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international groundwater resources assessment centre

International workshop on new technologies for the acquisition of information on transboundary aquifers

Minutes of the GEF-TWAP workshop

Organized by IGRAC and UNESCO-IHP

Utrecht, April 15 – 16th 2010

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Abstract

On April 15-16th, IGRAC and UNESCO-IHP organized in Utrecht an international workshop on new technologies and the use of alternative information sources for conducting global groundwater assessments.

For two days, about 35 renowned water experts of various international organizations discussed how innovations in the field of remote sensing and global hydrological modelling could contribute to these assessments. The use of proxy information to estimate global groundwater demand and use was discussed. Furthermore, a number of existing global groundwater assessment programs such as WHYMAP, IGRAC and GEO were presented. The final session was dedicated to the 'data for all' concept, which refers to the ownership and sharing of subsurface data and information generated by oil, mining and drinking water companies.

The workshop specifically aimed at how these technologies and programs may contribute to the Transboundary Water Assessment Program planned by the Global Environmental Facility (GEF). IGRAC in cooperation with others is developing the methodology related to groundwater for this assessment for GEF.

Participating organizations were BGR, Deltares, ETH-Zurich, FAO, Fugro, GEF, IGRAC, PBL, Shell, Twente University, UNEP, UNESCO, University of Arizona, University of Frankfurt, University of Texas, Utrecht University, Vitens and WaterWatch.

1 Introduction

1.1 Background of TWAP

The Global Environmental Facility (GEF) has commissioned the design of a Transboundary Water Assessment Programme (TWAP). The future execution of this TWAP will allow GEF, policy makers and international organizations to set science-based management choices and priorities for financial resource allocation to certain transboundary water bodies, among them aquifers, that are considered most under stress. Furthermore, the TWAP will document the impacts of their investments and programmes in transboundary water management.

The TWAP transboundary aquifer assessment will produce two products:

- *Identification and general characterization of individual transboundary water systems:* identification implies recognition of the existence of the systems concerned. The general characterization serves as reference information, documenting the system and its setting. For transboundary aquifers, this may include properties such as location, countries involved, size, geometry (boundaries), predominant lithology, mean recharge, water use, environmental and socio-economic setting, etc.
- *Indicators:* Combinations of variables, but combined in such a way that they convey a clear message – and in the context of TWAP this should be a message related to the need for transboundary management, the main concerns of issues to be addressed and/or the feasibility of getting transboundary management into motion. The indicators are essentially meant for objective and consistent priority setting and resources allocation

Ideally, the identification, characterisation and the indicators are based on data and information regarding:

(i) Aquifer and groundwater system characteristics
(ii) Anthropogenic and natural drivers/stresses/disturbances, essentially pollution and level of abstraction, climate variability and change;
(iii) Human uses, socio-economic drivers and governance.

The quality and level of detail of this assessment will vary according to the "available knowledge and information". Often this knowledge and information are derived from conventional in-situ monitoring technologies. For this assessment, conventional technologies have some limitation in that they need inter- and extrapolation to cover the larges areas of this assessment, are different in extent, density and quality across borders and need consequent harmonization, only have limited forecasting potential and often not in the public domain. Within the TWAP Groundwater workgroup, it is assumed that the use of 'newly collected' data that could be obtained through non-conventional and 'innovative' technologies might overcome some of these limitations. These non-conventional technologies are:

- Airborne geophysics and remote sensing,
- Large scale and global hydrological modelling,
- Global groundwater observation programs and expert networks,
- Hidden data sources,
- Virtual Water and Water footprinting.

1.2 Workshop Objective

On April 15th and 16th, a workshop was organized by IGRAC and UNESCO in Utrecht. Various international experts were invited to inform the TWAP Groundwater workgroup on innovations in these non-conventional technologies that might be useful for and contribute to the future TWAP. The workshop participants are listed in annex 1. The workshop agenda is listed in annex 2.

The objectives of the workshop are:

- To be informed about innovation in non-conventional technologies;
- To discuss whether these new technologies allow cost-effective filling of gaps in conventional information coverage;
- To discuss whether these new technologies complement/extrapolate the available conventional information;
- To be informed how these new technologies may produce forecasts and scenarios that can be used in the TWAP;
- To identify which groundwater parameters can be derived from these technologies that need to be monitored over time in future possibly subsequent GEF TWAPs.

1.3 Report Overview

The second section gives a summary of the presentations form the various experts that fall in the above-described categories of non-conventional technologies. In section 3, many of the issues being discussed are described. Issues deal among others with data coverage and resolution of the various technologies, reliability of the data, forecasting potential, data ownership and data handling. Section 4 concludes with how these technologies may be applied in TWAP and what operational arrangements need further consideration.

