

# GUIDELINES FOR MULTIDISCIPLINARY ASSESSMENT OF TRANSBOUNDARY AQUIFERS



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# Guidelines for Multidisciplinary Assessment of Transboundary Aquifers

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Draft Version

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IGRAC is the UNESCO Global Groundwater Centre, it also works under the auspices of WMO, it is a corporate IAH partner and it is financially supported by the Government of the Netherlands.



The International Hydrological Programme (IHP) is the only intergovernmental programme of the UN system devoted to water research, water resources management, and education and capacity building.

## IGRAC

Westvest 7  
2611AX Delft  
The Netherlands

T: +31 15 215 2325  
E: [info@un-igrac.org](mailto:info@un-igrac.org)  
I: [www.un-igrac.org](http://www.un-igrac.org)

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# LIST OF ACRONYMS

ACE2 V31	Global digital elevation model
AQUASTAT	FAO's global water information system
ARCGIS	ESRI's Geographical Information System
CGIAR	Consultative Group for International Agricultural Research
CIESIN	Centre for International Earth Science Information Network
EAPRS Lab	Earth and Planetary Remote Sensing Laboratory
EC/JRC	European Commission / Joint Research Centre
EIA	Environmental Impact Assessment
ESA	European Space Agency
ESRI	Geographic information system company
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GEO-TIFF	public domain metadata standard
GGIS	Global Groundwater Information System
GGMN	Global Groundwater Monitoring Network
GGRETA	Groundwater Resources Governance in Transboundary Aquifers
GIS	Geographic Information System
GLC	Global Land Cover
GRUMP	Global Rural-Urban Mapping Project
GW	Groundwater
IGRAC	International Groundwater Resources Assessment Centre
IAH	International Association of Hydrogeologists
IHP	International Hydrological Programme
IIASA	International Institute for Applied Systems Analysis
IMS	Information Management System
ISARM	Internationally Shared Aquifer Resources Management
JMP	Joint Monitoring Program
L&I	Legal and Institutional
MCCM	Multi-Country Consultation Mechanism
MOU	Memorandum of Understanding
MIM	Meta-Information Module
OGC	Open Geospatial Consortium
POP	World Population Program
SDC	Swiss Agency for Development and Cooperation
SIDS	Small Island Developing States
SRTM	Shuttle Radar Topography Mission
TBA	Transboundary Aquifer
TWAP	Transboundary Waters Assessment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNGA	United Nations General Assembly
UNICEF	United Nations Children's Fund
USGS	United States Geological Survey
WFS	Web Feature Service
WHO	World Health Organisation
WMO	World Meteorological Organization
WMS	Web Mapping Service
WorldClim	set of global climate data





# SUMMARY

Transboundary aquifer or transboundary aquifer system means respectively, an aquifer or aquifer system, part of which are situated in different States. (UN ILC, 2008). The international aspect of a transboundary aquifer makes its management more complex than in a case of an aquifer located within the State borders. An informed and sustainable management of commonly shared aquifer asks for adequate knowledge of its characteristics, present state and trends. In order to acquire this knowledge, regular monitoring and assessment of the transboundary aquifer need to be performed. This document is a draft that aims at 1) presenting a methodology for multidisciplinary assessment of transboundary aquifers, and 2) providing guidelines for its implementation.

The methodology builds on the ISARM (Internationally Shared Aquifer Resources Management) programme led by UNESCO International Hydrological Programme (IHP) and the International Association of Hydrogeologists (IAH) since 2001 which is aimed at improving the understanding related to the governance and management of transboundary aquifers through a multidisciplinary approach. In the decade that followed, some aspects of shared groundwater resources (such as hydrogeological delineation and legal foundation for shared use and protection) received significant attention. Importance of others aspects (e.g. social, economic, environmental, etc.) has been recognized as well but not followed with a substantial elaboration. Implementation of the first phase of the Global Environment Facility (GEF) Transboundary Waters Assessment Programme (TWAP) project (completed in 2011) for which UNESCO-IHP was entrusted for the groundwater component, brought a substantial methodological development and created the main contours of the methodology for assessment of transboundary aquifers at the regional scale. In the following phase of the TWAP project (to be completed in 2015), the methodology has been further improved and applied in a global assessment of transboundary aquifers. The methodology developed for the regional/global assessment is indicator-based and uses aggregated values per aquifer, allowing comparative analysis and prioritizing according to risks and required interventions.

Further development of the TBA methodology took place in the still on-going Groundwater Resources Governance in Transboundary Aquifers (GGRETA) project funded by the Swiss Agency for Development and Cooperation (SDC). The methodology was elaborated for a detailed assessment at the transboundary aquifer level. This in-depth assessment takes in account spatial variability of aquifer characteristics and covers all relevant TBA aspects required for joint decision-making and TBA management.

These guidelines have been prepared to assist an in-depth assessment at the aquifer level. Nevertheless, they can also be used for the comparative, regional assessment by - among others- applying the aggregation procedure and paying additional attention to indicators. Regardless at which level the methodology is applied, it always includes data and information collection, processing and presentation. Due to differences in formats, standards, classifications and similar, harmonisation is the major processing activity. The outcomes of an assessment are visualized in maps, but also presented in tables, diagrams, pictures and references. A part of assessment where aquifer characteristics are interpreted through an extensive set of variable and parameter values can be seen as the general assessment. In the (subsequent) indicator based assessment, the outcomes of the general assessment are used as ingredients to form indicators; the indicators can provide easier understanding and comparison but also lead to additional insights in the state of TBAs.

In order to support the transboundary aquifer assessment and management, IGRAC has developed a web-based Information Management System (TBA-IMS). Practically, the system assists in data collection, storage, processing, visualisation and sharing of variety of data and information. The TBA-IMS is very interactive; it also has an extensive functionality for further analysis (such as map overlays and queries) and various authorization levels (e.g. assessment coordinator, national experts, public).

This document contains a draft version of the guidelines. Future updates will be made available via [www.un-igrac.org](http://www.un-igrac.org). In meantime, comments and suggestions are very welcome via [info@un-igrac.org](mailto:info@un-igrac.org).



# ACKNOWLEDGEMENT

The draft of the methodology guidelines presented in this document are the outcome of several initiatives, including the ISARM programme led by UNESCO and the International Association of Hydrogeologists (IAH) and the first phase of the TWAP project, funded by the Global Environment Facility (GEF). IGRAC and UNESCO-IHP are grateful to all experts involved in these initiatives who provided important input and/or feedback on the methodology for the multi-disciplinary assessment of transboundary aquifers. This methodology was also applied and further developed in two projects: The TWAP Groundwater component which is a comparative assessment of 199 transboundary aquifers worldwide; and the GGRETA project funded by the Swiss Agency for Development Cooperation (SDC), which entailed in-depth assessments of three transboundary aquifers. IGRAC and UNESCO-IHP are additionally grateful to the country and assessment coordinators and technical experts whose hard work and feedback further refined and informed this methodology.



1.





# INTRODUCTION

This document presents the draft of the methodology for the assessment of transboundary aquifers. The methodology aims to provide guidelines for conducting an aquifer assessment comprising collection, storage, processing and sharing of groundwater-related data and information. As such, the methodology covers various aspects relevant for management/governance of transboundary aquifers, including the state of the aquifer (in terms of groundwater quantity and quality) as well as the associated socio-economic, legal and institutional facets.

IGRAC and UNESCO-IHP have been involved for more than a decade in assessment of internationally shared aquifers and this methodology is a result of experience gained in various bilateral, regional and global assessment activities. The methodology builds on **ISARM** programme and its multidisciplinary approach to transboundary aquifer governance and management addressing hydrogeological, environmental, socio-economic and legal & institutional aspects. (UNESCO-IHP, 2001). This approach was gradually elaborated into a methodology for multi-disciplinary and detailed assessment of transboundary aquifers. By applying the methodology and encouraging cooperation amongst the countries sharing an aquifer, alternatives can be explored and a foundation for dialogue established for the collaborative management and governance of shared groundwater resources.

By applying this methodology the following objectives are pursued:

- i. Improving the knowledge of transboundary groundwater resources and increasing recognition of their importance and vulnerability by carrying out detailed assessments with the full participation of national experts,
- ii. Promoting and facilitating the exchange of information between the countries by establishing an information management systems (IMS) at Transboundary Aquifer (TBA) level,
- iii. Supporting countries in establishing cross-border dialogue and cooperation at governmental level, including a diagnosis of transboundary concerns, and
- iv. Increasing awareness of the UNGA Resolution on the Law of Transboundary Aquifers, as the basis for its implementation.

Comparative assessment vs. in-depth assessment: the assessment methodology can be applied both to transboundary aquifers at regional level and to a single transboundary aquifer. The regional assessment provides aggregated information on TBAs in the region that also results in a **comparative** analysis at that scale. The **in-depth** assessment focuses on a single transboundary aquifer, providing insight in spatial variability of important aquifer characteristics.

The methodology can be also applied at the regional/global level to provide a basic assessment and a **comparative** analysis among aquifers. This was done within the **TWAP** Groundwater (UNESCO-IHP, IGRAC, WWAP 2012). In this project, the methodology was applied to perform a comparative assessment of 199 transboundary aquifers where aquifers were described using 20 indicators that were calculated by combining various data. The advantages of this approach are that it provides new insights as well as a simple description of the groundwater resource.

The **in-depth** assessment methodology is currently being tested in the **GGRETA** project. The latter focuses on a single transboundary aquifer and is based on the TWAP Groundwater component indicator-based assessment methodology and provides additional aggregated information to indicators. Detailed assessments are conducted by teams of national experts in three selected case studies: the Trifinio Aquifer

Complex (El Salvador, Guatemala, Honduras); the Stampriet Transboundary Aquifer System (Botswana, Namibia, South Africa) and the Pretashkent aquifer (Kazakhstan, Uzbekistan).

The assessment of a TBA is only possible when the aquifer states are willing to cooperate to ensure a sustainable management of the shared groundwater resources. The governments, through responsible ministries, are the initiators of the assessment. Considering the multi-disciplinary character of the assessment and the complexity of domestic groundwater resources institutional setting, it is desirable that various ministries (for environment, agriculture, etc.) and other governmental organizations (knowledge centres, water boards) are involved in the assessment. A possible organigram of the multi-disciplinary assessment team is given in Figure 1. This is a basic organigram and can be extended if necessary. The Assessment Coordinator has a very important role in promoting and facilitating cooperation amongst the countries at both technical and governmental levels.

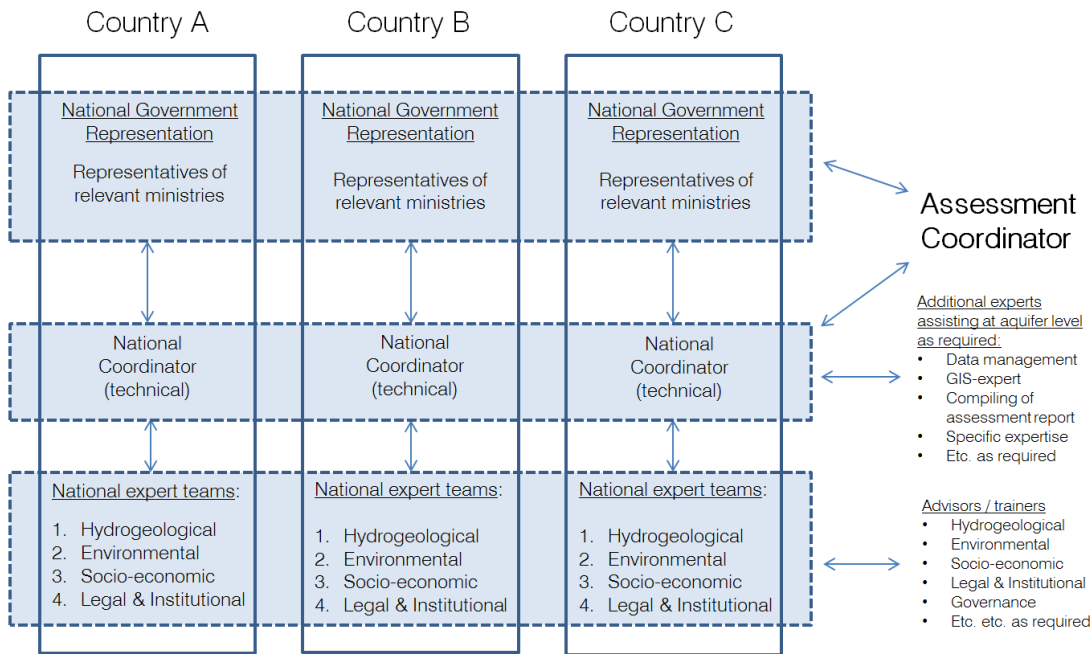


Figure 1 Suggested organigram for a multidisciplinary aquifer Assessment Team

Each country sharing the aquifer needs to establish a multi-disciplinary assessment team composed of specialists of each area of interest. The assessment team needs to be put together taking into consideration the aquifer complexity, the expected amount of data to be analysed and the number of professionals/organisations studying the aquifer. The composition of the assessment team and especially its diversity are of high importance for the success of the assessment because of the multi-disciplinary character of the assessment.

In order to support assessment and management of transboundary aquifers, a web-based information management system needs to be developed (**TBA-IMS**). The system is map-based and allows on-line upload of the map layers resulting from the assessment. In the TBA-IMS, the map layers can further be combined in order to create thematic maps. Additional data such as pictures, tables and documents can also be uploaded into the system. The uploaded data can also be made available to the general public, once the assessment is completed. Most of the data from the TWAP project are already published through a dedicated portal <http://twapviewer.un-igrac.org>.

This document provides the **guidelines for in-depth assessment of a transboundary aquifer** which is a detailed assessment at a TBA level. It gives an overview of data to be collected, the harmonisation and assessment procedures and of the information management system which support the whole process. The comparative assessment at the regional level follows the same methodology, only at less detailed level; practically, it means an assessment using a selection of the data (data priority # 1 from Table 2) and the 'core' indicators (from Table 6).

The presented methodology relies primarily on existing data. Depending on data availability and aquifer's specifics, some modifications of suggested assessment data content and/or steps might be needed for a specific case. After all, these are suggested guidelines and certainly not an instruction manual.

Section 2 of the document gives a brief overview of the methodology. Section 3 describes in more detail the data needed for the assessment. Harmonisation of data is discussed in the section 4, while the section 5 presents elements of the actual assessment – general and indicator-based. Finally, the role of TBA-IMS and its basic functionality are presented in the section 6. Several appendixes to the document contain additional info about the assessment methodology.

This document contains a draft version of the guidelines. Future updates will be made available via [www.un-igrac.org](http://www.un-igrac.org). In meantime, comments and suggestions are very welcome via [info@un-igrac.org](mailto:info@un-igrac.org). Comments received before 15 December 2015 can be included in the final version – planned to be published in the first quarter of 2016.



An aerial photograph of a patchwork of agricultural fields in various shades of green, yellow, and brown. A grid of semi-transparent green circles is overlaid on the image, with some circles being solid and others semi-transparent, creating a complex geometric pattern. In the top right corner, there is a solid orange rectangular area.

2.



# METHODOLOGY OVERVIEW

An overview of the main methodology steps is given in Figure 2. The multi-disciplinary assessment of a transboundary aquifer comprises the following:

- Data collection
- Harmonisation & aggregation
- Aquifer assessment: general assessment & indicator-based assessment
- Data management: the TBA-IMS

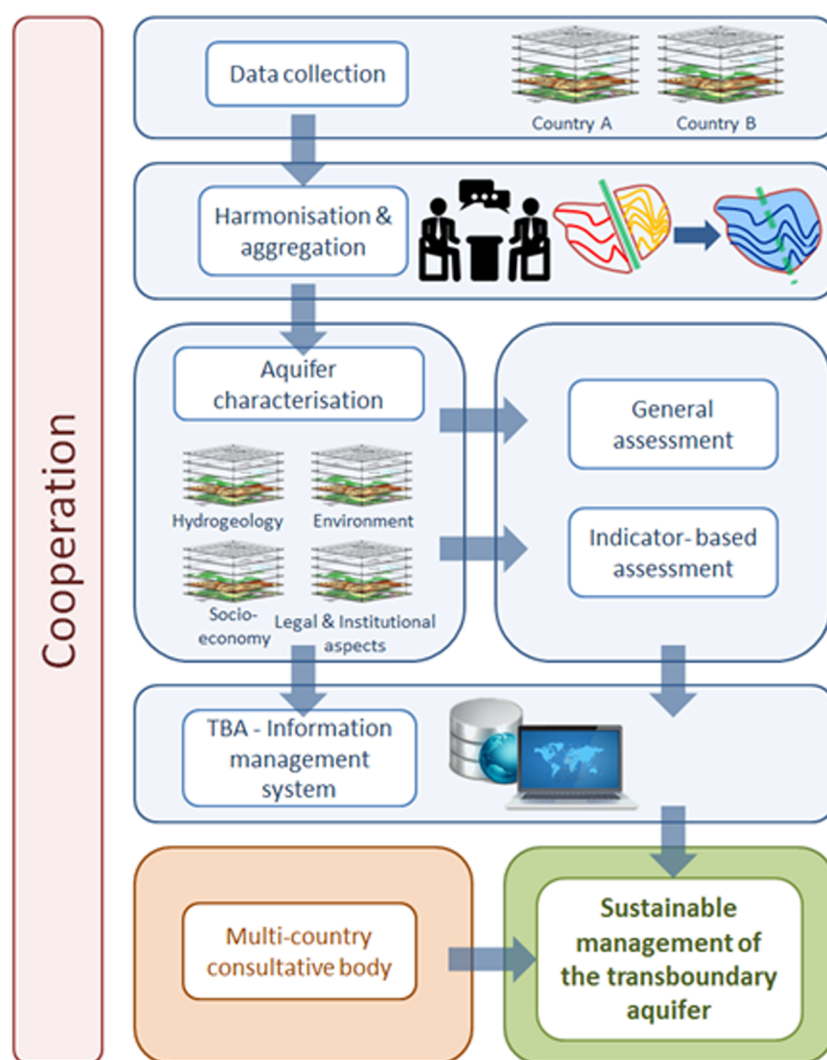


Figure 2 Schematisation of main methodology steps

During the first step of the assessment, the national experts have to carry out the **data collection** and then restructure it into clear tables, maps and other overviews. Each country involved has to analyse its own datasets taking into consideration the harmonisation & aggregation step. At this very early stage of the assessment there is already a necessity for dialogue to define standards for e.g. units, the timeframe, extent of the aquifer, etc. The data have to be collected and analysed individually for each country sharing the aquifer and then harmonized at the aquifer level.

**Harmonisation** (and aggregation, in a case of regional assessment) of the data takes place firstly at the country-segment level. The datasets need to meet the standards agreed in advance: the level of detail, the period of time and frequency of measurement, units, etc. If no data are available at the country-segment level, an expert judgement can applied but with a clear record of it. Harmonisation of data at the country-segment level is followed by the harmonisation at the aquifer level.

After these two methodology steps have been carried out, the actual assessment - **general assessment** and **indicator-based assessment** - can take place. A part of assessment where aquifer characteristics are interpreted through an extensive set of variables and parameters values can be seen as the general assessment. In the (subsequent) indicator based assessment, the outcomes of the general assessment are used as ingredients to form the indicators; indicators can provide easier understanding and comparison but also lead to additional insights in the state of TBAs.

The aim of applying of this methodology is to assess the current state of the resource, to identify current and potential transboundary issues and explore possibilities to common groundwater management. The outcomes of the assessment need to be easily understood and used by decision makers and even general public. This means that some effort needs to be put into producing an **assessment report** containing a clear and non-technical message, using thematic maps, tables and other graphical features accompanied with short explanations.

Thematic maps can be prepared in the **Transboundary Aquifer Information Management System (TBA-IMS)** where all the map layers are stored. TBA-IMS is used during the whole assessment process, starting from data collection to dissemination of results. It is also possible to store all kind of data in TBA-IMS. Hence, it is advisable to do not store raw data; the focus is on interpreted maps and results, easily understandable by policy makers and the public. The TBA-IMS does not intend to be a supra-national hydrogeological information system.

Table 1 summarizes the overall goals of the assessment, the outcomes and outputs. In parallel with the assessment of the resource, a collaboration mechanism needs to be put in place to ensure necessary contributions to the assessment as well as implementation of the outcomes, once the assessment is completed.

Table 1    *Assessment goals and outcomes*

Overall Goal	Outcomes	Outputs
(i) Comparative assessment Assess transboundary aquifers at regional level, allowing comparative analysis and prioritizing according to risks and required interventions in order to improve cooperation, prevent or mitigate problems and increase overall benefit from shared water resources	1. States sharing the aquifer(s) recognize the transboundary nature and importance of the resource, and agree to assess its current state and trends in order to define priority actions.  2. States sharing aquifer(s) agree to cooperate and implement priority actions for the protection and equitable utilization of the aquifers.	Assessment of the current conditions of the aquifer(s), including a diagnostic of transboundary concerns, conducted with the full participation of national experts.  A Mult-Country Consultation Mechanism (MCCM) established by aquifer states that meets regularly during the assessment.
(ii) In-depth assessment at TBA level Assess a transboundary aquifer in depth in order to improve cooperation, prevent or mitigate problems and increase overall benefit from shared water resources		







3.





# DATA COLLECTION

Usually data are collected from many data sources such as ministries, governmental and non-governmental institutes (e.g. geological surveys, water suppliers, agricultural organizations), universities, literature, etc. These data becomes available in various formats and different levels of detail (reports, scientific articles, data sheets, databases, maps, etc.) and from various sources. In general, the data is divided into six main **themes**:

- A. Physiography and climate
- B. Aquifer geometry
- C. Hydrogeological characteristics
- D. Environmental aspects
- E. Socio-economic aspects
- F. Legal and institutional aspects

The data collected and harmonized provides the components for the assessment report, describing all aspects of the aquifer. Some of the individual parameters are combined into indicators. The indicators are one of the instruments used to communicate the assessment results in a clear and simplified way. By combining different data into one indicator, additional information is generated, whilst at the same time a clear classification is given by simplifying large datasets into a limited number of indicators.

The method of collecting and processing data is to some extent different for some of the main themes. The data for themes A to E (see list above) are collected in dataset (maps, tables, reports, summaries, block diagrams, cross sections) whilst for theme F (legal & institutional aspects), the data is collected in the form of questionnaires. The difference in the methods is necessary because of the fact that these themes have different natures. This is a reflection of the often varied water management approaches, stakeholders' roles and policy issues on groundwater management and the administrative frameworks, which could be typical for each country sharing the aquifer.

## 3.1 DATA COLLECTION PROCESS

Firstly, the existing data needs to be collected by the team(s) of national experts. Each national team has the task of compiling this information in a structured and harmonized way in order to make it comparable with the data collected by the other aquifer states. It is a challenge to bring together all the available data from the various sources (ministries, governmental and non-governmental agencies, universities, scientific publications, international datasets, etc.) and filter the relevant datasets and possibly even have to create datasets from information provided by different organisations. A strong coordination in this initial phase is very important to judge the data quality and suitability for the assessment.

The benefits of collecting, keeping and presenting information in a systematic and structured way are that it:

- 1) allows changes in these parameters to be monitored over time (to evaluate if governance / management actions have been effective), and
- 2) makes it possible to store the information in an information management system for future use.

