, surface water and atmospheric water mass terms. These terms are often estimated using models (e.g. GLDAS for soil water) or other remote-sensing data and often have a large level of uncertainty. Therefore, although GRACE is increasingly used to observe trends in groundwater storage, caution is advised on the reliability of the results, due both to the processing technologies and the assumptions made in the process.

**Ad 22:** Data sets for SIDS follow the same methodology as outlined for transboundary aquifers. Information is available through UNESCO's Sustainable Living in Small Island Developing States Programme and is available via the UNESCO Portal.

**Ad 23**: Many useful global groundwater-related data sets and maps are available in the recently published book 'Les eaux souterraines dans le monde' (Margat, 2008).

### Information sources to be used by regional expert networks

This groups contains sources of information such as:

- Hydrological and geological maps and reports at aquifer, regional and national scales;
- In-situ measurements from terrestrial monitoring networks and various kinds of surveys (observation wells, borehole descriptions, geophysical bore logs, geophysical methods);
- Results from regional groundwater and hydrological modelling studies; and
- Satellite-based and airborne remote-sensing studies.

These sources of information are diverse and will differ in scope, detail and even existence from one TBA or SIDS to another. This diversity provides a main challenge for TWAP Groundwater across TBAs and SIDS. How should the results from the various regional assessments carried out by the regional expert networks be harmonized?

In this respect, it is worth mentioning that some of the TBAs are already assessed in detail within the frameworks of ISARM and GEF International Waters. Both programmes provide frameworks, guidelines and methodologies for TBA delineation, characterisation and diagnostics. It is assumed that results from the ISARM and GEF IW TBA studies are relatively easily comparable. For the TBAs that have not already been assessed in the ISARM and GEF frameworks, the regional expert networks will face the challenge that most of the information is organized nation-wise and hence needs cross-boundary harmonization and interpretation.

A global information system that may assist in this respect is WHYMAP's Web Mapping Application which contains a large number of national and regional hydrogeological maps[47].

## Data collection and projection methods:

### 1. Groundwater quantity

Projected groundwater stress indicators will be based on extrapolation of globally, regionally and nationally available groundwater data from terrestrial observations and remote sensing (satellite and air-borne based) measurements, its assessment (taking the current situation as initial conditions) and its use for different types of simulation and forecasting models. Existing data as well as data to be measured in the future will be explored, evaluated and used for model calibration and validation. Development of models based on theoretical assumptions, not considering existing databases (in which will be collected every year for longer time-series data) will be reflected in a low credibility of the model results obtained.

**Terrestrial measurements:** climatic, groundwater and surface water data from existing monitoring networks (precipitation, temperature and other climatic data, groundwater level and spring discharge data, surface water flow and discharge data) are monitored in countries by national or state monitoring networks; geological and hydrogeological maps of transboundary aquifers provide data about, for example, aquifer geometry, rock permeability, and groundwater flow nets; and relevant data are available on soil and land-use maps and risk maps (e.g. inundation areas).

**Remote-sensing measurements:** spatial resolution and lower accuracy satellite-based measurements, including the most promising gravimetric and radar altimetry methods, are very useful, but do not yet provide accurate data for evaluating groundwater level fluctuation and storage. Space-based data therefore have to be calibrated and validated according to data acquired from in-situ terrestrial observations. Future decades may see the development of satellite methods that enlarge possibilities for more accurate groundwater detection. Various international satellite-based programmes (e.g. WHYCOS – World Hydrological Cycle Observing Programme, IGWCO – Integrated Water Cycle Observation, IGOS – Integrating Global Observing System, GRACE – Gravity Recovery and Climate Experience, GOCE Gravity Field and Steady –State Ocean Circulation Explorer) provide spatially- and temporally-coherent time-series data at the global and regional level and political boundary-free views of major elements defining the water cycle. With respect to groundwater, the most promising is the GRACE mission implemented particularly in studies focused on the assessment of variations in groundwater storage and their comparison with groundwater level changes measured in monitoring wells. Low spatial and temporal resolution and uncertainty in groundwater level measurements in the order of tens of centimetres is registered for aquifers with spatial extent lower than 150000 km$^2$. Satellite imagines of vegetation cover, land use and soil type in recharge areas and their topography provide useful data, for example for groundwater recharge evaluation.