2 Summary of workshop presentations

2.1 Airborne geophysics and remote sensing

Airborne geophysics for aquifer mapping, Job Nijman, Fugro
There are four main airborne geophysics technologies, of which the Electro-Magnetics (EM) techniques are the most suitable for identifying and characterizing aquifers. With EM, an electromagnetic field is created and the conductivity of the subsurface is measured at various depths using different frequencies. The result is a continuous surveying profile both horizontally and vertically (as opposed to point data from boreholes). For correct interpretation, the obtained information is combined with in-situ information *(ground truthing).*

The airborne EM technique is useful to map large and especially suited to survey hardly accessible or dangerous areas. It is less suitable for urban areas because of all kinds of infrastructure objects interfering with the subsurface signal. Airborne EM is used for example in early warning systems, modelling, monitoring of contamination, risk assessment and for mapping of saline water intrusion. Groundwater levels can be detected with an accuracy of 20-30 cm. Currently, there is no remote technique that will do any better, not even radar. Surveying costs are largely dependent on area size and grid density (resolution). Surveyed and processing of a 1km length flight line costs about $1,500.

Airborne EM has much potential for the water sector, but is not widely used at present because of the water sector's often fragmented nature. Presently, the main clients of EM are government departments dealing with mineral exploration. They normally hold the intellectual property rights (IP) to the data and determine whether to make it publicly available (as in Australia) or classify it 'inaccessible' (even to other ministries within the country). Since mining organisations are mostly not interested in the shallow parts of the subsurface, data surveyed at that depth is often not processed to cut costs.

Remote Sensing, Evapotranspiration & Groundwater Interactions, Ivo Miltenburg, Water Watch
The large benefit of using satellite-based technologies like Remote Sensing (RS), is that decennia of collected and processed imagery are already available (and often accessible via the internet). With remote sensing technologies, there is a trade off between spatial and temporal resolution. This can be resolved by combining images of different spatial and temporal resolutions: e.g., low resolution daily MOD with high resolution LANDSAT (25 images per year).

Evapotranspiration (ET), comprises often 90% of the water flow in the water cycle. In many water balance studies, ET is 'estimated' as the residual term of the water balance. WaterWatch is now capable of determining ET with their RS SEBAL-model with much more confidence, making the rest of the water budget more reliable. The SEBAL-method requires only limited ground truthing.

In areas where and during periods of time when the water balance is relatively simple (e.g., no precipitation, little surface water groundwater interaction, limited surface water use), the determined ET forms a proxy to estimate groundwater abstraction. This results often in better estimates than trying to quantify groundwater abstraction directly by counting and summing the pump capacity of millions of small pumps). The ET method gives insight in where groundwater is abstracted, used or lost.

In areas where precipitation (P) and river runoff (R) are fairly known, groundwater recharge can be estimated by subtracting R and ET from the P term. Obviously, the estimating groundwater abstraction and recharge using ET becomes more reliable when all the other water balance terms are well known (ground truthing)

GRACE satellite imagery, Bridget Scanlon, University of Texas
GRACE satellite imagery can be used to monitor changes in total water storage at a 10 day to monthly timescale. What it cannot see are differences between saline, brackish and fresh water. At this moment, the spatial resolution of GRACE is still coarse only allowing very large scale (global) analyses. However, by using ground truthing and downscaling technologies successful GRACE groundwater applications were made for regional scales (400,000 to 200,000 km^2, for the US High Plains).

The GRACE satellites produce gravimetric data, which are processed in three processing centres around the world. Each of the processing algorithms gives slightly different results. GRACE measures changes in the earth's gravity field and is therefore useful to detect changes in the earth's total water column. The groundwater part of this water column is obtained by removing ice caps, soil water, surface water and atmospheric water mass terms. These terms are often estimated using models (e.g. GLDAS for soil water) or other remote sense data and often have a large level of uncertainty. Therefore, although GRACE is increasingly used to observe trends in groundwater storage, caution is advised on the reliability of the results. Both due to processing technologies and due to assumptions made in the process.

A Google Earth product has been developed that provides GRACE total water storage changes from CSR (monthly), GRGS (10 day), GLDAS soil moisture and output from 4 models.

2.2 Global & large scale hydrological modelling

Global modelling of renewable groundwater resources, use and storage variations, Petra Döll, University of Frankfurt
Recently, studies were conducted combining the WATERGAP model (a global distributed hydrological flow and stock model with 0.5° spatial resolution) and GRACE. It is emphasized that a lot of uncertainty comes with using and combining these technologies. Both technologies are uncertain in themselves, and uncertainty is introduced with the input data being used. For example, many different precipitation data sets exist, each slightly different. If you use them as model inputs, the outputs vary significantly.