The methodology is based on the principle that the main source of data is existing data. It is expected that not all of the necessary data is available in each of the countries involved. In that case, the data can still be used for the assessment, but the harmonisation at TBA level might be missing. One of the outcomes of the data collection phase is the identification of data gaps that could possibly be filled in with new fieldwork.

There are some key elements that are crucial to discuss and agree upon before/during the data collection phase of the assessment. A selection of these elements is presented below.

## Agreement and common understanding on the aquifer boundaries and level of detail to be included in the assessment

- The national teams need to make sure that they agree on what they are going to be assessing and what level of detail they want to achieve. It is especially important to define the boundaries of the aquifer and the geometry of its layers at the beginning of the assessment activities. For example: on different sides of the border different aquifer layers might be important. A specialist might initially not even be aware of the fact that they are talking about different hydrogeological units. It is therefore crucial that all the parties involved have a common understanding of the aquifer in the initial stages of the assessment.
- Whether the unit(s) to be assessed is an aquifer or if it is an aquifer system consisting of multiple hydraulically connected aquifers needs to be analysed and agreed upon. Outlining a conceptual model of the aquifer / aquifer system can be a useful tool already in the very early stages of the assessment. If the assessment is to be performed over an aquifer system with different aquifer units, all the parameters, variables, maps, tables and other information needs to be compiled, as much as possible per aquifer unit.
- The focus is on the assessment of transboundary groundwater resources, but it might also be relevant to include a national aquifer in the assessment. For example, where a deeper transboundary aquifer is overlaid by a shallow national aquifer. Even if the aquifers are not hydraulically connected, they can be connected through other factors such as socio-economics. In such a case it is relevant to include the national aquifer in the assessment to get a full understanding of the situation and to be able to perform a complete analysis.

### Agreement between aquifer states needed on:

- ✓ Aquifers/ hydrogeological units to be assessed.
- ✓ If sufficient data are available to assess multiple aquifer layers individually
- ✓ Are national aquifer(s) included in the assessment?
- ✓ What are the geological boundaries of the aquifer?

## Type of data needed for the assessment

Table 2 gives an overview of the data to be collected and analysed. This is the complete list of data needed for the **in-depth** assessment at TBA level. The priority classification gives how important the dataset is for the assessment of the aquifer. The sets of data given priority # 1 are also used in the **comparative** assessment. Hence, the datasets given priority # 1 are used to calculate the 10 'core' indicators and priority # 2 are used to calculate 10 additional indicators. Priority # 3 is important but less crucial for the assessment. In Appendix 1 a detailed description of the data to be collected is provided. Hence, the parameters and variables are explained and a brief description is given of how the data can be presented in the assessment.

Table 2 List of detailed data to be collected, grouped in themes

Parameters, variables and information to be collected	Priority*
<b>A. Physiography and climate</b>	
A.1. Temperature*	1
A.2. Precipitation*	1
A.3. Evapotranspiration	1
A.4. Land use*	
A.4.1. Groundwater-fed agricultural land	3
A.4.2. Groundwater-irrigated land	3
A.4.3. Groundwater-supported wetlands and ecosystems	3
A.4.4. Areas with land subsidence	3
A.5. Topography: elevation data*	2
A.6. Surface water network (rivers, lakes, swamps, reservoirs, canals, etc.)	3
<b>B. Aquifer geometry</b>	
B.1. Hydrogeological map	3
B.2. Geo-referenced boundary of the Transboundary Aquifer	1
B.3. Depth of water table/piezometric surface	2
B.4. Depth to top of aquifer formation	2
B.5. Vertical thickness of the aquifer	2

Parameters, variables and information to be collected	Priority*
B.6. Degree of confinement	2
B.7. Aquifer's cross section	3
<b>C. Hydrogeological characteristics</b>	
C.1. Aquifer recharge	
C.1.1. Natural recharge	1
C.1.2. Return flows from irrigation	1
C.1.3. Managed aquifer recharge	1
C.1.4. Induced recharge	1
C.1.5. Extent of recharge zones	3
C.1.6. Sources of recharge	2
C.2. Aquifer lithology	3
C.3. Soil types	2
C.4. Porosity	3
C.5. Transmissivity and vertical connectivity	2
C.6. Total groundwater volume	2
C.7. Groundwater depletion	1
C.8. Natural discharge mechanism	2
C.9. Discharge by springs	2
<b>D. Environmental aspects</b>	
D.1. Groundwater quality (suitability for human consumption)	1
D.2. Groundwater pollution	1
D.3. Solid waste and wastewater control	
D.3.1. Wastewater being collected in sewerage systems	3
D.3.2. Wastewater treated	3
D.3.3. Solid waste being stored in controlled fields	3
D.4. Shallow groundwater table and groundwater-dependent ecosystems	2
<b>E. Socio-economic aspects</b>	
E.1. Population (total and density)*	1
E.2. Groundwater use	
E.2.1. Total volume groundwater abstraction	1
E.2.2. Groundwater abstraction for domestic use	2
E.2.3. Groundwater abstraction for use in agriculture and livestock	2
E.2.4. Groundwater abstraction for commercial and industrial use	2
E.3. Surface water use*	
E.3.1. Total volume of surface water use	1
E.3.2. Surface water for domestic use	2
E.3.3. Surface water use for agriculture / livestock	2
E.3.4. Surface water for commercial and industrial use	2
E.4. Dependence of industry and agriculture on groundwater	3
E.5. Percentage of population covered by public water supply	3
E.6. Percentage of population covered by public sanitation	3
<b>F. Legal and institutional aspects**</b>	
F.1. Transboundary legal and institutional framework	1
F.2. Domestic legal and institutional framework	1
F.2.1. Ownership of groundwater	2
F.2.2. Water resource planning	3
F.2.3. Groundwater resource abstraction and use	2
F.2.4. Abatement and control of groundwater pollution	2
F.2.5. Other water resource protection measures	3
F.2.6. Government and non-government water institutions	2
F.2.7. Implementation, administration and enforcement of the legislation	2

\* National or local data can be used; this information is also available from global datasets (see Table 4).

\*\* The legal and institutional aspects are assessed by questionnaires.

In this guideline the terms 'map layers' and 'thematic maps' are related to products of the assessment. A map layer is a file prepared with GIS tools that contain only one geo-referenced feature, which could be a polygon, line or point feature. A thematic map is the combination of map layers prepared to better interpret or understand a variable or parameter.

## 3.2 DATA FORMAT

The preferred data format depends on factors such as the type of data and the amount of data available. For example: for data that are time dependent it is necessary to structure these into tables (e.g. in Microsoft Excel) and to visualise them in time-series graphs. In addition, the national experts also have to make decisions on the interval in which the data has to be extracted and, if there are different units, to decide which one would be best used in the assessment. Data that have a spatial variability are preferably shown in maps. Maps often give a quicker impression of the situation than tables or text descriptions. They can also be as detailed as possible and show differences per country, regions and sub-regions, etc. Appendix 1 gives the suggested data formats for each of the parameters and variables to be collected. Below are some general explanations of the various formats.

### I. Geo-referenced information and thematic maps

Spatial information on location and/or the spatial distribution of relevant data is required for the assessment. Relevant information needs to become available in digital form. This means that existing paper maps may need to be digitized. Often is information only available at the national level. In order to make it possible to create maps for the whole transboundary aquifers, the aquifer states need to agree on the map format (i.e. coordinate system, projection, scale).

Map scale: it is difficult to give a preferred scale for thematic maps without knowing the level of detail in which data is available. One very practical criterion is choosing a map scale that allows maps to be printed on A3 format for easy reproduction and inclusion in reports.

For uploading and viewing maps in the TBA-IMS, the maps have to be available in digital format and the files have to meet certain criteria that are described in Table 3 Table 3. These standards are recommended to be used in the data processing in order to optimize data storage and sharing in the TBA-IMS.

Table 3 Desired format for digital maps / spatial information

Map formatting	
Format	<p><b>Editable formats (preferred format):</b></p> <p>Raster (e.g. digital elevation model)</p> <p>Polygon features (e.g. an aquifer's boundary)</p> <p>Linear features (e.g. rivers)</p> <p>Point features (e.g. location of wastewater treatment plants)</p> <p><b>Non-editable formats:</b></p> <p>TIFF Geo-referenced images (e.g. additional information such as hydrogeological maps)</p>
Coordinate system and projection	<p>Maps needs to be provided in an <b>ARCGIS-compatible geographic coordinate system</b>, so that all the maps can be transformed and re-projected into a common coordinate system.</p> <p>For the purpose of uploading geo-referenced data to the <b>TBA-IMS</b>, maps need to be in the World Geodetic System of 1984 (WGS84) and not projected.</p>
Map scale	<p>The map scale for the assessment outputs needs to be agreed on by the aquifer states. The choice depends on the level of detail of the available information, striking the right balance between the very detailed and scarcer information.</p>
Compatibility	<p>Digital files need to be provided in formats that are compatible with ESRI ARCGIS products.</p>

## II. Tabular information

For tabular data, especially those constructed as time series, aquifer states need ideally to agree on a time period and interval for which data is used to calculate averages / statistics and to construct maps. Which time period is the most suitable mostly depends on the data availability from the different countries (choose the most recent time period for which all the countries have data). For the statistical calculations (average, minimum, maximum) it is important to use the same period of time for every state.

Examples of time-dependent variables are:

- Groundwater-level monitoring
- Groundwater depletion
- Discharge by springs
- Groundwater abstraction
- Temperature
- Precipitation

## III. Text

For the characterization of the aquifer and reporting purposes, the information and data provided need to be put in text format. However, to achieve the assessment as proposed by this methodology, the assessment team needs to focus on the procurement of quantitative and systematic data in the form of maps, tables, time series or cross sections. Therefore, descriptive information needs to be concise with references to the original sources of information.

## IV. Additional information from global datasets

It is anticipated that not all of the data listed in Table 2 is available. For some of the data, global datasets can be an alternative source of information. The known and readily available datasets are listed in Table 4. The limitation of global datasets is that the resolution of the data might be low in relation to the scale of the aquifer. Also some of the global datasets might be derived from models or predictions instead of measured data. Therefore it is recommended to try as much as possible to find information at local and national level.

Table 4 Alternative sources for information - global datasets

Variable name	Years covered	Database name	Source
Population density, gridded	2010	GRUMP	CIESIN
Population density projections, gridded	2000-2100	POP	IIASA
Land cover 2009	2009	Globcover V2	ESA
Land cover 2000	2000	GLC 2000	EC/JRC
Precipitation	1950-2000	Precipitation (30 sec)	WorldClim
Temperature	1950-2000	min/max temp (30 sec)	WorldClim
Water withdrawals	1988-2007	Aquastat	FAO
Digital elevation model	2009	ACE2 V31	EAPRS Lab



4.





# HARMONISATION & AGGREGATION

Harmonisation of data and information at aquifer level is a crucial phase in the assessment of transboundary aquifers. Most data is generated at national level, based on standards of the national institutions, (e.g. geological surveys). Where these standards differ between countries it is necessary to agree on a common standard for the purpose of the transboundary aquifer assessment. The national teams have to establish the necessary communication channels in order to be able to bridge these differences between the national segments of the aquifer and the produced qualitative results useful for groundwater management at aquifer level. Figure 3 gives a diagram representing the harmonisation process.

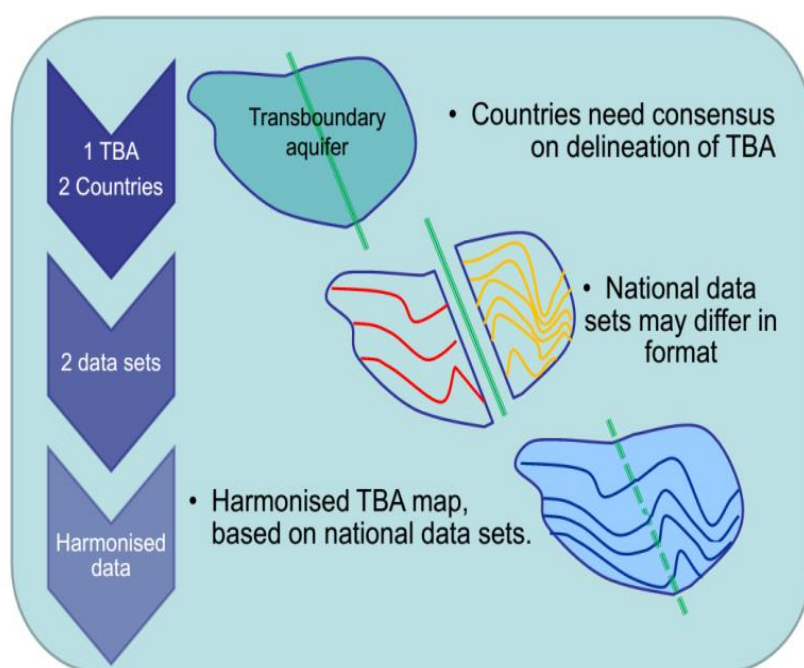


Figure 3 Diagram representing the harmonisation process

To enable interpretation, analyses and visualisation across the borders, one of the key activities is to re-structure the data in a uniform way. Harmonisation of data at aquifer level starts when the national experts from the aquifer states share and compare the collected information. Each hydrogeology and geology team have to judge and summarize its own datasets to be able to proceed in the harmonisation process. The first things that need to be agreed upon are the aquifer geometry for both the horizontal and the vertical extension of the aquifer and, in the case of an aquifer system, the aquifer units into which it is divided. In most cases this process also implies some harmonisation of geological classifications across the border. As a minimum a comparison of nomenclature used for lithostratigraphic units needs to be carried out and the layers forming the aquifer need hydrogeological definitions. After this process, the spatial distribution of the aquifer (or aquifer system) in each of the countries and at TBA level should be clear.

To be able to present information in map format across the transboundary aquifer it is necessary to agree on a coordinate system and scale for the map outputs of the project, as mentioned in Section 3. Existing maps might have to be converted into the chosen format. It is advisable to use the standards given in Table 3.

There are several other elements that need to be harmonized in order to classify the parameters for the aquifer level. Some elements have already been explained in Section 3.1 as they are essential to be agreed upon before data collection starts. Below is a selection of the elements that need to be discussed for the harmonisation process:

- Harmonisation of classifications, such as land use classifications, hydrogeological formations, lithology classifications, types of water use, etc. For example: in the methodology it is suggested that all the different types of surface water use are grouped into three main categories: 1) domestic water use, 2) agricultural / livestock watering and 3) industrial and other commercial use (see table 2 ), socio-economic aspect E3). It is important for the aquifer states to agree what types of water use fall under which category. For example, to agree that groundwater used as a source for bottled water is part of 3) industrial and commercial use and not 1) domestic water use.
- Harmonisation of standards used to make a judgement. For example, to classify groundwater quality, in order to determine if the water is suitable for human consumption. The countries involved might use a different set of analyses and also different thresholds of concentrations to judge if water is suitable for human consumption. When producing maps of interpreted data such as a map on 'suitability for drinking water supply' it is prudent that countries use the same sets of data and thresholds. If this is not feasible then what criteria are used in each country should be clearly described.
- Harmonisation of statistical and interpolation techniques: to harmonize data for analyses and presentation purposes it is necessary to summarize, aggregate or interpolate the original data. It is necessary for the national experts to discuss this and agree how it can be done. Typical operation areas:
  - i. Summation or aggregation: summation of variables to produce aggregated values for a certain geographic area; abstraction data might be available per groundwater well / borehole and for different time periods. In order to summarize and visualize this information it may be useful to aggregate information per municipality.
  - ii. Average over time: For time-dependent data historical records for different time periods and with different sampling intervals may be available. When reporting average values, this needs to be discussed and an agreement reached on which time period the average is calculated.
  - iii. Spatial interpolation: Data from point measurements, such as precipitation or groundwater levels, need to be interpolated to create maps for the whole aquifer. Interpolation techniques are for example 'Inverse Distance Weighted' or 'Kriging'. The national experts from each aquifer state should agree on which interpolation technique is to be used for each relevant data type.
- Harmonisation of intervals between the isolines on maps, such as spatially interpolated values of temperature or precipitation, contour lines, spatial distribution of recharge values, porosity, transmissivity or population density.
- Harmonisation of time series periods and intervals; data from groundwater monitoring wells, precipitation, temperature, and groundwater abstraction need to be harmonized both in the period length chosen for the data analyses and the time interval. Which time period is the most suitable depends largely on the data availability in the different countries (choose the most recent time period for which all countries have most data).

**Elements of data harmonisation:**

- ✓ Aquifer's geometry
- ✓ Coordinate system and scale for maps
- ✓ Interpolation techniques
- ✓ Harmonisation of classifications
- ✓ Aquifer's conceptual model

**Main outputs at the end of this phase:**

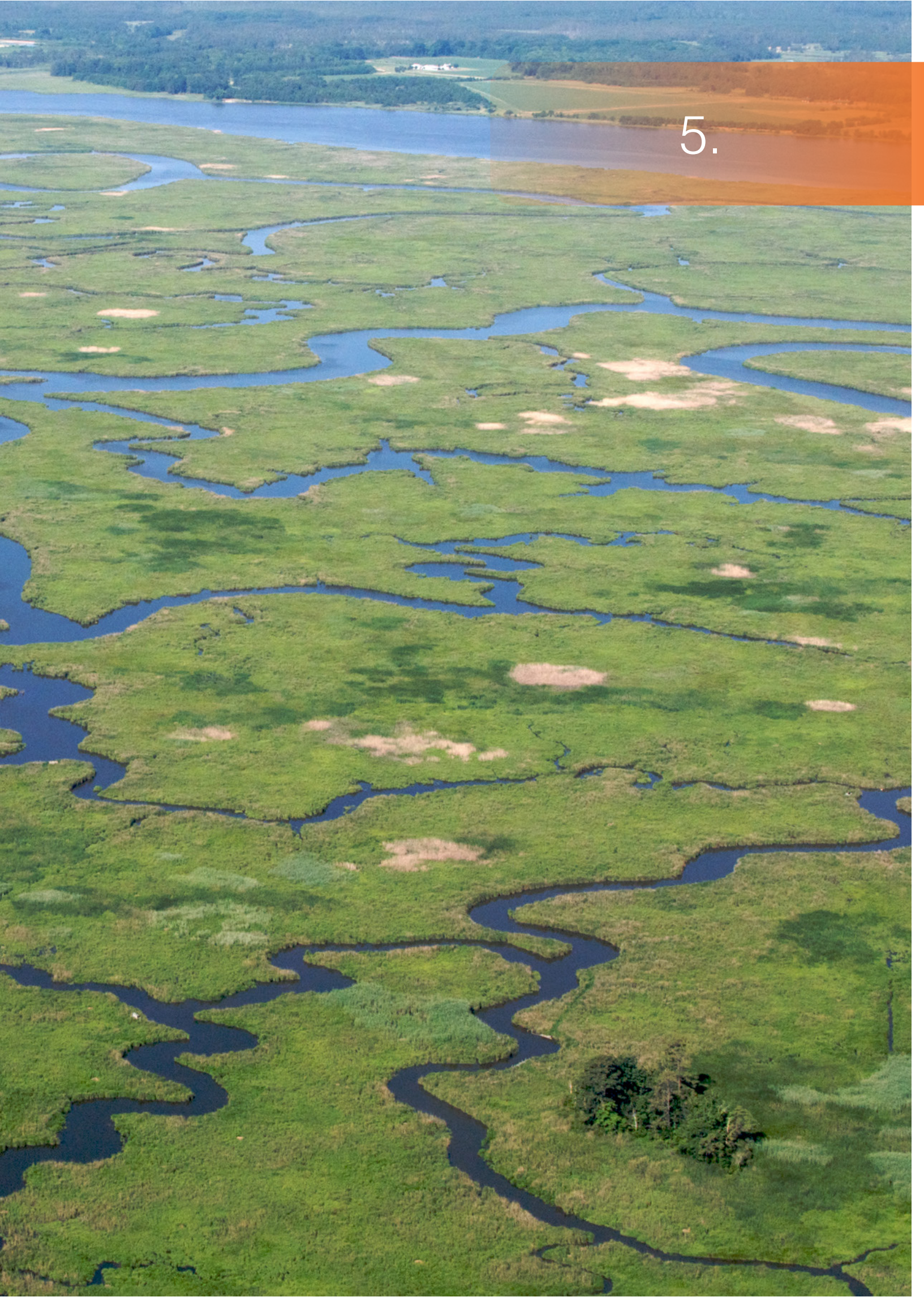
- ✓ Harmonised set of maps for the aquifer
- ✓ Harmonised datasets
- ✓ Data needed for the calculation of indicators

The suggestions given above on harmonisation are neither conclusive nor complete. Regular and open communication between national experts is the key to successful harmonisation. Aggregating data at aquifer level is not advised. When none of the aquifer states have any collected data for a certain parameter, some considerations need to be made on not including that parameter in the assessment.









5.



# AQUIFER ASSESSMENT

## 5.1 GENERAL ASSESSMENT

The general assessment takes place when all the raw data is interpreted to characterize the aquifer in all aspects – hydrogeological, environmental, socio-economic and legal & institutional. The outcomes of this kind of assessment are map layers describing the system expressed in parameters, regimes and variables. The previous sections described which type of data has to be collected and how these data can be harmonised. These steps should result in clearly structured and harmonised datasets preferably in the form of maps and tables that can be seen as preparatory work for the actual assessment. Sometimes, depending of the kind of data, source and geographical distribution, it is not possible to prepare map layers or tables, but only a short text summarizing the current situation which can be used in the assessment report. Other sets of data, such as GEO-TIFFs, could also be used for the assessment, but they are rather complicated to be harmonised at TBA level. However such data are still very useful when they cover all the aquifer states.

The general assessment generates the basic characterization necessary to understand and explain the aquifer dynamics. This can be done by describing the dynamics and relationships in the assessment report but will have an extra dimension if translated into graphic representations: thematic maps, cross sections, 3D diagrams describing the conceptual model, graphics, charts, tables, etc. These are powerful features in the communication with the decision makers and the general public as they have already been interpreted and made easier in order to understand the impact of various processes on the groundwater quantity and quality.

### Visualisations of the transboundary aquifer

- ✓ Thematic maps
- ✓ 2D cross sections
- ✓ 3D representation of the conceptual model
- ✓ Diagrams
- ✓ Graphics
- ✓ Charts
- ✓ Tables

### Thematic maps

The thematic maps are going to be generated for the aspects of the aquifer grouped in themes A to E (see Table 2). If enough detailed information is available and national experts also succeed in harmonizing the data at aquifer level, map layers can be made for several of these datasets. By combining the map layers, thematic maps can be created, which should be clear and simple enough to be informative for decision makers and the general public.

The legal and institutional aspects (theme F) are mostly not suitable to be expressed in graphical features. They are used for the calculation of the indicators and are tackled later in this section. In Table 1 an overview is given of the possible aspects of the aquifers that can be presented as thematic maps and/or map layers.

Note that not all data can be presented as map layers. The description of the data and the expected data format is given in Appendix 1.