Geophysical methods provide useful data for TWAP Groundwater both for identification and

[47] http://www.whymap.org/nn_354266/whymap/EN/Map__Applications/map__applications__node__en.html?__nnn=true

characterization of transboundary aquifers. They are effective if there is marked contrast between the rock environment, groundwater body and pollution plumes. Ground gravimetry and magnetometry as well as aerial aero-magnetometry and aero-radiometry are commonly employed for studying fractured aquifers and tectonically disturbed zones exhibiting high fracture porosity. Continuous electromagnetic profiling measurements with high lateral resolution and resistivity methods with high vertical resolution are most frequently used for detecting aquifer geometry and spatial extent as well as pollution plumes and their movement. However, other geophysical techniques are also applied, such as magnetometry and electromagnetic induction, for example for identification of point pollution undergrounds spills, or borehole logging methods, for example for detection of groundwater – saline water interface. Airborne electromagnetic techniques for identification and characterization of aquifers have been presented by J. Nijman at the Utrecht workshop (see Annex 5). In many countries geophysical methods support hydrogeological investigation and groundwater-related geophysical measurements and data will be very useful for developing indicators that present initial hydrogeological conditions as a base for the development of projected indicators.

**Models:** Several simulation, forecasting, pollution transport and other types of models can be used for the development of projected groundwater stress indicators. However, groundwater-related models have several limitations and their calibration by the use of time-series data acquired from terrestrial measurements is needed. Several models have been proposed for development of TWAP status indicators and can also be used for the development of projected indicators, for example the Water GAP Global Hydrological Model (Döll, et al., 2003) for diffuse groundwater recharge at the global scale in combination with WHYMAP programme (Groundwater Resources Map of the World and other WHYMAP maps), the Global NEWS model for global nutrient transport (Seitzinger, et al., 2005), and the Water GAP Global Hydrological Model for the impact of climate change on groundwater recharge (Döll, et al., 2003) for simulation modelling of different climate scenarios to 2050. Other climatic models include ECHAM4 (Rockner, et al., 1996) and the HadCM3 model (Gordon, et al., 2000). Simulation modelling is particularly important for the development projected groundwater indicators expressing the potential influence of climate change and human impacts on groundwater systems.

The Remote Sensing SEBAL–model[48] may be applied for the determination of evapotranspiration in areas (groundwater basins, aquifers) where precipitation and river runoff are fairly well known and groundwater recharge can be estimated by subtracting direct runoff and evapotranspiration from precipitation. Utrecht University has developed a Global hydrological model PCR – GLOBWB for estimating groundwater recharge.

Other suitable models will be identified later by experts in groundwater modelling.

**2. Groundwater quality**

**Terrestrial measurements:** Automatic intelligent compact multi-parameter measurement loggers placed in monitoring and other types of wells and provided with retrieval software, evaluation modules and remote transmission systems, are advanced equipments available for in-situ groundwater quality measurement (e.g. electric conductivity, pH, redox potential, dissolved oxygen, salinity, chloride, temperature, turbidity). Assessment of monitored data supports groundwater quality modelling and formulation of projected groundwater stress indicators. However, for more complex groundwater quality assessment, complementary groundwater chemical analysis in laboratories will be needed.