It is shown how global hydrological models like WATERGAP can be used to determine groundwater abstraction. In Brazil for example, they have a lot of information on wells, but nothing on abstraction. Again, using direct methods (or data) to obtain total abstraction is therefore not possible. Fiedler and Doll (2008) used census data to determine irrigation water demand.

The WATERGAP model was used to determine human vulnerability to climate change. Two climate models were compared, each running two scenarios. A sensitivity index was developed, taking into account Q90 (low flow in nine out of 10 months) and HDI (Human Development index). Obviously, it is the people's dependency on groundwater resources that make them vulnerable to changes in the groundwater system. Döll advices GEF-TWAP to take into account the vulnerability of people, when deciding where to put money, and not just to look at physics.

In future, the WATERGAP group want to include groundwater use in its model simulate changes in storage and groundwater levels. This will allow determine vulnerabilities of people and ecosystems depending on groundwater.

Döll emphasizes that there is a strong need for groundwater data availability. Her incentive in contributing to TWAP is that data resulting from the GEF-TWAP assessments may feed back into global models improving their performance and usability.

Climate variability and change in the US Southwest, impact on water resources, Juan Valdés, University of Arizona

ICIWaRM, the UNESCO International Center on Integrated Water Resources Management is introduced. ICIWaRM capitalizes on diverse capabilities and broad technical resources of many US institutions currently engaged in the development and application of IWRM methods and their transfer to developing nations and nations in transition around the globe. The centre's initial emphasis is in Central and Latin America and Africa.

According to Valdés, the partitioning of precipitation over runoff & ET is the main challenge in understanding the water cycle in arid areas. He shows that our understanding of water and climate have changed over the years. We now see trends in temperature, but less so in precipitation. He emphasizes that we should be aware of feedback processes between water, climate and precipitation. Further, he again raises the issue of uncertainty, from both input data and the models themselves. One way of dealing with this is to run for example 21 models, each giving different results, and then selecting the two that perform 'best' for the problem at hand.

According to Valdés, the problem is not so much that the data does not exist. However, how you can extract it since data sets are vast and time-consuming to handle. Therefore, SAHRA developed software for data extraction that is openly available (SAHRA data extraction and grid processing)

Finally, Valdés talks about the concept of 'capture'. Groundwater table decline may induce the recharge form overlying surface water bodies. Hence positioning groundwater abstraction near to rivers and lakes, may capture some of this surface water and prevent it from running off into a sink. He notes that recharge is also affected by changes in partitioning of precipitation between snow and rain. Less snow can mean that less recharge will take place at the mountain front.

Global Nutrient Loading Modelling & Submarine Groundwater Discharge , Lex Bouwman, PBL & Hans Dürr University of Utrecht

Bouwman discusses his work with the IMAGE model. This is a whole suit of coupled global distributed models, simulating various parts of physical and socio-economic systems. IMAGE takes historical data from 1970 to present, and uses scenarios for the future (MEA-millennium ecosystem scenarios).

IMAGE contains a global water balance model (form the University of New Hampshire) Utrecht University added nutrient cycling to it. PBL developed 'nutrient management story lines', as these were not available in the MEA-scenarios. Nutrient balances are important environmental indicators and must be included in all five GEF-TWAP assessments.

With respect to N and P use efficiency, the addition of fertilizers prevents soil nutrients from being depleted. In China, soils even are saturated by excess fertilizer application and nutrients possibly leak into aquifers. In Europe, after 1970, use of fertilizers decreased and the efficiency therefore increased.

A global depletion of P is expected (due to mining). Bouwman's results are not alarming when it comes to overall depletion, but P concentrations are high in soils. We are constantly moving P from grassland to agricultural lands. Bouwman emphasizes that there is a scarcity of data on the global scale and that scenarios indicate the importance of management.

He continues with presenting work by Dürr on Submarine Groundwater Discharge (SDG). The N to P ratio for rivers is 14:1, while in groundwater it is >16:1. The reason for this is that nitrate retention is more efficient than P retention. Sites with high N in SGD and river high-N are found to coincide.

Estimating non-renewable groundwater abstraction using water demand as a Proxy, Yoshi Wada, Utrecht University

Wada shows a method where IGRAC's GGIS-country statistics for groundwater abstraction are downscaled to 0.5° based on total water demand. Utrecht University has developed a global hydrological model (PCR-GLOBWB) estimating groundwater recharge Results of subtracting groundwater abstraction from groundwater recharge show that problems occur in Northern India and Pakistan. This corresponds to the GRACE study by Familigietti,. However, Wada's model results show a higher intensity. Wada's results suggest that groundwater depletion is more sensitive to changes in abstraction than to recharge.

The model also has limitations. It does not allow for lateral groundwater flow. The argument behind this is that the most dynamic part of lateral groundwater flow has scales less than the model grind dimensions .However, because of this limitation, hot spots are visible around some of the larger cities with high groundwater abstraction. Aquifers however might be larger than the 0.5° cell size used here.