**Table 1 Overview of potential map layers and thematic maps to be generated**

<b>A. Physiography and climate</b>
A.1. Temperature
A.2. Precipitation
A.3. Evapotranspiration
A.4. Land use
A.5. Topography: elevation data
A.6. Surface water network
<b>B. Aquifer geometry</b>
B.1. Hydrogeological map
B.2. Geo-referenced boundary of the Transboundary Aquifer
B.3. Depth of water table/piezometric surface
B.4. Depth to top of aquifer formation
B.5. Vertical thickness of the aquifer
B.6. Degree of confinement
<b>C. Hydrogeological characteristics</b>
C.1. Aquifer recharge
C.2. Aquifer lithology
C.3. Soil types
C.4. Porosity
C.5. Transmissivity and vertical connectivity
C.7. Groundwater depletion
C.9. Discharge by springs
<b>D. Environmental aspects</b>
D.1. Groundwater quality (suitability for human consumption)
D.2. Groundwater pollution
D.3. Solid waste and wastewater control
D.4. Shallow groundwater table and groundwater-dependent ecosystems
<b>E. Socio-economic aspects</b>
E.1. Population (total and density)
E.2. Groundwater use
E.3. Surface water use
E.5. Percentage of population covered by public water supply
E.6. Percentage of population covered by public sanitation

The map below (Figure 1) gives a (fictitious) example of a thematic map. The map consists of information from several map layers:

- Aquifer delineation and national boundaries;
- General direction of groundwater flow (to be provided by national experts): could be derived from the maps of groundwater levels/piezometric levels. The general direction of groundwater flow can be indicated by means of arrows. In the case of aquifer systems, it might be necessary to provide different maps for different aquifer layers;
- Major recharge zones: a map outlining where the major recharge areas are located. In the case of an aquifer system this may need to be depicted identifying each recharge zone with the related aquifer unit;
- Location of groundwater-dependent ecosystems;
- Zones of priority, emerging issues and concerns such as zones of major groundwater pollution and zones of large withdrawals (to be provided by the national experts): a (sketch) map depicting zones of special interest / concern, for example, zones with major groundwater pollution, zones with major groundwater abstractions, zones at risk of pollution etc. This should be agreed on by all the national experts.



It is possible to combine all kinds of map layers stored in a geo-referenced database such as TBA-IMS into a map to visualize a certain parameter or issue in the aquifer region. Also, analyses of the available data can be made by combining map layers with demographic data, e.g. population density x groundwater use. More understanding on the possibilities and advantages of the TBA-IMS is given in Section 6.

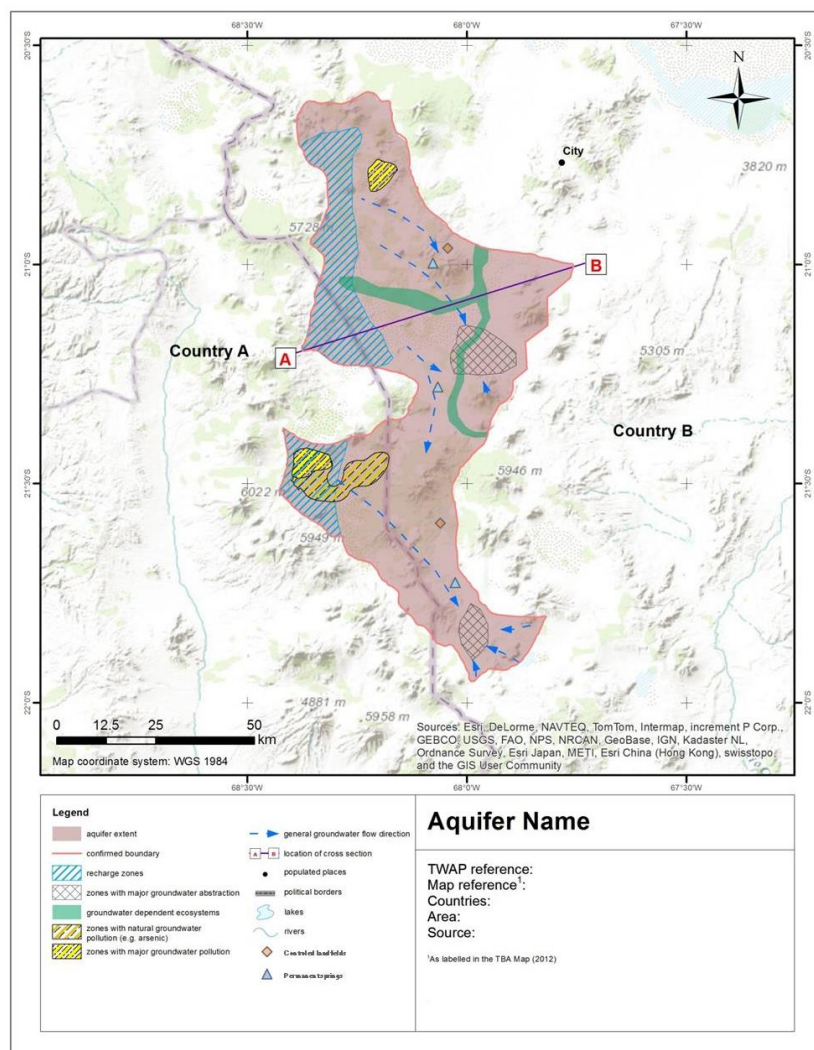


Figure 1 Fictitious example of a thematic map of a complete Transboundary Aquifer

## Cross sections

Cross sections are powerful tools (2D) used to visualize sub-surface structures and conceptual models of aquifers. Cross sections can show crucial aquifer features such as the relation between aquifer layers in aquifer systems, the depth to the aquifer or vertical flow patterns that can allow us to better understand for example possible movement of pollutants (time spans and pathways). Therefore, for the purpose of improving groundwater management and governance, focus should be on the conceptual links between the aquifer element and processes influencing groundwater quality and quantity (i.e. a diagram showing the relations between recharge areas, polluted areas, abstraction points, etc.). It is also possible to use cross sections to give an overview of the hydrogeology of the aquifer, with detailed descriptions of each aquifer layer and hydrogeological features. In addition it is possible in the legend to give the name of each aquifer layer, including the lithological classification and predominant type of porosity zones with natural salinity, and other characteristics.

Cross sections can be prepared with other tools to create a digital image (e.g. jpg, tiff, pdf). These images can be stored and visualized in the information management system throughout the meta-data module, but cannot be combined to create thematic maps. See Figure 2 for some examples of cross sections.

The cross section could include features such as:

- i. Main aquifer formation/layers
- ii. For aquifer systems it could also clearly depict aquitards / aquicludes
- iii. General direction of groundwater flow
- iv. Main geological features, such as faults
- v. Location of country borders
- vi. Indication of relevant hydrological features such as:
  - a. recharge zones,
  - b. discharge zones,
  - c. zones of major groundwater abstractions and/or
  - d. zones of groundwater pollution.

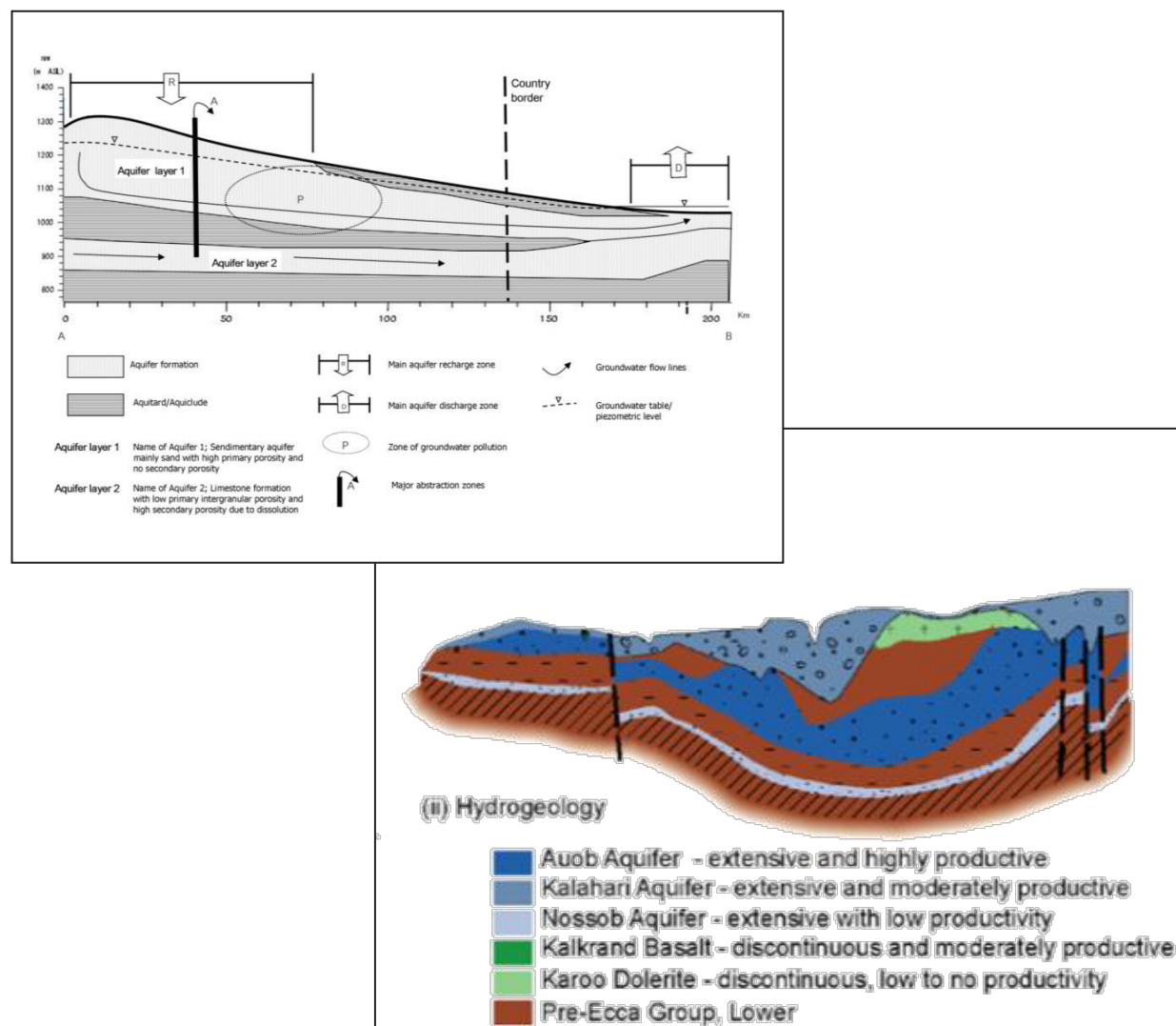


Figure 2 Fictitious examples of cross sections. Source IGRAC and (JICA 2002)

## Block diagrams showing the aquifer's conceptual model

3D hydrogeological conceptual models are a synthesis of data assimilated into a graphical representation. They are a combination of map views and cross sections. They can combine the horizontal spatial distribution of attributes and factors affecting the aquifer with the vertical distribution of the aquifer units. As not all information can be included in such a synthesis exercise, the conceptual model needs to represent the most relevant and common features of the aquifer dynamic (e.g. where water is recharging, in which direction groundwater flows, etc.), the current state of the resource (e.g. location of the main polluted areas) and possible future problems (e.g. location of main landfills or large well fields) for the complete aquifer. The interaction amongst the aquifer layers can also be presented in the block diagram in order to give a better understanding of the dynamics of the hydrogeological system and, for example, to point areas where groundwater could be extracted.

It is not possible to generate block diagrams from the information management system. Block diagrams needs to be prepared with other tools to create a digital image (e.g. jpg, tiff, pdf). These images can be stored and visualized in the information management system. Figure 3 gives an example of a block diagram prepared by the United States Geological Survey for a conceptual model of the Floridan Aquifer System. Note that this example presents mainly hydrogeological dynamics, and, in the context of this methodology, would be missing some additional interpreted features such as the source of pollution, recharge areas, etc.

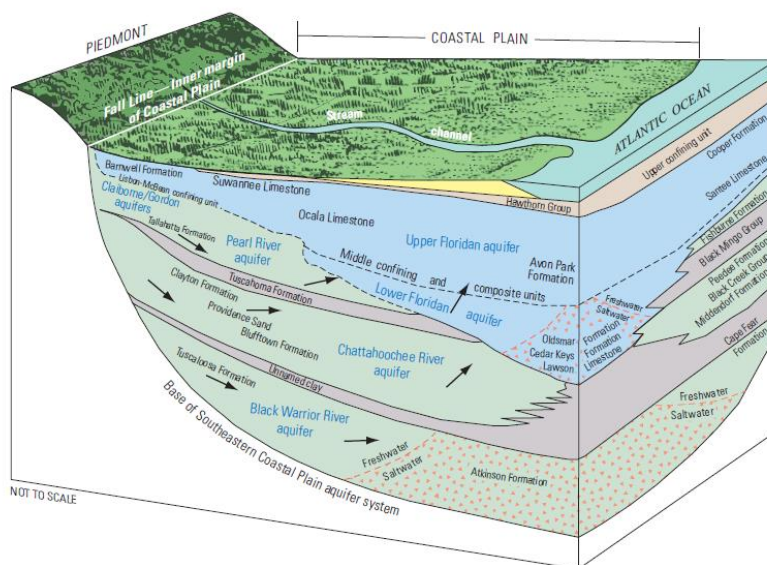


Figure 3 Generalized block diagram of the Floridan aquifer system, Williams and Kuniansky (USGS 2015).

## 5.2 INDICATOR-BASED ASSESSMENT

An important component of the assessment methodology is the use of indicators to summarize and represent complex information in a more intuitive and meaningful way. Indicators are particularly useful when comparing different geographical units. This can be sub-regions of the transboundary aquifer: for example, to highlight differences between the country segments, between different administrative units (municipalities or provinces) or between different land use types. Some indicators can also be used to highlight differences between different aquifer layers or even between different transboundary aquifers. To what level of detail indicators for different geographical units can be produced depends on the level of detail and the geographic spread of the available information.

Indicators are no more than a tool and thus should not replace the information and knowledge contained in more detailed reports. Nevertheless, they have a number of strengths that could help achieving progress in a diagnostic analysis:

- Indicators are very strong in passing a message. They summarise in a nutshell a number of very important aspects of the system considered and bring them under attention of decision-makers, planners and other persons that do not read the entire report.
- Indicators may help integrating information from different disciplines and thus support the development of a holistic view. In particular, they may integrate hydrogeological with socio-economic and ecological aspects. The wider, holistic view will contribute to a more successful dialogue between the different categories of scientists involved and other stakeholders.
- Indicators may help differentiating between issues of major concern and secondary issues.
- Indicators are strong on summarizing briefly whether and why the aquifer is so important that significant governance and management attention is required.

The indicators can be broadly used for all sets of data, from themes A to F. Assessing data by calculating indicators is done by analysing the data and structuring it into a range of levels. **Error! Reference source not found.** gives a list and short description of the indicators, which are compiled based on the parameters and variables described in Section 3. Table 2 gives an overview of all the indicators to be calculated. In total there are 32 indicators proposed, from which 16 are developed for the themes A to E and 16\* are developed for the legal and institutional aspects (theme F). In the column 'Core' in Table 2 the core indicators are given with the letter 'Y'. They are also marked in light blue in **Error! Reference source not found.**

Table 2 List of indicators to be calculated

#	Indicators	Core
<b>1 - Defining or constraining the value of aquifers and their potential functions</b>		
1.1	Mean annual groundwater recharge depth	Y
1.2	Annual amount of renewable groundwater resources per capita	Y
1.3	Natural background groundwater quality	Y
1.4	Aquifer-buffering capacity	
1.5	Aquifer vulnerability to climate change	
1.6	Aquifer vulnerability to pollution	
<b>2 - Role and importance of groundwater for humans and the environment</b>		
2.1	Human dependency on groundwater	Y
2.2	Human dependency on groundwater for domestic water supply	
2.3	Human dependency on groundwater for agricultural water supply	
2.4	Human dependency on groundwater for industrial water supply	
2.5	Ecosystem dependency on groundwater	
2.6	Prevalence of springs	
<b>3 - Changes in groundwater state</b>		
3.1	Groundwater depletion	Y
3.2	Groundwater pollution	Y
<b>4 - Drivers of change and pressures</b>		
4.1	Population density	Y
4.2	Groundwater development stress	Y
<b>5 - Enabling legal and institutional environment for transboundary aquifer resources management at TBA level*</b>		
5.1	Transboundary legal framework	Y
5.2	Transboundary institutional framework	Y



## 6 - Enabling domestic legal and institutional environment for the management of the national parts of transboundary aquifer resources \*

6.1	Policy framework	
6.2	Legislative/regulatory framework for groundwater resources	Y
6.3	Legal status of groundwater	
6.4	Groundwater planning framework	
6.5	Regulatory framework of groundwater abstraction and use	
6.6	Regulatory framework for the protection of GW from point source pollution	
6.7	Regulatory framework for the protection of GW from non-point source ('diffuse') pollution	
6.8	Regulatory framework for the protection of GW recharge processes from manmade interferences	
6.9	Legislative/regulatory framework implemented	
6.10	Legislative/regulatory framework enforced	
6.11	Customary water rights	
6.12	Formal institutional framework (government)	Y
6.13	Formal institutional framework (users)	
6.14	Informal institutional framework	

\* 16 Indicators developed for the legal and institutional aspects.

### Calculating indicators

Calculating an indicator is an excellent way to interpret data and present it in a simpler and more understandable manner to the non-scientific public. The use of indicators allows the data to be assessed in as much detail as possible and using the same approach. In addition, it allows all the data available to be used in the assessment and if the data availability is limited, the assessment is still possible. The calculated indicator can be used to represent the geographical distribution of parameters and values throughout the aquifer by means of map layers, and also to present their variations over time in tables and graphs. In order to be able to calculate the indicators, **Error! Reference source not found.** presents the formula for the 16 indicators related to the themes A to E (except for the legal and institutional aspects).

In order to calculate an indicator for a transboundary aquifer it is necessary to first aggregate the input data to the level of the aquifer. If insufficient data is available to calculate the aggregated values accurately it may still be possible to estimate the aggregated values using expert judgement. When inferring data one needs to report it clearly to make sure the reader understands the constraints on the presented results.

The indicators for the Legal and Institutional (L&I) aspects aim to analyse the current status of the transboundary and the domestic L&I framework of relevance to the transboundary aquifer. Domestic legal and institutional frameworks are, in fact, directly instrumental to the effectiveness of transboundary frameworks and, in particular, to compliance with obligations stemming from TBA-relevant bi- and multi-lateral treaties and agreements.

The 16 L&I indicators have been singled out for data collection and analysis, in a bid to consistently characterize the great diversity of transboundary legal and para-legal instruments and institutional arrangements and of domestic legislation and institutions, of relevance to transboundary aquifers. The scores assigned to the L&I indicators (see **Error! Reference source not found.**) are an attempt to quantify qualitative-type data, and to arrive thus at some approximate measurement of the indicators which make up the legal and institutional frameworks for the governance of TBAs, at the transboundary but also at the domestic level. Such measurements may prove useful in the eventual assessment of such frameworks.

Figure 4 shows an example of an indicator-based assessment from which a map layer is made. Transforming calculated indicators into map-layers is a powerful way of presenting the results of this kind of assessment.

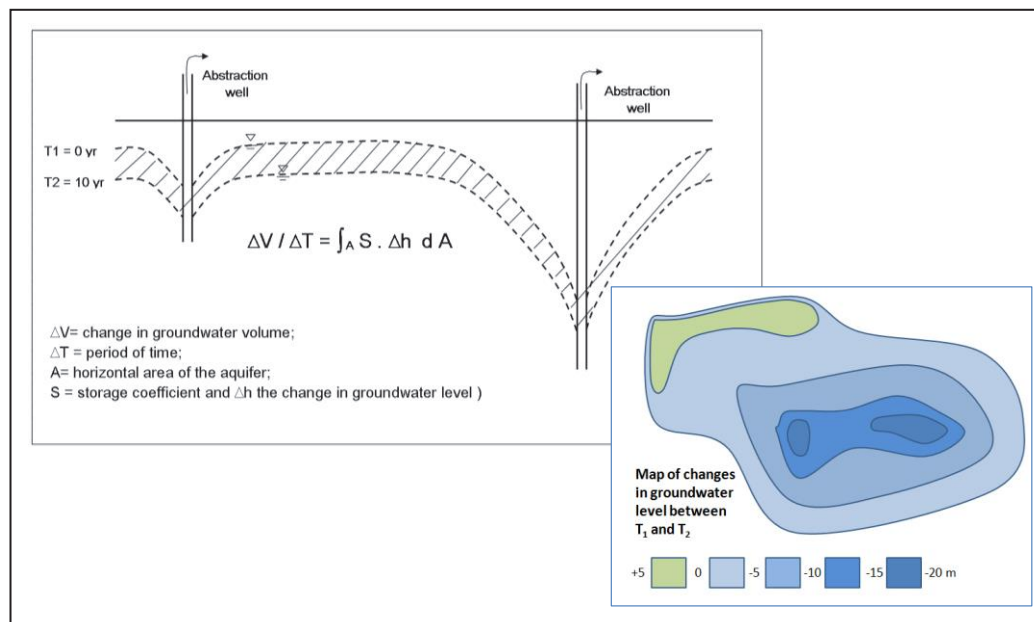


Figure 4 Example of indicator calculated and presented as a map-layer

### 5.3 ASSESSMENT REPORT

The assessment report needs to focus on describing the current situation of the transboundary aquifer in terms of water quantity, water quality, socio-economics, and environmental, legal and institutional aspects. The report should describe current issues including, root-cause analyses and if possible give suggestions for action. The report needs also to describe potential future issues and opportunities for development. The target groups for the report are decision makers and other stakeholders. This means that technical descriptions and jargon needs to be avoided as much as possible.

To prepare the assessment report it is useful to use the drivers, pressure, state, impact, response (DPSIR) framework (EEA 2010). The integrated assessment report is supposed to include nine chapters starting with an introduction to the assessment in Chapter 1. The main drivers and pressures are covered in Chapter 2, state variables are presented in chapters 3, 4 and 5, impacts and responses are discussed in chapters 6 and 7, and conclusions and recommendations are presented in chapters 8 and 9. An overview of the chapter contents for the assessment report is given below:

1. Introduction: background of the assessment, objectives, people and organizations involved, and assessment approaches (existing data, etc.);
2. Drivers and pressures on the aquifer: including climate, population, household and industrial development;
3. Hydrogeological characterization and conceptual model of the TBA including aquifer boundary, size, volume and change in stored water, groundwater (GW) flow and depletion;
4. Socio-economic and environmental features: GW quality and pollution, and GW use. Emerging trends;
5. Legal and institutional settings;
6. Impacts of changes in use, availability and quality of GW on resource-dependent communities and the environment;
7. Policy, legal and institutional responses to the challenges ahead;
8. Conclusions from the assessment;
9. Recommendations for multi-country consultation and action.

## Questions to be addressed in the integrated aquifer assessment - related to hydrogeological, socioeconomic, environmental, and legal/institutional variables and indicators

The following table (Table 7) gives a list of questions that need to be answered with the aquifer assessment, and key variables and indicators that are useful in answering these questions. The questions prepared are related to chapters 2 - 6. The questions **in bold** are key questions for which water managers want to have answers. However the answers to such questions depend on assumptions about future development and people's behaviour in response to change. To help answer these questions, scenarios and suppositions can be used in conjunction with variables and indicators.