**Remote-sensing measurements:** satellite-based groundwater quality measurements are not yet being applied. Air-borne photographic methods combined with geo-botanical methods have been used in many countries and are effective for the early detection of soil and shallow groundwater pollution. Both methods are based on the response of vegetation cover to the presence of specific substances in the soil and shallow groundwater. The state of health of the plants and the presence or

[48] http://www.waterwatch.nl/tools0/sebal.html

absence of certain plant species and communities are helpful tools to reveal the presence of pollution in the soil and water environment. Several species can be used as photo-indicators of different types of pollution, for example the negative response of nitrophobic species to an abundance of nitrogenous matter, algal blooms in coastal zones, dwarf growth of Scots Pine which manifest toxic effects of heavy metals. IR photography detects vegetation stress manifested by loss of reflectance. Common species of corn cultivated in soils above shallow groundwater with a high content of nitrate show increased growth, cover density and show as dark green. Such remote techniques and methods produce supplementary and useful data for more precise transboundary groundwater quality and pollution identification and for evaluation of stresses on groundwater quality.

**Models:** Hydro-geochemical modelling strongly depends on the quality and consistency of available groundwater chemical and isotopic data. In addition, one needs to know the hydrogeological conditions, i.e. the minerals which can be dissolved or precipitate and the processes which may occur in the groundwater system and which are kinetically and thermo-dynamically possible. Furthermore, a conceptual groundwater flow model is desirable with which to calculate travel time and to support the establishment of a relationship between the initial and final chemical composition of the studied groundwater system. The use of statistical methods, particularly factor and cluster analysis, can provide the reliable data needed for geochemical modelling, groundwater chemistry studies and the formulation of projected groundwater quality indicators. According to Glynn and Plummer (2005) present-day hydro-chemical modelling of a groundwater system has to deal with mineralogical constraints, limitations in the knowledge of thermodynamics and kinetic reactions and uncertainties in the knowledge of the groundwater system of large aquifers. Hydro-chemical data scarcity is reflected in limitations of the use of models for the development of projected groundwater quality indicators in the Level 1 TWAP assessment.

In case of groundwater pollution, deterministic transport models are often applied to study the mechanism of nitrogen transport and transformation processes in the crop-soil-water-rock environment and nitrate vertical movement and lateral dispersion in the aquifer system. However, to obtain credible model outcomes on a transboundary aquifer scale, many climatic, hydrological, soil, unsaturated-zone and aquifer measurements and observations must be realised as well as collection and evaluation of agricultural data related to the origin, type and amount of nitrogen fertilizers used and the form and time of their application with respect to agricultural products, sowing procedures, crop rotation / monocultures and irrigation regime (if applied). Data-demanding deterministic models for groundwater nitrate pollution projection will therefore be applied on a larger scale in the Level 2 global TWAP assessment on aquifers in developed countries with long-term monitoring programmes producing climatic, soil, water and agriculture-related data.

The Global Nutrient Export from Watersheds model (Siebert, et al., 2010) has been used to estimate coastal nutrient loads and sources in 1970 and 2000. The model has also been used to evaluate future trends in coastal nutrient delivery for 2030 and 2050. Implementation of the Global News model to support TWAP objectives is proposed. In the case of groundwater, the model may provide estimates of dissolved organic and inorganic nitrogen and would allow assessment of total estimated loads of nitrate in tonne/yr for 2030 and 2050 as well as identifying current problem areas with respect to nitrogen pollution, and identifying major nutrient (nitrogen) sources.

**Additional considerations regarding Economic Process Indicators**

Consideration of the economic, social and environmental implications of water-use practices involves consideration of human behaviour and responses to changing conditions. While indicators related to gross domestic product or the percentage of people with access to potable water provide information on the general state of the economy and/or health, they do not provide insights into an region's ability to modify behaviour through pricing signals, or enable the tracking of changes in utilization and/or reallocation of water. Looking at processes related to water pricing, however, can provide information on a region's capacity to affect the allocation of resources through price signals and measure the associated results. Such information is useful for assessing whether the costs of infrastructure investment and/or maintenance, as well as ongoing operational costs, can be recovered over time through rates.