Another limitation is that the model does not allow for surface water induced groundwater recharges. Hence, the effect of '**capture** pumping' is not taken into account. Therefore, instead of possibly depleting an aquifer, often part of the base flow is pumped up. The Ogallala for example gets 5% of its water from base flow, and changes in recharge are due to changes in land use.

FEWS, a scale-neutral tool for data sources and model results assimilation for a Global water prediction system, Jaap Kwadijk, Deltares

FEWS was originally developed as a flood forecasting system. It can be used for many other purposes. In the field of flood forecasting, typically the various research and water management institutes existing in a drainage basin developed their own model. FEWS has been developed to handle and combine data from these multiple models. It is assumed that it removes some of the reluctance with organisations to combine the full suit of exiting models instead of sticking to the one in which they had invested. By now, FEWS is linked to about a hundred models, and it can deal with many different data types.

Data handling for GCMs can be done with FEWS in a simulation or in an operational mode. Another possibility is to use FEWS to compare GCM outcomes. For example, you could put together all the IPCC data, run the IPCC models and scenarios and then provide the results. FEWS tries to create added value to the models and datasets of the various autonomous research and water management institutes. The institutes are allowed to operate FEWS themselves, but the Deltares FEWS team is also willing to do it for the institute and simply provide the results. This produces a beneficial situation, as there is no need for the organisations to change their own monitoring and modelling systems.

FEWS was successfully used in combination with groundwater models in the UK and USA.

2.3 Global groundwater observation programs and expert networks

GEO & GGMN, Sophie Vermooten, IGRAC
The water cycle is complicated. To improve our understanding of this cycle, data is collected and analyzed. Many different systems and formats are used for that. The Group on Earth Observations (GEO, not to be confused with the UNEP Global Environmental Outlook) felt there is a need to globally coordinate all these efforts. Furthermore, they stimulate and try to facilitate data sharing and improving the interoperability of the systems and their corresponding data. As part of GEO, the Global Earth Observation System of Systems (GEOSS) was initiated. GEOSS will provide decision-support tools to a wide variety of users. As with the Internet, GEOSS will be a global and flexible network of content providers allowing decision makers to access an extraordinary range of information at their desk. This 'system of systems' will proactively link together existing and planned observing systems around the world and support the development of new systems where gaps currently exist. (http://www.earthobservations.org)

GEOSS includes a task on Integrated Products for Water Resource Management and Research (TASK WA-08-01), which includes '*in-situ networks, satellite missions (and existing space-borne Earth observing systems) and emerging assimilation and prediction capabilities*…' Relevant GEOSS products are 1) information layers on soil moisture, runoff, groundwater and precipitation, 2) water cycle data integration, 3) pilot projects for improved Water Discovery and Quality Assessments and 4) Global Water Quality Monitoring.

IGRAC is responsible for the groundwater part in GEOSS. IGRAC has initiated the Global Groundwater, Monitoring Network (GGMN) in order to collect and accommodate in-situ groundwater data from monitoring and fieldwork surveys on a global scale. It is assumed that GGMN can be used for a periodic (ideally monthly) assessment of the global change of groundwater resources. To facilitate this, GGMN software has been developed. In the next phase, a global network of experts will be installed that feed their groundwater data, information and knowledge into the system. A near future pilot is foreseen in Sub-Saharan Africa. The periodic assessments resulting form these efforts may contribute to the ground truthing for RS and global models, as presented in other presentations.

GGMN requires that experts import their own point data and aggregate it to a 1° resolution. The aggregation step is assumed to help to avoid the pitfall of political sensitivities in case of direct sharing of raw data. IGRAC will further harmonize the information, e.g. at country borders. The expert network of The GGMN-network will be set up along the lines of UNESCO-IHP. It is reminded that for some aquifers, particular project platforms were set up in the past (like some of the ISARM groups). It is considered important to include these experts as well.

GGMN will initially focus on collecting groundwater parameters that are relatively easy to retrieve: groundwater levels and EC. At a later stage, additional groundwater parameters like abstraction data and quality data can be collected. IGRAC has done assessments of fluoride and arsenic in the past. GGMN will be an open access took free to be used by anyone. It is proposed to embed GGMN in several international water programs like IGWCO, GEO, GTN-H, Graphic, AEGOS and WWAP.

WHYMAP, Willi Struckmeier, BGR
There is a lot of region-based hydrogeological information available around the world. WHYMAP consisting of IAH, UNESCO-IHP and BGR, combined this information in a single, global hydrogeological map.

Existing regional hydrogeological maps, with different formats and representation were harmonized. They were published as continental and global maps at 1:10 million and 1:25 million scales. WHYMAP is now concentrating on developing and presenting more detailed information on the forty major aquifers, as these store most of the groundwater reserves. This information will contain aquifer cross-sections and flux and storage information.