Table 3 Questions to help in preparing the assessment report

Questions	Key variables needed to answer questions	Indicators
<i>Drivers and pressures (Chapter 2)</i>		
<ul style="list-style-type: none"> <li>What are the main external drivers affecting the aquifer and its users?</li> <li>What are the main pressures on the aquifer and its users?</li> </ul>	A1, A2 Annual rainfall and temperature by country and region E1 Population by country and region (total and density) A4 Land use and land cover (growth in incomes)	
<i>The groundwater resource (Chapter 3)</i>		
<ul style="list-style-type: none"> <li>What are the boundaries of the aquifer?</li> <li>How much water is in the aquifer?</li> <li>Which direction is water flowing in the aquifer?</li> <li><b>How much water can we sustainably take from the aquifer per year (in each country, by main users)?</b></li> <li>At what threshold will further development (rural and urban) be constrained by lack of water?</li> <li>How much does climate change affect the aquifer?</li> </ul>	B2 Aquifer boundary B3-B5 Aquifer size (horizontal and vertical dimensions) C1 Aquifer recharge C6 Total groundwater volume C7 GW depletion (direction of main GW flow of aquifer & volume of GW)	1.1 Mean annual GW recharge depth 1.2 Annual amount of renewable GW resource 1.4 Aquifer-buffering capacity 3.1 GW depletion
<i>Quality of the groundwater resource (Chapter 4)</i>		
<ul style="list-style-type: none"> <li>How clean is the water in the aquifer?</li> <li><b>How much water is suitable for different uses (domestic, cattle, irrigation, industry)?</b></li> <li>At what threshold will the impacts of urban and rural development on water quality become unacceptable?</li> <li>At what level of groundwater extraction will 'environmental uses' be affected?</li> </ul>	D1 Natural GW quality and natural GW contaminants D2 GW pollution D3 Waste and wastewater control	1.3 Natural background GW quality 3.2 GW pollution
<i>Use of the groundwater resource (Chapter 4)</i>		
<ul style="list-style-type: none"> <li>How much water is taken from the aquifer each year?</li> <li><b>How much GW is taken per person?</b></li> <li><b>What proportion of GW is taken by domestic users, farms and other enterprises</b></li> <li>How stressed is the aquifer?</li> <li><b>How long can we sustain the current level of extraction?</b></li> </ul>	E2 GW use by country and by user group <ul style="list-style-type: none"> <li>o domestic</li> <li>o agriculture</li> <li>o industry</li> <li>o (environment)</li> </ul> E4 Dependency of user groups on GW E5, E6 Percentage of population covered by public water supply and sanitation D4 Shallow groundwater table	2.2-2.4 Human dependency on GW by country and by user group 2.5 Ecosystem dependency on groundwater 4.1 Population density 4.2 GW development stress
<i>Legal and institutional settings (Chapter 5)</i>		

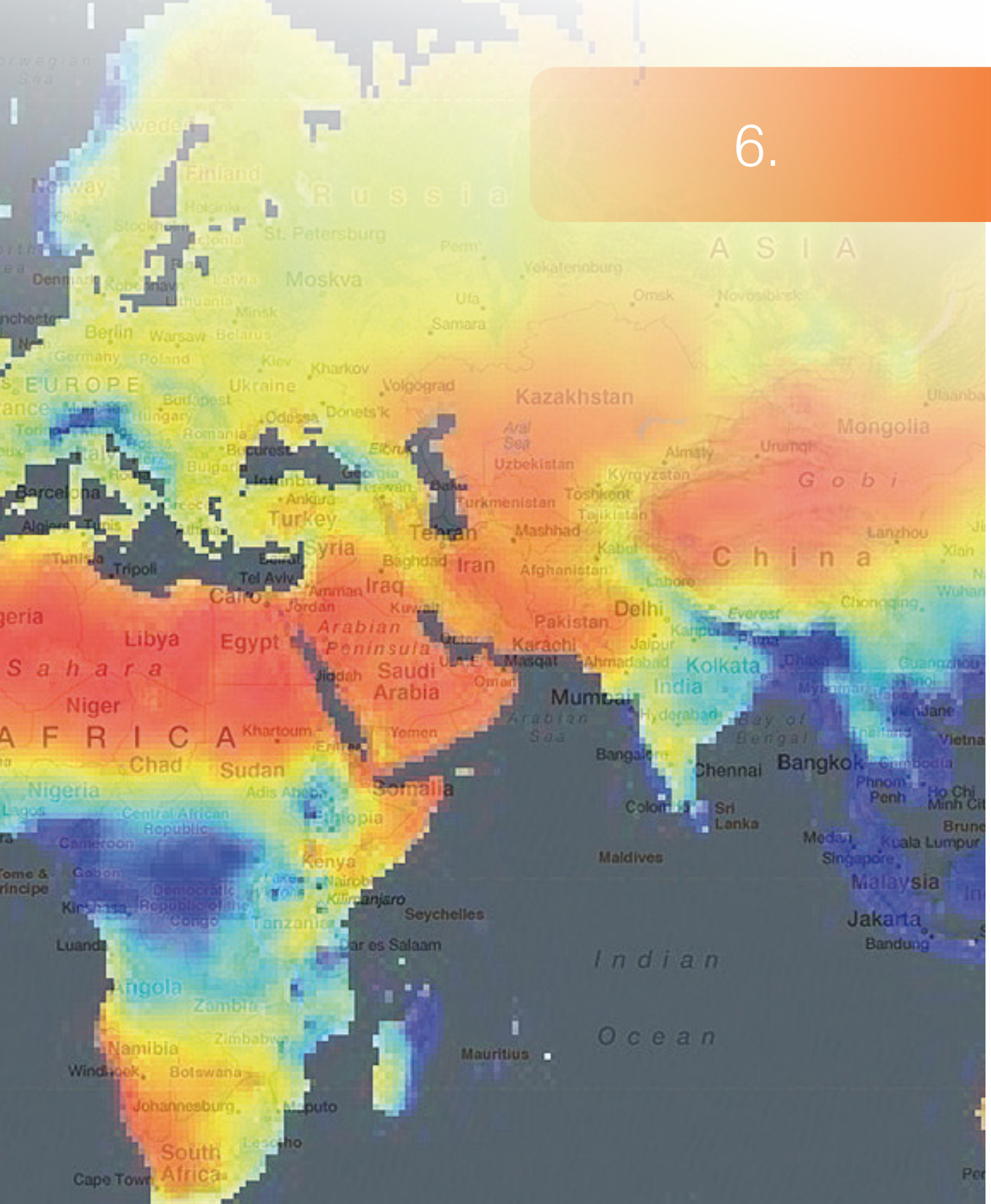


<ul style="list-style-type: none"> <li>• What multi-country cooperation arrangements already exist for managing shared water resources and how effective have they been?</li> <li>• Can the existing multi-country legal agreements and institutions for transboundary cooperation on water management be adapted to manage the Stampriet aquifer more effectively?</li> <li>• Do existing national laws and institutions provide the basis for effective management of national segments of the Stampriet aquifer?</li> </ul>	5.1 Transboundary legal framework 5.2 Transboundary institutional framework 6.1, 6.2, 6.4 National policy legislative and planning framework 6.5 National regulatory framework for GW abstraction and use 6.6, 6.7 National regulatory framework for GW pollution 6.9 Implementation of legislative/regulatory framework 6.12-6.14 Formal and informal institutional framework	5.1 Existence and comprehensiveness of TBA-relevant treaties/agreements 5.2 Existence and comprehensiveness of TBA-relevant institutional framework 6.1-6.10 Existence, comprehensiveness and effectiveness of domestic groundwater legislation 6.12&6.13 Existence and articulation of formal institutional arrangements for groundwater resources management, at government and users' level
<i>Impacts of the use of the groundwater resource (Chapter 6)</i>		
<ul style="list-style-type: none"> <li>• How is the GW resource being changed by human development?</li> <li>• <b>Is the resource becoming more polluted and what are the impacts?</b></li> <li>• <b>What would be the impacts of cutting GW use?</b></li> </ul>	<ul style="list-style-type: none"> <li>• Trends in GW level and quality</li> <li>• Impacts of GW pollution on human use (and environmental assets)</li> <li>• Impacts on human communities of increasing, reducing or stopping GW use</li> </ul>	





6.





# DATA MANAGEMENT

Multidisciplinary assessment of a transboundary aquifer results in a large amount of data and information. Harmonizing and structuring these data is important in order to be able to analyse them and later on to publish the analysis. In order to support the transboundary assessment and management, IGRAC has developed a web-based information management system for a transboundary aquifer assessment (TBA-IMS). The TBA-IMS is a tool that assists in data collection, storage, processing, visualisation and sharing of various kinds and formats of data and information. The TBA-IMS is part of GGIS, which contains a variety of data information on groundwater worldwide.

The TBA-IMS is a map-based system with advanced user interactivity. For example, authorised user can directly upload (geo-referenced) map layers generated by the assessment. Additional information such as tables, figures, documents and other sources/forms of data can also be uploaded into the TBA-IMS or other parts of GGIS. The TBA-IMS is meant for storage of interpreted rather than raw data because the main focus of the system is use of the assessment outcomes. The TBA-IMS also makes it possible generate new pieces of information by combining map layers and through the queries. Figure 8 shows a screenshot of the TBA-IMS viewer developed in the framework of the GGRETA project.

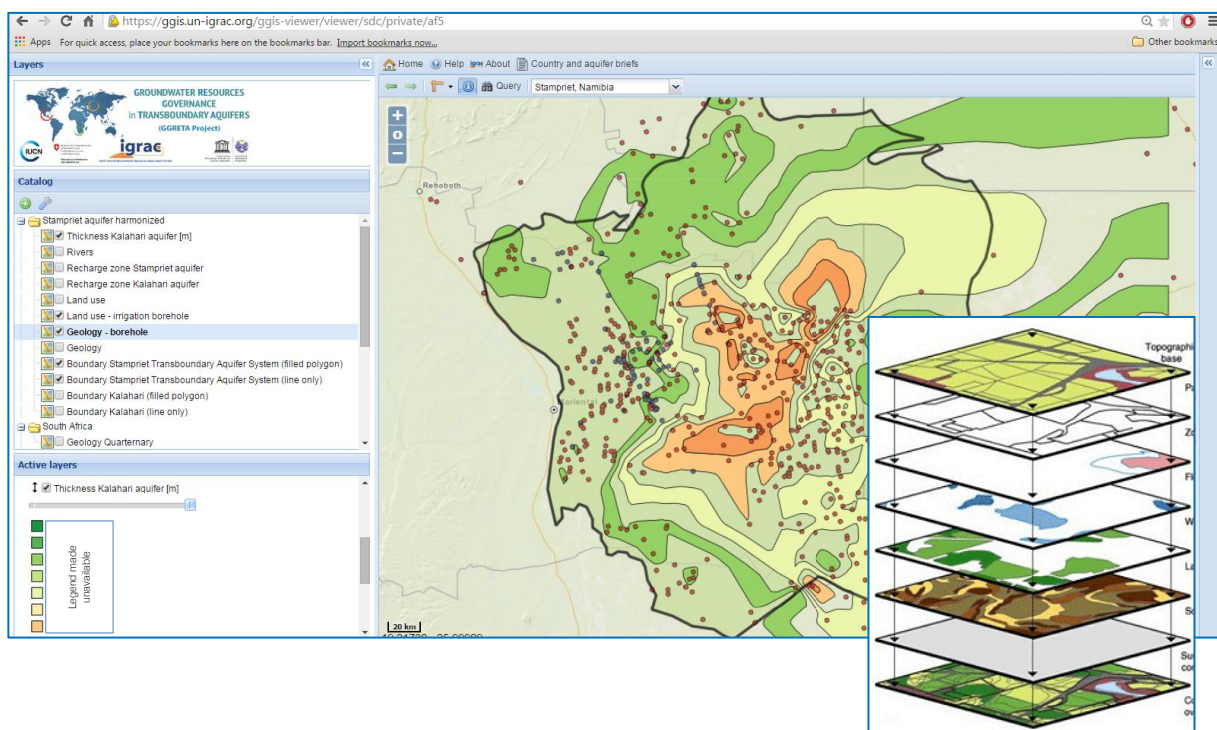


Figure 8 Example of the TBA-IMS viewer and different map layers

The ownership of the data stored in the TBA-IMS remains with the data providers (the aquifer states, and their national assessment teams). It is possible to make maps and other forms of data publically available, but it is also possible to make maps available only to authorized users; this is particularly useful for sharing draft maps. The assessment coordinator is authorized in TBA-IMS to publish project results hence made those available for the general public. The possibility of making the map layers available for download also in shape-file format will probably be included in the new version of TBA-IMS.

## 6.1 THE TBA INFORMATION MANAGEMENT SYSTEM

The TBA-IMS is designed and maintained by IGRAC, in close cooperation with UNESCO-IHP and the national assessment teams. The information management system has been designed in such a way that it is easy to set up a dedicated workspace for new aquifers / projects. The database is accessible to the assessment teams and the government representatives during the assessment trajectory. They also decide on accessibility of the assessment results to the global groundwater community and public.

The information management system has two view modes:

1. In the **public viewer**, the general public is able to navigate using a map view and search for information related to transboundary aquifers by clicking directly on the geographical units of interest. Information such as attributes at aquifer level or indicators values derived from the assessment are displayed in an interactive map view. Meta information is accessible to facilitate interpretation of the assessment results.
2. The **protected workspace** is a password-protected part with access to the database - national experts, assessment and national coordinators, GIS experts and the system administrator have access to a password-protected workspace to manage the groundwater information related to the country or aquifer they are responsible for. The workspace facilitates uploading and updating of data. Data quality is user and the system controlled.

The following types of data can be uploaded in the TBA-IMS:

- ✓ GIS data: map layers, rasters and TIFF images;
- ✓ Tabular data and time series (xls);
- ✓ Images (JPEG, PNG, PDF): cross sections, 3D diagrams or any type of graphically available information that could help with the visualisation of the aquifer / aquifer system characteristics;
- ✓ Documents in PDF;
- ✓ Metadata: all data and information are provided with metadata, describing aspects such as: data source, uncertainty range, method etc.

The TBA-IMS meets all the requirements of the OGC international data standards; therefore the data uploaded to the TBA-IMS can easily be shared and integrated with other external information systems. To allow this, the TBA-IMS uses Web Mapping Services (WMS) and Web Feature Services (WFS) to distribute maps and data. In the same way, data from external sources can easily be integrated in the TBA-IMS.

## 6.2 DATA COLLECTION AND PROCESSING FOR THE TBA-IMS

National expert teams have the main responsibility for the data collection. This process is facilitated and coordinated by the Assessment Coordinator and is based on the guidelines of this document. At country level, the National Coordinator provides support to the experts and lead cooperation with other aquifer state(s).

Data processing includes the steps required to transform raw data collected by the national experts into structured and harmonized products at aquifer level. Data from different sources needs to be structured into tables and databases which are consistent internationally. A significant part of the work is related to the processing of map information, including digitizing, reclassification of map information, merging of national segment information, creation of new maps and/or spatial calculations. To implement these tasks the assessment team needs a good knowledge of GIS or a GIS specialist is part of the assessment team. The assessment coordinator, with the assistance of a GIS specialist, should ensure that data meet the quality standards required (in terms of format, harmonisation etc.).

So far, TBA-IMS has been used to support the assessment in the TWAP and GGRETA projects. During these projects, trainings were organized in order to enable national experts to independently manage the database by the end of the projects. Figure 9 shows the different roles in the data management. Note that there are two or more national expert teams, one for each aquifer state.

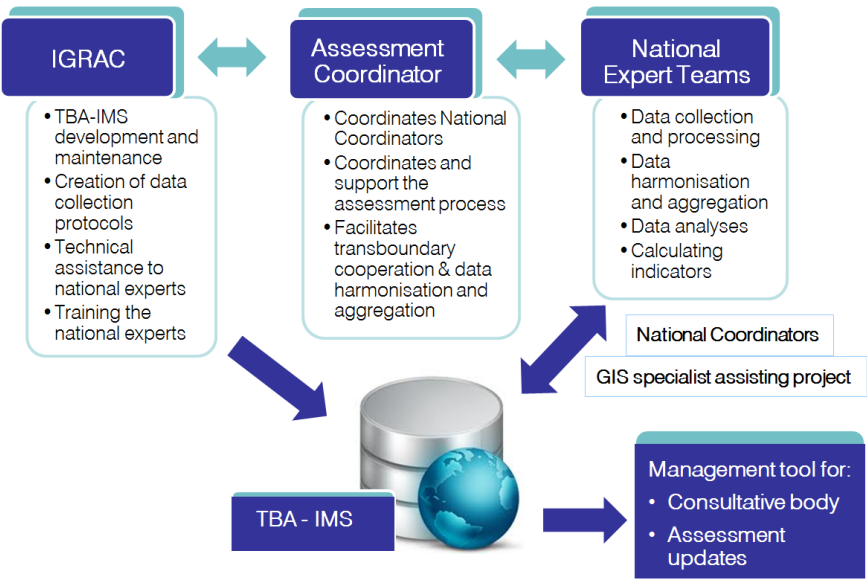


Figure 9 Data management in the TBA-IMS

To ensure consistent data collection, processing and better coordinate the harmonisation, there are different authorization given to the users. The **general public** is able to view the information published in the public viewer that results from the project. It also has access to final project documents and is able to generate customized datasets for viewing / downloading. The **national expert teams** have access to the data management in the project workspace related to their specific country in order to perform basic maintenance tasks and to visualize data. The **assessment and national coordinators** have access to the project workspace at both the TBA-level data and (all) the country-specific data to perform quality checks, contribute with data, if necessary, make the necessary quality control, and to upload data. Only the assessment coordinator is entitled to publish the data. The GIS expert has access to all the data in the project workspace in order to process data and generate outputs and eventually harmonize data amongst the countries. The **system administrator** (IGRAC) is responsible for setting up and managing user accounts and has access to the complete database for management purposes. IGRAC is also responsible for training the professionals using TBA-IMS and giving technical support afterwards.

### 6.3 THE GLOBAL GROUNDWATER INFORMATION SYSTEM (GGIS)

The TBA-IMS is available as a component of GGIS. GGIS is an interactive, web-based portal to groundwater-related information and knowledge. The GGIS provides groundwater information per country and per transboundary aquifer. It leads the user from global overview of aggregated information towards information briefs, in-depth aquifer assessments and related information sources in the Meta-Information Module. Additionally, the GGIS contains the Global Groundwater Monitoring Network (GGMN) module that is a participative, web-based network of networks, set up to improve quality and accessibility of groundwater monitoring information.



The GGIS has an open and extendable architecture that enables setting up dedicated workspaces for new aquifers/projects. The GGIS is meant for various categories of stakeholders, including both professionals and the general public. A snapshot of some of the GGIS components is shown below (Figure 10). The GGIS is accessible via <https://ggis.un-igrac.org>.

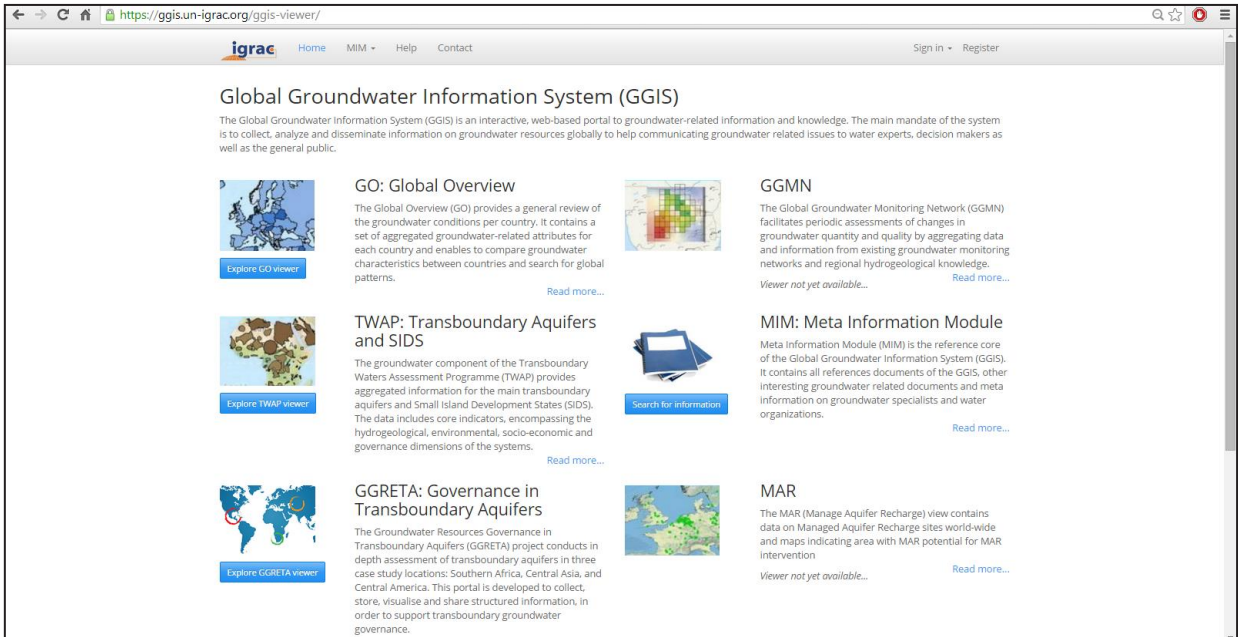
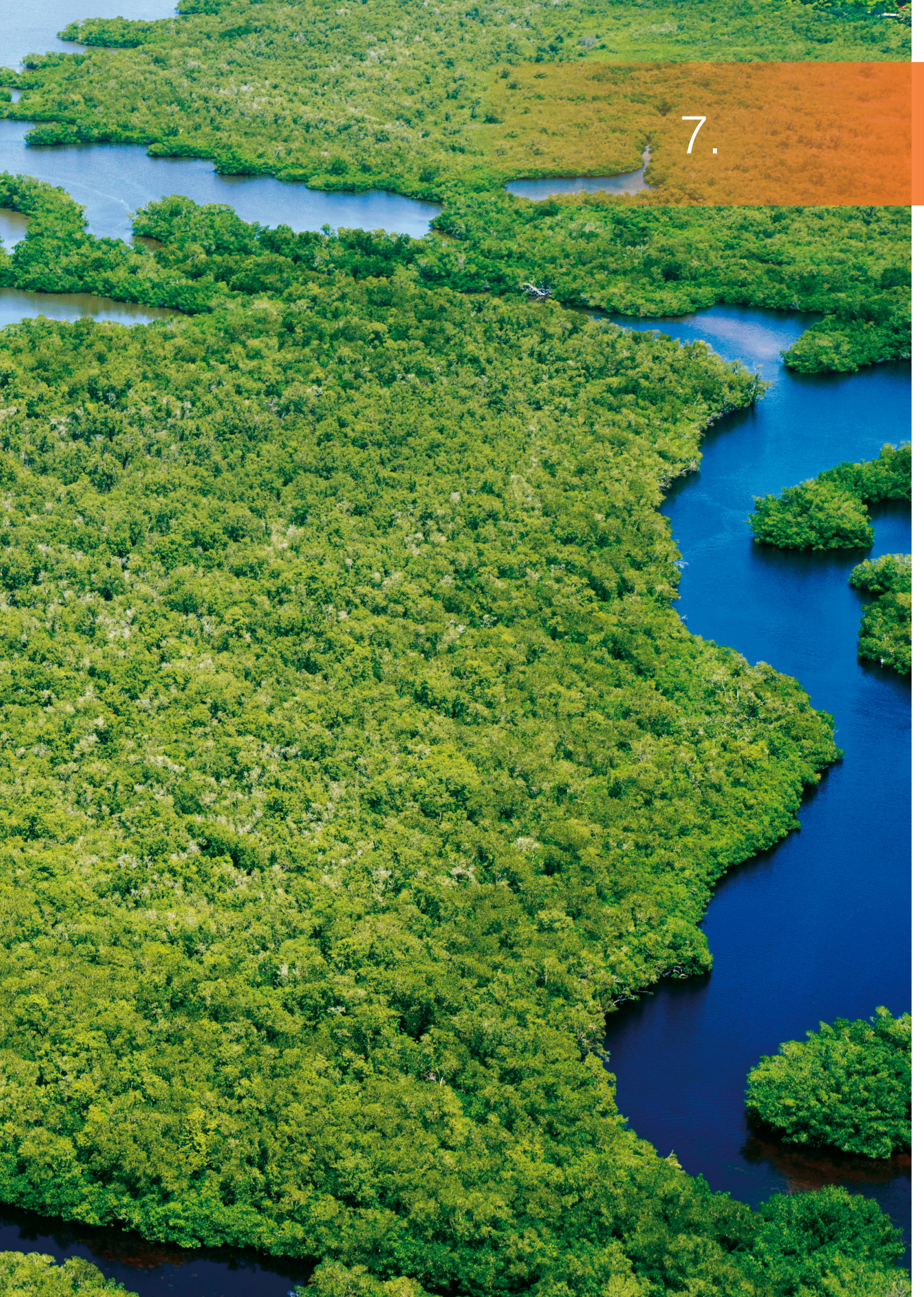


Figure 10 GGIS components: a snapshot







7.