Depending on the system for delivering groundwater, it may be pumped from an individual well, a community well or system of wells, or delivered via a spring. In all cases, an important metric is the extent to which water use is metered. As important is information on the mechanism for pricing water and approval of prices. A flat water rate that does not vary with usage will have little effect on water use behaviour. A rate structure that differs between water-using sectors, such as agricultural, municipal and industrial (which is commonly the case), may suggest the existence of subsidies for some water users. In addition to obtaining information about the water rates, it is important to know the mechanism and process for determining the rates and the entity responsible for setting them.

Questions that can be answered through questionnaires, if not available through readily accessible documents, include:

**Water utilization:**
Existence of water metering by sector (yes/no)
- Agricultural (yes/or no)
  - Individual user within sector (yes/no)
- Municipal (community)
  - Individual user within sector (yes/no)
- Industrial
  - Individual user within sector (yes/no)

**Measurement** (or estimation if not metered or reported officially) over time of water use by sector and type of water (if multiple sources of water are used):
Absolute quantities and also percentage distribution
- Agricultural
- Municipal (community)
- Industrial
- Environmental (if available)

**Water Pricing Structure**:
- Water pricing by sector: Information to include whether charges are in place, the structure of charges, the mechanism for determining the rates, including who actually sets the rates, by sector.
- Agricultural
- Municipal
  - Is there a basic amount of water included at no charge or with a fixed charge set at a reasonable level?
- Industrial
  - Is Industrial water provided through a municipal (community) water system or by wells owned by the industrial user?

**Water rate setting process where there is a community system in place**:
- Is the community water provided by privately-owned or publicly-owned water systems?
- Who determines the rate?
- What process is used by the rate-setting body?
  - Is there public input?
  - Are the rates based on the cost of infrastructure and operations?

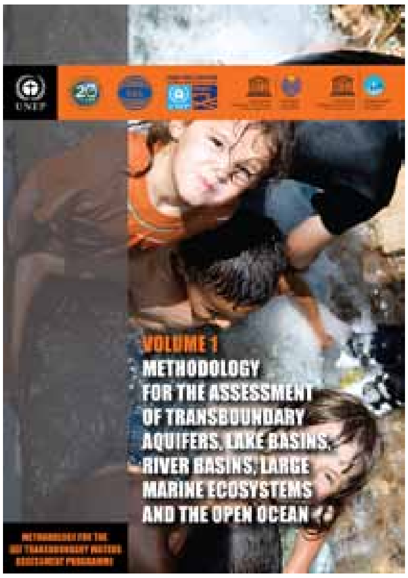
**Environmental Sector Considerations:**
Because groundwater use may have impacts on the natural environment, it will be important to know if the TBA region has mechanisms in place, and whether there are laws or other programmes that protect or provide a mechanism for consideration of environmental trade-offs associated with water use and changes to water-use patterns.

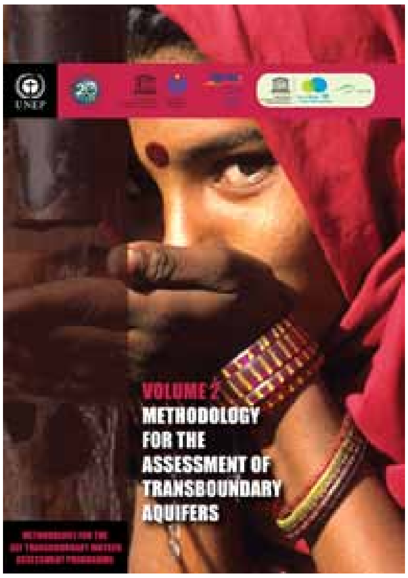
**Reallocation Considerations:**
As the economy grows, it is important to know whether water needs to be reallocated across sectors. If so, it will be important to know if the institutional structure allows for reallocation either by fiat or by economically-based transactions. A fiat system will include the quantification of water rights by user. An economically-based transaction system will allow for the sale or lease of water rights.