Note that not all of these largest aquifers are TBAs. Moreover, in the GEF-TWAP context numerous small aquifers will have to be dealt with that are not covered by the current WHYMAP efforts.

2.4 Hidden data sources

Shell – let's integrate the water and energy sectors!, Joppe Cramwinckel, Shell
The energy sector realizes more and more that it is increasingly being entangled with the water sector. Therefore, they seek to collaborate with the water sector further. The energy sector want to create win-win situations, putting to better use the water and data that this energy sector produces, but does not use their selves.

By 2015, the demand for energy and water will increase due to population growth and increased living standards. In addition to that, if the energy sector grows, and more biomass-based energy will be produced, it will become a much more water intensive sector (deduced from calculating the water footprints of different energy sources).

The water sector is largely unaware of the fact that the energy industry is also a large (saline) water producer. Together with oil and gas, up to 95% of the pumped up volumes consists of water. This water can be used (i.e. in saline agriculture), but usually it is just pumped back (thousands of m^3 /day). Because of the unintended generation this side product, the energy sector conducts (deep) aquifer management and often works closely together with ministries of water resources.

The oil industry uses seismic surveys to gather information from the subsurface. Since the oil and gas reserves are often found deeper, there is only limited interest in the shallow subsurface (first few 100s of meters below surface level). Often the data in the shallow depth profile is not processed and analyzed. Nevertheless, this could be done if incentives are found.

Earlier IGRAC has explored possibilities to cooperate with Shell. Legal complexity of data ownership brought the project to a halt. In most cases, the oil company or the surveying organisations like FUGRO do not hold the intellectual property over the data. Their exploration and surveying activities are mostly commissioned by of mining and energy departments of Nation States. Hence, data is often owned by the State. In order to improve sharing of already existing data and data coming form future surveying one have to look thoroughly into the judicial aspects of the contracting mechanisms between states and oil companies.

Cramwinckel draws attention to the FROG company (FRom Oil to Groundwater, http://www.frogtech.com.au), which was initiated some time ago.

Shell would like to collaborate more with the water sector and names Iraq as an opportunity for doing so. It is emphasized that collaboration should be sought where both partners will benefit. Because in the water sector cash flows are much smaller than in the energy sector, the monetary incentive must be especially large for the latter. Despite this hurdle, the majority of the GEF-TWAP members feel that collaboration between Shell and the water sector should be considered or at least encouraged in the GEF-TWAP recommendations.

The GEF-TWAP members pointed out that what would be needed are not raw data, but interpreted data. In other words the groundwater community needs the oil industry expertise and knowledge on deeper groundwater resources, more than the access to raw subsurface data. Shell acknowledges this and is willing to explore knowledge exchange with this respect, on short term.

Vitens – supplying drinking water in the Netherlands, Jan Jaap Buyse, Vitens
Vitens is the largest water company in the Netherlands, providing water to 4 million people. They use groundwater as the solely source for drinking water production, pumped up at about 120 sites.

Vitens manages its data through an online but non-public system, called Spatial Workshop. The other companies in the Netherlands are now also adopting this GIS system. The strength of the system is that it can deal with almost any data type. It allows directly viewing of photographs, reports, and observation well data in GIS. In the near future, Vitens wants to make their drinking water quality more insightful to their users through a public domain internet portal. Information on the drinking water distribution network is deliberately kept confidential because of terrorism threat concerns.

In the Netherlands, drinking water companies that abstract groundwater are obliged to monitor hydrological effects of that abstraction. This monitoring compliance is conditional for getting abstraction permits. The monitoring data is analyzed by Provinces who issue those permits. About 75% of this monitored data is made available to the public. The Dutch Institute TNO has the task and mandate to collect data from various groundwater and soil monitoring networks (including the ones from drinking water companies). Data is shared via web-portals at minimal cost.

2.5 Virtual water and water footprinting

Virtual Water and Water Footprints, Maarten Krol, Twente University
The water footprint of a product is the volume of fresh water used to produce the product, summed over the various steps of the production chain. It includes a temporal and spatial dimension (where did it come from?) and the type of water used (green, blue or grey). A distinction is made between direct and indirect water footprints, each of which consisting of the green, blue or grey footprints (see also www.waterfootprint.org). Traditionally, only direct blue water footprints are considered.

The value of the water footprint is that it gives insight in the relation between consumption in one place and the impact on water systems elsewhere. Based on this information one is able to make informed decisions, build awareness and thus change behaviours. You can look at the water footprint of a product, but also of a nation, a company, a consumer, a government, etc.