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- JICA. *The study on Groundwater Potential Evaluation and Management Plan in the Southeast Kalahari Artesian Basin in the Republic of Namibia*. study, Tokyo: Japan International Cooperation Agency, 2002.
- UNESCO-IHP. *Internationally Shared (Transboundary) Aquifer Resources Management - Their significance and sustainable management*. Framework document, Paris: UNESCO-IHP-VI, SERIES ON GROUNDWATER NO. 1, 2001.
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- UN-ILC. "Draft Articles on the Law of Transboundary Aquifers UN Doc. A/CN.4/L.724." *International Law Commission - UN*. 2008.
- USGS. "Floridan Aquifer System Groundwater Availability Study." *USGS*. 2015. <http://fl.water.usgs.gov/floridan/intro.html> (accessed 07 16, 2015).
- Wilson, Paul F. *Root Cause Analysis: A Tool for Total Quality Management*. Milwaukee: ASQ Quality Press, 1993.

## WEB REFERENCES

- GGIS: <https://ggis.un-igrac.org>
- TWAP: <https://ggis.un-igrac.org/ggis-viewer/viewer/twap/public/default>
- GGRETA: <https://ggis.un-igrac.org/ggis-viewer/sdc>
- GGMN: <https://ggmn.lizard.net>
- GRUMP (Population density): <http://sedac.ciesin.columbia.edu/data/set/grump-v1-population-count/data-download>
- POP (Population density projections): [http://www.iiasa.ac.at/web/home/research/researchPrograms/WorldPopulation/Wittgenstein\\_Centre\\_Data\\_Explorer.html](http://www.iiasa.ac.at/web/home/research/researchPrograms/WorldPopulation/Wittgenstein_Centre_Data_Explorer.html)
- Globcover V2 (land cover 2009): [http://due.esrin.esa.int/page\\_globcover.php](http://due.esrin.esa.int/page_globcover.php)
- GLC 2000 (land cover 2000): [http://www.glc.org/dat\\_1\\_en.jsp](http://www.glc.org/dat_1_en.jsp)
- WorldClim Precipitation / Temperature (30 sec): <http://www.worldclim.org/paleo-climate>
- Aquastat (water withdrawn): <http://www.fao.org/nr/water/aquastat/sets/index.stm>
- ACE2 (digital elevation model): <https://earth.esa.int/web/nest/downloads/sample-data>
- SRTM 90m Digital Elevation Data: <http://srtm.csi.cgiar.org/>

A coastal landscape featuring several large, rounded, light-colored rock formations on a sandy beach. The sky is a clear, deep blue. In the background, there are low, dark hills or mountains. A semi-transparent blue rectangular overlay is positioned on the right side of the image, containing the text "APPENDIX 1." in white, sans-serif, uppercase letters.

# APPENDIX 1.

# DETAILED OVERVIEW OF DATA TO BE COLLECTED



## A – PHYSIOGRAPHY AND CLIMATE

A.1. Temperature	
Description	Format
<p>Description of temperature in the aquifer area, including an overview of the temporal and spatial variation.</p> <p>Use data from meteorological stations in the aquifer area and as close as possible to the aquifer boundaries. Include data from meteorological stations outside the aquifer area to use in the interpolation process. Depending on data availability provide results such as mean annual temperature (mean minimum, mean maximum), graphs of monthly mean values per monitoring station, spatial distribution of mean temperature in the aquifer area (map), etc.</p>	Text: mean values
	Table + graphs: time series with monthly averages
	Map: raster or isolines
	Unit
	[Degrees Celsius]
	Priority for data collection
	1 (used in 10 core indicators)
	Available global datasets
	WorldClim (1950-2000)
Sub-questions / metainformation	Format
Describe the method used to interpolate map values (if relevant).	Text

A.2. Precipitation	
Description	Format
<p>Description of precipitation in the aquifer area, including an overview of the temporal and spatial variation.</p> <p>Use data from meteorological stations in the aquifer area and as close as possible to the aquifer boundaries. Include data from meteorological stations outside the aquifer area to use in the interpolation process. Depending on data availability provide results as mean annual precipitation (mean minimum, mean maximum), graphs of monthly mean values per monitoring station, spatial distribution of mean precipitation in the aquifer area (map), etc. Also describe type of precipitation (rainfall, snow) throughout the year.</p>	Text: mean values
	Table + graphs: time series with monthly averages
	Map: raster or isolines
	Unit
	[mm/yr], [mm/day], [mm/month]
	Priority for data collection
	1 (used in 10 core indicators)
	Available global datasets
	WorldClim (1950-2000)
Sub-questions / metainformation	Format
Describe the method used to interpolate map values (if relevant)	Text

A.3. Evapotranspiration	
Description	Format
<p>Evapotranspiration: water lost into the atmosphere through evaporation and plant transpiration<sup>[1]</sup>; includes both evaporation from surface water bodies and actual evapotranspiration from plants.</p> <p>Use data from meteorological stations in the aquifer area and as close as possible to the aquifer boundaries. Include data from stations outside the aquifer area to use in the interpolation process. Depending on data availability provide results as mean annual evapotranspiration (mean minimum, mean maximum), graphs of monthly mean values per monitoring station, spatial distribution of mean evapotranspiration in the aquifer area (map), etc.</p> <p><sup>[1]</sup> ESCWA &amp; BGR, 2012. Glossary of shared water resources. Technical, Socioeconomic and Legal terminology. United Nations, New York.</p>	Map: raster or isolines and
	Table: time series with monthly average
	Unit
	[mm]
	Priority for data collection
	1 (used in 10 core indicators)
	Available global datasets
	[-]
Sub-questions / metainformation	Format
Specify / describe the method used for the calculation of evapotranspiration.	Text
Describe the method used to interpolate map values (if relevant)	Text

A.4. Land use / land cover	
Description	Format
Land use is characterised by the arrangements, activities and inputs that people undertake in a certain land cover type to produce, change or maintain it.  Information on land use in the aquifer area is a key element to understanding the processes and context affecting the aquifer, e.g. to identify the locations of land use with the potential to pollute groundwater. Another example is to know which part of agricultural land is rainwater-fed, or irrigated with groundwater, or irrigated with surface water.  Usually land use maps are based on specific classifications at national level. As much as possible this classification should be standardised between aquifer states, in order to produce a harmonised map for the transboundary aquifer. If applicable and if sufficient information is available, make a differentiation in the maps for the following land uses:	Text: Describing land use including topics such as water needs, potential threats to (ground) water etc. Map: polygon features
	<b>Unit</b>
	[-]
	<b>Priority for data collection</b>
	3 (general characterisation)
	<b>Available global datasets</b>
	ESA, Globcover V2 (2009) EC/JRC, GLC 2000 (2000)
<ul style="list-style-type: none"> <li>Groundwater-fed agricultural land, differentiating between non-irrigated (rainwater-fed or groundwater-fed) and irrigated (irrigated by groundwater or irrigated by surface water);</li> <li>Groundwater-supported wetlands and ecosystems;</li> <li>Areas with land subsidence.</li> </ul>	
Sub-questions / metainformation	Format
If harmonisation between countries has led to new or different classifications, provide an overview ('translation key') describing how national classifications match the harmonised transboundary classification.	Text

A.5. Topography and elevation	
Description	Format
A suitable topographical map is needed which can be used as a background map to present thematic maps.  In addition it is useful to have a map of the elevation of the land surface with respect to mean sea level. The map is preferably be available as a digital elevation model for the whole aquifer area and its vicinities.  The interval between the curves needs to be agreed upon by all the aquifer states and to take into consideration the different geographical features.	Map: raster
	<b>Unit</b>
	[m] above mean sea level
	<b>Priority for data collection</b>
	2 (used in 10 additional indicators)
	<b>Available global datasets</b>
	EAPRS Lab, ACE2 v31 (2009) SRTM, CGIAR
Sub-questions / metainformation	Format

A.6. Surface water network	
Description	Format
Network of rivers, lakes, swamps and water reservoirs present in the aquifer's area. Often this data is available at national level.	Map: line and polygon features
	<b>Unit</b>
	[-]
	<b>Priority for data collection</b>
	3 (general characterisation)
	<b>Available global datasets</b>
	[-]
Sub-questions / metainformation	Format

## B – AQUIFER GEOMETRY

B.1. Hydrogeological map	
Description	Format
<p>The <b>hydrogeological map</b> brings basic geological information together with data on hydraulic and hydrochemical characteristics of the rocks and their usefulness for groundwater supply.<sup>[1]</sup></p> <p>Geological and hydrogeological maps are most often produced by national institutions, such as geological surveys. Therefore, ideally harmonisation should be achieved between the aquifer states.</p> <p><sup>[1]</sup> British Geological Survey (BGS), Hydrogeological maps, available at: <a href="http://www.bgs.ac.uk/research/groundwater/datainfo/hydromaps/home.html">http://www.bgs.ac.uk/research/groundwater/datainfo/hydromaps/home.html</a> [accessed in May 2014].</p>	Map: line and polygon features
	Unit
	[-]
	Priority for data collection
	3 General characterisation
Sub-questions / metainformation	Available global datasets
	[-]
Sub-questions / metainformation	Format
If harmonisation between countries has led to new or different classifications, provide an overview ('translation key') describing how national classifications match the harmonised transboundary classification.	Text

B.2. Geo-referenced boundary of Transboundary Aquifer / aquifer system	
Description	Format
<p>Polygon depicting outline of the whole aquifer, possibly including the delineation of each aquifer unit, or national aquifers.</p> <p><b>Please note:</b> this may be considerably different from the delineation of the outcrop of the aquifer. The map should consider the full horizontal extent of the hydrogeological formation.</p> <p>For <b>aquifer systems</b> make map layers that depict the delineation of the individual aquifers in the aquifer system. If this is not possible depict the complete aquifer system as if it were one single unit.</p>	Map: polygon feature
	Unit
	[-]
	Priority for data collection
	1 (used in 10 core indicators)
Sub-questions / metainformation	Available global datasets
	[-]
Sub-questions / metainformation	Format
B.2.1. What type of information is the delineation based on?	Text – describing how the aquifer was delineated
Based on no-flow boundaries	
Based on lithology / geology	
Based on groundwater quality	
Based on topography	
Based on administrative boundary	
B.2.2. Is the aquifer a single layer aquifer or are you describing an aquifer system consisting of two or more aquifers (layers) that are hydraulically connected?	Text – amount of aquifers in aquifer system and description of their hydraulic connectivity and distribution

B.3. Depth of water table / piezometric surface and groundwater flow direction	
Description	Format
<p>Distance from ground surface to groundwater table or piezometric level. If enough data are available it may be useful to visualise this information in two different ways:</p> <ul style="list-style-type: none"> <li>Depth of groundwater table (distance from ground surface to groundwater table), and</li> <li>Groundwater table / piezometric level in meters above sea level.</li> </ul> <p><b>Please note:</b> If applicable and if sufficient data are available, create maps for each aquifer / layer.</p>	Map: raster format or isolines
	Unit
	[m]
	Priority for data collection
	2 (used in 10 additional indicators)
Sub-questions / metainformation	Available global datasets
	[-]



Map indicating main directions of groundwater flow. This map can be constructed based on a map of groundwater levels [m above mean sea level], or it can be based on general knowledge.	Map: line features indicating flow direction
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B.4. Depth to top of aquifer formation [m]	
Description	Format
<p>Distance from ground level to the top of the aquifer formation. In unconfined aquifers this is zero (0) meters.</p> <p><b>Please note:</b> if applicable and if sufficient data are available, create one map for each aquifer / layer.</p>	Map: raster format or isolines (shape-file)
	<b>Unit</b>
	[m]
	<b>Priority for data collection</b>
	2 (used in 10 additional indicators)
<b>Sub-questions / metainformation</b>	<b>Available global datasets</b>
	[-]

B.5. Vertical thickness of the aquifer (system) including aquitards / aquicludes	
Description	Format
<p>The vertical thickness of the aquifer (system) is the distance between the top and the bottom of the aquifer (system) formation.</p> <p>Please note: for aquifer systems maps should be provided for each aquifer layer and each aquitard / aquiclude.</p>	Map: raster format or isolines
	<b>Unit</b>
	[m]
	<b>Priority for data collection</b>
	2 (used in 10 additional indicators)
<b>Sub-questions / metainformation</b>	<b>Available global datasets</b>
	[-]

B.6. Degree of confinement	
Description	Format
<p>Indicate for each aquifer the degree of confinement:</p> <ul style="list-style-type: none"> <li>• Whole aquifer unconfined</li> <li>• Whole aquifer confined</li> <li>• Whole aquifer semi-confined</li> <li>• Aquifer mostly unconfined but some parts confined</li> <li>• Aquifer mostly confined but some parts unconfined</li> <li>• Aquifer mostly semi-confined but some parts unconfined</li> </ul> <p>Preferably which part of (each) aquifer is unconfined, confined or semi-confined needs to be clearly indicated on a map.</p>	Text
	Map: raster format or polygons
	<b>Unit</b>
	[-]
	<b>Priority for data collection</b>
<b>Sub-questions / metainformation</b>	2 (used in 10 additional indicators)
	<b>Available global datasets</b>
	[-]

B.7. Representative cross sections	
Description	Format
Cross sections are powerful tools to visualise sub-surface structures and	Format: high resolution

<p>conceptual models of aquifers. Therefore please provide one (or more) representative schematised hydrogeological cross section.</p> <p>The cross section should include features such as:</p> <ol style="list-style-type: none"> <li>1. Main aquifer formation/layers</li> <li>2. For aquifer systems: also clearly depict aquitards/ aquicludes</li> <li>3. General direction of groundwater flow</li> <li>4. Main geological features, such as faults</li> <li>5. Location of country borders</li> <li>6. Indicate relevant hydrological features such as: <ul style="list-style-type: none"> <li>• recharge zones,</li> <li>• discharge zones,</li> <li>• zones of major groundwater abstractions and/or</li> <li>• zones of groundwater pollution.</li> </ul> </li> <li>7. In the legend: give the name of each aquifer layer, including the lithological classification and predominant type of porosity zones with natural salinity, arsenic and/or fluoride.</li> </ol>	graphical files in one of the following formats: tiff, jpg, pdf, Microsoft Publisher, PowerPoint, Word
	<b>Unit</b>
	[-]
	<b>Priority for data collection</b>
	3 (general characterisation)
	<b>Available global datasets</b>
	[-]
<b>Sub-questions / metainformation</b>	

## C – HYDROGEOLOGICAL CHARACTERISTICS

<b>C.1. Aquifer recharge</b>	
<b>Description</b>	<b>Format</b>
<p>Recharge is the replenishment of groundwater. Total recharge can be split into several categories:</p> <ul style="list-style-type: none"> <li>• Natural recharge</li> <li>• Return flows from irrigation</li> <li>• Managed aquifer recharge</li> <li>• Induced recharge (= recharge to an aquifer that occurs when a pumping well creates a cone of depression that lowers an adjacent water table below the level of a stream or lake, causing the stream or lake to lose water to the adjacent groundwater aquifer. Source: <a href="http://www.groundwater.org">www.groundwater.org</a>)</li> </ul> <p>Depending on data availability, as much as possible information on the above should be collected and described, preferably in map format and tables.</p> <p>Map information: zones where significant natural recharge occurs; locations where return flows, managed aquifer recharge or induced recharge occurs. If possible the maps should also indicate the distribution of the recharge values.</p> <p>Please note: for aquifer systems, if relevant, provide different maps for different aquifers (layers) of the aquifer system.</p>	<p>Depending on data availability:</p> <p>Map: polygon recharge zones</p> <p>Map: raster format or isolines of recharge values</p> <p>Tables: recharge values per year and/or per category</p>
	<b>Unit</b>
	[m <sup>3</sup> /yr] or [km <sup>3</sup> /yr]
	<b>Priority for data collection</b>
	1 (used in 10 core indicators)
	<b>Available global datasets</b>
	[-]
<b>Sub-questions / metainformation</b>	
<p><b>Time variability:</b></p> <p>Is there significant difference between years in terms of volume and frequency of recharge? If so, describe this variability:</p> <ul style="list-style-type: none"> <li>• Time interval between extreme events [years]</li> <li>• Average recharge rate for years with extreme events [m<sup>3</sup>/yr]</li> <li>• Average recharge rate for years without extreme events [m<sup>3</sup>/yr]</li> </ul>	Text
Areal extent of area(s) with significant recharge [km <sup>2</sup> ]	Text
What percentage of total groundwater recharge is natural recharge? [%]	Text
<p>Specify which type(s) of recharge occur. Indicate the most predominant source of recharge. If possible try to indicate how much these sources contribute to total recharge [%]. Choose from the categories listed below:</p> <ol style="list-style-type: none"> <li>1. Precipitation on aquifer area</li> <li>2. Runoff into aquifer area</li> <li>3. Infiltration from surface water body</li> <li>4. Recharge from glaciers</li> </ol>	Text



5. Human-induced recharge	
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C.2. Aquifer lithology		
Description		Format
Describe each aquifer in terms of lithology. First characterise the aquifer by choosing the most prominent lithology class from the list below:		Text describing lithology, including lateral and vertical variations
<div><div><div><input type="radio"/> Sediment - Sand</div><div><input type="radio"/> Sediment - Gravel</div><div><input type="radio"/> Sediment - Silt - Clay</div></div><div><div><input type="radio"/> Sedimentary rocks - Shale</div><div><input type="radio"/> Sedimentary rocks - Sandstone</div><div><input type="radio"/> Sedimentary rocks - Limestone</div><div><input type="radio"/> Sedimentary rocks - Dolostone</div><div><input type="radio"/> Sedimentary rocks - Evaporite</div></div><div><div><input type="radio"/> Crystalline rocks - Granite</div><div><input type="radio"/> Crystalline rocks - Basalt</div><div><input type="radio"/> Metamorphic rocks</div></div></div>		<div>Unit</div> <div>[-]</div> <div>Priority for data collection</div> <div>3 (general characterisation)</div> <div>Available global datasets</div> <div>[-]</div>
Next describe the heterogeneity of the aquifer (lateral and vertical variation in lithology).		
For aquifer systems describe the lithology of each aquifer and aquitard.		
Sub-questions / metainformation		

C.3. Soil types	
Description	Format
<p>Soil media refers to the uppermost portion of the vadose zone characterised by significant biological activity. Soil is considered the upper weathered zone of the earth. The type of soil has a big impact on the amount of recharge that can infiltrate and therefore on the ability of pollutants to reach the water table <sup>[1]</sup>. Classify the soils present in the aquifer area based on the following classification<sup>[1]</sup>:</p> <ol style="list-style-type: none"> <li>1. Confining layer</li> <li>2. Silt/clay</li> <li>3. Shale</li> <li>4. Limestone</li> <li>5. Sandstone</li> <li>6. Bedded limestone, sandstone, shale</li> <li>7. Sand and gravel with significant silt and clay</li> <li>8. Metamorphic/igneous</li> <li>9. Sand and gravel</li> <li>10. Basalt</li> <li>11. Karst limestone</li> </ol> <p><sup>[1]</sup> Aller, L. et al. (1987) DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeologic settings. United States of America Environmental Protection Agency, EPA/600/2-87/035.</p>	<p>Map: polygon features</p>
	<b>Unit</b>
	[-]
	<b>Priority for data collection</b>
	2 (used in 10 additional indicators)
	<b>Available global datasets</b>
	[-]
Sub-questions / metainformation	

C.4. Porosity	
Description	Format
Describe the porosity for each aquifer, according to the list below:	Text
	<b>Unit</b>
	[-]
	<b>Priority for data collection</b>
	2 (used in 10 additional indicators)
	<b>Available global datasets</b>

Primary Porosity [only one answer possible]	Secondary Porosity [only one answer possible]	Connectivity [only one answer possible]	[-]
<input type="radio"/> 1.1. High primary porosity fine/medium sedimentary deposits <input type="radio"/> 1.2. Very high primary porosity gravels/pebbles <input type="radio"/> 1.3. Low primary porosity intergranular porosity	<input type="radio"/> 2.1. Secondary porosity: Dissolution <input type="radio"/> 2.2. Secondary porosity: Weathering <input type="radio"/> 2.3. Secondary porosity: Fractures <input type="radio"/> 2.4. No secondary porosity	<input type="radio"/> 3.1. High horizontal connectivity <input type="radio"/> 3.2. Low horizontal connectivity	
<b>Definitions:</b> <i>Voids</i> (interstices) are defined as open spaces within subsurface unconsolidated sediments and rock formations, allowing fluids to flow or be stored underground <sup>[1]</sup> . <i>Primary porosity</i> : porosity formed during the deposition of the sediment or from vesicles in igneous rocks. <i>Secondary porosity</i> : porosity formed by either dissolution or fracturing after lithification of the rock. <i>Connectivity</i> : interconnected porosity that contributes to groundwater flow. <sup>[1]</sup> J. Margat and J. van den Gun, 2013. Groundwater around the World. A Geographic Synopsis. CRC Press/Balkema, Leiden, The Netherlands.			
<b>Sub-questions / metainformation</b>			