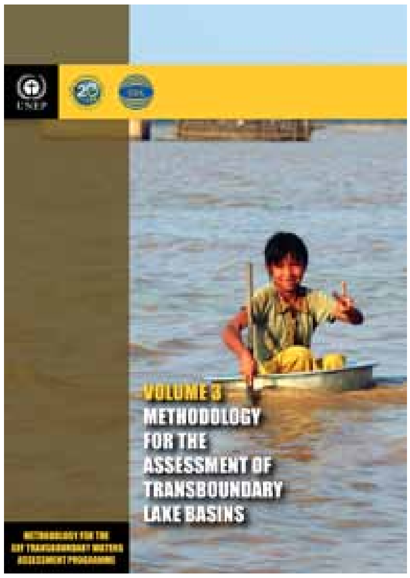
- Are water rights quantified?
    - Who establishes the water rights or permits?
- Can they be changed?
    - Who can change the water rights or permits?
- How can the water rights or permits be changed?

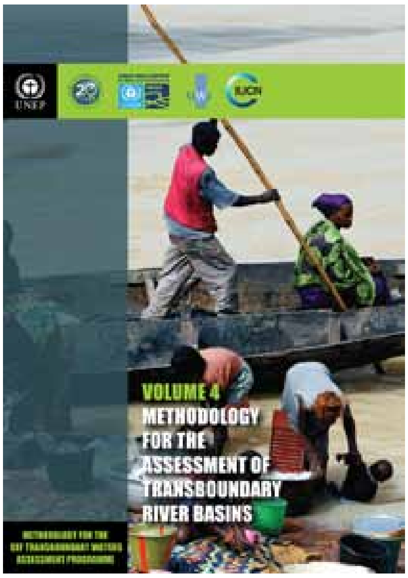
# METHODOLOGY FOR THE GEF TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

## Volumes 1-6

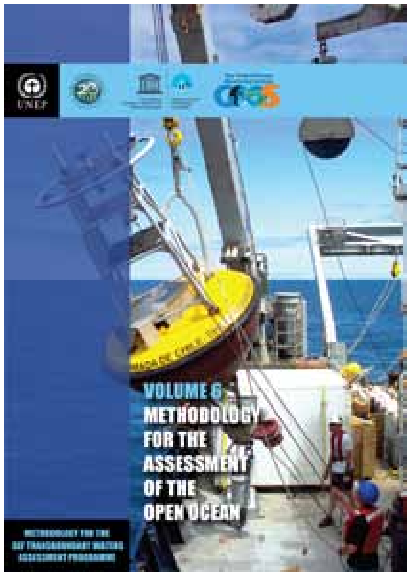






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The water systems of the world - aquifers, lakes, rivers, large marine ecosystems, and open ocean - support the socioeconomic development and wellbeing of the world's population. Many of these systems are shared by two or more nations and these transboundary resources are interlinked by a complex web of environmental, political, economic and security interdependencies. In order to address this challenge UNEP, under the auspices of the GEF, coordinated over a 2 years period from 2009 to 2011 the implementation of the Medium Size Project (MSP) entitled "Development of the Methodology and Arrangements for the GEF Transboundary Waters Assessment Programme (TWAP)".

This Project produced methodologies for transboundary water systems. The final results of this Project are presented in the following six volumes:

Volume 1 - Methodology for the Assessment of Transboundary Aquifers, Lake Basins, River Basins, Large Marine Ecosystems and the Open Ocean;
Volume 2 - Methodology for the Assessment of Transboundary Aquifers;
Volume 3 - Methodology for the Assessment of Transboundary Lake Basins;
Volume 4 - Methodology for the Assessment of Transboundary River Basins;
Volume 5 - Methodology for the Assessment of Large Marine Ecosystems; and
Volume 6 - Methodology for the Assessment of the Open Ocean.

This Project has been implemented by UNEP in partnership with the following lead agencies for each of the water systems: the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) for transboundary aquifers including aquifers in small island developing states (SIDS); the International Lake Environment Committee (ILEC) for lake basins; UNEP-DHI Centre for Water and Environment (UNEP-DHI) for river basins; and Intergovernmental Oceanographic Commission (IOC) of UNESCO for large marine ecosystems and the open ocean.

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