The socio-economic impact of groundwater use in transboundary aquifers will be considered in TWAP. Water footprints could be relevant for GEF-TWAP Groundwater if a distinction is made between the surface water and groundwater footprint and when virtual water transfers between the national segments of transboundary aquifers could be quantified. The work of Döll and Wada could serve as a basis.

Virtual water transfers forms an alternative type of internationally shared water besides the rivers, lakes, oceans, LMEs and groundwater systems. Within TWAP, it could be considered as a crosscutting theme.

3 Discussion

3.1 Conventional versus non-conventional technologies

Essentially, the following non-conventional technologies or techniques were discussed:

- Airborne geophysics and remote sensing,
- Large scale and global hydrological modelling,
- Global groundwater observation programs and expert networks.

Within the TWAP Groundwater workgroup, it was assumed that these technologies might provide easily accessible, TWAP relevant groundwater data and information with large-scale coverage, sufficient resolution and reliability. This as opposed to what are considered as conventional groundwater technologies with in-situ point-wise monitoring of groundwater parameters, local representation, limited coverage and poor public access. Examples of such conventional technologies are:

- measuring groundwater level, Ph, EC and temperature in observation wells,
- taking groundwater and soil samples and analyzing properties like groundwater quality, porosity and permeability,
- drilling descriptions and borehole geophysics,
- local hydraulic testing like pumping tests and slug tests.

Besides, using non-conventional techniques also the possibility of filling of data and information gaps by using people's expert judgement were discussed. A number of global groundwater observation and surveying programs is applying this successfully. ISARM used questionnaires sent to large networks of relevant experts to derive information on various aspects of transboundary management. The GGMN of IGRAC also intends to make use of experts' network to facilitate global and ongoing groundwater monitoring. The high quality of WHYMAP's global hydrogeological map is from peer reviews of large groups of regional experts.

Hidden potential sources of data were presented . These data sources are assumed to reside in surveying organisations and industries that rely upon subsurface knowledge such as mining, oil exploration and water production. These data and information sources may be produced by either conventional or non-conventional technologies. Often this data is not easily and directly accessible because of data ownership and intellectual property issues.

Finally, the concept of virtual water and water footprinting were discussed. The concepts describe a possibly sixth type of transboundary water linking the terrestrial water bodies (rivers, lakes and groundwater) with precipitation and soil water. These concepts are considered as potentially worthwhile to include that in the interlinkages.

Coverage, groundwater properties, resolution of the non-conventional techniques
Airborne geophysics provides the opportunity to generate groundwater related data and information covering hundreds of square kilometres (covering aquifers or even whole countries). Resolutions differ from meters to hundreds of square meters. Each new coverage in time needs a completely new surveying sweep. Airborne geophysics may provide information on groundwater level (radar), aquifer geometry (EM), groundwater salinity and groundwater quality.

The satellite-based remote sensing provides data on large scales and having possibly global coverage. Some of the satellites cover different parts of the world in each sweeping round.

Spatial resolutions differ from meter to hundreds of km scale. Temporal resolutions differ from daily to multi-annual scales. RS may provide information on changes in groundwater storage (GRACE) and indirectly on groundwater recharge and groundwater abstraction in some areas where water balances are simple and precipitation and evapotranspiration can be quantified through RS.

Most of the existing global hydrological models have a global terrestrial coverage and spatial resolutions of 0.5°. Temporal resolutions are daily (as in the Utrecht University model PCR-GLBWB) or monthly (as in WATERGAP and in the IMAGE Nutrient fate model of PBL). The models simulate groundwater recharge, base flow to rivers and lakes. Some of the models simulate river and lake infiltration into the groundwater reservoir. However, none of these global hydrological models simulate lateral groundwater flow or the effects of groundwater abstraction on groundwater level or groundwater storage. In addition, these global hydrological models still do not contain the physical properties of the large aquifers (transmissivity, storage, dimensions, interlinkages with other aquifer and surface water).

Consistency, harmonization and access
The main advantage of the above-described technologies is that they provide groundwater data and information over large areas that are generated with one consistent method. This avoids data harmonization and interpretation that might be needed in case of having different groundwater departments or organizations using different conventional in-situ technologies. The global data generated by RS and results from global hydrological models are hardly owned by countries. Using such data may overcome the problem of getting no access to the often nationally organized conventional data.

Reliability & data assimilation
One of the issues largely discussed during the workshop is the reliability of the data coming from the non-conventional technologies. All airborne and satellite-based geophysical or remote sensing technologies need some level of ground truthing in order to validate interpretation of the data. Similarly, global hydrological models require calibration and verification of its modelled variables by using measured data. It is generally agreed that inclusion of in-situ data generated by conventional technologies remains essential.

It is discussed how to value expert's information retrieved via questionnaires and for example IGRAC's GGMN. Obviously, there will be issues of subjectivity in person's feedback that need to be dealt with. Furthermore, this approach needs harmonization of the obtained results across national borders as feedback will be biased and based on different applied national hydrological practices.