C.5. Transmissivity and vertical connectivity	
Description	Format
Describe for each aquifer the transmissivity [m <sup>2</sup> /day] and/or conductivity [m/d] in terms of average, minimum and maximum and its spatial distribution. If sufficient data are available provide a map of the spatial distribution	Text: if sufficient data Map: raster format or isolines
<b>Definition:</b> transmissivity is the rate at which water is transferred through a unit width of an aquifer under a unit hydraulic gradient <sup>[1]</sup> . Hydraulic conductivity is the capacity of the porous media to transmit water <sup>[2]</sup> <sup>[1]</sup> World Meteorological Organization (WMO) and UNESCO International Hydrological Programme (IHP), 2012. International Glossary of Hydrology. WMO, Geneva, Switzerland. <sup>[2]</sup> J. Margat and J. van den Gun, 2013. Groundwater around the World. A Geographic Synopsis. CRC Press/Balkema, Leiden, The Netherlands.	Unit
	[m <sup>2</sup> /d] or [m/d]
	Priority for data collection
	2 (used in 10 additional indicators)
<b>Sub-questions / metainformation</b>	Available global datasets
	[-]
For aquifer systems also describe the vertical connectivity between the aquifers (layers) and if sufficient data are available also describe the spatial distribution of the vertical connectivity. It can be qualified in terms such as low, medium or high connectivity. Vertical connectivity can also be expressed as vertical resistance [days].	<b>Text:</b> if sufficient data. <b>Map:</b> raster format or isolines

C.6. Total groundwater volume	
Description	Format
Estimate the total volume of water in each aquifer. If sufficient data are available (and if applicable) try to differentiate between water suitable for human consumption and water of inferior quality (see also under parameter C.2).	<b>Text</b> <b>Unit</b> [m <sup>3</sup> ] or [km <sup>3</sup> ] <b>Priority for data collection</b> 2 (used in 10 additional indicators)

	<b>Available global datasets</b>
	[-]
<b>Sub-questions / metainformation</b>	

<b>C.7. Groundwater depletion</b>	
<b>Description</b>	<b>Format</b>
For each aquifer estimate or calculate groundwater depletion. <b>Definition:</b> Groundwater depletion is the reduction of the stored volume of groundwater in an aquifer. It is a quantity aggregated over the entire aquifer system. In this case the estimated groundwater depletion will be representative of current conditions and related to a relatively long period (for example, the period 2000-2010). It is expressed in m <sup>3</sup> /yr. (Note that in some cases the 'depletion' may be negative, i.e. accretion or increase of the stored volume). The decrease in groundwater volume in the aquifer is estimated either based on groundwater level observations (taking into account the locally valid storage coefficient) or by using a groundwater simulation model. Please note that groundwater depletion is distinctly different from the cone of depression around a pumping well.	<b>Text:</b> based on tabular information <b>Maps:</b> raster format or isolines <b>Unit</b> [m <sup>3</sup> /yr] or [km <sup>3</sup> /yr] <b>Priority for data collection</b> 1 (used in 10 core indicators) <b>Available global datasets</b> [-]
<b>Sub-questions / metainformation</b>	

<b>C.8. Natural discharge mechanisms</b>	
<b>Description</b>	<b>Format</b>
Describe the discharge mechanisms for each aquifer using general terms, by indicating the most predominant discharge type or by trying to quantify each type [m <sup>3</sup> /yr] or [%]. Natural discharge mechanisms can be: 1. Springs 2. River baseflow 3. Outflow into lakes 4. Submarine outflow 5. Evapotranspiration 6. Groundwater flow into another aquifer	<b>Text</b> <b>Unit</b> [-] or [%] or [m <sup>3</sup> /yr] <b>Priority for data collection</b> 2 (used in 10 additional indicators) <b>Available global datasets</b> [-]
<b>Sub-questions / metainformation</b>	

<b>C.9. Discharge by springs</b>	
<b>Description</b>	<b>Format</b>
Try to quantify the total discharge of all springs originating from the aquifer / aquifer system. Depicting the (major) springs (including annual discharge per spring) in a map can be very useful. <b>Definition:</b> a spring is considered to be any place in the aquifer area where water emerges naturally from rock or soil onto land, or into surface water, i.e. artesian springs, fault springs, joint springs, mineral springs or thermal springs <sup>[1]</sup> .	<b>Text</b> Optional: map with locations of springs and (estimated) discharge per spring. <b>Unit</b> [m <sup>3</sup> /yr] or [km <sup>3</sup> /yr]



<sup>[1]</sup> World Meteorological Organization (WMO) and UNESCO International Hydrological Programme (IHP), 2012. International Glossary of Hydrology. WMO, Geneva, Switzerland."	Priority for data collection
	2 (used in 10 additional indicators)
	Available global datasets
	[-]
Sub-questions / metainformation	

## D – ENVIRONMENTAL ASPECTS

D.1. Groundwater quality / suitability for human consumption	
Description	Format
In many aquifers not all groundwater is suitable for human consumption, for example, because of high salinity, high arsenic or fluoride concentrations. Try to quantify to what extent the groundwater in each aquifer is NOT suitable for human consumption due to natural reasons. In many cases it is difficult to quantify this exactly, but it is possible to indicate by approximation the areas of the aquifer where groundwater is found of which the natural quality does NOT satisfy local drinking water standards. This means: indicate parts of the aquifer with, for example, high natural arsenic or fluoride concentrations or high natural salinity. Based on this, map estimates can be made of the percentage or volume of the aquifer that is not suitable for human consumption. This includes situations where human activities have mobilised elements that were already naturally present in the aquifer.	Text and maps (polygon or raster)
	Unit
	[-]
	Priority for data collection
	1 (used in 10 core indicators)
	Available global datasets
	[-]
Sub-questions / metainformation	
Indicate to what depth natural groundwater quality does NOT satisfy local drinking water standards: 1. Only superficial layers 2. Significant part of the aquifer 3. The whole thickness of the aquifer	
Indicate which are the main pollutants of natural origin affecting natural groundwater quality and provide a map if possible: <ul style="list-style-type: none"> <li>Natural salinity</li> <li>Fluoride</li> <li>Arsenic</li> <li>Others, please specify</li> </ul>	Text and maps (polygon features indicating occurrence)
Notes on harmonisation between countries	
Countries sharing a transboundary aquifer may have different standards with regards to 'suitability for human consumption'. Ideally the countries have to agree on the same standard.	

D.2. Groundwater pollution	
Description	Format
Try to quantify to what extent the groundwater in each aquifer is affected by pollution resulting from human activity. In many cases it is difficult to quantify pollution exactly, but it is possible to indicate by approximation the areas of the aquifer where pollution occurs. Based on this map estimates can be made of the percentage or volume of the aquifer that is or may be affected by pollution. <b>Definition:</b> pollution is considered to be any aspect of water quality (chemical, biological, thermal) which is caused by people and which interferes with the intended use of the groundwater. Here we assess pollution by defining the zones	Text and maps (polygon indicating major pollution sites / polluted zones)
	Unit
	[-]
	Priority for data collection
	1 (used in 10 core indicators)
	Available global datasets

with groundwater pollution in the aquifer area. This can be zones with pollution from point sources (e.g. industrial spills) or zones, which suffer from diffuse pollution (for example, from agriculture practices).	[-]
<b>Sub-questions / metainformation</b>	
Indicate to what depth groundwater is affected by pollution: 1. Only superficial layers 2. Significant part of the aquifer 3. The whole thickness of the aquifer	
Indicate the most important sources of groundwater pollution in the aquifer: 1. Landfills / waste disposal sites 2. Households 3. Municipalities 4. Industrial waste disposal 5. Military sites 6. Agricultural practices (irrigation, pesticides, fertilizers) 7. Mining activities 8. Oil/gas production and / or transport activities 9. Leakage through boreholes 10. Other, specify:	
Indicate the most important pollutants affecting aquifer's groundwater quality: 1. Salinization 2. Nitrogen species 3. Hydrocarbons 4. Pathogenic agents 5. Pesticides 6. Heavy metals 7. Industrial organic components 8. Thermal pollution 9. Other, specify:	

<b>D.3. Solid waste and wastewater control</b>	
<b>Description</b>	<b>Format</b>
Give an insight into: <ul style="list-style-type: none"> <li>The amount of wastewater being collected in sewerage systems</li> <li>Wastewater being treated in treatment plants before being discharged and location of treatment plants</li> <li>Solid waste being stored in controlled landfills and location of controlled landfills.</li> </ul> Depending on the availability this can be presented as percentages or just as a number: for example, the amount of wastewater collected in sewage systems as	Text, table and maps (point features)
	<b>Unit</b>
	[depending on available data]
	<b>Priority for data collection</b>
	3 (general characterisation)
	<b>Available global datasets</b>

<p>a percentage of total wastewater, or the number of households connected to sewage systems as a percentage of the total number of households. When this level of detail is not feasible it could be presented per municipality if there is a sewage system [yes/no]. Alternatively indicate the amount of sewage treatment plants and landfills.</p> <p><b>Definitions:</b></p> <p><b>Sewage or wastewater</b> is the water output of a community after it has been fouled by various uses <sup>[1]</sup></p> <p><b>Wastewater treatment plant:</b> a plant where, through physical-chemical and biological processes, organic matter, bacteria, viruses and solids are removed from residential, commercial and industrial wastewaters before they are discharged into rivers, lakes and seas <sup>[2]</sup></p> <p><b>Solid waste:</b> discarded solid materials. Includes agricultural waste, mining waste, industrial waste and municipal waste <sup>[3]</sup></p> <p><sup>[1]</sup> World Meteorological Organization (WMO) and UNESCO International Hydrological Programme (IHP), 2012. International Glossary of Hydrology. WMO, Geneva, Switzerland.</p> <p><sup>[2]</sup> European Environment Information and Observation Network (EIONET). GEMET Thesaurus. Available at: <a href="http://www.eionet.europa.eu/gemet/concept/9144">http://www.eionet.europa.eu/gemet/concept/9144</a> [Accessed in May 2014].</p> <p><sup>[3]</sup> European Environment Agency (EEA). The EEA Glossary. Available at: <a href="http://glossary.eea.europa.eu/">http://glossary.eea.europa.eu/</a> [Accessed in May 2014].</p>	<p>WHO/UNICEF, JMP (1990, 1995, 2000, 2005, 2010)</p> <p>AQUASTAT</p>
<b>Sub-questions / metainformation</b>	

<b>D.4. Shallow groundwater table and groundwater-dependent ecosystems</b>	
<b>Description</b>	<b>Format</b>
<p>Shallow groundwater tables can be related to the occurrence of groundwater-dependent ecosystems. Areas with shallow groundwater tables can also be more vulnerable to pollution of the aquifer.</p> <p>Therefore it is useful to indicate the extent of the aquifer where the depth to the groundwater table is less than 5 m below the soil surface. This can be based on the map of groundwater levels (see A.2).</p>	Text or map (preferably)
	<b>Unit</b>
	[-]
	<b>Priority for data collection</b>
	2 (used in 10 additional indicators)
	<b>Available global datasets</b>
	[-]
<b>Sub-questions / metainformation</b>	
Describe the occurrence of groundwater dependent ecosystems. Describe where these ecosystems occur.	Text or map (preferably)

## E - SOCIO-ECONOMIC ASPECTS

<b>E.1. Population density and total population per municipality</b>	
<b>Description</b>	<b>Format</b>
<p>Density of population is the amount of people living in the aquifer area per km<sup>2</sup>. It is foreseen that in most cases population data is linked to administrative units that most likely does not coincide with the exact areal extent of the aquifer.</p> <p>Alternative sources of information can be available as global datasets, such as the global density population estimates provided by the Socioeconomic Data and Applications Centre (SEDAC) hosted by CIESIN at Columbia University (<a href="http://sedac.ciesin.columbia.edu/">http://sedac.ciesin.columbia.edu/</a>).</p>	Map (raster and/or polygon feature)
	<b>Unit</b>
	[Inhabitants/km <sup>2</sup> ] or [Inhabitants]
	<b>Priority for data collection</b>
	1 (used in 10 core indicators)
	<b>Available global datasets</b>



	CIESIN, GRUMP (2010) IIASA, POP (2000-2010)
<b>Sub-questions / metainformation</b>	
Give the percentage of female and male population from the total population in the aquifer's area	%
Give the percentage of rural and urban population in the aquifer's area	%
What is the population annual growth rate?	[Inhabitant/yr]
It is possible that people outside the aquifer area are dependent on the (ground) water resources in the aquifer area. If that is the case, please specify/describe.	

<b>E.2. Groundwater use **</b>	
<b>Description</b>	<b>Format</b>
<p>Provide a complete overview of groundwater being abstracted from the aquifer through boreholes and wells, including a breakdown of total volume per water type (fresh, brackish and saline) and per type of water use. See example table below.</p> <p><u>Water type</u><sup>[1]</sup></p> <p><b>Freshwater:</b> water with less than 1 000 mg/l dissolved solids.</p> <p><b>Brackish water:</b> water containing dissolved solids in a concentration between 1 000 and 10 000 milligram per litre.</p> <p><b>Saline water:</b> water containing dissolved solids in concentrations of more than 10 000 milligram per litre.</p> <p><u>Water use</u> (types of water use to be distinguished):</p> <ol style="list-style-type: none"> <li><b>Domestic water use:</b> <ol style="list-style-type: none"> <li>From private wells/boreholes</li> <li>Public water supply from groundwater</li> </ol> </li> <li><b>Agricultural / livestock watering:</b> <ol style="list-style-type: none"> <li>Irrigation</li> <li>Livestock</li> <li>Aquaculture</li> </ol> </li> <li><b>Commercial and industrial water use:</b> <ol style="list-style-type: none"> <li>Mining</li> <li>Industry</li> <li>Energy production</li> <li>Tourism sector (e.g. recreational use)</li> <li>Bottled water, production of soft drinks, breweries.</li> <li>Etc.</li> </ol> </li> <li><b>Environmental use</b> (e.g. protection of groundwater-dependent ecosystems, providing water for wildlife)</li> </ol> <p>Depending on how much information is available the information should be organised in tables indicating abstraction volumes per year, per type of water use and per water type (see example below).</p> <p><u>Level of detail:</u> Abstraction data may be available for administrative units (e.g. municipalities) rather than per well. Therefore, if data is available at municipality level, please provide a map showing values of total groundwater abstraction per local administrative unit (e.g. municipality) and type of use.</p> <p><sup>[1]</sup> J. Margat and J. van den Gun, 2013. Groundwater around the World. A Geographic Synopsis. CRC Press/Balkema, Leiden, The Netherlands.</p>	<p>Text</p> <p>Tables: see example below</p> <p>Maps: point data of (major) abstractions, category and yearly volume and polygon features</p>
	<b>Unit</b>
	[m <sup>3</sup> /yr] or [km <sup>3</sup> /yr]
	<b>Priority for data collection</b>
	1 (used in 10 core indicators) and 2 (used in 10 additional indicators)
	<b>Available global datasets</b>
	FAO, AQUASTAT
<b>Sub-questions / metainformation</b>	

\*\*Example table - overview of water use

**This is a table that could be used to collect data for E2 – Groundwater use.** It is recommended to maintain the main categories of water use (domestic, agricultural/livestock, commercial and environmental). The subcategories can be modified according to aquifer-specific uses.

	Volume of groundwater abstraction [m <sup>3</sup> /yr] or [km <sup>3</sup> /yr]				Volume of surface water use [m <sup>3</sup> /yr] or [km <sup>3</sup> /yr]				Volume of ground and surface water use
	Fresh	Brackish	Saline	Total	Fresh	Brackish	Saline	Total	Total water use
<b>1) Domestic water</b>									
a) Public water supply									
b) Private									
<b>2) Agricultural / livestock</b>									
a) Irrigation									
b) Livestock									
c) Aquaculture									
<b>3) Commercial and industrial water</b>									
a) Mining									
b) Industry									
c) Energy production									
d) Tourism (e.g. recreational)									
e) Bottled water, production of soft drinks, breweries.									
<b>4) Environmental</b>									
<b>Total water use per water type</b>									

E.3. Surface water use	
Description	Format
<p>It is very useful to know how dependent a population is on groundwater. For this purpose the use of groundwater can be compared to the total water use / use of surface water.</p> <p>Provide information in table format on surface water use, using the same categories of water type and water use as for groundwater use. See E.2 above for classifications and further description.</p>	Text
	Tables
	Maps: point data of (major) abstractions, category and yearly volume and polygon features
	<b>Unit</b>
	[m <sup>3</sup> /yr] or [km <sup>3</sup> /yr]
	<b>Priority for data collection</b>
	1 (used in 10 core indicators) and 2 (used in 10 additional indicators)
	<b>Available global datasets</b>
	FAO, AQUASTAT
Sub-questions / metainformation	

E.4. Dependence of industry and agriculture on groundwater	
Description	Format
<p>Percentage of the industry and agriculture depending on groundwater supply.</p> <p>Sections E.2 and E.3 provide information of the ratio between groundwater use and surface water use.</p> <p>To complete the picture of information it is necessary to describe which proportion of industry (or agriculture) is not dependent on surface or groundwater.</p> <p>This parameter can be expressed in the number of industries / businesses or in terms of contribution to GDP (\$).</p>	Text , table and diagram/chart
	<b>Unit</b>
	[-]
	<b>Priority for data collection</b>
	3 (general characterisation)
	<b>Available global datasets</b>
	[-]
Sub-questions / metainformation	

E.5. Percentage of population covered by public water supply	
Description	Format
<p>Percentage of total population in the aquifer area covered by public water supply.</p> <p>Water supply data may be linked to administrative units. In this case data can be shown as the percentage of population covered by public water supply per local administrative unit (e.g. municipality).</p> <p><b>Definition:</b></p> <p><b>Public water supply</b> refers to water withdrawn by public and private water suppliers and delivered to users. Public water suppliers may provide water to domestic, commercial, and industrial users, to facilities generating thermoelectric power, for public use, and occasionally for mining and irrigation<sup>[1]</sup></p> <p><sup>[1]</sup> W. E. Templin, R. A. Herbert, C. B. Stainaker, M. Horn, and W. B. Solley. Water Use. In USGS, National Handbook of Recommended Methods for Water Data Acquisition. Available at: <a href="http://pubs.usgs.gov/chapter11/chapter11C.html">http://pubs.usgs.gov/chapter11/chapter11C.html</a> [Accessed in May 2014].</p>	Text, table and map: polygon features
	<b>Unit</b>
	%
	<b>Priority for data collection</b>
	3 (general characterisation)
	<b>Available global datasets</b>
	[-]
Sub-questions / metainformation	

E.6. Percentage of population covered by sanitation	
Description	Format



<p>Percentage of total population in aquifer area with access to sanitation.</p> <p>Sanitation data may be linked to administrative units. In this case data can be shown as the percentage of population covered by public water supply per local administrative unit (e.g. municipality).</p> <p><b>Definitions:</b></p> <p><b>Sanitation</b> generally refers to the provision of facilities and services for the safe disposal of human urine and faeces. Inadequate sanitation is a major cause of disease worldwide and improving sanitation is known to have a significant beneficial impact on health both in households and across communities. The word 'sanitation' also refers to the maintenance of hygienic conditions, through services such as rubbish collection and wastewater disposal <sup>[1]</sup>.</p> <p><sup>[1]</sup> World Health Organization. Health topics, Sanitation. Available at: <a href="http://www.who.int/topics/sanitation/en/">http://www.who.int/topics/sanitation/en/</a> [Accessed in May 2014]</p>	Text, table and map: polygon features
	<b>Unit</b>
	%
	<b>Priority for data collection</b>
	3 (general characterisation)
	<b>Available global datasets</b>
<b>Sub-questions / metainformation</b>	[-]

## F – LEGAL AND INSTITUTIONAL ASPECTS

### F.1 TRANSBOUNDARY LEGAL AND INSTITUTIONAL FRAMEWORK

1. Is there an agreement/treaty/MOU or other legal instrument in effect between your country and the neighbouring countries and which is specific to the aquifer<sup>1</sup>?

YES/NO

If the answer is **YES**, does the agreement/treaty/MOU provide for:

3. Rules of engagement for the utilization of the aquifer waters?  
YES/NO
4. Rules of engagement for the protection of the aquifer waters from pollution or other kinds of threats?  
YES/NO
5. Institutional arrangements (commission, committee, other)?  
YES/NO
6. Rules for the settlement of disagreements?  
YES/NO

If the answer is **NO**, is there an agreement/treaty/MOU or other binding or non-binding instrument signed by your country (e.g. a global, regional or bi- or multi-lateral instrument<sup>2</sup>) which provides:

7. Principles for the utilization of shared water resources?  
YES/NO
8. Principles for the protection of shared water resources from pollution or other threats?  
YES/NO
9. Principles for cooperation on shared water resources, including institutional arrangements ?  
YES/NO
10. Principles for the settlement of disputes in relation to shared water resources?  
YES/NO

### F.2 DOMESTIC LEGAL AND INSTITUTIONAL FRAMEWORK

11. Is there legislation on the statute books covering freshwater resources (e.g. Water Resources Act, Natural Resources Act, Environment Act, Water Services Act, Local Government Act, Mining Act, Town & Country Planning Act, relevant regulations under these acts, civil code, or municipal by-laws) of specific relevance to the project area? YES/NO

<sup>1</sup> List and attach copy of the agreement or treaty or MOU analyzed

<sup>2</sup> Ditto

12. Does the legislation analysed apply to groundwater?  
YES/NO
13. Are there official policy documents that complement/substantiate the legislation on the statute books?  
YES/NO  
(If the answer is **YES** please indicate relevant instrument)

#### F.2.1. Ownership of groundwater (If the answer to Question 10 is YES)

14. Do landowners own groundwater under their land?  
YES/NO
15. Does the legislation provide that groundwater is public property (or held by the State in trust for the public)?  
YES/NO

#### F.2.2. Water resources planning

16. Does the legislation provide for/mandate the preparation of water resources plans, at what level (master plan, catchment plans)?  
YES/NO
17. If the answer is **YES**, have the plans mandated by the legislation actually been prepared and formally adopted, and when?  
YES/NO

#### F.2.3. Groundwater resources abstraction and use

18. Is water abstraction/use subject to licensing?  
YES/NO
19. Are there exceptions to licensing requirements (e.g. minor uses)?  
YES/NO
20. Are abstraction licences subject to a term of duration?  
YES/NO
21. Are abstraction licences subject to payment of charges?  
YES/NO
22. Is the drilling of wells subject to a permit?  
YES/NO
23. Can licences/permits be reviewed and amended by the Government?  
YES/NO
24. Can licences/permits be suspended or terminated (and under what circumstances)?  
YES/NO
25. Can water abstraction permits be traded (i.e. bought/sold for a price)?  
YES/NO
26. Is an EIA required for proposed well drilling/water abstraction projects?  
YES/NO
27. Are groundwater users obliged to monitor/report extractions/groundwater levels?  
YES/NO
28. Is illegal well drilling/water abstraction sanctioned, and if so with what penalties?  
YES/NO

#### F.2.4. Abatement and control of groundwater pollution

29. Is the discharge of waste/water into water bodies, on or under the ground, subject to a permit?  
YES/NO

30. Are permits subject to a term of duration?  
YES/NO
31. Are standards of effluent quality provided for/in effect?  
YES/NO
32. Are ambient water quality standards for receiving waters provided for/in effect?  
YES/NO
33. Are wastewater discharge permits subject to payment of charges?  
YES/NO
34. Can permits be reviewed and amended by the Government?  
YES/NO
35. Can permits be suspended or terminated (under what circumstances)?  
YES/NO
36. Is an EIA required for proposed waste/water discharge projects?  
YES/NO
37. Is monitoring/reporting of groundwater quality the obligation of dischargers?  
YES/NO
38. Is contamination from closed/disused wells regulated, and if so how?  
YES/NO
39. Is the use/control/disposal of hazardous substances regulated, and if so how?  
YES/NO
40. Is illegal discharging of waste/water sanctioned, and if so with what penalties?  
YES/NO

#### F.2.5. Other water resources protection measures

41. Does the legislation regulate land cultivation practices that can result in pollution of groundwater?  
YES/NO
42. Does the legislation require that the impact of urban and rural land development projects on water resources be taken into account in the context of land development permit procedures?  
YES/NO

#### F.2.6. Government and non-government (including informal) water institutions

43. Is there a government institution at national/central level responsible for the administration of the legislation analyzed?  
YES/NO
  44. Is there a government institution at intermediate (i.e. provincial, river basin, other) level responsible for the administration of the legislation analyzed?  
YES/NO
  45. Are government institutions at the local level responsible for the administration of the legislation analyzed?  
YES/NO
  46. Are water user organizations (WUO's) provided for in the legislation?  
YES/NO
- If the answer is **YES**, are there any operational, and with what tasks?
47. Are specialized water courts provided to adjudicate water disputes and if so, are they operational?  
YES/NO
  48. Are informal groups (water users, conservation bodies, local government bodies) in existence on the ground?  
YES/NO



If the answer is **YES**, please provide (and document) the following information:

- ✓ rules about access, use, storage, and exchange of water among group members,
- ✓ rules about membership (who can belong to, and who decides about who can belong and how),
- ✓ rules about decision-making (who decides what, and how),
- ✓ rules about monitoring of compliance with the rules, and about enforcement of the rules,
- ✓ rules about information sharing among group members.

#### F.2.7. Implementation, administration and enforcement of the legislation on the statute books

49. Have any of the acts of parliament listed under Q10 been implemented (through implementing regulations)?  
YES/NO

If the answer is **YES** please list the implementing regulations.

50. Are records of actual administrative action taken by the competent government authorities under any of the legislative provisions covered by headings F.2.3, F.2.4 and F.2.5 available and accessible?  
YES/NO

If the answer is **YES**, please indicate which legislative provisions have actually been acted upon by which arm of government and at which level (central, intermediate, local).

51. Are records of enforcement action by the competent law enforcement authorities of the legislative provisions covered by questions 27, 37, 38 and 39 available and accessible?  
YES/NO

If the answer is **YES**, please indicate which legislative provisions have actually been enforced, and what the outcome of the law enforcement process has been.



## APPENDIX 2.

# INDICATORS



<b>1 - Defining or constraining the value of aquifers and their potential functions *</b>					
<b>No</b>	<b>Categories and indicator names</b>	<b>Indicator definitions</b>	<b>Units</b>	<b>Classification/ scoring</b>	<b>Remarks</b>
1.1	Mean annual groundwater recharge depth (mean annual recharge volume per unit of area)	Long-term mean groundwater recharge, including manmade components (return-flows, induced recharge, artificial recharge), divided by area.	mm/year	1. Very low: < 2 mm/yr 2. Low: 2 - 20 mm/yr 3. Medium: 20 - 100 mm/yr 4. High: 100 - 300 mm/yr 5. Very high: > 300 mm/yr	Low time-dependency, but margin of uncertainty is greater than possible variations over time.
1.2	Annual amount of renewable groundwater resources per capita	Long-term mean groundwater recharge, including manmade components, divided by the number of inhabitants of the area occupied by the aquifer.	m <sup>3</sup> /yr/capita	1. Low: < 1000 2. Medium: 1000 - 5000 3. High: > 5000	Time-dependency mainly related to the number of inhabitants
1.3	Natural background groundwater quality / suitability for water consumption	Percentage of the area occupied by the aquifer where groundwater is found of which natural quality satisfies local drinking water standards.	%	1. Very low: < 20% 2. Low: 20 - 40% 3. Medium: 40 - 60% 4. High: 60 - 80% 5. Very high: > 80%	Suitability for drinking water used as criterion. It is accepted that local drinking water standards may vary.
1.4	Aquifer-buffering capacity	Ratio between volume stored and long-term mean groundwater recharge (equivalent to mean residence time).	year	1. Low: < 10 years 2. Medium: 10 - 100 years 3. High: > 100 years	Mainly meant as a simple proxy for the aquifer's resilience to climatic variability
1.5	Aquifer vulnerability to climate change	Extent of expected groundwater budget regime change in response to change in climatic conditions.	ordinal score	1. <i>Low</i> : confined aquifers containing only fossil water or receiving negligible recent recharge. 2. <i>Medium</i> : aquifers with low level of recharge with limited interaction with other components of the hydrological cycle, due to location at considerable depth and/or hydraulic confinement. 3. <i>High</i> : aquifers actively interacting with streams, atmosphere and/or sea (e.g. coastal aquifers, SIDS, shallow water-table aquifers, karst aquifers)	Class 1 corresponds to 'non-renewable groundwater'.

1.6	Aquifer vulnerability to pollution	Percentage of its horizontal area where the aquifer is considered moderately to highly vulnerable to pollution.	%	1. Very low: < 20% 2. Low: 20 - 40% 3. Medium: 40 - 60% 4. High: 60 - 80% 5. Very high: > 80%	Approximate criteria for <i>Moderately to highly vulnerable</i> : > 100 in DRASTIC method If data availability is limited make use of GOD method where > 0,3 would be the threshold.
<b>2 - Role and importance of groundwater for humans and the environment</b>					
No	Categories and indicator names	Indicator definitions	Units	Classification/ scoring	Remarks
2.1	Human dependency on groundwater	Percentage of groundwater in total water abstraction for all human water uses.	%	1. Very low: < 20% 2. Low: 20 - 40% 3. Medium: 40 - 60% 4. High: 60 - 80% 5. Very high: > 80%	Abstraction of water includes the quantity used and all losses.
2.2	Human dependency on groundwater for domestic water supply	Percentage of groundwater in water abstraction for domestic water use.	%	1. Very low: < 20% 2. Low: 20 - 40% 3. Medium: 40 - 60% 4. High: 60 - 80% 5. Very high: > 80%	Abstraction of water includes the quantity used and all losses.
2.3	Human dependency on groundwater for agricultural water supply	Percentage of groundwater in water abstraction for agricultural water use (mainly irrigation).	%	1. Very low: < 20% 2. Low: 20 - 40% 3. Medium: 40 - 60% 4. High: 60 - 80% 5. Very high: > 80%	Abstraction of water includes the quantity used and all losses.
2.4	Human dependency on groundwater for industrial water supply	Percentage of groundwater in total water abstraction for industrial water use.	%	1. Very low: < 20% 2. Low: 20 - 40% 3. Medium: 40 - 60% 4. High: 60 - 80% 5. Very high: > 80%	Abstraction of water includes the quantity used and all losses.
2.5	Ecosystem dependency on groundwater	Percentage of the aquifer's area where the aquifer has a phreatic water level shallower than 5 m below surface.	%	1. Very low: < 5% 2. Low: 5 - 10% 3. Medium: 10 - 25% 4. High: 25 - 50%	Phreatic water level taken as a proxy

2.6	Prevalence of springs	Total annual groundwater discharge by springs, divided by mean annual groundwater recharge.	%	5. Very high: > 50% 1. Very low: < 5% 2. Low: 5 - 10% 3. Medium: 10 - 25% 4. High: 25 - 50% 5. Very high: > 50%	Springs are very sensitive to changes in groundwater budget. Therefore a meaningful indicator of change.
<b>3 - Changes in groundwater state</b>					
No	Categories and indicator names	Indicator definitions	Units	Classification/ scoring	Remarks
3.1	Groundwater depletion	Observed current rate of long-term progressive decrease in groundwater storage (accompanied by steadily declining groundwater levels), expressed as an equivalent depth of water averaged over the aquifer.	mm/year	1. Absent to very low: < 2 mm/yr 2. Low: 2 - 20 mm/yr 3. Medium: 20 - 50 mm/yr 4. High: 50 - 100 mm/yr 5. Very high: > 100 mm/yr	Depletion should target a long-term trend; short-term variations due to climatic variability should be discarded.
3.2	Groundwater pollution	Observed polluted zones as a percentage of total aquifer area (due to pollution causing water quality to exceed drinking water quality standards).	%	1. Very low: < 5% 2. Low: 5 - 10% 3. Medium: 10 - 25% 4. High: 25 - 50% 5. Very high: > 50%	Local drinking water quality standards as a criterion.
<b>4 - Drivers of change and pressures</b>					
No	Categories and indicator names	Indicator definitions	Units	Classification/ scoring	Remarks
4.1	Population density	Number of people per unit of area on top of the aquifer.	Persons/ km <sup>2</sup>	1. Very low: < 1 p/km <sup>2</sup> 2. Low: 1 - 10 p/km <sup>2</sup> 3. Medium: 10 - 100 p/km <sup>2</sup> 4. High: 100 - 1.000 p/km <sup>2</sup> 5. Very high: > 1.000 p/km <sup>2</sup>	
4.2	Groundwater development stress	Total annual groundwater abstraction divided by long-term mean annual groundwater recharge.	%	1. Very low: < 2% 2. Low: 2 - 20% 3. Medium: 20 - 50%	Measure for the degree of modification of the groundwater budget (repercussions for outflow



					4. High: 50 - 100% 5. Very high: > 100%	and storage)
<b>LEGAL AND INSTITUTIONAL ASPECTS</b>						
<b>5 – Enabling environment for transboundary aquifer resources management (at bi- or multi-national level)</b>						
No	Categories and indicator names	Indicator definitions	Scoring	Classification/ scoring	Remarks	
5.1	Transboundary legal framework [Q1 through Q9]	A. Existence and comprehensiveness of an agreement/treaty/MOU in force, specific to the transboundary aquifer (TBA).  B. Existence of a non TBA-specific agreement/treaty/MOU in force, or other non-binding instrument, of relevance to TBA.	The higher the score the more articulate and comprehensive the transboundary legal framework.	1. (No agreement in existence nor under preparation, if known) [Q1] 2. (Non-binding instrument endorsed, of relevance to TBA) [Q1] 3. (Non TBA-specific agreement exists) Add: +1 if it includes utilization of TB waters [Q6] +1 if it includes protection of TB waters from pollution [Q7] +1 if it includes settlement of disputes [Q9] +1 if it includes institutional arrangements (commission, committee, other) [Q8] +1 if it includes other matters (specify) 4. (TBA-specific agreement exists) Add: +2 if it includes utilization of TBA waters [Q2] +2 if it includes protection of TBA waters from pollution [Q3] +2 if it includes settlement of disputes [Q5] +2 if it includes institutional arrangements (commission, committee, other) [Q4] +2 if it includes other matters (specify)	If no agreement/ treaty/ MOU exists specific to the TBA, other treaties or agreements may exist (notably at the regional level), and/or non-binding instruments (such as UN resolutions, or declarations) at global or regional level, providing for trans-boundary (TB) waters in general, which are of relevance to the TBA, if only by implication. These need to be accounted for in order to accurately characterize this indicator.	
5.2	Transboundary institutional framework Q4, Q8]	Existence, mandate (and presumed capabilities) of institutions or institutional arrangements for managing the TBA.	The higher the score the more articulate and comprehensive the	1. (No bi- or multi-national trans-boundary institution in existence with mandate for TBA) 2. (Bi- or multi-national trans-boundary	The bi- or multi-national TBA institution is characterized by the nature and extent of its mandate, as spelt out in the relevant legal	

			transboundary institutional framework.	institution exists with mandate for TBA) [Q4 or Q8] Add: + 1 if it covers data collection and exchange, and monitoring + 1 if it covers utilization of TBA waters (water allocation) + 1 if it covers protection of TBA waters from pollution + 1 if it covers the resolution of disputes 3. (institution has staff and a budget)	instrument (treaty, agreement, MOU). However, the institution's capability - in terms of staffing and budget - to deliver on its assigned mandate is also relevant. While the table captures both elements, their adequacy relative to the institution's assigned mandate is highly speculative, and impossible to characterize objectively. Item No. 3 should include established posts and posts which are actually encumbered.
<b>6 – Enabling environment for transboundary aquifer resources management at domestic level (for national implementation of TBA treaty/agreement/MOU)</b>					
No	Categories and indicator names	Indicator definitions	Scoring	Classification/ scoring	Remarks
6.1	Policy framework [Q12]	Extent of groundwater-specific policy coverage	The higher the score the more extensive the policy coverage	0. (There is no policy explicitly or implicitly covering groundwater) [Q12] 1. (Groundwater is covered/touched upon by other policies) [Q12] 2. (Official groundwater policy exists) [Q12]	
6.2	Legislative/regulatory framework [Q10, Q11]	Existence of groundwater-specific legislation and regulation in the statute books	The higher the score the more groundwater-specific the legislation/regulation on the statute books	0. (There is no legislation covering explicitly or only implicitly groundwater) [Q10+Q11] 1. (Groundwater covered by non-groundwater-specific legislation) [Q10+Q11] 2. (Groundwater-specific legislation exists) [Q10+Q11]	Legislation includes acts of parliament (primary legislation) and government regulations (secondary or subordinate legislation). If available, ministerial orders and circulars are also relevant.
6.3	Legal status of groundwater [Q13, Q14]	Ownership, trusteeship, control of groundwater	The higher the score the more groundwater is attracted in the sphere of public/government	1. (Groundwater is owned by the overlying landowner - private ownership) [Q13] 2. (Groundwater is mixed public/private property) [Q13+Q14] 3. (Groundwater is public property)	Groundwater may have public property status under a variety of legal constructs (public ownership or domain, public trust or guardianship, superior user and the right of control vested in

6.4	Groundwater planning framework [Q15]	Legislation on groundwater management planning (inventory/assessment/monitoring, allocation, pollution control) on the statute books	al control The higher the score the more groundwater-specific planning mechanisms provided for in legislation/regulation	[Q14] 1. (Legislation provides for water resources planning) [Q15] 2. (With specific reference to groundwater) [Q15]	The reference here is to legislation providing for a national water master plan, and/or basin/aquifer management plans, and associated governmental functions such as, notably, inventory, assessment and monitoring.
6.5	Regulatory framework of groundwater abstraction and use [Q17 through Q27]	Comprehensiveness of groundwater abstraction/use legislation/regulation on the statute books	The higher the score the more comprehensive the coverage of GW abstraction/use in legislation/regulation	1. (GW abstraction requires a licence/permit/concession) [Q17] Add: +1 if exceptions are made to licensing requirements [Q18] +1 if licences are time-restricted [Q19] +1 if charges levied on licences in respect of GW [Q20] +1 if well drilling requires a permit/licence/authorization [Q21] +1 if licences, etc. can be reviewed and amended by government [Q22] +1 if licences, etc. can be suspended or terminated by government [Q23] +1 if licences, etc. can be traded (bought and sold) for a price [Q24] +1 if EIA required for well drilling/GW abstraction licence, etc. applications [Q25] +1 if GW users must monitor and report to government [Q26] +1 if unlawful behaviour is sanctioned with penalties [Q27]	Charges must be kept distinct from administrative fees. Charges reflect the 'user pays' principle, and tend to be payable at regular intervals for the life of the licence. Administrative fees tend to be one-off, and are levied in connection with the administrative processing of licence applications, renewals, or other administrative actions. They are not a true reflection of the 'user pays' principle.
6.6	Regulatory framework for the protection of GW from point source pollution [Q28 through Q39]	Comprehensiveness of groundwater pollution control legislation/regulation on the statute books (point source pollution)	The higher the score the more comprehensive the coverage of GW pollution control from point sources in legislation/regulation	1. (Discharging waste/water on the ground, under the ground requires a permit) [Q28] Add: +1 if permits are time-restricted [Q29] +1 if permits are subject to observance of standards of effluent quality [Q30] +1 if permits are subject to	Charges are a reflection of the 'polluter pays' principle. See in this regard the remarks under 6.5



					observance of quality standards/objectives of receiving water bodies [Q31] +1 if charges levied on permits ('polluter pays' principle) [Q32] +1 if permits can be reviewed and amended by government [Q33] +1 if permits can be suspended and terminated by government [Q34] +1 if EIA required for waste/water discharge permit applications [Q35] +1 if permittee must monitor and report to government [Q36] +1 if contamination from closed/disused wells regulated [Q37] +1 if use and disposal of hazardous substances regulated [Q38] +1 if unlawful waste/water discharge sanctioned with penalties [Q39]	
6.7	Regulatory framework for the protection of GW from non-point source ('diffuse') pollution [Q40, Q41]	Comprehensiveness of groundwater pollution control legislation/regulation on the statute books (non-point source pollution)	The higher the score the more comprehensive the coverage of GW pollution control from non-point sources in legislation/regulation on	1. (Cultivation practices restricted/prohibited) [Q40] Add: +1 if construction projects above and underground must take into account/prevent/minimize GW quality impacts [Q41] +1 if mining activities must take into account/prevent/minimize GW quality impacts	This section seeks to capture the interface between GW and land use/land use practices (including landfills and waste dumps), and between GW and uses of the subsurface space (for transport, storage, conveyance of waste) and resources (mining, oil drilling), from the standpoint of the impact of the interface on GW quality.	
6.8	Regulatory framework for the protection of GW recharge processes from manmade interferences [Q41]	Comprehensiveness of existing legislation/regulation of manmade interferences with GW recharge processes	The higher the score the more comprehensive the protection of GW recharge in legislation/regulation on	1. (Land use plans/underground construction projects must take into account/prevent/minimize risk of interfering with natural GW recharge processes) [Q41] Add: +1 if mining activities must take into account/prevent/minimize risk of interfering with natural GW recharge processes	This section seeks to capture the interface between GW and uses of the subsurface space (for transport, storage, conveyance of waste) and resources (mining, oil drilling), from the standpoint of the impact on GW recharge i.e. GW quantity.	
6.9	Legislative/regulatory	Performance of groundwater	The higher the	1. (GW abstraction and use licences	Action by the government	

	framework implemented [Q16, Q49]	legislation/regulation in force	score the more effective the legislation/regulation (is presumed to be)	<p>granted (and reviewed, suspended, terminated) and relevant records available and accessible) [Q49] Add: + 1 if waste/water discharge permits granted (and reviewed, suspended, terminated) and relevant records available and accessible [Q49] + 1 if administrative action taken by government under regulatory framework for the protection of GW from non point-source (diffuse) pollution, and relevant records or other evidence available and accessible [Q49] + 1 if administrative action taken by government under regulatory framework for the protection of GW recharge processes from manmade interferences, and relevant records or other evidence available and accessible [Q49] + 1 if water plans mandated by the legislation are in effect [Q16]</p>	<p>authorities responsible for the administration of the legislation is evidenced by the number and kinds of administrative licences/permits issued, reviewed, renewed, suspended, or terminated, and by the relevant records. A water plan 'in effect' is a plan that (a) has been prepared and (b) formally approved, under the relevant planning provisions of the law.</p>
6.10	Legislative/regulatory framework enforced [Q50]	Performance of groundwater legislation/regulation in force	The higher the score the more effective the legislation/regulation (is presumed to be)	<p>1. (Violations of GW abstraction and use regulation punished, and relevant evidence/records available and accessible) [Q50] Add: + 1 if violations of waste/water discharge regulation (for the protection of GW from point-source pollution) punished, and relevant evidence/records available and accessible [Q50] + 1 if violations of regulatory framework for the protection of GW from <u>non</u> point-source (diffuse) pollution punished, and relevant evidence/records available and accessible [Q50] + 1 if violations of regulatory framework</p>	<p>(a) The monitoring and inspection practice and records of the government water administration, (b) the record of fines and other administrative penalties meted out by the government water administration, and (c) the record of criminal prosecutions, successful or not, in the case of criminal behaviour, all provide useful evidence of the enforcement of water legislation.</p>

6.11	Customary water rights  [no corresponding questions in the Questionnaire]	Are customary water rights accounted for by the legislation? Is the interface between formal groundwater abstraction/user rights and customary water rights/practices acknowledged and regulated?	The higher the score the more articulate the statutory response to the issues addressed here	for the protection of GW recharge processes from manmade interferences punished, and relevant evidence/records available and accessible [Q50] +1 if GW users' and waste/water permit holders' behaviour monitored, notably through field inspections [Q50]	In many rural areas of the world access to water by the local population for household use and to support subsistence livelihoods is governed by customary law, and tends to be effectively out of the reach of formal water legislation. Inevitably, the two systems – the formal and the customary – interface at points of interaction, e.g. when formal water abstraction rights are granted for the development of water resources in use by local populations under customary law/practices. Unless the area of interface and interaction of the two systems is mapped out and regulated by formal legislation, then conflict and inequity of access are likely to ensue.
6.12	Formal institutional framework (government)  [Q42, Q43, Q44]	Groundwater-relevant governmental institutional landscape	This item is score-resistant. No scoring is therefore provided (except for coordination mechanisms in place, if any).	1. Provide a description of the groundwater-relevant government administration at a. national/central level b. regional level c. local level 2. Indicate if, and if so what, kind of coordination mechanisms exist: a. vertically across different levels of government b. horizontally across different	Formal groundwater institutions include government and legally-constituted (ground)water users' organizations. These are contrasted to the informal groundwater-relevant institutions in 6.14.  Please provide information on the internal organization, levels of staffing (established and encumbered posts) and the



				government administrations, and 3. score them by reference to the Metcalfe Table	budget of any groundwater- relevant government administration.
6.13	Formal institutional framework (users) [Q45]	Engagement of formal groundwater user groups in developing and managing the resource	The higher the score the more significant the role of GUOs (is presumed to be) in the formal institutional landscape	1. (Groundwater users' organizations (GUOs) are provided for by the water legislation or other legislation (e.g. civil code)) [Q45] Add: +1 if legally-formed GUOs exist on the ground and perform a range of functions (specify)	In addition to developing and managing groundwater for the benefit of members, water users' organizations formed in accordance with the legislation can take on a range of quasi- governmental functions, such as groundwater monitoring and policing of wells.
6.14	Informal institutional framework [Q47]	Engagement of informal (ground)water users' groups, conservation groups, local government bodies in developing and managing the resource	The higher the score the more articulate the informal institutional landscape	1. (Informal groundwater groups/bodies exist and operate on the ground) [Q47] Add: +1 if rules about access, use, storage, exchange of water are included +1 if rules about joining/leaving the group are included +1 if rules about decision-making are included +1 if rules about compliance monitoring & enforcement are included +1 if rules about information sharing are included	If such groups/bodies exist, it is necessary to document the rules by which they function, and the water-related rules they administer (and enforce).

\*Core indicators are coloured in light blue. Additional indicators are unmarked (white).