Increasingly, the concept of data assimilation is applied in water management studies. It combines direct and indirect, hard and soft data and information coming from various conventional and non-conventional technologies. FEWS is one of the tools available technically facilitating easy combinations of technologies and sources.

Forecasting and scenarios
Time-series statistical analyses of data coming from measuring and monitoring technologies provide the possibility to extrapolate some of the variables into the future and make projections. Models provide the opportunity to simulate scenarios in which complex assumptions on how the world will evolve, are defined.

3.2 Data existence, accessibility and handling

Raw data existence and processing

Almost all relevant measured and collected groundwater data needs some level of analysis or processing before getting meaningful for groundwater management. Hence, one has to distinguish carefully between the amount of raw data that exists globally and the amount that has already been processed and hence is interesting for us. Although many satellite-provided raw data have a global coverage, this does not necessarily mean that processed information exist at the same degree of coverage. Often, the processing takes place only for a certain limited area that is of interest to a specific stakeholder.

The same limitation holds for the seismic surveys and bore log information that is for example collected and processed by mining and oil industries. Since these organisations are often not interested in the shallow parts of the subsurface, the collected data in this depth profile commonly remain unprocessed.

Data ownership & accessibility

The workgroups initial assumption that the oil and mining industry (and the companies that provide surveying services to it) has access to and gathers very valuable subsurface information on deep groundwater resources data proved valid. The raw data is normally owned by national governments who grant the industries concessions and licences for exploration. If collaboration with the mining and oil companies is sought in the TWAP process in the hope to open up hidden sources of data, one has to realize the need to include those national governments in the dialogue and negotiations as well.

Experiences from oil and mining industry and the surveying companies describe a situation inhibiting sharing even more. They are often commissioned to do their surveying activities by one single governmental ministry or department dealing with oil, gas or mining resources. In many countries, governmental tasks and mandates to develop and manage subsurface renewable natural resources (like groundwater) and non-renewable resources (like oil and gas) are highly sectorized and fragmented over various departments. Lack of communication or even competition between those departments lead to situations where even within countries possibly mutually relevant data and information is not shared.

Data capture and handling

Besides the willingness to share aspect of the data there are some technical issues as well. Some of the described datasets are extremely large. High resolution remote-sensing imagery with large coverages are increasingly been made accessible from web-portals. However, one needs specialized software and advanced computing facilities to capture and handle such data. IT-companies like IBM are already offering their services to facilitate this for organisations that want to work with that data.

4 Conclusions for GEF-TWAP

Characterisation & indicators
The Groundwater workgroup members generally agreed that most of the presented Technologies, programs and alternative data sources may be very useful for TWAP.
The Groundwater part of TWAP is going to consist out of two parts:

1. Identification and characterisation of Transboundary aquifers and SIDS;
2. Indicators on which GEF can prioritize their future activities.

For both parts, the technologies presented in the workshop may have a role. For the former part, spatially distributed data may enable the understanding of groundwater systems. For the latter part, relevant indicators per TBA (or national segments of it) and SIDS may be based on a combination of averaged and aggregated forms of existing data layers that were presented during the workshop. It was also concluded that the non-conventional techniques of geophysics, RS and global modelling provide many opportunities for the assessments of the other type of transboundary water.

The nutrient loading and fate modelling by PBL was considered relevant and may be included in the methodology to describe and possibly quantify nitrogen interlinkages between some of the systems. Virtual water trade and water footprinting is considered an useful concept in describing a 6^{th} type of transboundary water, linking rivers, groundwater and lakes (blue water) with precipitation and soil moisture (green water) and recycled waste water (grey water).

Costs & time constraints
At this stage, a methodology for the groundwater part of the Transboundary Waters Assessment Program is developed. It is assumed that GEF will base the assessment strongly on the outcomes of this MSP-project. It is furthermore assumed that the first assessment will take place in the period 2013-2015 and that GEF is going to invest 10-15 M$ on it.

One has to question how to spend most wisely the presumed amount of funds made available by GEF. It is very unlikely that the funds are sufficient for covering expenses of new surveying projects, processing of large amounts of raw data or adjusting global models such that they simulate groundwater processes better. On top of these likely budgetary constraints, one needs to consider carefully the time that is needed to perform such activities and see whether they fit in the assessment planning.

Partnering
It was agreed by all workgroup member that much efficiency and possible cost reductions can be derived from combining various programs. TWAP, ISARM, GEOSS, IGRAC,WHYMAP, UNEP GEO and possibly others are all seeking to improve the knowledge on the status and management of water systems. Despite the fact that all of them have slightly different objectives servicing different stakeholder they all make use of the same amount of data and information, generated with the same technologies by the same organisation. They are also similar in the fact that most of them have limited budgets

In order to avoid duplication and improve efficiency and to use economics of scale, partnerships need to be developed between the programs and the organisations able to provide the data and information and between the programs themselves.