A landscape photograph showing a calm body of water in the foreground, reflecting the sky and the distant mountains. A group of white flamingos is wading in the shallow water. In the background, there are brown, arid hills and a prominent, conical volcano under a clear blue sky with a few wispy clouds. A semi-transparent blue horizontal band is overlaid across the middle of the image, containing the text 'APPENDIX 3.' in white.

## APPENDIX 3.

# FORMULAS TO CALCULATE INDICATORS



The formulas to calculate the 16 indicators for theme A, B, C, D, and E are given in this appendix.

### 1.1 Mean annual groundwater recharge ‘depth’

Mean annual recharge volume per unit of area. The value represents the area-standardised groundwater recharge as it is over a larger area (for example, the country segment or the whole TBA extension) and not just over the recharge area only.

- Indicator per country segment:

$$R_{ac} = \frac{R_c}{A_c} \text{ [m/yr]}$$

With:

$R_c$  = average annual volume of recharge per country segment ( $\text{m}^3/\text{yr}$ )

$A_c$  = surface area of TBA in country segment ( $\text{m}^2$ )

$R_{ac}$  = mean annual groundwater recharge ‘depth’ (m/yr)

- Indicator aggregated at aquifer level:

$$R_{TBA} = \frac{\sum_{c=1}^n A_{c,n} \times R_{c,n}}{\sum_{c=1}^n A_{c,n}} \text{ [m/yr]}$$

With:

$n$  = number of countries (c)

$R_{c,n}$  = average annual volume of recharge per country segment ( $\text{m}^3/\text{yr}$ )

$A_{c,n}$  = surface area of each TBA country segment ( $\text{m}^2$ )

$R_{TBA}$  = long-term mean groundwater recharge, including manmade components of the country segment [m/yr] aggregated at TBA level

### 1.2 Annual amount of renewable groundwater resources per capita

The value represents the population-standardised groundwater recharge. Population is the population living ‘on top’ of the aquifer. The indicator excludes people living outside the aquifer area but who might somehow be depending on the aquifer.

For population data, locally / nationally available data can be used, but data on population are also available from global datasets such as: <http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-count-future-estimates/data-download>

- Indicator per country segment:

$$R_{popc} = \frac{R_c}{Pop_c}$$

With:

$R_c$  = average annual volume of recharge for all country segments of the TBA ( $\text{m}^3/\text{yr}$ )

$Pop_c$  = number of people (population) living on top of the country segment of the TBA (capita).

$R_{popc}$  = annual renewable groundwater resources per capita ( $\text{m}^3/\text{yr/capita}$ )

- Indicator aggregated at aquifer level:

$$R_{poptba} = \frac{\sum_{c=1}^n Rc\_n}{\sum_{c=1}^n Popc\_n}$$

With:

N = number of countries

Rc = average annual volume of recharge for each country segment of the TBA (m<sup>3</sup>/yr)

Pop<sub>c\_n</sub> = number of people (population) living on top of each country segment of the TBA (capita).

R<sub>poptba</sub> = annual renewable groundwater resources per capita [m<sup>3</sup>/yr/capita]

### 1.3 Suitability for water consumption / natural background quality

- Indicator per country segment:

$$SWC_c = 100 - NSWC_c$$

With:

NSWC<sub>c</sub> = percentage of surface area of the country segment where natural groundwater quality DOES NOT satisfy local drinking water standards [% km<sup>2</sup>]

SWC<sub>c</sub> = percentage of the area of the country segment where natural groundwater quality satisfies drinking water standards [% km<sup>2</sup>]

- Indicator aggregated at aquifer level:

$$SWC_{TBA} = \frac{\sum_{c=1}^n (SWC_{c\_n} \cdot A_{c\_n})}{\sum_{c=1}^n A_{c\_n}}$$

With:

n = number of countries

SWC<sub>c</sub> = suitability for water consumption (%) per country segment

A<sub>c</sub> = surface area of the country segment [m<sup>2</sup>]

SWC<sub>TBA</sub> = percentage of the aquifer's area where natural groundwater quality satisfies drinking water standards [%]

### 1.4 Aquifer buffering capacity

Ratio between volume stored and long-term mean groundwater recharge (equivalent to mean residence time)

- Indicator per country segment:

$$ABC_c = \frac{V_c}{Rc}$$

With :

V<sub>c</sub> = total groundwater volume in country segment [km<sup>3</sup>]

Rc = average annual volume of recharge [m<sup>3</sup>/yr]

ABC<sub>c</sub> = aquifer-buffering capacity indicator per country segment of the TBA [yr]

- Indicator aggregated at aquifer level:

$$ABC_{TBA} = \frac{\sum_{c=1}^n V_c}{\sum_{c=1}^n Rc}$$

With :

$V_c$  = total groundwater volume in country segments [ $\text{km}^3$ ]  
 $Rc$  = average annual volume of recharge in country segments [ $\text{m}^3/\text{yr}$ ]  
 $ABC_{TBA}$  = aquifer-buffering capacity indicator for the complete TBA [yr]

### 1.5 Aquifer vulnerability to climate change:

Extent of expected groundwater budget regime change in response to change in climatic conditions

- Indicator aggregated at aquifer level:

IF ALL in AVCCc = 1. Low Aquifer Vulnerability to Climate Change  
 THEN: AVCCtba= 1. Low Aquifer Vulnerability to Climate Change

IF ALL in AVCCc = 2. Medium Aquifer Vulnerability to Climate Change  
 THEN: AVCCtba=2. Medium Aquifer Vulnerability to Climate Change

IF ALL in AVCCc = 3. High Aquifer Vulnerability to Climate Change  
 THEN AVCCtba=3. High Aquifer Vulnerability to Climate Change

ELSE:

$$AVCC_{TBA} = \text{round} \left( \frac{\sum_{c=1}^n AVCC_c \times A_c}{\sum_{c=1}^n A_c} \right)$$

(basically this is the area-weighted average of the country segment results

AVCCc: Aquifer Vulnerability to Climate Change: Extent of expected groundwater per Country Segment of the TBA:

1. Low Aquifer Vulnerability to Climate Change
2. Medium Aquifer Vulnerability to Climate Change
3. High Aquifer Vulnerability to Climate Change

- Indicator per country segment:



IF HCc='2. Whole aquifer confined' OR '6. Aquifer mostly confined, but some parts unconfined' AND Rc<0.002  
 THEN AVCCc='1. **Low** Aquifer Vulnerability to Climate Change'

ELSE IF Rc>0.1 OR GWLc<10.0  
 THEN AVCCc='3. **High** Aquifer Vulnerability to Climate Change'

ELSE IF PALc='Sedimentary rocks - Limestone' OR PALc=='Sedimentary rocks - Dolostone' AND PSPc=='2.1. Secondary porosity: Dissolution'  
 THEN AVCCc='3. **High** Aquifer Vulnerability to Climate Change'

ELSE IF PALc=='Sedimentary rocks - Limestone' OR PALc=='Sedimentary rocks - Dolostone' AND PSPc Different from '2.1. Secondary porosity: Dissolution'  
 THEN AVCCc='2. **Medium** Aquifer Vulnerability to Climate Change'

ELSE THEN AVCCc='2. **Medium** Aquifer Vulnerability to Climate Change'

With:

HC<sub>c</sub> = hydraulic condition in the country segment of TBA

1. Whole aquifer unconfined
2. Whole aquifer confined
3. Whole aquifer semi-confined
4. Aquifer mostly unconfined, but some parts confined
5. Aquifer mostly confined, but some parts unconfined
6. Aquifer mostly semi-confined, but some parts unconfined

Rc = long-term mean groundwater recharge, including manmade components of the country segment [m/yr] per country segment

AVCCC = Aquifer Vulnerability to Climate Change Indicator per country segment of the TBA [classification]

- 1.Low. Confined aquifers containing only fossil water or receiving negligible recent recharge.
- 2.Medium. Weakly recharged aquifers with limited interaction with other components of the hydrological cycle, due to location at considerable depth and/or hydraulic confinement.
- 3.High. Aquifers actively interacting with streams, atmosphere and/or sea (e.g. coastal aquifers, SIDS, shallow water-table aquifers, karst aquifers)

GWLc = Depth to groundwater table [m]

PALc = Predominant aquifer lithology

- Sediment - Sand
- Sediment - Gravel
- Sediment - Silt - Clay
- Sedimentary rocks - Shale
- Sedimentary rocks - Sandstone
- Sedimentary rocks - Limestone
- Sedimentary rocks - Dolostone
- Sedimentary rocks - Evaporite
- Crystalline rocks - Granite
- Crystalline rocks - Basalt
- Metamorphic rocks

PSPc = Predominant secondary porosity

- 2.1. Secondary porosity: Dissolution
- 2.2. Secondary porosity: Weathering
- 2.3. Secondary porosity: Fractures
- 2.4. No secondary porosity

## 1.6 Aquifer vulnerability to pollution

Percentage of aquifer area where the aquifer is considered moderately to highly vulnerable to pollution. The indicator used here is 'GOD-Adapted'. This is adapted from *Foster, S.S.D., (1998) Groundwater recharge and pollution vulnerability of British aquifers: a critical overview*. In: *Robins, N.S. (ed.) Groundwater Pollution, Aquifer*.

- Indicator per country segment:

$$\text{GOD\_adapted\_c} = (\text{HCc} * \text{GWLc} * \text{PALc})$$

IF GOD\_Adapted < 0.3 THEN GOD\_Adapted<sub>c</sub> = Low vulnerability

IF GOD\_Adapted > 0.3 AND < 0.5 THEN GOD\_Adapted<sub>c</sub> = Moderate vulnerability

IF GOD\_Adapted > 0.5 THEN GOD\_Adapted<sub>c</sub> = High vulnerability

With :

HC<sub>c</sub> = hydraulic conditions in the country segment of TBA

1. Whole aquifer unconfined = 1
2. Whole aquifer confined = 0.2
3. Whole aquifer semi-confined = 0.4
4. Aquifer mostly unconfined, but some parts confined = 0.8
5. Aquifer mostly confined, but some parts unconfined = 0.3
6. Aquifer mostly semi-confined, but some parts unconfined = 0.5

GWL<sub>c</sub> = Depth to groundwater table

1. 100 m = 0.4
2. 50 - 100 = 0.5
3. 20 - 50 m = 0.6
4. 10 - 20 m = 0.7
5. 5 - 10 m = 0.8
6. 2 - 5 m = 0.9
7. < 2 m = 1.0

PALc = Aquifer's lithology

1. Sediment - Sand = 0.6
2. Sediment - Gravel = 0.7
3. Sediment - Silt - Clay = 0.5
4. Sedimentary rocks - Shale = 0.5
5. Sedimentary rocks - Sandstone = 0.7
6. Sedimentary rocks - Limestone = 0.9
7. Sedimentary rocks - Dolostone = 0.9
8. Sedimentary rocks - Evaporite = 0.8
9. Crystalline rocks - Granite = 0.6
10. Crystalline rocks - Basalt = 0.8
11. Metamorphic rocks = 0.6

GOD-Adapted: Groundwater vulnerability to pollution Indicator. Adapted from Foster, S.S.D. 1998. Groundwater recharge and pollution vulnerability of British aquifers: a critical overview. In: Robins, N.S. (ed.) Groundwater Pollution, Aquifer Recharge and Vulnerability. Geological Society, London, Special Publications,

- Indicator aggregated at aquifer level:

$$GOD - Adapted_{TBA} = \frac{\sum (GOD - Adapted_c \cdot A_c)}{\sum_{c=1}^n A_c}$$

IF GOD\_Adapted < 0.3 THEN GOD\_Adapted<sub>c</sub> = Low vulnerability

IF GOD\_Adapted > 0.3 AND < 0.5 THEN GOD\_Adapted<sub>c</sub> = Moderate vulnerability

IF GOD\_Adapted > 0.5 THEN GOD\_Adapted<sub>c</sub> = High vulnerability

## 2.1 Human dependency on groundwater

Percentage of groundwater in total water use

- Indicator per country segment:

$$HDG_c = \frac{Q_{GWC}}{Q_{BWC}} \times 100$$

With :

$Q_{GWC}$  = total groundwater abstractions of country segment [ $m^3/yr$ ] for 2010

$Q_{BWC}$  = total blue water (freshwater) abstraction in the country segment [ $m^3/yr$ ] for 2010

$HDC_c$  = human dependency on groundwater in country segment [%]

- Indicator aggregated at aquifer level:

$$HDC_{TBA} = \frac{\sum_{c=1}^n Q_{GWC_n}}{\sum_{c=1}^n Q_{BWC_n}} \times 100$$

With:

$n$  = number of countries

$Q_{GWC_n}$  = total groundwater abstractions of country segment [ $m^3/yr$ ] for 2010

$Q_{BWC_n}$  = total blue water (freshwater) abstraction in the country segment [ $m^3/yr$ ] for 2010

$HDC_{TBA}$  = human dependency on groundwater in TBA [%]

## 2.2 Human dependency on groundwater for domestic water use

Percentage of groundwater in total domestic water use.

- Indicator per country segment:

$$HDGDom_c = \frac{Q_{GWDc}}{Q_{BWDc}} \times 100$$

With :

$Q_{GWDc}$  = groundwater abstractions for domestic water use in country segment [ $m^3/yr$ ]

$Q_{BWDc}$  = total blue water (freshwater) abstraction for domestic water use in the country segment of the TBA [ $m^3/yr$ ]

$HDGDom_c$  = human dependency on groundwater for domestic water use in country segment [%]



- Indicator aggregated at aquifer level:

$$HDGDom_{TBA} = \frac{\sum_{c=1}^n Q_{GWDc}}{\sum_{c=1}^n Q_{BWDc}} \times 100$$

With:

n = number of countries

$Q_{GWDc}$  = groundwater abstractions for domestic water use of country segment [ $m^3/yr$ ]

$Q_{BWDc}$  = total blue water (freshwater) abstraction for domestic water use in the country segment of the TBA [ $m^3/yr$ ]

$HDGDom_{TBA}$  = human dependency on groundwater for domestic water use in TBA [%]

## 2.3 Human dependency on groundwater for agricultural water use

Percentage of groundwater in agricultural water use.

- Indicator per country segment:

$$HDGA_c = \frac{Q_{GWA_c}}{Q_{BWA_c}} \times 100$$

With :

$Q_{GWA_c}$  = groundwater abstractions for agricultural water use of country segment [ $m^3/yr$ ]

$Q_{BWA_c}$  = total blue water (freshwater) abstraction for agricultural water use in the country segment of the TBA [ $m^3/yr$ ]

$HDGAgr_c$  = human dependency on groundwater for agricultural water use in country segment [%]

- Indicator aggregated at aquifer level:

$$HDGA_{TBA} = \frac{\sum_{c=1}^n Q_{GWA}}{\sum_{c=1}^n Q_{BWA_c}} \times 100$$

With:

n = number of countries

$Q_{GWA_c}$  = groundwater abstractions for agricultural water use of country segment [ $m^3/yr$ ]

$Q_{BWA_c}$  = total blue water (freshwater) abstraction for agricultural water use in the country segment of the TBA [ $m^3/yr$ ]

$HDCATBA$  = human dependency on groundwater for agricultural water use in TBA [%]

## 2.4 Human dependency on groundwater for industrial water use

Percentage of groundwater in industrial water use.

- Indicator per country segment:

$$HDGI_c = \frac{Q_{GWIC}}{Q_{BWIC}} \times 100$$

With :

- $Q_{GWIC}$  = groundwater abstractions for industrial water use of country segment [ $m^3/yr$ ]
- $Q_{BWIC}$  = total blue water (freshwater) abstraction for industrial water use in the country segment of the TBA [ $m^3/yr$ ]
- $HDGI_c$  = human dependency on groundwater for industrial water use in country segment [%]

- Indicator aggregated at aquifer level:

$$HDGI_{TBA} = \frac{\sum_{c=1}^n Q_{GWIC}}{\sum_{c=1}^n Q_{BWIC}} \times 100$$

With:

- $n$  = number of countries
- $Q_{GWIC}$  = groundwater abstractions for industrial water use of country segment [ $m^3/yr$ ]
- $Q_{BWIC}$  = total blue water (freshwater) abstraction for industrial water use in the country segment of the TBA [ $m^3/yr$ ]
- $HDGI_{TBA}$  = human dependency on groundwater for industrial water use in TBA [%]

## 2.5 Ecosystem dependency on groundwater

- Indicator per country segment:

$EDG_c$  = percentage of country segment with groundwater-dependent ecosystems.  
 If groundwater-dependent ecosystems have not been mapped: report percentage of aquifer area where depth to groundwater table is less than 5 m below soil surface.  
 $EDG_c$  = ecosystem-dependency on groundwater Indicator per country segment [%]

- Indicator aggregated at aquifer level:

$$EDG_{TBA} = \frac{\sum_{c=1}^n (EDG_c \times A_c)}{\sum_{c=1}^n A_c}$$

With:

- $N$  = number of countries
- $A_c$  = surface area of the country segment [ $km^2$ ]
- $EDG_c$  = percentage of the country segment with groundwater-dependent ecosystems or if these data are not available: area with a phreatic water level shallower than 5m below surface [%]

## 2.6 Prevalence of springs

Total annual groundwater discharge by springs, divided by mean annual groundwater recharge

- Indicator per country segment:

$$PS_c = \frac{Q_{sc}}{Rc} \times 100$$

With :

$Q_{sc}$  = total groundwater discharge by springs in country segment [ $m^3/yr$ ]

$Rc$  = average annual volume of recharge [ $m^3/yr$ ]

$PS_c$  = prevalence of springs [%]

- Indicator aggregated at aquifer level:

$$PS_{TBA} = \frac{\sum_{c=1}^n Q_{sc}}{\sum_{c=1}^n Rc} \times 100$$

With :

$Q_{sc}$  = total groundwater discharge by springs in country segment [ $m^3/yr$ ]

$Rc$  = average annual volume of recharge [ $m^3/yr$ ]

## 3.1 Long-term groundwater depletion (m/yr)

Observed current rate of long-term progressive decrease in groundwater storage expressed as equivalent depth of water averaged over the entire area and per year.

- Indicator per country segment:

$$GWDEPL_c = \left( \frac{\Delta V_c \times 10^9}{A_c} \right) [m/yr]$$

With :

$\Delta V_c$  = groundwater depletion per the country segment [ $km^3/yr$ ] between 2000-2010

$A_c$  = surface area of the country segment [ $m^2$ ]

$GWDEPL_c$  = observed current rate of long-term progressive decrease in groundwater storage per country segment (accompanied by steadily declining groundwater levels), expressed as an equivalent depth of water averaged over the entire aquifer [ $m/yr$ ]



- Indicator aggregated at aquifer level:

$$GWD_{TBA} = \frac{\sum_{c=1}^n (A_c \times GWDEPL_c)}{\sum_{c=1}^n A_c}$$

With :

- n = number of countries (c)
- $A_c$  = surface area of country segment [ $m^2$ ]
- $GWDEPL_c$  = observed current rate of long-term progressive decrease of groundwater storage per country segment (accompanied by steadily declining groundwater levels), expressed as an equivalent depth of water averaged over the aquifer [m/yr].
- $GWDEPL_{TBA}$  = observed current rate of long-term progressive decrease in groundwater storage for the complete aquifer (accompanied by steadily declining groundwater levels), expressed as an equivalent depth of water averaged over the aquifer [m/yr].

### 3.2 Groundwater pollution

Observed zones with groundwater polluted by human actions (expressed as a percentage of total aquifer area).

- Indicator per country segment:

```

if GWPOL_quanc = '1. No pollution has been identified'
THEN GWPOLc = 'No pollution has been identified'
if GWPOL_quanc = '2. Some pollution has been identified / suspected but areal extent not specified'
THEN GWPOLc = 'Some pollution has been identified'
if GWPOL_quanc = '3. Significant pollution has been identified'
THEN GWPOLc = GWPOL_percc

```

With:

GWPOL\_quanc = identification of groundwater pollution;

1. No pollution has been identified
2. Some pollution has been identified
3. Significant pollution has been identified

GWPOL\_percc = percentage of the area of the country segment of TBA where groundwater is polluted [%]

GWPC = groundwater pollution indicator per country segment (semi-quantitative)

- Indicator aggregated at aquifer level:

IF all in GWPOL\_quanc\_n = '1. No pollution has been identified'

THEN GWPOLtba='No pollution has been identified'

IF any in GWPOL\_quanc\_n= '2. Some pollution has been identified / suspected but areal extent not specified'

THEN GWPOLtba='Pollution has been identified, but cannot be specified per TBA'

IF all in GWPOL\_quanc\_n = '3. Significant pollution has been identified'

THEN

$$GWPOL_{TBA} = \frac{\sum(GWPOL_{percc} \cdot A_c)}{\sum_{c=1}^n A_c}$$

OTHERWISE: GWPOLtba= 'At least some pollution has been identified in the TBA'

With:

n = number of country segments

A<sub>c</sub> = surface area of the country segment [km<sup>2</sup>]

GWPOL\_quanc\_n = Identification of groundwater pollution:

1. No pollution has been identified

2. Some pollution has been identified

3. Significant pollution has been identified

GWPOL\_percc\_n = percentage of area of each country segment of the TBA where groundwater is polluted [%]

GWPOL<sub>TBA</sub> = groundwater pollution indicator for the complete TB (semi-quantitative)

#### 4.1 Population density

For population data, locally / nationally available data can be used, but data on population are also available from global datasets such as GRUMP (Population density, gridded, SEDAC) or POP (Population density projections, gridded, IIASA).

#### 4.2 Groundwater development stress

Total annual groundwater abstraction divided by mean annual groundwater recharge

- Indicator per country segment:

$$GDS_c = \frac{Q_{Gwc}}{R_c} \times 100$$

With :

R<sub>c</sub> = average annual volume of recharge [m<sup>3</sup>/yr]

Q<sub>Gwc</sub> = total groundwater abstractions in country segment [m<sup>3</sup>/yr]

GDS<sub>c</sub> = groundwater development stress indicator per country segment of TBA

- Indicator aggregated at aquifer level:

$$GDS_{TBA} = \frac{\sum_{c=1}^n Q_{Gwc}}{\sum_{c=1}^n Rc} \times 100$$

With :

Rc = average annual volume of recharge [m<sup>3</sup>/yr]

Q<sub>Gwc</sub> = total groundwater abstractions in country segment [m<sup>3</sup>/yr]

GDS<sub>TBA</sub> = groundwater development stress indicator per TBA



# GUIDELINES FOR MULTIDISCIPLINARY ASSESSMENT OF TRANSBOUNDARY AQUIFER

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Transboundary aquifer or transboundary aquifer system means respectively, an aquifer or aquifer system, part of which are situated in different States. The international aspect of a transboundary aquifer makes its management more complex than in a case of an aquifer located within the State borders. An informed and sustainable management of commonly shared aquifer asks for adequate knowledge of its characteristics, present state and trends. In order to acquire this knowledge, regular monitoring and assessment of the transboundary aquifer need to be performed. This document describes a methodology for multidisciplinary assessment of transboundary aquifers and gives the guidelines for its implementation.



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## IGRAC

Westvest 7  
2611AX Delft  
The Netherlands

T: +31 15 215 2325  
E: [info@un-igrac.org](mailto:info@un-igrac.org)  
I: [www.un-igrac.org](http://www.un-igrac.org)