Appendix 1: Workshop participants

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Appendix 2: Workshop agenda

	Thursday, April 15th	
08:30	Registration & Welcome	
09:00	Opening, welcome by GEF, UNESCO, IGRAC, Deltares, UNEP	Al Duda, Alice Aureli, Peter Letitre, Kees Bons, Jaap van Woerden
09:15	Background on TWAP, objective and scope of workshop	Chairman (Andrea Merla)
09:30	Mapping aquifers with airborne geophysical techniques	Job Nijman (FUGRO)
10:00	Water Resources Modelling and Remote Sensing	Ivo Miltenburg (WaterWatch)
10:30	GRACE application in water management	Bridget Scanlon (University of Texas)
11:00	Tea & Coffee Break	
11:30	Discussion on role of synoptic monitoring in TWAP	All, Chairman (Andrea Merla)
12:00	Global modeling of renewable groundwater resources, use and storage variations	Petra Döll (University of Frankfurt)
12:30	Climate variability and change in the US Southwest: impact on water resources	Juan Valdes (University of Arizona)
13:00	Lunch	
14:00	Global nutrient loading modelling & Submarine Groundwater Discharge	Lex Bouwman (PBL)
14:30	Group discussion on global hydrological modelling and TWAP	All, chairman (UNESCO)
15:00	Estimating Non-renewable Groundwater Abstraction Using Water Demand as a Proxy	Yoshi Wada (University of Utrecht)
15:30	Tea & Coffee Break	
16:00	Group discussion on way forward & day's wrap up	All, chairman (UNESCO)
17:00	Social event	
	Friday, April 16th	
09:00	Registration & Welcome	
09:30	Recapitulation of most important facts of yesterday's session	Chairman (Frank van Weert)
09:45	Water foot-printing & Virtual water trade	Maarten Krol (Twente University)
10:15	Discussion on use of proxy information	All, chairman (Frank van Weert)
10:45	Whymap	Willi Struckmeijer (Whymap)
11:00	Tea & Coffee Break	
11:30	FEWS scale-neutral tool for data sources and model results assimilation	Jaap Kwadijk (Deltares)
12:00	GEO, IGRAC and Global Groundwater Monitoring Network	Sophie Vermooten (IGRAC)
13:00	Lunch	
14:00	Interfaces oil & gas and groundwater management	Joppe Cramwinckel (Shell)
14:30	Discussion on 'data for all' or publicly sharing of water information	All, chairman (Frank van Weert) with contributions of Jan Jaap Buyse (Vitens)
15:00	Panel Session	Speakers, chairman (Andrea Merla)
15:30	Conclusions, way forward & Closing Statements	Chairmen, Peter Letitre, Alice Aureli
16:00	Social event	

Appendix 3: Presentations

All presentations are available as pdf files from www.igrac.net
Under Special projects à GEF-TWAP development
http://www.igrac.net/publications/416

The following links might not work correctly in Internet Explorer, but will work in most other browsers.

Airborne geophysics and remote sensing

- Airborne geophysics for aquifer mapping, Job Nijman, Fugro
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=144

- Remote Sensing, Evapotranspiration & Groundwater Interactions, Ivo Miltenburg, Water Watch
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=143

- GRACE satellite imagery, Bridget Scanlon, University of Texas
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=145

Global & large scale hydrological modelling

- Global modelling of renewable groundwater resources, use and storage variations, Petra Döll, University of Frankfurt
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=141

- Climate variability and change in the US Southwest, impact on water resources, Juan Valdés, University of Arizona
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=146

- Global Nutrient Loading Modelling & Submarine Groundwater Discharge, Lex Bouwman, PBL & Hans Dürr University of Utrecht
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=140
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=142
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=155 (not presented)

- Estimating non-renewable groundwater abstraction using water demand as a Proxy, Yoshi Wada, Utrecht University
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=147

- FEWS a scale-neutral tool for data sources and model results assimilation for a Global water prediction system, Jaap Kwadijk, Deltares
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=151

Global groundwater assessment programs and expert networks

- GEO & GGMN, Sophie Vermooten, IGRAC
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=153

- WHYMAP, Willi Struckmeier, BGR
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=152

Hidden data sources

- Shell - let's integrate the water and energy sectors!, Joppe Cramwinckel, Shell
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=149
- Vitens - supplying drinking water in the Netherlands, Jan Jaap Buyse, Vitens
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=148

Virtual water and water footprinting

- Virtual Water and Water Footprints, Maarten Krol, Twente University
  http://www.igrac.net/dynamics/modules/SFIL0100/view.php?fil_Id=150

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